EFFECTIVENESS OF STANDARDIZED FOOD-GRADE TANKER SANITARY WASH PROTOCOLS

By

PAUL P. WINNICZUK

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Paul P. Winniczuk

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Improperly cleaned tankers may be a source of foodborne bacterial and allergen cross-contamination, particularly with non-dedicated tankers. Tanker cleaning procedures are practical guidelines but may not have adequate details in some critical cleaning parameters. This research was undertaken to validate two sanitation protocols for their effectiveness to remove microorganisms and food soils.

To assist in validating the wash protocols, a model tanker with a barrel partially constructed of Plexiglas was used. The model tanker aided in visually determining wash flow characteristics of CIP systems and the cleaning effectiveness. All washes were conducted at the University of Florida, Citrus Research and Education Center in Lake Alfred to better control the washing parameters. The Juice Products Association's Type 2 and 4 washes were evaluated with three different CIP devices. Appropriate food slurries containing microorganisms were applied to predetermined areas of the tanker and allowed to dry for 24 hours. After washing, sample sites (100 cm^2) were evaluated for microorganisms, residual soils, and allergens by standard microbiological methods and commercial test kits.

The wash protocols can be effective to clean a tanker if the appropriate CIP parameters are used. For rotating CIP devices, important parameters are flow rate and pressure, head rotation speed, and nozzle extension length while important parameters for stationary devices are flow rate and pressure, and installation positions of centering and pitch. When using the appropriate CIP parameters both type 2 and 4 wash protocols were effective to reduce microorganisms by 5 log units per 100 cm^2 in all sample sites of the tanker. Both washes were also effective to reduce their respective soils by at least 4 log units (<3 μg/100cm^2 and <1 μg/100cm^2, respectively).

The current research indicates that JPA Type 2 and 4 wash protocols if properly adhered to and when the proper CIP system parameters are used, can be effective to reduce microorganisms and soil residues to non-recoverable or low levels. It is extremely important to ensure that the CIP system is operated at the optimum conditions for flow impact and volume.

CHAPTER 1
INTRODUCTION

Foods

Liquid food products make up a large part of the food industry in America and other parts of the world. Liquid foods are those food products that are typically consumed as beverages (e.g., milk and juices) or as ingredients by industrial food processing facilities such as dairies and bakeries. These liquid foods include pasteurized eggs, soy milk and oil, other vegetable oils, and peanut butter base. Milk and orange or apple juices are enjoyed by many people nationally. These foods once were local production products or seasonal. The advent of bulk transport and storage of these products has meant that these products may not have seasonal or regional limitation. Hauling liquid foods by bulk over-the-road tankers is more efficient and cost effective compared to hauling in smaller volume drums and bins. Costs of hauling bulk juice and then packing in a regional facility (independent juice packagers or dairies) are usually less than packing in one location and distributing the packaged product to other areas. Much effort has been instilled to ensure the quality and safety of these products through pasteurization and sanitation research. However, the cleanliness of the bulk transport tanker has not been fully evaluated. Many raw liquid foods undergo pasteurization or other food-safety processing steps prior to being consumed thereby masking the tanker sanitary condition. However, some liquid foods (for example, juice concentrates or sweetener syrups) may not undergo this food safety treatment which increases the risk of foodborne bacterial illness if the tanker is not cleaned properly. Therefore the sanitary condition of the bulk transport tanker is more important for proper food safety for these products. This was the case with a tanker that hauled raw liquid eggs prior to hauling ice cream mix (FDA 1996). Also, due to the wide variety of food products that are hauled, there is a potential for cross-contamination of one food type to another. This becomes important when a potentially allergenic food product (e.g., milk, eggs, peanut products, and soy milk products) is hauled and the tanker is not properly cleaned out prior to loading with another food product. This situation may occur when pasteurized milk is hauled before the tanker is used to haul not-from-concentrate orange juice or other juices. In this situation, a person that is allergic to milk proteins may have a reaction to the orange juice due to residual milk proteins from an improperly cleaned tanker. Proper cleaning also has implications to the FDA Code of Federal Regulations Good Manufacturing Practices (21CFR110) (FDA 2003), and the AFDO Guidelines for Food Transportation (AFDO 2004) in that residual foods in the tanker may be considered “filth” (if spoiled) or “deleterious” or “potentially hazardous” (in the case of allergens) which would make the next product “adulterated” and potentially unsuitable for human consumption.

Tankers

Food-grade over-the-road tankers are large with dimensions of 39 to 41 ft long (11.8 to 12.5 m) and a barrel diameter of 63 to 79 in (160 to 200 cm) with an entry in the middle and a product discharge at the rear bottom. Cleaning a tank of these dimensions can be difficult. Food-grade tankers are primarily cleaned by a clean-in-place (CIP) process. CIP cleaning regimens are theoretically sound but need to be properly reviewed to ensure it is effective in cleaning a tanker of all remaining food products. CIP processes can be broken down into four factors that are required to properly clean a tanker. These are 1) cleaning time, 2) solution temperature, 3) detergent concentration, and 4) cleaning solution mechanical action. Proper cleaning will use a combination of these that are cost effective. Each factor has its limits in which a minimum level is needed to clean while an excessive amount does not produce better results and is more costly. Also, excessive levels of some factors may be detrimental to cleaning efficiency. Water quality and the nature of the soil (residual food product) are other factors that affect proper cleaning but are not traditionally addressed. Published investigations evaluating CIP cleaning have been conducted with vertical tanks in which the CIP device is positioned equal distance to the walls of the tank. Transport tankers can be considered a horizontal tank in that all the tank walls are not equal distance to the CIP spray device. There is little research on these types of tanks. Research that has been conducted has been on raw products (Richter 1975; Steele 1997) or with shorter or compartment tankers (Bell et al. 1994). Results of these investigations indicate that some residue may remain in tankers after cleaning. Seiberling (2003) published an overview of CIP cleaning in which tankers are considered a special horizontal tank. There is also little independent research on the differences in the sprayer devices. With water conservation being important, the use of low volume, high pressure sprayers is becoming more common.

Currently, there is not an effective single standard to clean tankers. There are various cleaning procedures for tankers which are defined by CIP equipment manufacturers, chemical suppliers, industry guidelines, or facility experience however these procedures, in general, have not been validated. Provisions of the Pasteurized Milk Ordinance (PMO) (FDA 2003) detail requirements for the construction and sanitation of wash facilities as well as licensing and tagging requirements, but leave specific procedures for tanker cleaning to the dairy processor or wash facility. In 1990, the U.S. Congress issued the Sanitary Food Transportation Act designating the US Department of Transportation as the regulatory agency. The objective of this Act was to protect the public from contamination from the transportation of food and other consumer products. The Act mentioned that food, cosmetics, and other products shall be transported without the risk of contamination. While leaving specifics to industry personnel, the Act recommends that a third party validate the wash protocols, and is thus the foundation for other guidelines. The Food Industry Transportation Coalition (FITC) has written the Bulk Over-the-Road Food Tanker Transport Safety and Security Guideline (FITC 2002) which are voluntary guidelines for handling tankers used to haul food and other products. These guidelines do not specify tanker cleaning procedures, but recommend that personnel follow the current Good Manufacturing Practices (cGMP) (FDA 21CFR 110) and Hazard Analysis Critical Control Point system (HACCP) (9CFR 417) and/or customer, manufacturer, or chemical supplier recommendations. The Juice Products Association (JPA) "Wash Guidelines for the Tanker Industry" contains some information regarding tanker cleaning but also leaves specifics to each tanker wash facility and to "manufacturer or chemical supplier recommendations." These guidelines leave much of the specifics in a "gray area" with certain CIP parameter open to interpretation. Also, these guidelines have not been validated by a third party as to their effectiveness. FDA reiterated these guidelines in their "Bulk Over-the-Road Food Tanker Transport Safety and Security Guidelines." This guideline again leaves much of the specifics on tanker cleaning to facility, customer, manufacturer, systems manufacturer, and chemical supplier recommendations. A general point is made that the cleaning solutions and procedures "should be appropriate to clean and sanitize internal surfaces." Also, the FDA issued the Guidance on Bulk Transport of Juice Concentrates and Certain Shelf Stable Juices that is a general review of recommended cleaning protocol. The guidance emphasizes post-cleaning handling of the tanker (seals and documents). FDA leaves the proof that a tanker is properly cleaned to the producers, transporters, and users of the juice since they are responsible for the ultimate safety of their product. The JPA Wash Guidelines were adopted by the FDA for the Juice HACCP Rule (FDA 2004) that deals with orange and other juices or juice concentrates that do not undergo further processing. The JPA Wash Guidelines suggest that a tanker can be washed properly without risk or at least a reduced risk of microorganism or allergen contamination. However, proper validation of the wash types has not been performed.

The objectives of this research are

1. Conduct a baseline study to review and evaluate CIP supplier recommended equipment parameters suggested for tanker cleaning,

2. To determine effective CIP equipment performance by using a novel approach to evaluate the equipment performance,

3. To evaluate and validate the effectiveness of wash protocols for the juice industry, specifically for food-grade water-soluble soils (Type 2) and food-grade food allergen soils (Type 4) using 3 CIP devices and operating systems.

This research may have implications for a standardized national tanker wash procedure in which not only the citrus industry, but also the dairy, caloric sweetener, and edible oils industries will benefit. Also, this research may provide information on the better understanding and performance of CIP spray devices and potentially improving the performance of these devices.

CHAPTER 2
LITERATURE REVIEW

Industry Practices

Transported Volume

Many liquid food products are transported by bulk over-the-road tankers. These include milk, juices, eggs, oils, sweeteners, and other food-grade liquid products. Transport tankers have a typical volume of 18,000 to 26,000 l (5,500 to 7,000 gallons) with an average net weight of 19,958 kg (44,000 pounds) that is based on the US Department of Transportation's Federal Highway Administration (DOT FHWA) regulations for gross vehicle weight limit of 80,000 pounds (36,287 kg) for federal highways (US DOT 2006) and as required by 23 CFR Part 658. Some states may allow larger transportation weights on a permit basis (US DOT 2006).

Unfortunately, compiled statistics for the overall volume of food products hauled do not exist. However, it is possible to extrapolate the volume of the liquid food transport industry by investigating the key segments. According to US Department of Agriculture Economic Research Services (USDA/ERS) statistics, the US fruit juice and fruit juice beverage market was valued at approximately $18 billion in 2004 (USDA ERS 2006) with a per capita consumption of 5.9 single strength equivalent (SSE) gallons annually. Based on previous conversations with industry representatives coupled with known statistics, it is estimated that over 80% of all citrus juice consumed in the US is transported by tanker-truck at some point before entering the final retail package. Mid-sized juice packaging companies in Florida handle about 8,000 tankers per year (Parish PC 2003). It is likely that the four largest citrus processing companies in Florida load and unload more than 15,000 tankers each, while the smallest processors load 2,000 to 3,000 tankers of juice per year. Based on the personal communication and the statistics of the USDA ERS (2006), it is estimated that juice processors loaded approximately 146,000 tankers total per year bound for final packaging. This does not include loads used for the intermediate transport between company facilities. An estimate of total citrus juice transports including intra-company transported juice is 293,000 loads per year. Combined with other juices (apple and grape), it is estimated that there are approximately 507,000 tanker loads of juice being transported per year. US milk production in 2005 was approximately 176.9 billion pounds with over 53 billion pounds consumed as fluid milk having a value of approximately $18 billion in the retail market (NASS 2006). Per capita consumption of beverage milk in 2005 was approximately 180 pounds or 20.9 gallons (NASS 2006). Approximately 155.7 billion pounds of milk are hauled by bulk transport for beverage and processed milk, utilizing over 3.5 million transport loads (44,000 pounds per load) per year (NASS 2006). Transported milk loads include fluid milk for dairy processing, as well as manufactured products (cheese, yogurt, powdered milk). Another product that is largely moved by tanker-truck is vegetable oils (corn, soy, cottonseed, sunflower, canola, and peanut). Based on information from the Corn Refiners Association (2006) and NASS (2006), there are approximately 23.2 billion pounds of vegetable oils produced annually (corn: 2.47 billion, soy: 18.71 billion, cottonseed: 0.92 billion, sunflower: 0.31 billion, canola: 0.63 billion, and peanut: 0.17 billion pounds). It is estimated that 85% of all oils have to be transported some time during the oil production and use (raw oil or refined). Based on these statistics, it is calculated that there are over 889,000 tanker loads (44,000 lbs per tanker) of oil per year. Liquid sugars such as sucrose and high fructose corn syrup (HFCS) are also hauled by bulk tankers. Corn Refiners Association statistics (2005) indicate that there was 23.5 billion pounds of HFCS shipped annually. With an estimated 80% of the HFCS shipped by over-the-road tanker-trucks (refined HFCS only), it is calculated that there are over 427,000 tanker loads of HFCS annually. Hauling of unrefined corn syrups was not determined but it is expected to be at least the same volume as the refined HFCS. Combining all products, it is estimated that there is over 5.7 million tanker loads used by food processors each year.

According to the U.S. Department of Transportation (DOT) 2002 Census of Transportation (DOT 2002), there are approximately 231,000 registered food-grade tanker trailers in the US that are used to haul liquid food products. This includes over-the-road transports and farm pick-up tanker-trucks. Farm pick-up tanker-trucks are those that pick up milk directly from a dairy farm while the over-the-road transports haul liquid foods from one facility to another. Based on the US Economic Census data (US Census Bureau 2004), there were approximately 75,200 food grade tanker-trucks on the nation's highways. This means that each tanker potentially averages 78 hauls per year that may require subsequent washes.

Tankers

Tankers can haul liquid food products over long distances and may contain the food product for many days prior to being unloaded (DOT 2005). Some tankers are also loaded onto ships and transported overseas to other countries. Most tankers are manufactured to 3A specifications (3A 2002) and are insulated to limit product temperature changes to approximately 2°F within a 24 hour period at 75°F (3A 2002). For example, when orange juice is loaded into a tanker at 35°F and an ambient temperature of 75°F, after 24 hours the product temperature should not reach a temperature higher than 37°F. All specifications of food grade tankers are listed in 3A standards 05-15 (3A 2002). Standard over-the-road tankers are comprised of a barrel with a manway installed in the top center, 2 bulkheads (fore and aft) with a discharge port and valve in the aft, a ladder to reach the manway, and the standard hitch plate, landing gears, and wheels. Figure 2-1 is a diagram of the key tanker components.

The barrel and the bulkhead comprise the food-contact vessel. A tanker can be insulated or not depending on the composition of a normal load. If insulated, the insulation is sandwiched between the food-contact vessel and an outer shell. All openings are fitted with dust covers and at least one sealing fixture. Valves for food-grade tankers are either the plunger or butterfly type. Plunger type valves consist of a valve body, plunger, plunger seal, plunger cap, and dust cap. The valve body is manufactured from one piece of metal with a tapered mating surface for the seal and is secured to the tanker by bolts with a flange plate. Opposite to the flange plate is a threaded end where the plunger cap is attached. Plungers have a seal end where an o-ring seal is installed and a handle end that is used to operate the valve. The plunger cap is between the ends and is used to secure the plunger to the body by a threaded cap. The valve is operated by inserting the plunger into the body until the plunger seal comes in contact with the machined surface of the body making a tight seal. Butterfly valves consist of a valve body, seal, and butterfly plate. The valve body consists of two pieces, a flange end that attaches to the tanker and a discharge end that allows fluids to be discharged. The two ends are held together by bolts and compression plates where the seal is placed and compressed. The butterfly plate is also installed between the two body ends. In the closed position, the butterfly plate is held tight against the seal. To open the valve, the butterfly plate is turned 90° that places the plate perpendicular to the opening. Since the butterfly plate is held in place by compression, it is not easily removed. Due to easier disassembly for cleaning, the plunger type valve is preferred for food tankers. Chemical tankers can use any valve type but if the tanker's primary use is for food, the plunger valve is usually installed. Transport tankers overall length is 11.9 to 13.4 m (39 to 44 ft) with an inside barrel length of 11.6 to 13.1 m (38 to 43 ft). Barrel diameter is 1.4 m (4.5 ft) for a chemical tanker and 1.6 to 1.8 m (5.3 to 5.8 ft) for food grade tankers. Figure 2-2 is a photograph of a typical over-the-road tanker.

Dedicated Tankers

Tankers may or may not be dedicated to one type of food. For a tanker to be designated as "dedicated", it can only haul one type of product. Ideally, to prevent product cross-contamination, a dedicated tanker is desirable. FDA in their "Guidance for Industry" (FDA 2003) recommended that dedicated tankers would be ideal to transport certain foods since the risk of product cross-contamination is controlled. However, dedicated tankers may not be adequate for the microbial aspect of cleaning since a cleaning regime may not effectively eliminate or reduce microbial contamination. If the tanker cannot be cleaned and sanitized properly, it can still be a source of potential foodborne pathogen contamination even though it is not a product cross-contamination issue. Liquid sugar, primarily sucrose or high fructose corn syrup (HFCS), is one example of a product that usually is hauled only by dedicated tankers. Milk is another product that may be hauled only by dedicated tankers. A dedicated tanker may make over-the-road trips completely empty (termed "deadheading") since it cannot haul another food product (other than a similar product) back to its original location. The practice of deadheading is costly and is generally not an economically reasonable practice for a company (NTTC 2005). Many tankers are not dedicated thereby allowing the tanker company to haul any type of liquid food in return trips that makes transportation costs more efficient. For instance, on a particular day, the tanker may haul pasteurized milk from Location A to Location B. After unloading, the tanker will be cleaned and may haul orange juice back to Location B, since that commodity is not available in Location B. When tankers are used under these conditions, the tanker needs to be cleaned properly to remove any residue of the previous product and to ensure that foodborne pathogens are reduced or eliminated. Sanitary tankers are generally required under FDA inspection according to current GMPs (21CFR110) (FDA 2003), and the Association of Food and Drug Officials "Guidelines for Food Transportation" (AFDO 2004). Under the

Food, Drug and Cosmetic Act and FDA regulations, a food product is considered adulterated if it contains illegal residues of filth, or potentially hazardous substances, or is prepared, packed or held under insanitary conditions. Thus, transport of food products in an improperly cleaned tanker would constitute food adulteration.

Regulatory

Issues and Regulations

The cleanliness of liquid food tankers has been questioned due to a major bacterial foodborne outbreak in 1994 (FDA 2001). In this outbreak, a tanker that hauled raw liquid eggs was not properly cleaned and sanitized prior to hauling an ice cream mix that received no further thermal processing. An estimated 224,000 people contracted salmonellosis (due to *Salmonella enteritidis*) after eating the ice cream with 507 confirmed cases (Hennessy et al., 1996). Also, a tanker was partly implicated in a 1997 outbreak from not-from-concentrate (NFC) orange juice when a tanker hauled orange juice from Mexico was contaminated with *Salmonella* contaminated ice (FDA 2000). An earlier incident that may have caused foodborne illness may have been caused by an improperly cleaned tanker occurred when pasteurized milk was hauled from Mexico to the US (Chomel 1994). This outbreak was of regional concern affecting approximately 120 people. In 2003, the report of the use of food-grade tankers to haul non-food grade industrial wastes again put the spotlight on tanker sanitation (Isbitts 2003).

Hazard Analysis and Critical Control Points (HACCP) System

Because of these potential sources of outbreaks and due to the transport of juice concentrates and certain single strength juices that may carry potential pathogens, FDA became involved with tanker cleanliness and food safety (FDA 2003). Due to the potential for human pathogens in juices (*E. coli* in apple juice and *Salmonella* in orange juice) FDA put forth the HACCP regulation for fruit and vegetable juices (FDA 2004). HACCP system is a management system focused on preventing problems that may lead to unsafe foods. The management system is a common-sense application of technical and scientific principles of food production from field to table (Stevenson 1999), and involves evaluation of all aspects of food production and manufacture, and attempts to prevent, eliminate or reduce the risk of food hazards. Food hazards can be biological, chemical, or physical in nature and are considered as those that are reasonably likely to cause illness or injury, if not controlled (Stevenson 1999). The HACCP regulation stated that juices would be required to undergo treatment at the final processing facility to achieve a 5-log unit reduction of the pertinent microorganism prior to packaging, and, in addition, assure safety from potential chemical and/or physical hazards. Potential chemical hazards that may be present in juice and juice products include potential food borne allergens via cross-contamination during manufacture; improper storage and use of chemicals (e.g., detergents, sanitizers, additives, pesticides, environmental contaminants), and mycotoxins (e.g., aflatoxin, patulins, others) due to mold contamination. Physical issues include potential contamination with glass, metal, and wood fragments. By strict interpretation of the FDA Juice HACCP rule, processors would be required to apply a 5-log reduction process to juice concentrates at the final processing facility, even if a 5-log reduction was previously achieved during the concentration process at another facility and the concentrated juice is simply transported to the final facility for packaging. In response to this requirement, the juice industry proposed, as part of their HACCP plan, that under current industry practices, bulk over-the-road food grade tankers are cleaned and sanitized to a point that does not cause nor contribute to the transfer of potential pathogens, allergens, or other harmful food borne components. Thus, tanker cleanliness is part of a juice HACCP plan, and the effectiveness of cleaning procedures and the cleanliness of over-the-road tankers needs to be verified to ensure that the potential hazards are addressed. The JPA guidelines (JPA Model Tanker Wash Guidelines for the Fruit Juice Industry 2002) were developed in response to this rule. The JPA guideline describes, in general, how to clean a tanker with the appropriate cleaning regimes and cleaning products. The guidelines emphasize the use of a CIP system as a method to clean and sanitize without personnel entering the tanker. The CIP system is described to be able to “impinge” clean the inside walls of the tanker. These guidelines do not specify exact conditions, and while they represent industry best practices, they have not been validated for efficacy.

In the FDA Guidance for Industry: Guidance on Bulk Transport of Juice Concentrates and Certain Shelf Stable Juice, Final Guidance, FDA decided to consider the industry proposal on the over-the-road transport of juices and juice concentrates. As stated in the guidance, …’FDA is concerned with the potential for contamination during bulk transport of juice, as noted below, we have decided to consider the exercise of enforcement discretion as to the single facility requirement provided that certain conditions are met.’ It seems that in deciding whether to enforce standards, FDA is basing the rule enforcement on the situation and the information and documents that are gathered during the investigation of the safety deviation. Information that will be pertinent to the decision is what pre-requisite programs are used and applied, how the HACCP plan was determined, what information is available and how it is used by the affected facilities during this crisis, and what type of deviation occurred. Further enforcement discretion criteria as discussed in the guidance are below (FDA 2003) and can be used for legal actions. FDA intends to consider the exercise of enforcement discretion for covered products when the following three conditions are met:

1. The producer and user (receiver) establish appropriate prerequisite programs and sanitation standard operating procedures (SSOPs) for the bulk transport of covered products.

2. The producer and user designate as a critical control point (CCP) in their respective HACCP plans, the bulk transport of covered products from the production facility to a separate facility for further processing and final packaging.
3. The producer and user establish control measures to prevent, reduce to acceptable levels, or eliminate the risk of contamination or recontamination of covered products during bulk transport.

In the event that there is a rule violation, these criteria are used to determine product withdrawal requirements, product recall, and other penalties.

Cleaning

Food Contact Surfaces

Due to the fact that food supplies nutrients to microorganisms, food contact surfaces have to be cleaned on a regular basis (Katsuyama 1993). According to the FDA cGMPs, 'All food-contact surfaces, including utensils and food-contact surfaces of equipment, shall be cleaned as frequently as necessary to protect against contamination of food' (FDA 2005). Thus, the cleaning of food contact equipment is the action that removes all food residues and cleaning agents from a surface to ensure that the ensuing food is protected from contamination. Cleaning can be performed manually or by mechanical means. Cleaning processes whether manual or mechanical, use the same basic principles to accomplish the task. Effective cleaning requires the proper temperature for cleaning, proper cleaning action, the proper chemical solution concentration, and the proper cleaning time (Marriott 1999). A simple abbreviation for these parameters is "TACT." For manual cleaning, in which a person is in physical contact with the cleaning solutions and the surfaces, the cleaning parameters have to be within safe levels for the person not to be injured (Katsuyama 1993). In manual cleaning, temperature and detergent concentration have to be adequate to remove soils and the cleaning parameters must be within safe levels to ensure that the person is not injured. Cleaning time will be dependent on the person's willingness to work and how well they were trained while the cleaning action is the amount of effort the person will exert to remove soils. Some food contact surfaces or equipment such as over-the-road tankers are designed for mechanical cleaning that requires less exposure of workers to harsh cleaning chemicals and environments. This method is the CIP method in which the cleaning action is replaced by fluid flow and pressure instead of human power. In CIP cleaning the detergent temperature and concentration can be increased to be more effective without injury to the person. CIP processes should be performed to optimize each parameter and to be cost effective (Katsuyama 1993). CIP parameters and standard cleaning procedures are both based on the understanding of what and how to clean. The "how" is the above mentioned cleaning parameters while the "what" is the soil that is to be removed. Soils are defined as residue material that must be removed from a surface. Soils include dirt, grease, and other foreign materials and residue from the previous food product.

Soils

When discussing any cleaning regimen, it is important to start with the soil that is to be removed. Discussion of any cleaning regimen begins with an understanding of the soil to be removed. Not all soils are alike and the differences can be important to effective cleaning. Table 2-1 presents the solubility characteristics of various soils (Marriott 1999). Soils can be classified as water soluble or water insoluble. With water soluble soils, the water readily dissolves the soil and these can be flushed or otherwise removed from the vessel easily. The soils readily are dispersed in the water without re-depositing on the surface. With water insoluble soils, water itself has almost no affect on the soil and a solvent is required to aid the water in the removal process. Solvents are detergents or non-polar solutions that are used to dissolve water insoluble soils.

Microorganisms

Soils also include microorganisms that are entrained in product residue or are present from post-hauling contamination or surface colonization. Microorganisms that can affect a tanker can be as varied as the products and include spoilage, pathogenic, and transient types. Spoilage microorganisms are those microbes that will spoil the product over time if not properly dealt with. Examples of spoilage microorganisms are yeast (*Saccharomyces cerevisiae*, *Pichia membranaefaciens*), bacteria (*Bacillus circulans*, *Alicyclobacillus acidoterrestris*, *Lactobacillus plantarum*, *Leuconostoc mesenteriodes*, *Streptococcu lactis*) and mold (*Penicillium citrinum*, *Aspergillus flavus*, *Geotrichum candidum*) (Jay 2001). Pathogenic microorganisms include the bacteria, such as *E. coli* O157:H7, *Salmonella* species, *Staphylococcus aureus*, and *Clostridium botulinum* and the molds, such as *Fusarium acuminatum* and *Fusarium moniliforme* (Stevenson 1999). Yeasts are less likely to be pathogenic in foods however some may be found (example *Candida albicans*) particularly in water that may cause skin irritations (Tournas 1999). Transient microorganisms typically do not cause spoilage and are not pathogenic but are a nuisance to the microbiologist when evaluating samples. Microorganisms are transient depending on the product since in one product, the microbe is transient but in another may be a spoilage or pathogen type. In orange concentrate, *Bacillus cereus* may be considered transient while in milk, it is a potential pathogen (Bennett 2001). Unlike soils, microorganisms can be entirely removed during cleaning or their population can be reduced by removal or destruction. Removal is by the cleaning that occurs whereas destruction is the inactivation of cells by detergent or sanitizer chemical reactions or by thermal (heat) destruction.

Detergents

Detergents are complex solutions of cleaning, wetting or surfactants, and sequestering agents and may be polar solutions (e.g., acidic, neutral, alkaline), or non-polar solvents. In general, the function of detergent ingredients is to aid in chemically solubilizing the soils (cleaning and wetting agents) and to suspend or retain the soils in solution so they can be discharged from the surface (wetting and sequestering agents). A detergent will have hydrophobic and hydrophilic ends. These are important for soil solubilizing and for soil emulsification for removal ease (Marriott 1999). Specific type and chemical makeup of detergents will also dictate the amount to use (Marriott 1999) and application parameters. Marriott (1999) provides a table that indicates soil types and best used detergent. Non-polar solvents are derived from plant oils (e.g., d-limonene) or are petroleum based (Showel 2006). They have specific uses and usually require a detergent wash and rinse after use. These solvents are not required in cleaning typical food soils. Neutral pH detergents are useful for manual cleaning since the detergent is less corrosive to the skin. Emulsification is accomplished with added surfactants. Acidic detergents are useful for dissolving mineral soils that are left by the food product, by water deposits such as from calcium and magnesium salt precipitates, or by the cleaning agent particularly from alkaline cleaning (Katsuyama 1993). Alkaline detergents are useful to clean most if not all organic material that comprise normal human food as they effectively remove most complex carbohydrate, protein, and fat component removal (Marriott 1999).

When dealing with detergents, the concentration is very meaningful. Detergent concentration is the useful concentration that aids in removing the soils and is dependent on the soil. Low detergent concentrations may be ineffective while high concentrations may not be cost effective or detrimental to soil interaction. The proper detergent used will be dictated by the soil that is being removed. In general, most food soils will be combinations of organic material (sugars, carbohydrates, protein, and fat) and minerals. For example, orange juice is composed of water (88%), carbohydrates (11%) with a small amount of protein (0.5%), fats and oils (0.4%), and minerals (0.3%) (Fennema 1996). Percent and type composition make this soil easy to clean. Milk on the other hand is composed of water (87%), carbohydrates (4.6%), fat (3.9%), protein (3.3%), and minerals (0.7%) (Fennema 1996). Thus, due to higher fat and protein levels, milk soil is more difficult to remove by cleaning than juice. Table 2-2 lists some other typically hauled foods and their components. Most of these soil components can be removed with alkaline detergents. These soils can be solubilized easily in the alkaline nature of the detergent. If the soil is stubborn, the use of chlorine in the alkaline detergent aids in the peptizing of the organic soils particularly proteins (Katsuyama 1999). Peptizing is the re-distribution of the organic material molecules into smaller fragments in order to make the protein easier to remove. The chlorine used is typically hypochlorite and when the detergent is in the use-concentration has a free chlorine concentration in the range of 50 to 100 ppm free chlorine. Due to the high pH of alkaline detergents (10.5 to 11.5 pH), the chlorine is not a sanitizer agent but only as an aid to soil removal (Broze 1999 Showel 2006).

Removal of Potential Allergens During Cleaning

When dealing with soils as "potentially hazardous", the component that is critical for allergen control is the protein. Allergens are proteins that illicit an adverse, immune-mediated reaction to the food (Taylor 1993). With an allergen protein, the human immune system causes an abnormal immunological reaction via the immunoglobulin E (IgE) response to the protein (Yeung 2004). In extremely reactive people, the symptomatic response may be anaphylactic shock which can lead to death (Taylor 1993). A cell mediated response, which is not as crucial, is a delayed reaction immunological response. FDA recognizes eight major food products as causing the majority of food allergies (FDA 2005). Other foods may produce allergenic reactions but these are less common. FDA's "Big 8" is milk, eggs, peanuts, tree nuts, soy, fish, crustaceans, and wheat. Milk (as fluid milk or cream), eggs (as pasteurized liquid egg whites or pasteurized liquid whole egg), peanuts (as peanut butter base), soy (as soy milk and raw soy oil), and wheat (as bread flavor or enhancer or yeast slurry) are the major food allergen containing products that are hauled by tanker-trucks. Combinations of products such as an ice cream mix that would contain milk and eggs may also be hauled by tankers and each allergen component would have to be recognized. Some liquid foods such as refined soy oil may not be listed as allergen-containing since the protein content is negligible due to the refining process (see Table 2) and is exempt from the allergen labeling requirements (FDA 2006). Since most allergens are proteins, special care may be needed to remove them from the tanker surface. As shown in Table 2-1, the use of an alkaline detergent is preferred for proper removal of the protein. The addition of 50 ppm free chlorine at the high pH is recommended as an aid to protein removal. Also, proteins as well as sugars and fats can be affected by heat. This is important for proteins since proteins can still have allergenic properties even after heat treated and denatured (FDA 2005). Watrous (1975) found that an 18°F (10°C) increase in temperature between 90 and 185°F (32 to 42°C) will double the cleaning efficiency. However, above 185°F (85°C) heat-induced interactions occur that bind the milk proteins more tightly to the equipment surface (or "foul" the surface), decreasing cleaning efficiency and potentially leaving a residue. Bradley (1982) found that cleaning milk at 60°C (140°F) appeared to be optimum to remove all milk residues with respect to the detergent. Milk protein residues were quantified after washing in a test-wash solution and were found to be effectively removed at 72°C (161.6°F) (Rasmussen 1978) while a tenacious milk residue was found after cleaning at 77°C (170.6°F). Tenacious milk residue was characterized as being lipid in nature and thought to be a heat induced complex of protein and fat

(Maxcy 1974). These studies seem to indicate that there is a temperature limit when cleaning protein foods and foods in general.

Temperature

As stated above, temperature impacts the detergent effectiveness as well as the characteristics of the soil, and is important to help with the energy requirements for soil removal. Higher temperatures allow the detergent's chemical reactions to be more effective and to also soften soils so that they interact with the cleaning fluid better (Broze 1999). With oil and fat soils, temperatures above the melting point are needed to liquefy the soil for improved chemical reaction. As a rule of thumb, wash water should be at least 2.8°C (5°F) above the melting point of the fat (Katsuyama 1993). Conversely, excessively high temperatures can be detrimental to proper soil removing as pointed out above. Use of excessively high temperatures can bind soils to the surface that makes these soils harder to remove (Watrous 1975; Sikorsky 2001). High temperatures can also cause undesirable chemical reactions between the water, detergent, and soil (Culter 1975 Broze 1999 Lai 2005 Showel 2006). According to Katsuyama, cleaning solutions ideally should be applied between 54 to 71°C (130 to 160°F). Most detergents also have a maximum detergent usage level that once exceeded may cause inactivation of the detergent constituents (Culter 1975 Katsuyama 1993 Broze 1999 Ecolab 2006 Showel 2006). Heat transfer from the cleaning fluid to the surface may also be a source of concern since soils are not only dependent on the temperature but the energy that is applied. As little as 40 kJ/mole of protein or ~40 Btu is adequate to initiate denaturation changes of the protein (Sikorsky 1997). Since heat energy is transferred, the energy in hot water can be transferred to the steel. The fluid volume and the fluid's temperature change can be sufficient to release adequate energy to initial food component changes such as protein denaturation. The phase changes of a cleaning solution can be very detrimental to cleaning since the steam (of high temperature washing) can release more energy (up to 1000 Btu) to the surface than the actual liquid fluid phase (Sikorsky 1997; Singh 2001). Depending on the vapor temperature for typical cleaning, there is approximately 100 kJ/kg more energy in the vapor than in the liquid fluid that can create more damaging affects to the soil (Singh 2001).

Action: Cascade and Impingement

The cleaning action is defined as the kinetic energy that is applied to remove the soil. Cleaning action can be low as in gravitational flow of the fluids down a surface (cascade action) or high as in a high pressure nozzle applied force (impingement action). Some CIP devices may use a vibrating brush or a sonic element for the action. These devices are rare for tanker cleaning but are used in smaller applications. Cascade action can be applied with low pressure but requires relatively large volumes. Adequate fluid flow (pressure and volume) is needed to allow the CIP device to project the cleaning solutions to the intended surface while the volume on the surface is critical to solubilize, disperse, and lift the soil from the surface and then to flush it down and out to the drain. Once the cleaning solutions are on the surface, the action is steady throughout the vessel. Impingement cleaning also requires a certain amount of flow. In impingement cleaning, solution flow is used to remove the soil by abrasion. After the primary impingement (abrasive) action, fluid flow needs to be adequate to move the soil to the drain. Unlike cascade action, the impingement action has different regions on the contacted surface (Efrid 1998). Initial contact is the normal impingement or stagnation region and is approximately 1.5 stream diam. The next region is the transition region in which the stream is redirected axially on the surface. This region is about four stream diameters. The final impingement region is the wall jet region which extends to six stream diameters. This region is cleaning the surface due to the impingement jet moving along the wall and can be considered shear cleaning (Efrid 1998). As the wall jet region gets further from the impingement source, the impingement energy gradually dissipates. Greater than six stream diameters, the impingement energy falls off so that any further cleaning is due to cascade action. At this point, it is important to ensure that there is adequate fluid to move soils down and out the drain. No matter what method is used, it is vital that an adequate amount of fluid is used to ensure that the soil is removed from the vessel.

Impingement impact force is significant for cleaning with this device. Maximum impingement cleaning occurs within the first 1/3 m (1 ft) of the discharge of the fluid (Singh 2001; White 1979). Factors such as the fluids momentum (involving fluid mass and velocity), frictional forces, and temperature affect the force. A small fluid mass would have less force compared to a large mass at the same velocity. Impact force is also affected by the energy loss due to sudden expansion, as would occur in a tanker when the fluid leaves the nozzle (Singh 2001). Once the fluid leaves the nozzle, friction with air will slow the fluid particularly if there is no continued force behind it when the rotating device is moving (Lechler 2005).

To evaluate fluid coverage whether for cascade or impingement cleaning, a riboflavin solution can be used (Voss 1999; FDA 1998). The riboflavin solution is a safe water-soluble dye that can be used for most food or pharmaceutical production applications. Riboflavin solutions (0.02% w/v in water) are applied onto the surface to be cleaned and then rinsed off with the available equipment typically with ambient temperature water and without the use of detergents. This procedure strictly evaluates the cleaning action coverage. After sufficient time has elapsed for fluid coverage, the surfaces are evaluated with a black light (UV light at 630 to 650 μm) to determine riboflavin residue which if found indicates a lack of cleaning action coverage (Voss 1999).

Cleaning Time

The time element is the cleaning time in which all the cleaning parameters are allowed to perform. As with the other parameters, the proper time is important since if the time is too short, the surface may not be cleaned properly while too long of time may not be cost effective. Typically, if the other parameters are low (temperature, concentration, action) a longer cleaning time is needed to clean the surface. If time is essential, then increasing one or a combination of the other parameters may be useful to achieve the same cleaning efficiency.

Previous Cleaning Studies

A survey of tanker cleanliness was conducted to determine the extent of tanker sanitation issues (Winniczuk unpublished). Two wash protocols were evaluated as to their effectiveness to clean tankers. The wash protocols are Type 2 – Cleaning for Water Based Products and Type 4 – Cleaning for Potential Allergen Containing products (JPA 2006) and are available at the JPA website (www.juiceproducts.org). These two wash protocols were chosen as the most likely protocols that would have the biggest impact to the industry. Type 2 wash is a wash to remove water based or easily cleaned food products. Most of these liquid foods are water soluble. According to the JPA Food Commodity list (Appendix A) Type 2 food items are juices, sweeteners, some acid solutions, and alcohol products. These items are mostly water soluble substances. For a Type 4 cleaning, there is a concern that these foods may contain a food allergen. A food allergen is usually a protein component of that food. Most of these foods also contain fats or oils which are not fully water soluble. The lists contain liquid dairy products, liquid egg products, soybean products, wheat containing products, and peanut containing products. All these food products may contain proteins that may cause allergenic reactions in some individuals. These proteins may be harder to remove during the tanker cleaning. With regards to potential allergens, the cleaning of tankers is very important. Unless the tanker is dedicated, there is a risk of cross-contamination. At this time, there is not a definite threshold level for food allergens in foods nor what residue is acceptable. According to some food processing manuals, equipment is considered clean if the food-contact surface is free of visible residue (FPA 2004). However, FDA is critical on equipment cleaning and requires a consistent “no residual” on equipment in order to prevent cross-contamination (FDA 2006). In their “Guidance on Inspections of Firms Producing Food Products Susceptible to Contamination with Allergenic Ingredients” with regard to CIP cleaning of food contact surfaces, they evaluate whether equipment can be cleaned and what the cleaning procedures are. The “no residual” is based on the detection limit of the method used to monitor. FDA has not determined what methods are suitable or what the minimum requirements are. Thus, cleaning failure is left to their discretion during a full audit of the facility. The exact definition of “allergen clean” still needs to be defined.

The tanker survey conducted from 2004 to 2006 indicated that over-the-road tankers might still have potential foodborne pathogens and potential food allergenic proteins remaining after cleaning in various sample sites (Winniczuk unpublished). In Florida, *E. coli, Salmonella,* and *Listeria* were found in 25%, 0.6% and 0.6% respectively in post-cleaned over-the-road food-grade tankers. A cooperating study in Virginia, with dairy transports only, found the levels after cleaning at 65%, 0%, and 0% respectively. Coliform and fecal coliform residual were 60% and 31% in Florida and 92% and 51% in Virginia. For three potential allergens, milk, egg, and peanut, (only evaluated in Florida) the residual (at least 1 ppm/100cm^2 or µg/100cm^2) after washing with the appropriate wash type, was found in 38 of 52 previous load milk tankers, 1 of 3 previous load egg tankers, and 0 of 2 previous load peanut product tankers, respectively. Since the results of the study were found to be not acceptable to the industry, further research was conducted to validate the wash protocols for the juice industry.

To determine whether these results were typical, a review of literature found that milk in dairy tankers was found to contain potential pathogens after the tanker was cleaned (Steele 1997). If the tanker was not cleaned properly, there is a potential that the pathogens may be transferred to the next product. A tanker study in 1975 (Richter) again with milk tankers, found that tankers were cleaned adequately with various CIP methods as long as the CIP sprayer conditions were properly met. However, even under ideal conditions, a surface film was found in some tankers indicating some sort of food or cleaner residue. Bell et al. (1997) evaluated the use of Adenosine Tri-Phosphate (ATP) bioluminescence testing for the cleanliness of tankers. Their research was to determine if ATP measuring methods could be used to assess whether a tanker was clean. Their conclusion was that ATP-bioluminescence testing was a useful tool in aiding to determine whether tankers are clean. However, some of their findings indicated that even after cleaning there was a risk that the tankers may still contain residual microorganisms or milk residue. They found that in 63 to 89% of surfaces tested ATP was still recovered even though no microorganisms were recovered. This indicated that residual milk may still have been on the surface. The research did not identify the soils. Paez (2003) also evaluated the use of ATP-bioluminescence for assessing the cleanliness of milking equipment, bulk tanks, and transport tankers. They did not address the cleaning methods but only evaluated the use of ATP-bioluminescence tests. They also concluded that ATP-bioluminescence can be useful to determine the cleanliness of tankers prior to the application of a chemical sanitizer. Their results indicate that after cleaning a tanker, there were still some unclean sites. Results showed that after cleaning, 33 to 72% of the samples were considered “caution” or “dirty” by the ATP method. Again, no microorganisms were recovered so the cause of the high ATP values is presumed to be residual food with residue dead microbial cells as a possible other cause. The limited amount of research on tanker cleaning may be contributed to the fact that most liquid food products will be pasteurized by some method prior to getting to final consumption (PMO 2003). Typically, a bacterial reduction process effectively deals with the microorganisms but may not affect the residual food (potential allergens). This seems to indicate that another look at tanker cleaning is needed one that removes the soils. Past research indicates that even after cleaning, some residue of the previous load was present. Previous research evaluated tanker cleaning using standard microbiological testing and ATP-bioluminescence as an aid to determining the tanker cleanliness. Even though it was reported that residues were present based on the elevated ATP levels or post-clean visual residues, the residue identity and quantity were not determined.

Assessment of Cleaning/Sanitizing Performance

A discussion about cleaning cannot be concluded until there is an understanding of what is clean. How does one determine the surface is clean? Small amounts of residual food may be sufficient to nourish microorganisms that can become potential health hazards (Kulkarni 1974). In this case, cleaning may be a function of time after cleaning to ensure a safe product. How much allergen residue is too much? Allergen residue may not be affected by time since whatever residue is left may not change over time. With regard to the CIP device fluid coverage test (riboflavin test), they only indicate that the fluid can reach the bulkhead or other areas of the tanker and remove a water-soluble soil however it does not indicate whether the cleaning fluid can remove the actual soil under the typical cleaning parameters. Applying the food or a replacement product may be ideal but requires more effort. What other method can be an aid to determine how clean? This question has been asked for numerous years (Kulkarni et al. 1974).

Visual inspections are subjective and depend on the person, the light source, the observation angle, and whether the surface is wet or dry (Kulkarni 1974). With visual inspections of a surface, the observation of residual food or soil is the first item to look for (Katsuyama 1993). If no apparent food residue is seen, the appearance of the surface is needed. Surface appearance can be seen as shiny stainless steel with no residues, white or other colored residue, and water residue patterns. A shiny stainless steel surface can indicate a clean surface whereas white or colored residue can mean mineral stone, carbohydrate, protein, or fat residue. Water residues on a wet surface can indicate the presence of food residue. On clean surfaces, water tends to sheet as it moves down a surface. If dirty, the water can bead, channel or form droplets (Kulkarni 1974). Also, observations on a wet surface or after it has dried are important to understand if the surface is truly clean. Kulkarni et al suggests that on a dry surface during the inspection, water should be sprayed from a bottle to see how it reacts. This water should react similar to the above wet surface drainage patterns. Visual inspections may not be strict enough to find microorganisms or minute amounts of food residue that could be a concern. Also, all areas of the equipment may not be easily visually inspected as with pipes or tanks or large vessels. Rinse tests of the equipment may be conducted which can be quick and easy. A rinse test is one in which the equipment, after cleaning is rinsed with water and a visual inspection of the rinse water is made. One can also perform microbiological or chemical tests on the rinse water. Again, this test can miss some aspect of the equipment cleanliness. This test also relies on knowing that the water-dispersing device is functioning correctly.

ATP (Adenine Tri-Phosphate)

The use of microbiological or chemical tests is an improvement to visual inspection of the cleanliness but traditional methods can take time. The equipment might be used in a dirty condition long before the sanitation results are available (Marriott 1999). Just-in-time methods such as the ATP measuring devices or the measurement of residual soils (sugars, proteins, fats) is an improvement and currently can be accomplished quickly (FDA 2005). ATP measuring equipment such as BioTrace's Lightning® or Charm Sciences Firefly® is convenient and useful tools to measure residue. This equipment uses a specific swab that is used to pick up residue from a surface. Swabs are then placed into its retaining tube and activated with enzymes and buffer solutions. These release the cleaned surface ATP that was picked up by the swab. They react with the luciferin/luciferinase in the tube and cause a release of energy as light. The activated swab is placed in a reader that measures the light energy and reports the results as relative light units (RLU). The luciferin/luciferase combination of energy release is similar to that of the firefly (*Photuris pyralis*) (Lyon 2000). Various researchers have evaluated the use of ATP measuring devices (Bell 1997; Paez 2003) and found them acceptable for general cleaning purposes. However, their use is limited to what areas can be swabbed by the inspector. Also, the use of ATP measuring has limits of detection in that trace amounts of residue may not be detected or may not differentiate whether the surface is dirty by microbial or food residue. Some units are improving in their detection and differentiation levels and are reported to be able to measure minute amounts of allergens (Charm Sciences 2005).

Allergen Residues

Measuring residual food soils is moving forward with the detection of proteins and allergens being fairly new (Taylor 2001). Research on allergen detection has been ongoing at the University of Nebraska with a number of practical test kits being developed (FDA 2000). Neogen has a method of measuring residual proteins and sugars that can be used as an aid to the sanitarian (Neogen 2004). These devices measure only the residual food component. As with ATP, these materials do have certain limitations. Use of allergen measuring test kits are an aid to determining whether a surface is free of a specific soil (allergen) (Hefle 2003). Most allergen test kits are based on the enzyme-linked immunosorbent assay principle. This method uses a monoclonal antibody of the protein to hold the protein in a microwell. This is the first step in which the test material is added to the microwell. After a reaction time, the well is washed with buffered water and an enzyme-labeled antibody is added that attaches to the protein. After a second wash, a color substrate is added to cause a color reaction. After sufficient reaction time, a stop reagent is added and the color intensity is measured (visually or electronically) and is an indication of the amount of protein (Neogen 2005). These kits are used with a positive control for comparison purposes. Allergen kits are specific and can provide much information to the sanitarian about the cleaning effectiveness.

Clean-In-Place (CIP) Devices

In preliminary validation work ("painted" tanker study) of the survey project, it was noticed that some microorganisms, residual allergens, and some residual food solids (juice pulp or milk residue) were still on the inside surface of the tanker barrel and bulkheads even when the tanker cleaning was followed appropriately. This did not seem possible if the cleaning stream from the CIP lance was hitting the area. In additional work of examining the validation of CIP sprayers, it was found that some parameters of the CIP system might be detrimental to the proper cleaning action of the CIP stream (Winniczuk unpublished). Without the CIP stream actually reaching all the walls, it was concluded that the cleaning regime as written by JPA cannot be properly validated. Soil removal from the surface has to have the fluid contact with the associated detergent and action otherwise cleaning performance may be limited (Seiberling 1999). Any work on the tanker wash validation study should first evaluate the CIP process in order to know that the water stream (including chemical cleaners and sanitizers) is reaching all parts of the inside tanker walls and what is the condition of the stream. CIP spray device manufacturer's recommended a stream validation method which is to place the device outside the tanker positioned along the tanker (if a motor is used, the motor is turned off) and to turn the water on (Peacock 2004 Spraying Systems 2005 Ecolab 2005). Fluids are discharged from the nozzle and should go past the end of the tanker. If the fluid does not go past the tanker end, another nozzle and flow rate combination should be used. Other validation methods are available. One is to listen to the sound when the stream hits the tanker walls. An issue with this method is that echoes may be misleading. Another method is to spray a dilute riboflavin solution (0.02% w/v) on the inside tanker surface followed by running a wash cycle or test spray pattern (Voss 1999). Hydrated riboflavin fluoresces when activated by a UV light at 360 nm. After the test, the tanker or tank is entered and the cleaning or spray pattern is observed with the UV light. If there is an area of fluorescence, the CIP device parameters may be inadequate and they should be re-evaluated and new parameters tested (Voss 1999). Please note that this test is to determine whether the CIP system is capable of delivering the cleaning solutions to all contact areas and not necessarily clean the area. A final wash test is to inoculate the tanker surface with the offending soil and to run a wash and visually or by other method determine if the surface was cleaned by the device and operating parameters. To aid the pharmaceutical industry, FDA has issued the Guideline on General Principles of Process Validation. These guidelines can be applied to the food industry along with the FDA's Guide to Inspection Validation of Cleaning Processes.

In the JPA wash protocol, the application of the cleanser is "under high pressure through a CIP system." The JPA definition of "high pressure wash equipment" states that the equipment can "deliver the cleaning solutions with sufficient force to provide for impergement (sic) to the bulkheads of the tanker" (the term "impergement" probably means "impingement".) In the preliminary work, it was found that some of the bulkheads were not receiving any “impingement” force, which would mean there is very little cleaning action. In reviewing the equipment information, much of the equipment literature came from suppliers. Peacock Company, which supplies many of the CIP sprayer systems to Florida tank wash facilities, indicated that the system is operated at 21 gpm at 600 psi and up to 200°F (Peacock 2004). The system is a low volume high pressure system that theoretically is effective to clean the inside surfaces of a transport tanker by impingement action. The CIP device is operated by an air motor that can be adjusted by the supplied air pressure. Information regarding the rotation speed was not available in the company literature but was supplied when asked (Peacock 2004). The motor’s air speed is used to determine the proper wash cycle. The proper wash cycle determines whether a tanker can be cleaned effectively. Literature states that the system is a single pass type that eliminates the chance of cross-contamination as compared to a circulated system. This is useful with regard to allergen removal since the allergen would be cleaned off and discharged to drain instead of being circulated in the tanker and the CIP pipelines. Unfortunately, in the literature, there was no actual data to indicate the systems performance capabilities.

Spraying System Company, which manufactures CIP devices, indicated how the equipment operates and supplied fluid dynamic performance data but no wash data (SSI 2001). These CIP lances are reported to clean by impingement. Figure 2-3 is an example of a Spraying Systems unit.

Wash data was dependent on all the wash factors and was beyond the scope of the company. Supplier literature indicated that the spray devices operated in a cycle. Cycles were dependent on how fast the spray head was turning (rotation speed) and the various gear configurations. Spray head rotation is in two planes, a horizontal and vertical plane. The two planes can be seen in Figure 2-4. The horizontal plane rotates with the device body whereas the vertical plane rotates around the devices nozzles. Operating cycles were based on how fast the spray body and nozzles would return to its original horizontal and vertical starting point. During the cleaning cycle, the spray head and nozzles would “index” around the tanker thereby theoretically hitting all parts of the tanker internal surfaces with an “impingement” stream. Cycle time also determines how long the cleaning stream will be in a certain area. This can be considered the dwell or residence time in an area. Fast cycle times will have the cleaning stream in an area for a short period of time whereas long cycle times will leave the cleaning stream in an area longer. Indexing is the predetermined advancement of the nozzles after each rotation around the body. Indexing is accomplished by having gears that are off set by one or two teeth. For instance, a master gear would have 35 teeth and a slave gear would have 36 teeth. Typically the master gear is on the body while the slave gear is on the nozzles. During operation, the slave gear would advance by one tooth for each body revolution. This advances the slave gear by 10.3 degrees (360 degrees divided by 35 teeth). Other rotating devices which use the cleaning solutions to cause rotation perform in a similar matter (Gamajet 2002; Sellers 2003). Fluid driven devices typically use a vane or impeller that is installed in the fluids path to actuate the rotation and turn the gears. Gear sizes determine the rotation advance size (degrees). Indexing angles can range from 8 to 15 degrees. Examples of other rotating devices are shown in Figure 2-5 to 2-7.

All rotating CIP devices state they clean by impingement force. The impingement force is dependent on the flow rate volume and pressure. The volume supplies the needed water for cleaning while the pressure supplies the potential energy which combined with volume creates the cleaning force. Based on spray device literature, flow volume is more important for impact cleaning than the pressure (Pagcatipunan 2001). Therefore when attempting to increase impingement action, it would be more important to increase the volume than the pressure for any particular nozzle orifice. This is important since exceeding a critical pressure with the same volume from a particular nozzle, increases the risk of losing the cleaning stream and atomizing the fluids (Weisse 1968; Lechler 2004).

A non-rotating device works differently than the rotation devices. Non-rotating devices are spray balls in which there are many orifices in the ball that direct the fluids to the vessel surfaces (Figure 2-8). A unique spray ball that is used to clean tankers is the Klenz-Spray directional device (Figure 2-9). This device has the standard ball with two horns that are installed opposite each other. The horns have orifices in the end caps that when installed into tankers are positioned to direct the fluids at the bulkheads. This device according to the manufacturers has a limited impingement cleaning area but a very large cascade cleaning area (Klenz-Spray 2001).

Table 2-1. Solubility characteristics of various soils.

Type of soil	Solubility characteristics	Removal Ease	Changes induced by heating the surface
Monovalent salts	Water-soluble, Acid soluble	Easy to difficult	Interaction with other constituents with removal difficulty
Sugar – simple	Water-soluble	Easy	Carmelization and removal difficulty
Carbs – complex	Water-soluble, Alkali- soluble	Easy to difficult	Polymerization
Fat	Water-insoluble, alkali-soluble	Difficult	Polymerizations and removal difficulty
Protein	Water-insoluble, Slightly acid-soluble, Alkali-soluble	Very difficult	Denaturation and extreme difficulty in removal

From Marriott 1999

Table 2-2. Percent composition of some typical liquid foods.

	Food component percentage				
Product	Water	Carbohydrate	Protein	Fat	Mineral
Orange Juice[1]	88	11	0.5	0.4	0.3
Grapefrt Juice[1]	89	10	0.5	0.2	0.3
Liquid sugar[1]	22	77	0.1	0.0	0.5
Milk[1]	87	4.6	3.3	3.9	0.7
Eggs[1]	89	0.7	10.2	0.1	0.5
Peanut butter[1]	7.8	18.8	21.9	50.0	1.6
Soy oil[2]	0.0	0.0	0.0	100.0	0.0
Corn oil[3]	0.0	0.0	0.0	100.0	0.0

1 Fennema 1996
2 United Soybean Board 2007
3 Corn Refiners Association 2006

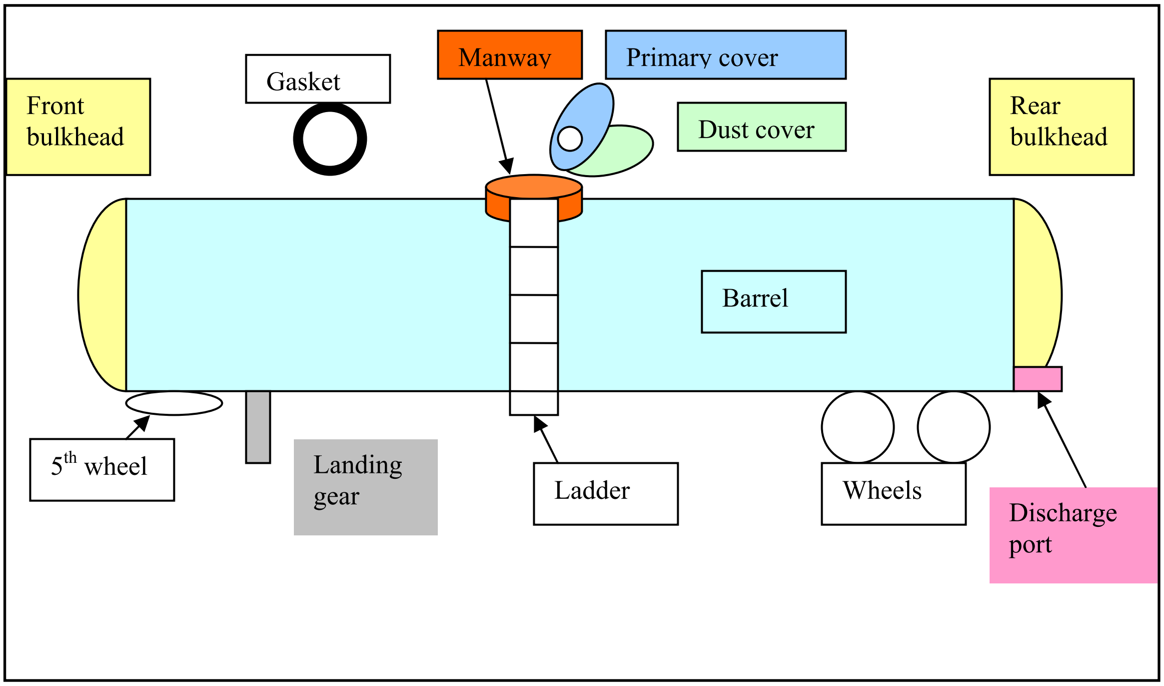


Figure 2-1. Diagram of tanker components.

Figure 2-2. A typical over-the-road tanker. (Winniczuk 2006)

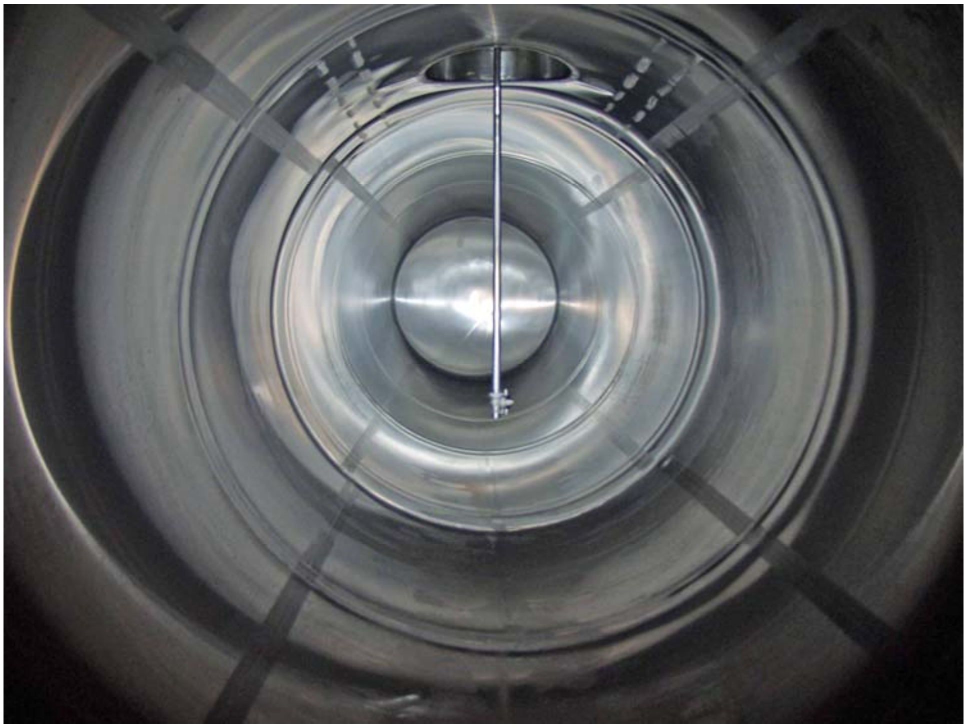


Figure 2-3. The Spraying Systems CIP device (AA190). (Winniczuk 2005)

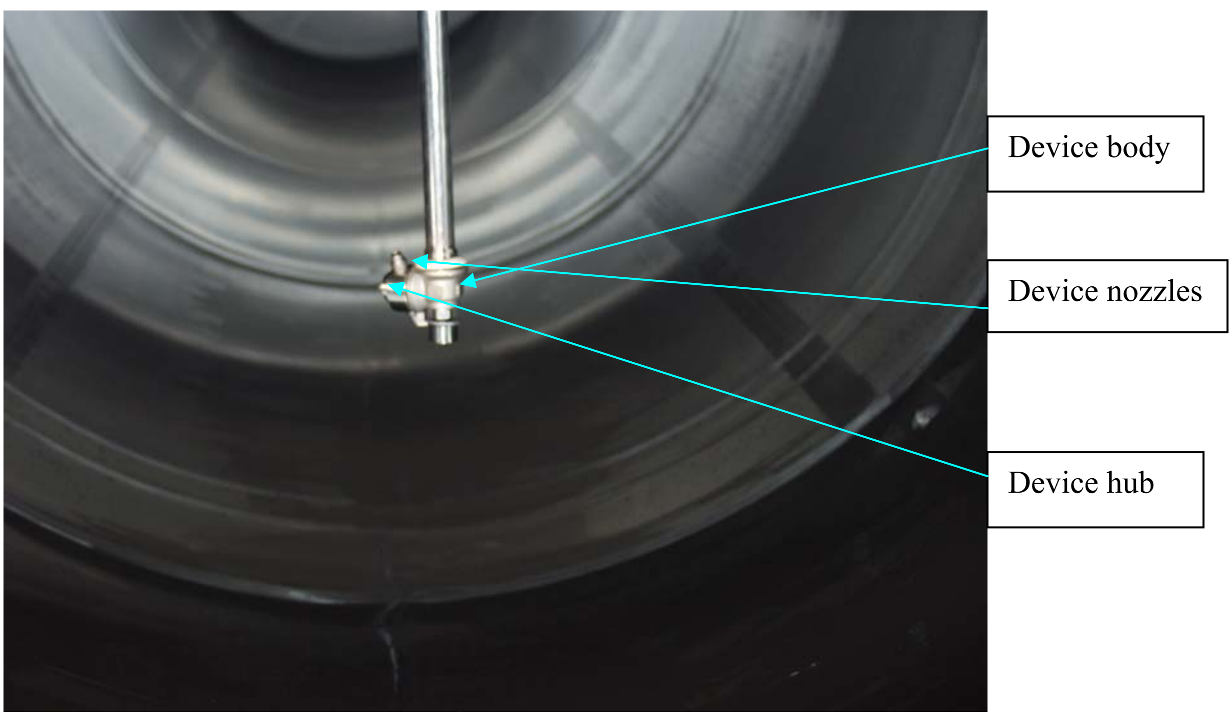


Figure 2-4. Close up of the AA190 spray head. (Winniczuk 2005)

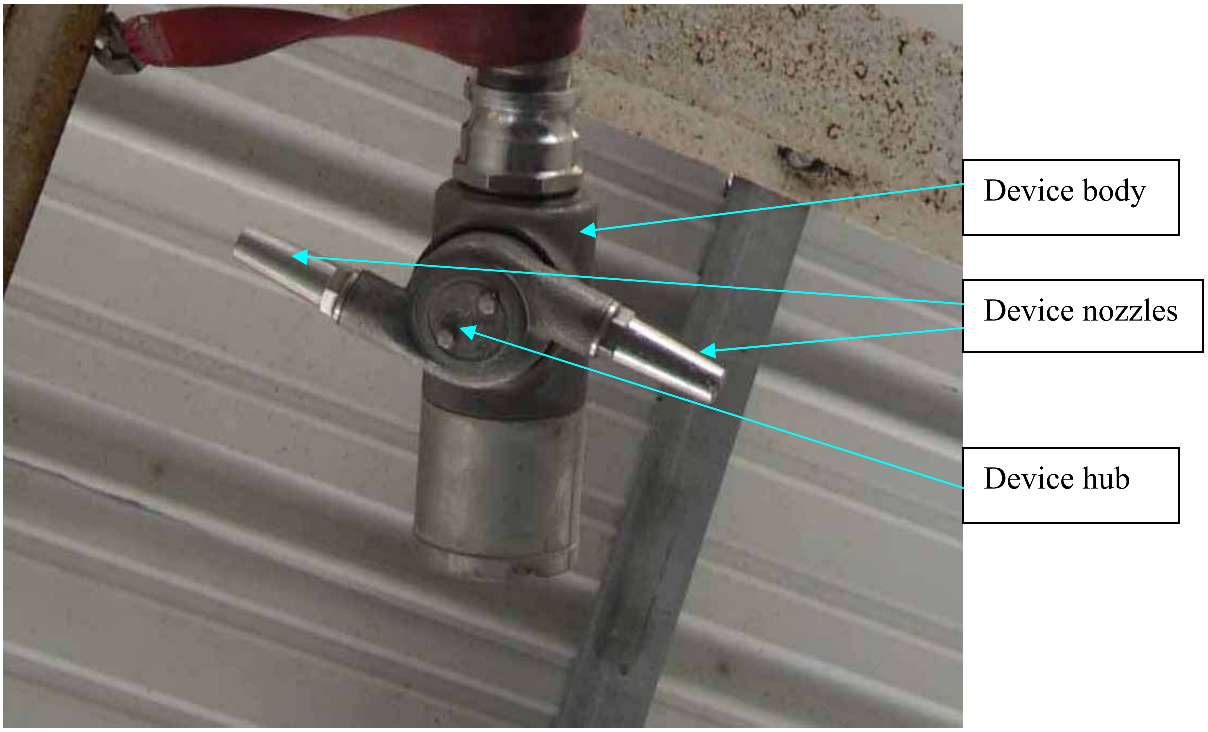


Figure 2-5. The Sellers 360. (Winniczuk 2005)

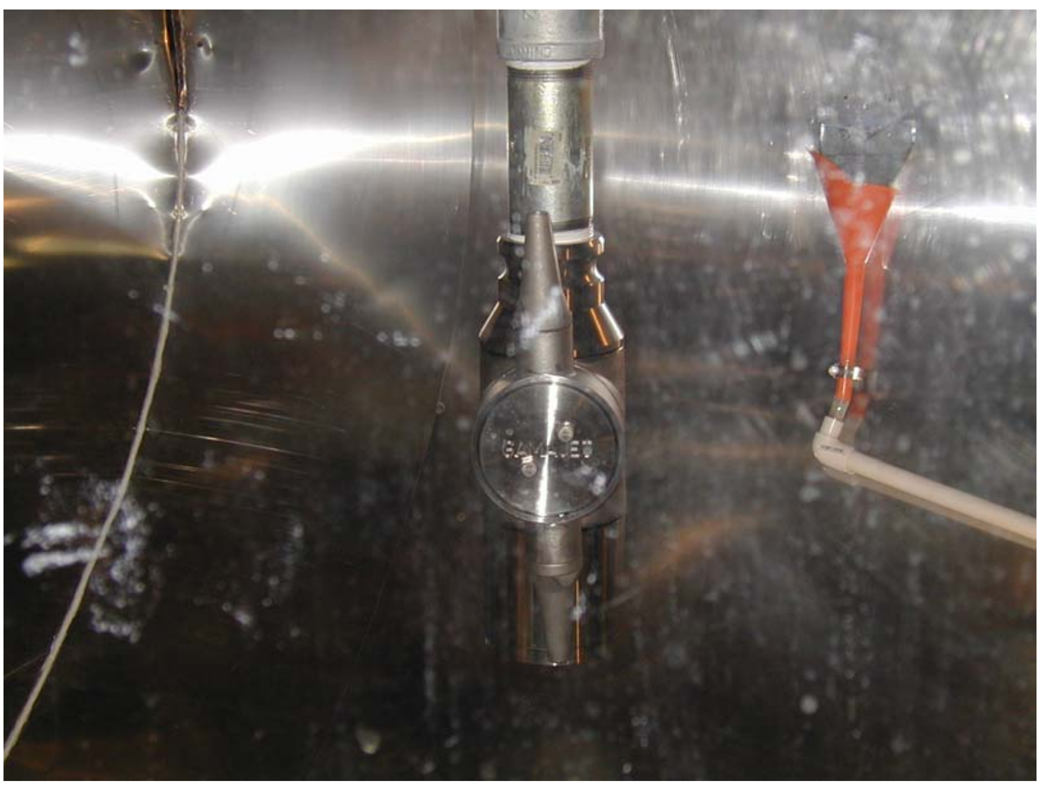


Figure 2-6. The Gamajet IV-GT. (Winniczuk 2007)

Figure 2-7. The Lechler M20. (Winniczuk 2006)

Figure 2-8. Typical cleaning spray balls. (Wise Sprayball Co. at www.wisespray.com)

Figure 2-9. The Klenz-Spray SB 8 directional spray ball. (Winniczuk 2005)

CHAPTER 3
BASELINE RESEARCH

Materials and Methods

Soil Slurry Production

Microorganisms. All microorganisms used in this research were obtained from the University of Florida Citrus Research and Education Center (UF CREC) culture collection of Dr. M. Parish. The microorganisms were chosen due to their innocuous nature and similarity to known juice microorganisms of pertinent importance as required by the juice HACCP rule (FDA 2001). *Bacillus megaterium* (ATCC 14581) was chosen as a surrogate for heat resistant juice spoilage bacteria (e.g., *Alicyclobacillus* species) (Parish 2001) while the yeast *Saccharomyces cerevisiae* (ATCC 2601) was chosen to simulate heat labile spoilage microorganisms. A generic *E. coli* (ATCC 23522) was chosen for heat resistance properties similar to the pertinent food safety microorganism (e.g., *Salmonella*) according to the Juice HACCP rule (FDA 2001). Bacteria (*B. megaterium* and *E. coli*) were grown in Tryptic Soy Broth (TSB), incubated for 2 days at 35°C while the yeast (*S. cerevisiae*) was grown in TSB incubated at 30°C for 2 days.

Single Strength orange juice. A 12° Brix single strength orange juice was prepared by diluting 55°Brix Valencia orange juice with 10% sinking pulp produced at the CREC (June 20-21, 2006) that was stored at -23°C (-10°F) with deionized water. Brix was confirmed with a digital refractometer (Model 10450 A.O. ABBE).

Type 4 soil slurry. Type 4 soil was an equal blend of single strength orange juice (12° ± 0.1Brix), pasteurized whole milk (Publix brand), pasteurized egg whites (Papetti's Liquid Egg), and commercial peanut butter (Publix Creamy brand). The mixture was pH adjusted to 5.5 with sterile 1% sodium hydroxide solution. Riboflavin was added to the mixture at 0.1% wt/wt for fluorescent visibility.

Preparation of food and microbiological slurries. TSB with the bacteria and yeast cultures were transferred to centrifuge tubes (120 x 15 mm 16 ml) and centrifuged at 3,000 rpm for 30 min using an International Clinical Centrifuge Model CL33726M-1 (International Equipment Company, Needham Heights, Mass.). The supernatant was removed from the tubes and the pellets were transferred to the food slurry by rinsing with fresh juice. The allergen slurry and microorganisms were blended well for 2 min at speed 7 using an Oster blender Model Osterizer Galaxie 14 (John Oster Manufacturing Company, Milwaukee, WI). Total mass of the slurry was at least 320 grams which was the minimum mass needed for the tanker surface application.

Inoculation and Application to Tanker Surfaces

The soil slurry was applied onto the tanker surface using a three inch sponge paint roller at the twelve designated sites as shown in Figure 3-1. Each site was 0.6 x 0.6 m. The slurry was rolled on in two directions perpendicular to each other. The soil slurry and all application tools were tarred prior to use and re-weighed after soil application. The difference of post application mass from the pre-application mass was the applied soil mass in the twelve areas. The estimated average inoculation was 1 gram per 100 cm2 with an estimated microbial population of 1,000,000 cfu/100cm2 for each microorganism and allergen concentrations estimated to be 7,000 µg/100cm2 for milk, 8,000 µg/100cm2 for egg, and 14,000 µg/100cm2 for peanut allergens. The allergen concentration was estimated from nutritional analysis data of the products. The soil was allowed to dry for 24 hours at ambient conditions.

Tanker Wash Rack Equipment

For the baseline work, all tankers were supplied by the cooperating wash racks (Bynum Transport, Auburndale FL or Indian River Transport, Winter Haven, FL). The tankers supplied were typically waste heel hold tankers that were not used for actual service or were service-use tankers that were pulled from service for this research. All tankers were at least six years old and had inside barrel length of 12.2 m (40 ft) seam to seam (barrel to bulkhead weld seam) and a diameter of 1.6 m (63 in). For all tankers, the manway was positioned equal distance (6.1 m) from each bulkhead and in the center of the barrel. All the tankers were food grade with AISI 304 stainless steel shell (AISI 2004) and an ASME No. 4 finish (ASME 2001). Prior to use, all tankers were first cleaned by the wash rack using a JPA Type 4 wash followed by a manual clean by the researcher. The manual wash protocol used to standardize residues was as follows;

- Rinse surfaces with ambient temperature water.
- Wash surface with warm water (43°C) and Dawn dishwashing detergent (Proctor and Gamble) (3 fl oz per 1 gallon water) using a green scrubby (3M Industries).
- Rinse with ambient temperature water.
- Wash surface with warm water (43°C) and Fisherbrand Sparkleen 1 for manual washing (Fisher Scientific, Pittsburgh PA) (1 oz per gallon water) using a new green scrubby.
- Rinse surfaces well with ambient temperature water.
- Allow the tanker to dry for 24 hours.

For this study, 12 sample sites were designated in the tankers for inoculation (Figure 3-1). It was deemed important that all sample site information was required to determine if a tanker is cleaned properly. Based on conversations with industry personnel, the bulkhead sites (1, 2, and 3 in the front and 8, 9, and 10 in the rear) were deemed the hardest to clean. The other inoculated areas were 1.2 meters fore and aft of the manway (Sites 5 and 6) and about 3.7 meters fore and aft of the manway for Sites 4 and 7. Also, included were Site 11 (the rear port, external of the flange gasket) and Site 12 (the hatch area including the gasket).

CIP Device and Cleaning

All washes were performed with the CIP system using standard operating procedures for the specific wash rack, strictly adhering to the appropriate guideline for Type 2 or 4 washes of the JPA Model Tanker Wash Guidelines for the Fruit Juice Industry and as directed by the wash facility. The CIP system was either a rotating-low volume, high pressure (R-LVHP) or a stationary-directional-high volume, medium pressure device (Sd-HVMP) operated at the wash rack's parameters based on the configuration and operating parameters suggested by the CIP system manufacturer. Detergent and sanitizer solutions were prepared according to the manufacturer directions and were evaluated for concentration before washing using manufacturer supplied test kits. Wash times were monitored by the facilities CIP system and by a manual clock.

Site Sampling

Tankers were sampled before and after cleaning for comparison purposes. Sample sites are seen in Figure 3-1 for wash-rack tankers. A Spongesicle® with 10 ml neutralizing broth (International BioProducts, Bothell, WA) was used for all swab samples. The before-cleaning sample sites were aseptically sampled by swabbing a 100 cm^2 (2 ½ by 2 ½ swipes of Spongesicle®) of tanker surface. The Spongesicle® was returned to the labeled bag and placed in a cooler with ice packs for the trip to the lab. After cleaning, all parts were replaced onto the tanker and the tanker was closed but not sealed. The after-cleaning samples were taken after the tanker was re-opened. After-cleaning samples were taken near the before-cleaning areas ensuring that the before-cleaning site was not re-sampled. All Spongesicles® were returned to their labeled bags and placed in a cooler with ice packs for the trip to the lab.

Water and sanitizer solutions were collected in a Spongesicle® with the sponge removed but the neutralizing broth retained. Samples were taken before the tanker at appropriate sampling ports if available. Samples taken after the tanker were collected from the rear port after 5 minutes of flow. Cleaning solutions were collected in sterile Whirlpak® bags with a neutralizing solution (0.5% sodium thiosulfate) (Fisher Scientific, Pittsburgh PA). If the collected solutions were hot (detergent solutions or hot rinse water), these were cooled in running tap water prior to placing in the cooler. Additional samples of inside food-contact or outside tanker surfaces were taken as needed to help understand some of the results. All samples were placed in the cooler and transported to the laboratory at the University of Florida Citrus Research and Education Center, Lake Alfred, FL for analytical testing.

Visual Assessment

Visual assessment of cleaning was accomplished by using the guidelines of Kulkarni (1974) and Richter (1975). Visual observations were not limited to the swabbed 100 cm2 but encompassed larger areas and areas that were not swabbed. The after-cleaning observations were performed prior to sampling the food contact surface. A hand-held (MagLight Model 3-D cell, Mag Instruments, Ontario, CA) or a head-mounted flashlight (Eveready Model KE, Eveready Industries, St. Louis, MO) was used for the internal observations. Some areas were touched by hand to feel for certain surface qualities. This was useful for pits, rust spots, cracks, residual soils, and other abnormalities. Visual clean assessment was determined immediately after cleaning and before surface sampling. Examples of what was expected for an unclean surface are; pulp, residual carbohydrates, fat spots (greasy areas due to fats or oils), blue stains (proteins), white stains (milk stone), any color particulates (pipe scale, sand, detergent residue), and water droplet adhesion (indicative of thin film soils).

Visual assessment of cleaning was assigned a numerical score using a 4 point Hedonic scale. Definitions of clean levels are

- 0 = clean surface (no visual residue, no stains, shiny stainless steel)
- 1 = slight amount of pulp present but no stains and surface has shiny stainless steel
- 2 = slurry is visually present but not at the same level as applied
- 3 = slurry is visually present at the same level as applied

Microbiological Analysis

All samples were plated the same day they were obtained. 90 ml aliquots of pre-warmed (45°C) 0.1% buffered peptone water (BPW) (International BioProducts) was aseptically transferred to each surface-swab Spongesicle® sample bag. The sponge of the Spongesicle® was massaged well for at least 60 seconds to release adhered bacteria into the BPW solution. For each liquid sample, pre-dilutions were not needed since it was deemed unnecessary other than for enumerations. All sponge and liquid BPW samples were then serially diluted to -3 and plated in the following manner;

1. *B. megaterium* populations: Samples were plated on Plate Count Agar (PCA) and incubated for 48 hours at 35°C. After determining the total population, the *E. coli* and yeast counts were subtracted to yield the total Bacillus count.

2. Generic *E. coli* populations: Follow methods as outlined for *E.coli*/Coliform Count Petrifilm® (3M, St. Paul, MN). A confirmation test on presumptive positive colonies was performed by aseptically transferring suspect colonies to 9ml tubes of EC-MUG broth (Difco) with an inverted Durham tube and incubated at 44.5°C for 24 hours. Growth, gas, and fluorescence were indicative of a positive result.

3. Presence of *E. coli*: Follow method as outlined by the Ecolite® (Charm Sciences, Lawrence, MA) all-in-one rapid test method using 20 ml of undiluted Spongesicle® sample and 80 ml of 45°C sterile DI water for dilution. Confirmation on presumptive positive samples was as above for populations.

4. *S. cerevisiae* populations: Samples were plated on potato dextrose agar (PDA) acidified with 10% tartaric acid to pH 3.5 +/- 0.2 (aPDA). Plates were incubated at 32°C for up to 5 days. Full counts were typically available at 3 days.

All microbiological analyses were performed in duplicate except for the Ecolite® test which was performed only once per sample. Positive controls were included in each set of sample sets for all protocols as a control for the method. Raw ingredients (juice, milk, eggs, and peanut butter) were also evaluated by these procedures to determine residual contributions.

Allergens

From the SpongeSicle™ sample bag from the microbiological analysis and after removing the required amounts of BPW solutions for the microbiology testing, aliquots of the SpongeSicle BPW were removed for allergen testing. Before-wash samples were serially diluted to -5 in order to be in the range of the test kits. Five milliliters each of dilutions -3 to -5 were placed in pre-labeled 6 x 9 inch sterile plastic bags (Fisherbrand Pittsburg, PA). For all post-wash samples, 5 mL was removed directly from the SpongeSicle BPW samples or the liquid samples and placed in pre-labeled 6x9 inch sterile plastic bags (Fisherbrand Pittsburg, PA). All bags were refrigerated until tested.

Prior to testing, allergen sample bags were removed from the refrigerator and warmed to 40°C and massaged and shaken well. Once warm, test kit procedures were followed for each allergen using a commercially available allergen test kit (Alert Allergen Test Kits, Neogen Corporation, Lansing, Mich.) for each allergen (Total Milk No. 8471, Egg No. 8451, and Peanut No. 8431). A micro-well reader (Stat Fax Model 321 Plus, Neogen Corporation, Lansing, Mich.) was used to read allergen levels in the wells to eliminate subjective evaluations of the wells (colorimetric evaluation). All wells were read at 650 nm at 24°C according to the manufacturer's specification. Allergen tests were performed once per sample but read three times within 2 min and averaged.

Statistical Analysis

The overall tanker wash validation was statistically analyzed with SAS Program version 3.1. Paired comparisons were completed using the Student t-test function of Excel 2003 (Microsoft Corp.).

Results and Discussion

Riboflavin

Preliminary tests of soil removal were tested with a 0.02% riboflavin solution as described by Von (1991). A riboflavin test is deemed an acceptable method of determining the adequacy of a wash protocol or at least the cleaning fluid coverage (Von 1991, FDA 1994). The riboflavin method is used as a factory acceptable test (FAT) for acceptance of equipment cleaning or clean-ability of the equipment (Von 1991, FDA 1994). The results of the preliminary tests at wash facilities (A and C) are seen in Table 3-1 that show that their CIP wash process appeared to adequately clean the riboflavin soil since no fluorescent residue was seen. Based on these observations, it was determined that the CIP procedure was adequate to clean a tanker. Upon further discussion of this project, it was deemed that a real soil should be used in a worse case situation. Therefore the Type 2 and Type 4 soils were developed with a riboflavin tracer.

Type 2 Soil

Preliminary tanker cleaning validation tests were conducted with the Type 2 soil with added riboflavin and microorganisms. The results in Table 3-2 indicated that the Type 2 wash was adequate to reduce soils and microorganisms to low or non-recoverable levels. No riboflavin was seen in any sample site while visual and microbial positive sites were seen in the bulkheads (Sites 1, 2, 3 for front and 8, 9, 10 for rear) which are the sites furthest from the spray device and the hatch area (Site 12) that was manually cleaned. The finding of visual residue (orange juice pulp) in Sites 1 and 8 may be expected since this is the area in the upper most corner of the bulkheads that is reported to be the hardest to clean (NTTC 2002). Pulp was also seen in the barrel closest to the bulkhead (Sites 2 and 3 for front and 9 and 10 for rear) which was not expected.

Considering the distance (approximately 6.1 m) and the wash fluid contact angle (calculated to be about 8 degrees based on the depth of the CIP device), the tanker's ends may be the hardest to clean by a CIP process and the pulp hardest to clean. Depending on the CIP device, the mechanical action may be very small at this distance and angle. Cascade cleaning devices may not be affected by distance or angle since the fluid quantity is the important aspect of cleaning as long as the fluid can reach the area. Impingement cleaning devices would be affected by the distance and angle with a large influence on the impingement cleaning force. Manual cleaning was completed on all tankers which may have had a large factor on the cleaning of the inoculated areas. Manual cleaning is an option in the JPA wash procedures (JPA 2006). It was practiced by all cooperating tanker wash facilities as a precursor to the CIP wash. All tankers were manually cleaned with a low volume, high-pressure hose system (3 to 6 Lpm at 68 bar) at ambient temperature (23 to 31°C) that may have had a large impact on soil removal in these areas. Manually cleaning with a high pressure hose also depends on the distance of the high pressure wand to the cleaning surface. Ideally, high pressure impingement cleaning should be close to the surface to be cleaned (NASA 1999). The cleaning force is reduced exponentially when the distance is increased (White 1979). Typically for manual cleaning, the operator would stand so that the high pressure wand's nozzle was within a m of the surface while on several occasions during the survey, the high pressure wand would be 1.5 to 3 m from the surface in order that the operator does not get wet (Fig 3-2). This procedural change may explain the few sites that had some residue with the potential that the further one stands from the surface, the less likely that all soils will be removed.

Visually, the Type 2 wash completely removed any trace of riboflavin but left minute traces of juice in some areas of the bulkheads and the manway (Table 3-3). Since riboflavin is water soluble, it may be easier to remove with small amounts of water, which may not make it a suitable wash tracer. The juice residue was seen as a pulp or as a film when the surface was dry. The pulp may have required a higher water volume to flush the material or some other cleaning factor needs to be increased. The amount of residue was not considered a major detriment to the cleaning protocol since the residue was considered low. Based on the Hedonic score, no riboflavin residue was seen in any sample at any level (based on fluorescence) whereas juice was seen as pulp or as a discoloration on the stainless steel when dry.

The Type 2 wash appeared to be effective for achieving a 6 log unit reduction in microbial populations even though some soil residue was seen. Table 3-3 shows the results of the surface inoculated microbial populations. The inoculation level prior to cleaning was approximately 6 log units for each microbe (*S. cerevisiae*, *B. megaterium,* and *E. coli*). The populations of *S. cerevisiae* and *E. coli* were totally reduced in all sample sites. It could not be determined whether the reduction was due to removal by the washing process or inactivation by the high temperature (>70°C for at least 10 min). For *B. megaterium*, some residual bacteria were recovered in some sample sites. Sites 1 and 10 were bulkhead locations while Sites 11 and 12 were the rear port and manway. The recovery of the bacteria in the bulkhead may be due to the non-removal of pulp material. Both Sites 1 and 10 had visual residue but no visual riboflavin and also no *S. cerevisiae* or *E. coli*. Sites 11 and 12 were sites that were manually cleaned which may not have been accomplished adequately. Site 12 also had visual residue (pulp) but no fluorescence (riboflavin). The recovery of *B. megaterium* is probably due to the inability of the wash and not to the high temperature since the bacteria’s vegetative cells are not heat resistance but the spores are (Jay 1995).

Please note that only 2 tankers were evaluated for this part and no statistical analysis was completed due to the few samples.

Type 4 Soil

The field work continued with a Type 4 soil with riboflavin. These results are seen in Table 3-4. These results were not expected considering the ideal results of the Type 2 wash. It appeared that the Type 4 wash as it was performed was inadequate to properly clean the soil. Riboflavin was significantly removed from the surfaces even though two sites (Sites 2 and 9 in different tankers) still retained some riboflavin. It was demonstrated that riboflavin was more easily soluble in water that would explain its easier removal. Visual soil residue was seen in many more tankers with the bulkhead areas having more visible soil. For the Type 4 wash, 9 tankers were evaluated with the center of the tankers (Sites 4, 5, 6, and 7) being less soiled than the ends. Visible residue was seen as low soiled areas that had the same appearance as the slurry. Basically, the soil slurry that was applied was not removed. It appeared that the manual cleaning process was inadequate to remove this soil. Considering that the manual cleaning process used ambient (~23°C or 73°F) water, some of the fatty components of the soil may have protected the area (Wilkins 1993). Typically, to remove fatty soils, a temperature at least 3°C (5°F) higher than the fats melt point should be used (Schmidt 2001). This soil slurry also contained proteins that may be harder to remove or may be cooked onto the surface by the high wash temperature (minimum discharge of 71°C [160°F] recommended by the JPA. To achieve this discharge temperature, a feed temperature of 80-88°C [176 – 190°F]) is required. Once cooked on, the protein soil (e.g., milk stone) will require a more severe cleaning regimen to remove it (Marriott 2006).

As with the Type 2 wash, *S. cerevisiae* and *E. coli* reduction appear to be easily accomplished. Both were found in the manually cleaned areas (Sites 11 and 12, rear port and manway respectively) which may be due to a lack of manual cleaning. *S. cerevisiae* was also found in one Site 1 (front top bulkhead) which may be due to the final rinsing. Conversely, *B. megaterium* was recovered in many more tankers and sample sites throughout the tanker indicating that it was not easily removed. Considering that the bulkheads had the highest recovery rates (33 to 55%) it appears that the wash is inadequate and that the Type 4 wash is not acceptable.

Sample sites were inoculated with an approximate 5 log unit inoculum (Table 3-5). Thus, for *S. cerevisiae* and *E. coli*, in general the Type 4 wash resulted in an approximate 5 log unit reduction. Manually cleaned sites had a lower reduction which may be due to the lack of training for proper cleaning or to post-cleaning contamination of the site. Even when microbial residue was recovered, it was low (1.23 log/100cm^2 or <20 cfu/100cm^2) with an effective 3 to 4 log unit reduction. Microbial reduction again is probably due to a combination of wash removal and thermal, chemical, or combined thermal/chemical inactivation. Conversely, *B. megaterium* being more heat and chemical resistant was recovered more frequently and at a higher population (up to 600 cfu/100cm^2). In CIP cleanable areas (Sites 1 to 10) populations were lower indicating wash removal and thermal or chemical inactivation while manual cleaned Sites 11 and 12 were due mostly to removal and chemical inactivation since clean-out-of-place (COP) solutions were not high enough for thermal inactivation (maximum temperature of 38°C [100°F]). It was surmised that vegetative bacteria were probably removed or inactivated while spores were retained in the soil slurry residue.

The residual soils were further identified by determining the allergen residue (part of the slurry). Table 3-6 shows the number of tankers that were positive for each allergen that was in the slurry. Peanut allergen material appeared to be cleaned easily by the wash while milk allergen material seemed to be the least cleanable. Again, the bulkheads seemed to have the highest recovery of allergens (milk, egg, and peanut) indicating a lack of cleaning effectiveness in these areas. Areas closer to be CIP device (Sites 4, 5, 6 and 7) seemed to have the best results. Again, this seemed to indicate that the Type 4 wash was inadequate for this soil. The residual soils may have been the reason that *B. megaterium* was able to be retained on the surfaces (Mosteller 1993).

Table 3-6 shows results of the riboflavin and visual scores and the residual allergen concentrations. Both riboflavin and visual scores are based on a visual observation of the residues with observations taken perpendicular and obliquely to the surface and when the surface was wet and dry. Riboflavin residue was seen in only two locations (Sites 2 and 9) and was at low concentrations since the fluorescence was not very visible or was spotty in the area (Fig 3-3). Soil was also visible under normal light. The soil concentration was determined by a Hedonic scale with 0 being clean (no visible residue wet or dry) and 3 being dirty at the level of inoculation. The average of the visual scores was typically below 1 which indicated that the area appeared clean when wet but had a residue when dry. A level of 1 was given when some residue was seen when inspected wet. Typical wet residues were traces of the slurry, greasy look, and water beading. It appeared that the bulkheads had the highest residue level indicating that these areas are harder to clean.

Sample sites were inoculated with an average allergen residue of >3.8 log units (6310 $\mu g/100cm^2$) (Table 3-6). After washing, the concentration of allergen residue was low, typically less than 1 log per $100cm^2$ (<10 $\mu g/100cm^2$). The results indicate that allergens were reduced by approximately 3 log units. Peanut allergens were least likely to be found and if found were very low (<0 log). This may be due to the fact that peanut proteins are water soluble globulins

(Fennema 1996; Breiteneder 2006) and may be intricately bound to the fats which make it easier to remove with heated wash fluids (Bigalke 1978). Milk and egg allergens had higher recovery rates which may be significant for the next product. The exact allergen residual levels that can be left on a surface are not known (Deibel 1997). Ideally, there should be no recoverable allergens or at least below the method's detection limit (Marriott 2006). Detection limits are presented in Appendix D. Egg allergen levels were relatively distributed equally throughout all sample sites with the highest levels in the bulkheads. Egg allergens averaged -0.4 log units/100cm^2 or 0.4 μg/100cm^2. This average is below the method's detection limit but is significant since egg allergens were recoverable up to 3 μg/100cm^2. Milk allergens (as whey and casein proteins) were recovered at higher concentrations with the lowest levels near the tanker's center. The fact that allergens were recovered at lower concentrations near the tanker's center which was closest to the CIP device, seems to indicate that the tanker's bulkheads may be harder to clean and therefore the more critical area to ensure cleanliness. Milk allergens in the tanker's center (Sites 4 to 7) were recovered at 0.1 to 0.5 μg/100cm^2 whereas at the bulkheads, allergen levels ranged from 0.4 to 49 μg/100cm^2. The bulkheads seem to be the critical cleaning areas when considering the removal of allergens. A HACCP plan should consider this and the cleaning protocol should emphasize cleaning these areas.

When considering the allergen residue, there is not a definite target residue value for clean this might be significant to prevent illness. The FDA (FDA 2003) states that the residue should be below the method's detection limit while Marriott and Gravani (2006) state that there should be no residue. The Food Processors Association (FPA) states that "allergen clean" is when the surface looks clean (Stevenson 2004). Food Allergy and Resource Program (FARRP) seem to indicate that a residue of about 10 ppm may be a safe level for most allergen sensitive consumers

(FARRP 2002). Table 3-7 is a compilation of potential allergen residues in foods that may cause a response from susceptible individuals (Bindsley 2006) and the equivalent surface residues from a tanker. The results indicate that allergen residue levels up to 500 μg/100cm^2 may be acceptable for the majority of allergen sensitive individuals (1:100 allergen sensitivity rate) while a level of 1 μg/100cm^2 may be acceptable for the most sensitive allergen individuals (1:1,000,000 allergen sensitivity rate). Given this information, the FDA and the Marriott and Gravani suggested residues should probably be used.

A high wash temperature may be ideal to remove or inactivate microorganisms but may be the cause of the allergen residues (Katsuyama 1991). Figure 3-4 shows the average temperatures for the standard Type 2 wash with a rotating, low volume, high pressure CIP device. The return temperature typically rose to the minimum wash temperature within 5 min after commencing the wash with feed temperatures reaching 87°C (188°F). Based on the baseline results, it was concluded that the high wash temperature combined with the detergents low residence time due to the rotating device and possibly the low fluid volume, left baked-on soils. Allergens are proteins and proteins can be denatured by heat with moist heat more damaging than dry heat (Maxcy 1974). A lower wash temperature may be needed to remove the allergens and still be effective to reduce microbial populations (Kulkarni 1974; Ecolab 2003). Various researchers have found that a reduced wash temperature is effective to reduce microbial contamination and adequately clean a surface (Wilkins 1993).

Wash Temperature

Since microorganisms and allergens should both be removed from a tanker, a modified wash procedure was tested utilizing a lower temperature than recommended by the JPA wash (71°C [160°F] minimum discharge). The results of using a feed temperature of 71°C (160°F) (discharge temperature of >52°C (125°F) instead of a discharge temperature of 71°C (160°F) are in Table 3-8. This temperature was used based on literature (Maxcy 1974; Wilkins 1993; Ecolab 2003). Results showed riboflavin was effectively removed and microorganisms were reduced but visual and allergen cleanliness were not achieved. The test's conclusion was that the wash temperature had little effect on the removal of the allergens and that something else may be a factor. During the lower temperature trials several observations seemed to indicate that the CIP devices were not performing as expected. Working with the tanker wash facilities, it was observed and eventually shown that the fluids from the CIP devices were not reaching all parts of the inside of the tanker (Fig 3-5) sufficiently to remove soils. However, the fluids as a mist with the heat were adequate to remove the water soluble riboflavin tracer. This result may indicate that the use of only riboflavin as a soil for determining cleaning performance may over-estimate the cleaning performance.

Conclusion

The baseline conclusion is that the wash protocol is not effective to properly clean a food-grade tanker. Based on the soils residues and visual observations and with regards to the few trials (2 trials for Type2 and 9 for Type 4), the wash protocol's lack of soil removal (microorganisms, soils, and allergens) may be due to the fact that the CIP devices were not properly distributing the cleaning fluids to all the tanker's internal surface areas and that the detergent concentration and temperature may not be the cause of this lack of cleaning. Based on the visual observation of the CIP fluid delivery as seen in Figure 3-5, it was determined that further validation studies could not be conducted until a review of the CIP systems and devices was conducted. It became apparent that the CIP system was not delivering wash fluids (water, detergents, and chemical sanitizer) to all parts of the tanker's interior which would affect the soil removal.

Table 3-1. Data from preliminary wash tests with riboflavin soil.

	Number of positive samples (n = 3)[1]			
	Facility A[3]		Facility C[4]	
Sample Sites[1]	Type 2	Type 4	Type 2	Type 4
1	0	1	0	1
2	0	1	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	1	1
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0

[1]Riboflavin 0.1% wt/vol was the only soil. [2]Sample sites are those as seen in Figure 3-1. [3]Facility A used R-LVHP CIP device. Operated at 75 Lpm @ 41 bar with no nozzle extensions and air motor speed at 2.8 bar. [4]Facility C used Sd-HVMP CIP device. Operated at 492 Lpm @ 4.7 bar installed randomly.

Table 3-2. Results of field validation for Type 2 wash with Type 2 soil.

	Number of samples positive for cleanliness quality (n = 2)[1]				
	Soil[2]		Microbiology[3]		
Sites	Riboflavin	Visual	Sacc	Bac	Ecoli
1	0	2	0	1	0
2	0	1	0	0	0
3	0	1	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	2	0	1	0
9	0	1	0	0	0
10	0	2	0	0	0
11	0	0	0	0	0
12	0	1	1	2	0

[1]Only 2 samples completed before determining device issues. [2]Riboflavin and visual assessment at wet conditions. [3]Results are the number of positive samples. Sacc = Saccharomyces cerevisiae Bac = Bacillus megaterium Ecoli = *E. coli* (generic)

Table 3-3. Type 2 post-wash average of residues per $100cm^2$.

Residue assayed	Average soil Hedonic score (n=2)		Average microorganism population (n=2) [3]		
	Riboflavin score [1]	Visual score [2]	Sacc	Bac	Ecoli
Inoculation level before wash	3 (0)	3 (0)	6.0 (0.1)	6.1 (0.2)	6.1 (0.2)
Sample Sites					
1	0 (0)	1.0 (1)	-1 (0)	-0.3 (0.5)	-1 (0)
2	0 (0)	0.5 (0.5)	-1 (0)	-1 (0)	-1 (0)
3	0 (0)	0.5 (0.5)	-1 (0)	-1 (0)	-1 (0)
4	0 (0)	0 (0)	-1 (0)	-1 (0)	-1 (0)
5	0 (0)	0 (0)	-1 (0)	-1 (0)	-1 (0)
6	0 (0)	0 (0)	-1 (0)	-1 (0)	-1 (0)
7	0 (0)	0 (0)	-1 (0)	-1 (0)	-1 (0)
8	0 (0)	0.5 (0.5)	-1 (0)	-1 (0)	-1 (0)
9	0 (0)	0.5 (0.5)	-1 (0)	-1 (0)	-1 (0)
10	0 (0)	1.0 (1)	-1 (0)	0.9 (0.2)	-1 (0)
11	0 (0)	0 (0)	-1 (0)	-0.3 (0.5)	-1 (0)
12	0 (0)	0.5 (0.5)	-1 (0)	-0.3 (0.5)	-1 (0)

[1]Riboflavin score based on 4 point Hedonic scale: 0 = clean (no visible residue) to 3 = dirty (residue similar to application level). Value in parenthesis is the standard deviation. [2]Visual assessment is based on wet and dry stainless steel on a 4 point Hedonic scale; 0 = clean (no visible residue) to 3 = dirty (visual residue similar to application level). Value in parenthesis is the standard deviation. [3]Microorganisms results are log values with the standard deviation in parenthesis. A value of -1 indicates no recovery. Sacc = Saccharomyces cerevisiae, Bac = Bacillus megaterium, Ecoli = *E. coli* (generic)

Table 3-4. Results of field validation work for Type 4 wash with Type 4 soil.

	Number of samples positive for cleanliness quality (n = 9)[1]							
	Soil residues[2,4]		Microbiology[3,4]			Allergen[3,4]		
Sites	Riboflavin	Visual	Sacc	Bac	Ecoli	Milk	Egg	Peanut
1	0 ba	8 ab	1 ba	5 ba	0 ba	8 ab	3 ba	1 ba
2	1 ba	3 bb	0 ba	3 bb	0 ba	6 bb	3 ba	1 ba
3	0 ba	3 bb	0 ba	2 bb	0 ba	3 bb	1 ba	1 ba
4	0 ba	1 bb	0 ba	0 bb	0 ba	2 bb	1 ba	0 ba
5	0 ba	0 bb	0 ba	1 bb	0 ba	0 bc	2 ba	0 ba
6	0 ba	0 bb	0 ba	2 bb	0 ba	1 bc	1 ba	0 ba
7	0 ba	0 bb	0 ba	1 bb	0 ba	1 bc	2 ba	0 ba
8	0 ba	1 bb	0 ba	3 bb	0 ba	7 bb	4 ba	1 ba
9	1 ba	3 bb	0 ba	4 bb	0 ba	5 bb	2 ba	1 ba
10	0 ba	2 bb	0 ba	3 bb	0 ba	7 bb	3 ba	1 ba
11	0 ba	2 bb	2 ba	3 bb	1 ba	2 bb	2 ba	0 ba
12	0 ba	0 bb	4 ba	7 ba	1 ba	6 bb	4 ba	1 ba

[1]9 tankers completed before determining device issues. [2]Riboflavin and visual assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty. [3]Results are the number of positive samples for Sacc (Saccharomyces cerevisiae), Bac (Bacillus megaterium), and Ecoli (*E. coli*). [4]First letter in each column indicates the significant difference ($P<0.05$) between sample sites for each test parameter. Second letter in each column is the significant difference ($P<0.05$) between test results (riboflavin to visual; Sacc to Bac to Ecoli; and milk to egg to peanut).

Table 3-5. Field work Type 4 post-wash log average and range population per $100cm^2$.

	Microorganism[2]		
	Saccharomyces	Bacillus	E coli
Average log population before wash[1]	5.45 (0.9) a	5.95 (1.0) a	5.83 (0.8) a
Sample Sites [3]			
1	-0.78 (0.27) b	0.37 (0.88) b	-1.00 (0) b
2	-1.00 (0) b	-0.14 (0.60) b	-1.00 (0) b
3	-1.00 (0) b	-0.78 (0.27) b	-1.00 (0) b
4	-1.00 (0) b	-1.00 (0) b	-1.00 (0) b
5	-1.00 (0) b	-0.63 (0.35) b	-1.00 (0) b
6	-1.00 (0) b	0.33 (0.79) b	-1.00 (0) b
7	-1.00 (0) b	-0.51 (0.39) b	-1.00 (0) b
8	-1.00 (0) b	-0.78 (0.27) b	-1.00 (0) b
9	-1.00 (0) b	0.03 (0.70) b	-1.00 (0) b
10	-1.00 (0) b	0.50 (0.84) b	-0.43 (0.47) b
11	1.23 (1.12) b	2.50 (1.91) b	0.53 (0.86) b
12	0.82 (1.01) b	1.88 (1.42) b	-1.00 (0) b

[1]Average value of 3 sample sites for each tanker before washing (n = 27). [2]Microorganism results are the average log values with the standard deviation in parentheses. A value of -1 log (0.1 µg/$100cm^2$) indicates no recovery. Letters in columns indicate difference compared to before wash control samples. [3]The sample sites are those in Figure 3-1.

Table 3-6. Type 4 average visual and allergen concentration per 100cm^2 .

	Soil		Allergen [4]		
	Riboflavin	Visual	Milk	Egg	Peanut
Residue assayed	Score [2]	Score [3]		Log population	
Average before wash[1]	3 (0)a	3 (0)a	3.93 (0.1)a	4.40 (0.8)a	4.51 (0.9)a
Sample Sites [5]					
1	0 (0)b	0.7 (0.4)b	0.22 (0.45)b	-0.31 (0.51)b	-1 (0)b
2	0.1 (0.1)b	0.6 (0.4)b	0.10 (0.63)b	-0.27 (0.54)b	-1 (0)b
3	0 (0)b	0.6 (0.4)b	-0.40 (0.50)b	-0.63 (0.37)b	-1 (0)b
4	0 (0)b	0.1 (0.2)b	-0.51 (0.43)b	-0.59 (0.40)b	-1 (0)b
5	0 (0)b	0.0 (0)b	-1 (0)b	-0.40 (0.48)b	-1 (0)b
6	0 (0)b	0.0 (0)b	-0.28 (0.57)b	-0.78 (0.27)b	-1 (0)b
7	0 (0)b	0.0 (0)b	-0.35 (0.57)b	-0.40 (0.48)b	-1 (0)b
8	0 (0)b	0.6 (0.4)b	0.82 (0.87)b	-0.40 (0.48)b	-1 (0)b
9	0.2 (0.1)b	0.5 (0.4)b	0.82 (0.87)b	-0.35 (0.52)b	-1 (0)b
10	0 (0)b	0.4 (0.3)b	0.83 (0.74)b	-0.31 (0.54)b	-1 (0)b
11	0 (0)b	0.1 (0.2)b	0.54 (0.93)b	-0.15 (0.64)b	-1 (0)b
12	0 (0)b	0.4 (0.3)b	0.56 (0.87)b	-0.27 (0.56)b	-0.91 (0.13)b

[1]Before wash average value of 3 sample sites for each tanker before washing (n = 27).
[2]Riboflavin assessment is visual inspection for fluorescence when wet on a 4 point Hedonic scale; 0 = clean. 3 = dirty (initial inoculum level). The result is the average value with the standard deviation in parenthesis. Letters in the column indicate difference from control.
[3]Visual assessment is based on wet inspection on a 4 point Hedonic scale; 0 = clean. 3 = dirty (initial inoculum level). The result is the average value with the standard deviation in parenthesis. Letters in the column indicate difference from the control.
[4]The results are the average log unit values with the standard deviation in parentheses. A value of -1 log indicates no recovery. Letters in the columns indicate difference from the control.
[5]The sample sites are those seen in Figure 3-1. For each site n = 9.

Table 3-7. Calculated allergen content in Single Strength Orange Juice (SSOJ) with variable surface residues on food contact surfaces.

				Allergen content in SSOJ based on post-wash surface residue ($\mu g/100cm^2$)[1]					
$\mu g/100cm^2$				0.1	1	5	10	20	500
Estimated mg per 240 ml serving [2]				$8x10^{-6}$	$8x10^{-5}$	$4x10^{-4}$	$8x10^{-4}$	$2x10^{-3}$	$4x10^{-2}$
	Sensitivity								
		mg range[3]							
Allergen	Group	Low	Target	Possible allergen response					
Milk	$1:10^2$	$2.8x10^{-1}$	$8.7x10^{-1}$	No	No	No	No	No	No
	$1:10^6$	$7.1x10^{-5}$	$5.9x10^{-4}$	No	Yes	Yes	Yes	Yes	Yes
Egg	$1:10^2$	$2.4x10^{-2}$	$1.5x10^{-1}$	No	No	No	No	No	Yes
	$1:10^6$	$3.3x10^{-6}$	$1.0x10^{-4}$	Yes	Yes	Yes	Yes	Yes	Yes
Peanut	$1:10^2$	$1.9x10^{-1}$	$6.6x10^{-1}$	No	No	No	No	No	No
	$1:10^6$	$5.0x10^{-4}$	$4.9x10^{-3}$	No	No	Yes	Yes	Yes	Yes
Soy	$1:10^2$	$1.3x10^1$	$4.1x10^1$	No	No	No	No	No	No
	$1:10^6$	$3.0x10^{-1}$	$2.4x10^0$	No	No	No	No	No	No

[1]Residues are per $100cm^2$. [2]The estimation is based on complete transfer of surface allergens to the next product and based on 6531 $100cm^2$ squares per 12.2 m long tanker. [3]Sensitivity and range data is based on research by Bindsley 2006.

Table 3-8. Results of field validation work for Type 4 wash with lowered temperature (71°C feed and ≥52°C discharge).

	Number of samples positive for cleanliness quality (n = 2)[1]							
Sample	Soil residue		Micro [5]			Allergen [6]		
Sites [2]	Riboflavin [3]	Visual [4]	Sacc	Bac	Ecoli	Milk	Egg	Peanut
1	0	2	2	2	0	2	2	0
2	1	2	0	2	0	2	2	0
3	0	2	0	1	0	2	1	0
4	0	1	0	0	0	2	1	0
5	0	0	0	0	0	0	2	0
6	0	0	0	0	0	1	1	0
7	0	0	0	0	0	1	2	0
8	0	1	2	2	0	2	2	0
9	0	2	1	2	0	2	2	0
10	1	2	0	2	0	2	2	0
11	0	2	0	2	0	2	2	0
12	0	0	0	0	1	2	2	1

[1] The results are the number of positive sample sites for the soil assayed.
[2] Sample sites are those seen in Figure 3-1. For each site n = 2.
[3] Riboflavin assessment is visual inspection for fluorescence when wet on a 4 point Hedonic scale; 0 = clean. 3 = dirty (initial inoculum level). The result is the number of positive sample sites. [4] Visual assessment is based on wet inspection on a 4 point Hedonic scale; 0 = clean. 3 = dirty (initial inoculum level). The result is the number of positive sample sites.
[5] The results are the number of positive samples for each microorganism. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic). A positive result was ≥1 cfu/100cm^2.
[6] The results are the number of positive samples for each allergen at ≥1 µg/100cm^2 using the Neogen Allergen test kit.

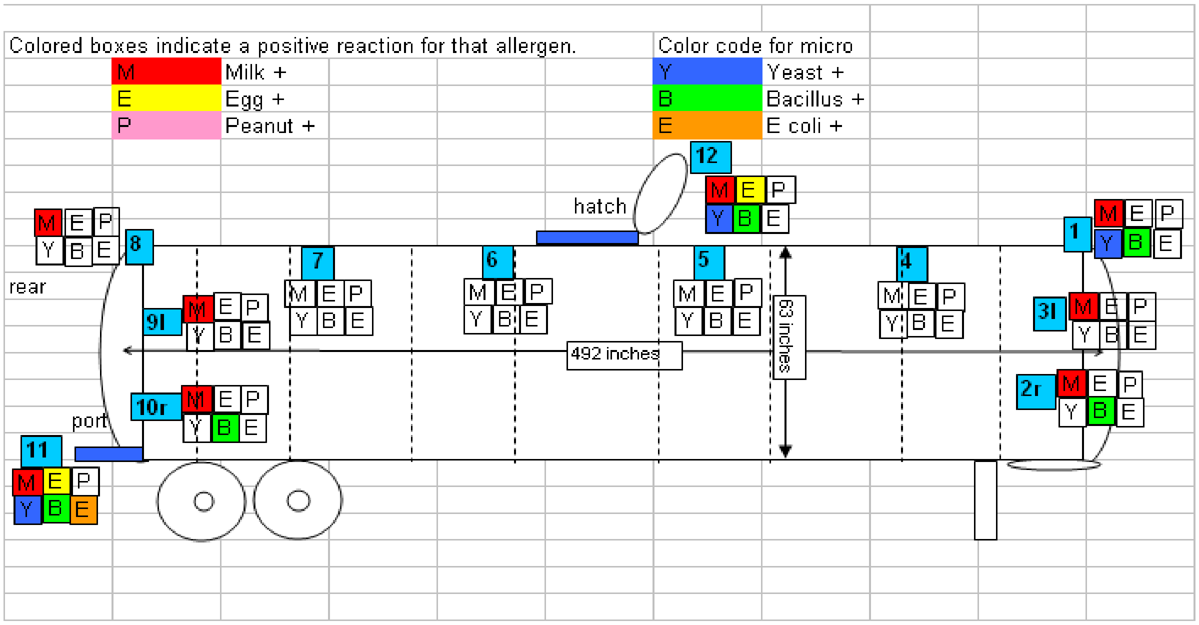


Figure 3-1. Inoculation sites on tankers for field survey work.

Figure 3-2. Manual cleaning of bulkheads. (Winniczuk 2005)

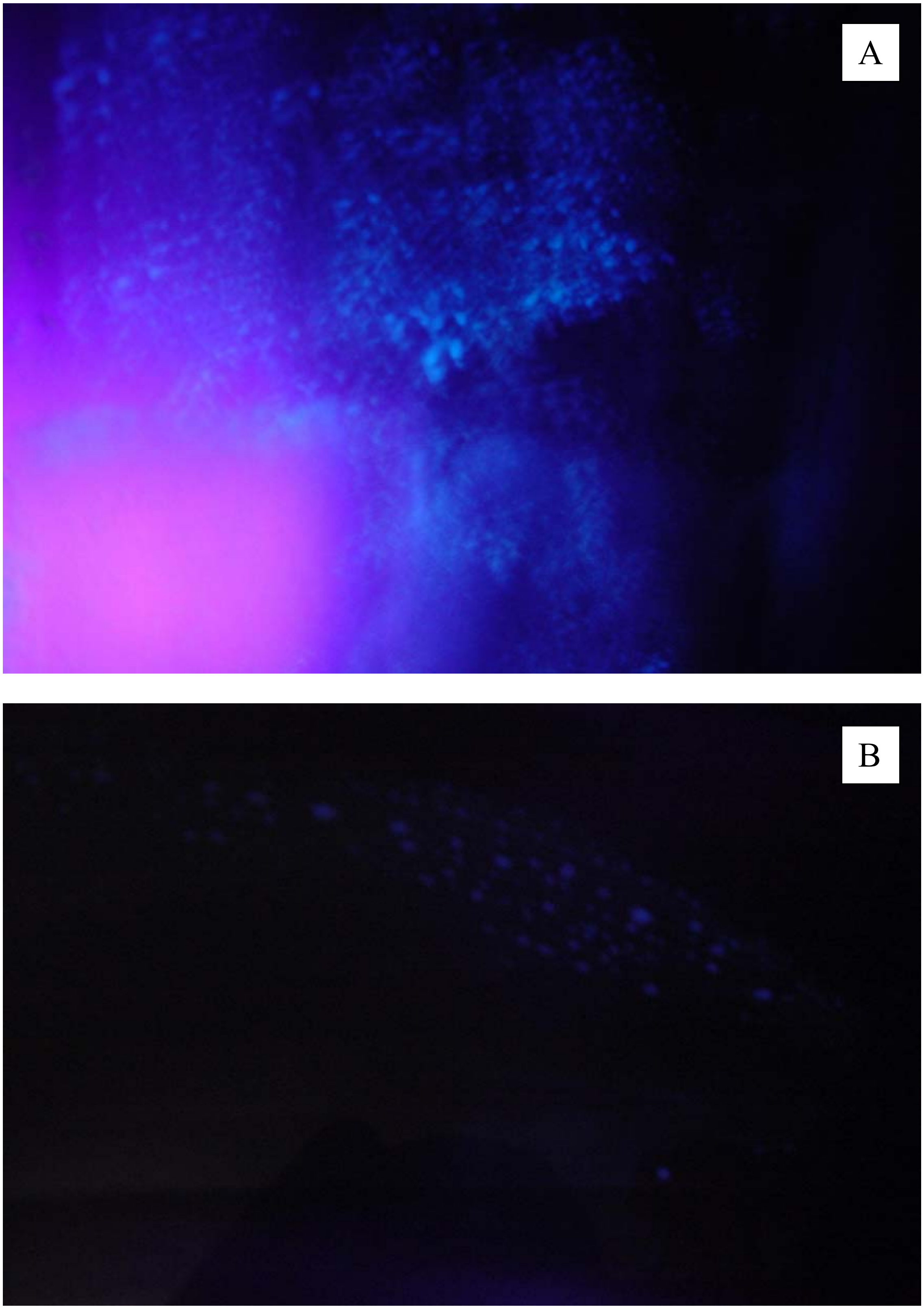


Figure 3-3. Riboflavin residue pre-wash (A) and post wash (B). Light blue is the fluorescent riboflavin.

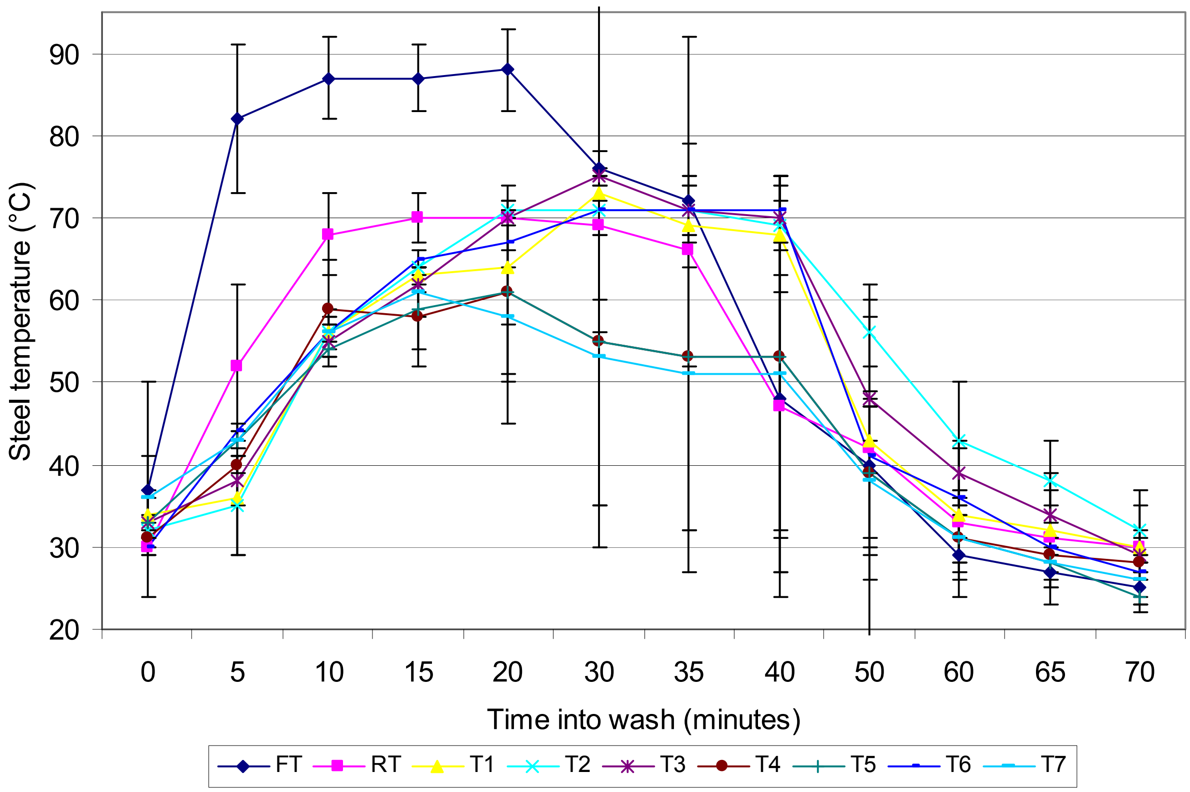


Figure 3-4. Temperature profile of tanker cleaning (R-LVHP device). (n = 6)
FT = feed temperature; RT = return temperature; T1 = front top bulkhead; T2 = 3 m from front bulkhead; T3 = 1 m forward of manway; T4 = 1 m aft of manway; T5 = 1 m from rear bulkhead; T6 = rear top bulkhead' T7 = discharge port.

Figure 3-5. Visual confirmation of CIP device. Figure is of the R-LVHP device installed 2/3 of tanker diameter into manway.

CHAPTER 4
THE CIP DEVICES

Introduction

Based on observations from the baseline work that showed that the fluids may not be contacting every internal surface area of the tanker, it was deemed important to confirm the CIP device performance prior to continued wash validation. Originally, the CIP devices were validated by the manufacturer's recommended procedures and were observed to be adequate. However, field observations indicated poorly cleaned areas when the JPA wash procedures were followed. Further, it appeared that under some flow conditions, there was neither fluid contact nor impingement at the tanker walls. A wash protocol cannot be properly validated if the CIP device cannot distribute the wash solutions properly. A CIP device that does not perform adequately may give misleading wash protocol results. It was, therefore, determined that a more in-depth investigation of CIP performance was needed prior to doing further cleaning protocol evaluation. These investigations have the following objectives: the first objective was to collect fluids at each sample site location within a tanker during cleaning. It was surmised that if fluids could not be collected at a sample site, then adequate cleaning could not be conducted in this area. The second objective was evaluate the removal of a mild water-soluble soil (11°Brix orange juice) from the sample area using an ambient temperature rinse. Adequacy of soil removal was determined by visual observation. Due to safety considerations (confined space permit required) and the inability to measure flow rate in a commercial tanker, a model tanker was fabricated with similar dimensions to those of a typical commercial liquid bulk tanker.

Materials and Methods

Tanker Equipment

As described above, because safety issues and limitations of the field trials, a laboratory model tanker (hereafter referred to as the UF C-Thru model tanker) was constructed. The UF C-Thru model tanker allowed visual observations of the internal surfaces without entering the tank (Figure 4-1). The tanker was constructed of a wood frame and a stainless steel and Lexan plastic tanker barrel. The wood was used to form a sturdy frame while the metal formed ¾ of the barrel allowing a surface area similar to real tankers. The Lexan plastic was chosen due to its high strength, flexibility, and temperature and chemical stability. The Lexan also allowed good visual observations with minimal distortion. The model tanker length from the manway center to the end was 6.7 meters (22 ft) with an overall length of 7.6 meters. The barrel diameter was 178 cm (70 in). These dimensions were used since they were representative of the current largest food grade tanker (Oakley PC 2005). The wood frame was built to the tanker dimensions (178 cm by 178 cm inside frame measurements) using cross-bars to make an octagon of 35.6cm for each side. Stainless steel sheets (13 ft by 4 ft, 18 gauge T304SS) were supplied by Oakley Transport (Lake Wales, FL). The interior or food contact side was polished to a #4 (150 grit) finish (AISI 2005) while the exterior or non-product contact side was a mirror or reflective finish (AISI 2005). The metal sheets were fitted into the wood frame to form the barrel. The metal provided the top, bottom, and one side of the barrel. The steel sheets were overlapped by 10 mm from front to back to allow drainage and installation of fasteners to each 2x4 cross-bar. In the open side of the barrel, Lexan plastic sheets (Lexan D210 Home Depot, Winter Haven, FL) were fitted with #10 nuts and bolts for metal connection and #10 ½ in stainless steel screws for the wood. A Bettes 19 inch diameter, 5-lug manway (compliments of Bynum Transport, Auburndale, FL and Brenner Tanks, Mauston, WI) was fitted to one side and secured with tie downs.

To collect the cleaning fluid, metal sluices constructed of 18 gauge galvanized steel and plastic funnels (Model FloTool 10701, Hopkins Manufacturing Corp., Emporia, Kansas), both locally purchased (The Home Depot), were attached to the tanker's stainless steel barrel walls with stainless steel bolts and nuts. Sluice and funnel locations were 0, 0.3, 0.9, 1.5, 2.1, 2.7, 3.4, 4.0, 4.6, 5.2, 5.8, 6.4, and 6.7 m (0, 1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, and 22 ft) from the spray device. Location 6.7 (6.7 m) was the bulkhead with two sample Sites 22c and 22t, which were the bulkhead center and top respectively. For the barrel sluices, the sluice top edge was placed at 1.52 m as measured along the barrel circumference from the tanker top center. The bulkhead sluices were placed at 15 cm (bulkhead top samples) and 110 cm (bulkhead center) from the bulkhead top. The top edge of the sluices were cut in a "V" and caulked to facilitate flow into the funnels. The funnels were connected to ½ inch polyvinyl chloride (PVC) tubing (Home Depot, Winter Haven, FL) that were directed to the rear of the tanker and into tarred, labeled pails.

During the wash cycle (15 min minimum based on JPA guidelines and wash facility standard operating practices), the fluids were collected at each location. Wash runs were repeated 3 times for each treatment. At the end of each wash run, the pails were weighed and the flow rate at each location from the CIP device was determined based on run time and area (1.52 by 0.1 m). The surface flow rates were determined using the following calculation (Equation 4-1);

$$(\text{lbs fluid collected x } 0.455 \text{ L/lb}) = \text{L collected} \div 15 \text{ minutes} = \text{Lpm} \div 0.152 \text{ m}^2 = \text{Lpm/m}^2 \quad (4\text{-}1)$$

lbs is the pounds of fluid collected at each site. 0.455 is the conversion of pounds to liters. 15 minutes was the collection time. Lpm is liters per minute.

Proper CIP device performance was based on whether the device was able to distribute the cleaning fluids to all internal areas of the tanker. Previous investigations (Bakka 1995; Seiberling 1999) suggested that a flow rate of 8.2 Lpm/m2 (0.2 gpm/ft2) is required for a heavily soiled tanker, 4.2 Lpm/m2 (0.1 gpm/ft2) for a light wash, and 1.6 Lpm/m2 (0.04 gpm/ft2) for rinsing. The objective for CIP performance testing was to collect cleaning solutions in all solution sampling sites. CIP devices were assessed by the highest recoverable solution rates at each sample site as determined by the volume as liters per minute per square meter (Lpm/m2) of cascade contact surface.

CIP Devices

Three different CIP device types that are in common commercial use were evaluated. CIP device brand names and models should be held confidential and are only used for example purposes in these investigations. The following work does not endorse nor repudiate any particular CIP device or supplier, but is a comparison of general device types. The research results only indicate the cleaning effectiveness of each particular device type, when used under the specific operating conditions. The following three representative devices were evaluated.

Rotating, Low Volume, High pressure (R-LVHP): The R-LVHP device is a low volume, high pressure device that is used in a one pass wash system, and is frequently used in commercial washing facilities. Examples include: the Spraying Systems AA190 and the Sellers Rotojet. Typical operating conditions at a tanker wash facility are 18 to 26 gpm at 500 to 1200 psi (68 to 98 Lpm at 34 to 83 bar) (flow rate and pressure measured at the pump discharge) with a 40 to 60 psi turret speed. Based on the device manufacturer's literature, these devices are reported to use impingement as the primary cleaning action with cascade cleaning as a secondary action. The Spraying Systems AA190 (supplied by the Spraying Systems Inc., Wheaton, Illinois) was used for this study. The manufacturer supplied the air regulator and filter and an array of nozzles. Nozzle extensions were purchased locally (The Home Depot).

Rotating, High Volume, Medium Pressure (R-HVMP): The R-HVMP device is a high volume, medium pressure CIP device. Examples include: the Sellers 360, Lechler M20, and the Gamajet IV-GT units. Based on manufacturer's literature, these devices are reported to use impingement as the primary cleaning action with cascade cleaning as a secondary action. Typical operating conditions at tanker wash facilities are: 85 to 100 gpm at 95 to 115 psi (pressure measured at the pump discharge) and a turret speed based on flow. Turret speed was visually measured at 16 rpm at 95 gpm and 110 psi. The Sellers 360 (supplied by Indian River Transport Inc., Winter Haven, FL) was used for this study.

Static Directional-High Volume, Medium Pressure (Sd-HVMP): The Sd-HVMP device is a stationary, directional CIP device that operates at high volume (range is 80 to 150 gpm) and has no moving parts. Examples include: the Klenz-Spray SB8 and the Sani-Matic TS-4. Based on manufacturer's literature, these devices are reported to clean by cascade action only and recommended operating parameters are 110 to 120 gpm @ 65 psi or 120 gpm @ 45 psi, respectively. Observations at the tanker wash facility indicated typical operating parameters of 90 gpm at 90 psi (pressure measured at the pump discharge). The Klenz-Spray SB-8 unit was supplied by Ecolab (St. Paul, MN), the manufacturer and was used for this study.

Calculation and Determination of Rotating Device Impingement Angles

Since rotating devices are reported to clean by impingement, the impingement angles were calculated and determined in the C-Thru tanker. Impingement angles were determined with the following equation (Equation 4-2);

$$1/\tan(\text{brl dis} \div \text{hd dis}) = \text{contact angle} \qquad (4\text{-}2)$$

Where Tan is tangent, ‘Brl dis’ is the barrel distance in m for the impingement point, and ‘Hd dis’ is the head distance into the tanker in m.

To confirm the angles, the impact angles were measured in the C-Thru tanker using a protractor. The CIP device was installed at the desired depth (86, 112, and 137 cm) into the tanker. A cotton string was attached to the device head and extended to the barrel at the sampling devices at the same head height. Impingement angles were only taken at the device head height at the barrel.

Determining Center and Degrees Off-Center for Sd-HVMP

To determine proper center and off-center installation of the Sd-HVMP device, a two point alignment system was used one on the manway neck and one on the bulkhead. The circumference of the manway and the bulkhead at 6.7 m was calculated and divided by 360° to determine the mm per degree. A cotton string was attached with a metal screw at the manway at the appropriate site and extended and attached to a screw to the respective site at the bulkhead. A plumb line bob was dropped from this string to aid in the alignment. A second string was attached to the device’s nozzle at the largest center orifice with metal wire. This string was extended to the bulkhead along the plumb line. The circumference was calculated using Equation 4-3 and Equation 4-4 for the distance per degree at the respective radii.

$$\Pi d = \text{circumference of circle (in mm)} \tag{4-3}$$

$$\text{circumference} \div 360 = \text{mm/degree} \tag{4-4}$$

Where “Π” is Pi and “d” is the diameter of the circle (manway at 0.48 m or bulkhead at 13.4 m)

Determining Pitch for Sd-HVMP

To test the Sd-HVMP pitch angle effect, an appropriately sized wooden wedge (Home Depot) was inserted in the front of the manway cover to obtain a high angle and in the back of the manway cover to obtain a low angle. To determine the pitch of the Sd-HVMP, the angle of the upturned nozzle was measured with a protractor, based on the vertical drop of the device. For the standard installation the vertical drop was the device's water pipe. For the other angles, a plumb line was dropped from the top of the C-Thru barrel and used as the vertical drop. The angle of the upturned nozzle was measured based on this vertical drop and not on the device's water pipe.

Device Qualification

To reduce the amount of final wash tests, the spray devices were qualified by administering an ambient temperature rinse to remove a water soluble soil. The qualifications allowed for the evaluation of the flow rate effect. Prior to a qualification run, the tanker stainless steel surface was cleaned following the previously mentioned manual cleaning process. The water soluble soil was an orange juice solution (11° Brix), prepared from orange juice concentrate (55° Brix) obtained from UF CREC stock (June 17, 2006 production). The juice was applied at 10° C with a manually operated spray bottle onto the stainless steel side of the C-Thru tanker from 0 to 6.7 m and the bulkhead and from the top dead center line to the top of the sluices. The inoculation strength was estimated at 0.8 gm/100cm^2. The inoculation was allowed to dry for at least 6 hours prior to qualification runs. CIP device qualifications were run at the evaluated device operating parameters with ambient temperature water and without the use of detergent. The Type 2 wash time guidelines were used for the qualification runs.

Soil Inoculation

Prior to inoculation with a soil, the C-Thru tanker's stainless steel was clean using the following procedure.

- Rinse surfaces with ambient temperature water.
- Wash surface with warm water (43°C) and Dawn dishwashing detergent (Proctor and Gamble) (3 fl oz per 1 gallon water) using a green scrubby (3M Industries).

- Rinse with ambient temperature water.
- Wash surface with warm water (43°C) and Fisherbrand Sparkleen 1 for manual washing (Fisher Scientific, Pittsburgh PA) (1 oz per gallon water) using a new green scrubby.
- Rinse surfaces well with ambient temperature water.
- Allow the tanker to dry for 6 hours.

The UF C-Thru model tanker was designed to be half the length of a typical over-the-road tanker since it was expected that a CIP device would wash in a symmetrical pattern so half a tanker was adequate to represent the entire wash procedure. With this in mind, the inoculation sites were increased in order to better understand the cleaning potential and to explain some of the findings in the field work. Again, prior to inoculation the tanker was manually washed as previously described. Inoculations sites in the UF C-Thru tanker were 1.2, 2.4, 3.7, 4.9, and 6.1 m (4, 8, 12, 16, and 20 ft) from the manway on the barrel. Barrel inoculation sites were in the upper 1/3 of the barrel except for Sites 4.9 and 6.1 m which had 2 zones for the sample site, an upper and lower site. The bulkhead at 6.7 m (22 ft) was also inoculated and was sectioned in 3 zones, 6.7t, 6.7m, and 6.7b. The purpose of zoning sample sites was to determine wash down movement of soils. Figure 4-2 shows a diagram of the UF C-Thru model tanker with the sample sites.

Cleaning Method

CIP device qualifications were run at the evaluated device operating parameters with ambient temperature water and without the use of detergent. The Type 2 wash time guidelines were used for the qualification runs.

Cleaning Assessment and Sampling

Visual assessment of cleaning was completed prior to swabbing an area. All swab sampling was accomplished with a SpongeSicle® with 10 ml neutralizing broth (International

BioProducts, Bothell, WA) following by microbial and chemical evaluations. All ATP and AccuClean tests were completed after the microbial sampling with every effort used to ensure the same sampling area was not used.

Statistical Analysis

The overall tanker wash validation was statistically analyzed with SAS 9.1 (SAS Institute Inc., Cary NC May 2007). Paired comparisons were completed using the Student t-test function of Microsoft Office Excel 2003 (Microsoft Corp. Bellevue, WA April 2006).

Results and Discussion

CIP Device Field Validation

For the field validations of the CIP devices, the validation was performed as suggested by the device or system manufacturing companies (SSI PC 2004, PCS PC 2005, LSS PC 2005, GJS PC 2005, ECO PC 2005). The validation procedure was observed on several occasions during the tanker wash survey and was repeated for this work.

Stationary, directional-high volume, medium pressure (Sd-HVMP)

The Sd-HVMP device was positioned outside a tanker so that the device was placed where it would be if inside the tanker and with the directional components pointed to the bulkheads. The water was turned on and the fluid reach was observed. Operating parameters and observations are in Table 4-1. When operated at facility conditions, the device would typically send the water 9.1 m (30 ft) and have a width of 4.6 m (15 ft). The directional nozzles sent the water in an arc that aided in the delivered distance. These nozzles were sufficient to deliver the fluid well past the 6.1 m bulkhead while the center ball combined with the directional nozzles were sufficient to deliver the water to cover the tanker's radius width (0.83 m). The solid stream portion was not that important for this device since as discussed with the manufacturer (Ecolab PC 2006), the device cleans by cascade forces and would deliver adequate wash fluids to cascade clean the tanker and that the device was angled to ensure that fluids would travel along the barrel to all locations. Since it was not possible to see the device inside the tanker, their explanation was plausible and realistic.

Rotating high volume, medium pressure (R-HVMP)

One of the manufacturers' suggested test method for this device was to remove the drive vane and to place the device along side a tanker, with the nozzles oriented toward the bulkheads, turn the water on, and observe the fluid reach. Most cooperating facilities were reluctant to disassemble the device due to warrantee issues. Most cooperating facilities were also reluctant to test this device in their wash bays while it was turning since it was expected to distribute water throughout the wash bay and would make a mess. At one cooperating facility, after removal of some electrical devices and protecting others with plastic sheeting, and without a tanker in the bay, did test their device for this research. The wash bay floor was measured and marked for the tanker dimensions. The device was hung from a ceiling support and braced well. The water was turned on and the water reach was observed. These results are also in Table 4-1. It was observed that the fluid easily reached 10.9 m in all directions that was expected since this is a rotating device in that the nozzles change direction during its cycle. However, the solid stream appeared to only have a 9.2 m reach. Since this device is reported to clean primarily by impingement, the solid stream is important to deliver the impingement force. Considering that our tankers' bulkheads were 6.1 m from the manway, this should be adequate. Any additional water flow would be an aid in the cascade cleaning effect.

Rotating low volume, high pressure (R-LVHP)

The manufacturer's suggested method of testing this device was to place the device along the side of a tanker with the air motor turned off, orient the nozzles toward the bulkheads, turn the water on, and observe the fluid reach. Again, the results are in Table 4.1. The fluid stream was observed to go past the tanker's bulkhead. The fluid was measured at 7.6 m which would be adequate to reach the tanker's bulkhead distance of 6.1 m. However, the solid stream, which would have the most impingement force, was seen only to 4.8 m which means that 1.3 m of the tanker, on either end, would not receive the impingement forces (Figure 3-5). Since this device cleans primarily by impingement forces, the last few m of the tanker would have to be cleaned by cascade forces. Based on facility and system manufacturer information, it was surmised that the device was adequate to perform its function. When the results were discussed with the system manufacturer, it was explained that the device does clean by both forces and with an adequate pre-CIP manual cleaning, should clean a tanker properly (Peacock Cleaning Systems PC 2004).

Based on the results in Table 4-2 and from discussions with the system or device manufacturer, it appears that the systems and devices should be adequate to clean the inside of a tanker. However, based on the results of the preliminary validation work this was not occurring for some reason. Based on observations from the outside of the tanker and to better understand the CIP device performance, a series of tests were run to determine the device performance. These results are seen in Table 4-2. Based on these results, it appears that there are some issues with how the CIP systems and devices are performing. Since working in an enclosed tanker is not the best option, an alternative method was needed to determine CIP system and device performance. The alternative was the construction of the UF C-Thru Model Tanker (Figure 4-1). The tanker was capable of being driven to a wash rack and having the CIP device inserted into the manway (Figure 4-3). With this tool, the device performance at the wash rack were better visualized and discussed with pertinent personnel.

Fluid Reach Performance Validation

RLVHP

Due to the positive microbiological and allergen results of the field trial validations that were believed to be factors of excessive heat or to the lack of proper CIP device performance (fluid contact, force), the CIP devices were evaluated in the pilot plant with the UF C-Thru Model Tanker. The results of the devices are in the following tables (4-7 to 4-9). Each device was operated according to manufacturer's suggested parameters and an upper and lower parameter. Performance was evaluated based on the fluid delivered and the cleaning potential.

Surface fluid delivery characteristics

Figure 4-5 shows the relative surface fluid volumes that are dispersed by this device. The highest surface volumes appear to be close to the device and within 2.1 m. Table 4-3 shows the surface collected fluid volumes as a percentage of the total collected. This data can provide some basic understandings of this device. Based on communications and literature provided by the system and device manufacturer, this device theoretically deliveries fluid somewhat equally throughout the tanker (PCS 2005 SSI 2005). The theory is based on the concept that the device rotates and delivers fluids in a 360 degree pattern. The fluid data collected from the tanker surface seems to indicate that most (70%) of the fluid was within 2 m of the device. Further down the barrel, the amount of fluid was diminished and at the barrel end, there was approximately 1.5% of the total fluid. The bulkhead did receive slightly more fluid at approximately 5.7%. These results may indicate that there may be a risk of poor cleaning the further one gets from the device. Since this device primarily cleans by impingement, it was important to determine the impingement force. Figure 4-6 is the relative force of this device showing that within 0.3 m (1 ft), the impact is at its maximum force and diminished the further one moves away from the device. Actual impingement pressures were not determined due to technical difficulties however data was collected with impact indicators (1G and 5G) (Teladrop impact indicators Model 1G and 5G, Telatemp Corporation, Fullerton, CA) to indicate levels of impact. These results are seen in Table 4-4. The impact indicators measure the g-force in 'gs' which is the gravity acceleration of a falling object (9.81 m/s^2 or 32.2 ft/s^2). The impact force is considered the g-force times the objects mass (F=ma). The lowest impact force was not consistently detectable after 2 m. Due to the rotation of the fluid, positioning the devices was extremely important. Devices had to be placed at positions that would be struck by the stream otherwise the result was no force. The conclusion of these exercises was that as the distance increased from the device, the impact pressure would decrease. This is similar to other research conclusions (Pagcatipunan 2006) and engineering principles (White 1077 Singh 2006).

Rotation speed

The results are separated by device type. The first discussion is on the rotating, low volume, high pressure device (R-LVHP). According to the system manufacturer, the rotation speed has no influence on the cleaning potential (Peacock 2005) however, the device manufacturer suggested it to be a significant parameter for effective washes (SSI, 2005) with a slow rotation speed providing better cleaning potential (SSI 2005). The device manufacturer's suggested air motor speed was 0.3 to 0.7 bar (5 to 10 psi) (Table 4-5) which was different than the CIP system manufacturer suggestion of 2.8 to 4.1 bar (40 to 60 psi) (Peacock 2004). Since air pressure was relative to facilities, air motor type, and to the age of the device (motor and head), it was necessary to correlate the supplied air pressure to the shaft rotation speed and therefore the CIP head rotation speed. These results are in Table 4-6. When the air supply was set at 0.3 bar, the device's shaft did not turn. It was found that the device would operate at this air pressure only when it started at 0.7 bar and then lowered to 0.3 bar. This process was highly unlikely to be practiced at the wash racks. Also, when fluids were going through the device (68

Lpm @ 24.1 bar), the rotation would stop when the air pressure was lowered to the 1 shaft rpm. This would not be an appropriate speed. However, the unit tested was a brand new device supplied by the manufacturer that may have required a higher air pressure to operate due to the new parts. Older devices with worn parts may work effectively at this low pressure but this was not tested. Conversely, a device with typical worn parts would require higher air pressure to operate due to the air leakage (SSI 2005). It was found that the lowest air supply to activate the rotation of the CIP device and to maintain the rotation speed when fluid was introduced into the device, was 0.6 bar (8 psi). All further rotation speed tests were run dry and wet since it was found that the fluids may have an effect on rotation speed. Based on these tests, it was observed that wash facilities were rotating relatively fast compared to the device manufacturer's suggested rotation speed of 0.3 to 0.7 bar (5 to 10 psi)(SSI 2004).

The rotation speed is important for effective cleaning since the fluids after leaving the nozzle have the same radial velocity as the nozzle and will have a tendency to continue in a radial arc instead of a straight stream (White 1979). This affects how the water behaves after the nozzle since once the fluid leaves the nozzle momentum energy carries the fluid to its destination (White 1979). The momentum energy is a product of the devices fluid volume (mass) and the rotation velocity. With a faster rotation speed, the fluid stream tends to bend more particularly with low volume (fluid mass) systems. Low volume systems disperse a small stream mass which is affected by the nozzle velocity more than a high volume system (Lechler 2005). Rotation speed is one of the CIP wash parameters that may be important.

For the R-LVHP devices rotation speed, tests were run at three flow rates (rate and pressure) for five rotation speeds including the wash rack rotation speeds (40 and 60 psi). The tests were run with the same nozzle set (nominal size 0030) but at different pressures (24.1, 27.6, and 31.0 bar) and therefore different flow rates (69, 74, and 75.8 Lpm). Table 4-7, 4-8, and 4-9 show the results of the test at 24.1, 27.6, and 31.0 bar respectively. Table 4-7 were the parameters that were seen at the wash racks. The highest tanker surface flow rates were seen at 0 m for each rotation speed and flow rates. Interestingly, it was seen that as the rotation speed increased, the flow rate at 0 m increased for each pressure. The differences were significant between Sites 0 and 0.3 based on the collected fluid volume (Table 4-7). This may be expected since as the rotation speed increases, the residence time of the stream at any location is decreased and there are more strikes occurring during the test time (each test run was 15 min). An explanation for rotation speed, residence time, delivered fluid volume, and strike number will be dealt with under the device observations. Under these conditions, it would be expected that the stream residence time would be longer at close distances and therefore have higher collected flow volumes. Rotation speed is the basis for a devices cycle time. Cycle time is defined as the time needed to make a complete cycle of the device or another way is the time needed for a nozzle to return to its starting position (SSI 2001). Table 4-5 shows the relationship between cycle time and rotation speed based on the manufacturer.

As the distance from the CIP device increased, the surface flow rates decreased indicating less water to these areas and potentially less cleaning. At 69 Lpm and 24.1 bar and 60 psi, the surface flow rates decreased to very small volumes with only 0.003 Lpm/m^2 being collected at the surface at 6.4 m away. This volume appears very small and may not be adequate to clean based on the literature values of 1.63, 4.88, and 8.14 Lpm/m^2 for rinsing, light, or heavy washing (Ecolab 2001; Lechler 2004). At the top bulkhead (Site BHt), no fluid was collected at 40 and 60 psi (equivalent to 20 and 22 shaft rpm) for any tested pressure whereas small amounts (0.004 to 0.077 Lpm/m^2) were collected at 30 psi respectively for pressures. Sample Site BHt was the top bulkhead and the furthest sample site from the device. The highest fluid volume was collected at the slowest rotation speed for each pressure tested. This seems to indicate that the slower speed is needed to be able to clean at this location. Even along the barrel (sample Sites 0 to 6.4), the slower rotation speed produced the largest collected fluid amounts. The collected volumes were higher and significantly different at the bulkhead Sites BHc and BHt and along the barrel from a minimum of 2.1 m away from the device for each operating pressure. Again, this result seemed to indicate that a low rotation speed would be needed to provide adequate cleaning volume. However, since the collected fluids are those that flowed into the sampling devices, the exact cleaning potential may not be fully understood. Some fluid may have reached these areas but because of surface deflection may not have been caught by the sampling devices. The fluid that deflects may still have cleaning ability but under the test procedure was not able to be measured. These results only provide an indication of the volumes that are getting to these areas. However, if no volume is collected, it may be surmised that since there is no cascade fluid, there may not be any cleaning since it is expected that surface deflected fluids would have a certain amount of forward momentum to carry to the next sampling point and therefore measurable.

It is important to note that the rotation speed has a direct effect on the fluids contact time (Singh 2001). With stationary devices, the fluid dispersion is constant as long as the device is dispensing fluids (Ecolab 2006). With rotating devices, the fluid dispersion and contact points are constantly changing along with the fluid dwell time (the time that the fluid contacts the surface). Once the fluid contact point moves, the amount of fluid decreases until the surface is dry. Also, the fluid contact is based on the distance from the device since a close distance has more contact. Table 4-10 is the calculated circumferences of the device at variance distances. For the tanker, a rotating device is cleaning a 1.2 m circle when the distance from the device is 0 m which is the distance from the device's head to the tanker surface at 0 m or to the tanker top based on the device's head being placed into the tanker at 0.6 m. At this distance, the circular motion of the cleaning tip has a circumference of 3.8 m that is the distance that the nozzles or the fluids' tips travel in 1 revolution. At the end of a 13.4 m tanker, the theoretical travel circumference is 42.1 m (138.2 ft).

The calculated fluid travel speed based on the device's distance is in Table 4-11 for the R-LVHP at 3 rotation speed. The fluid travel speed is the perceived velocity that the fluid is traveling at the given distance in a radial motion. Since the device's rotation speed is constant once set-up, the fluid's travel speed changes due to the distance, so that the fluid velocity appears slow (0.26 m/sec with a 4 rpm head rotation) at 0.6 m from the device and fast (2.81 m/sec) at 6.7 m from the device. This results in the fluid further away from the device covering more distance during a revolution. Also, since the device's rotation speed is constant and the fluid's travel speed increases with the distance, the fluid contact points (impingement point) will stay at any given area a shorter period of time the further one gets from the device and theoretically will supply less fluid in any given area (Table 4-12). This may be one reason for the reduced fluid volumes collected at the further distances from the device. It was calculated that at 4 rpm and at 1.5 m from the device, the impingement stream will pass a 100 cm swath in 0.15 sec and deliver 0.101 liters. At 10 rpm, the relative velocity is 1.60 m/sec and the stream passes 100 cm in 0.063 sec and delivers 0.043 liters and at 20 rpm, the stream moves at 3.19 m/sec and takes 0.031 sec to pass 100 cm and delivers 0.022 liters.

If the number of stream passes is determined, the results of Table 4-8 can be achieved. Deviation of the calculated values may be due to cascade volumes that come from other impingement strikes. At the furthest distance of 6.7 m, the slower rotation speed (4 rpm) provided the longest contact time and the highest theoretical delivery rates. This pattern was seen in the actual surface flow rate tests and may be the main reason for the surface flow rate results (Figure 4-7). The observed surface flow pattern may also be explained by the centripetal forces that act on the fluid. Centripetal force is defined as the center seeking force of an accelerated motion body in a circular path (Sternheim 1991). This force has an equation of:

$F_{cent} = mv^2/r$ where m = mass of fluid, v = velocity of fluid, and r = radius (4-5)

The equation shows that the force is proportional to the objects mass and velocity squared and inversely proportional to the radius. In this equation, the velocity appears to have a larger effect on the force than either the mass or the radius. This is the main explanation for the observed reduction in distance when the device was operated at the higher rotation speeds.

Based on these results it seems that a slow rotation speed is needed for low volume CIP systems. These results seem to justify visual observations of the preliminary work with the UF C-Thru tanker. For a higher volume system, further testing would have to be completed to determine similar effects. Higher volume systems have more water volume (mass) which may overcome the radial velocity issues.

Nozzle extensions

Nozzle extensions were used by one wash facility to aid in the stream dispersion. The wash facility installed extensions on only one unit and was not sure if it was beneficial (BTW PC 2005). To help with understanding why tankers were ineffectively washed, nozzle extensions were evaluated with the results in Tables 4-13 to 4-14. Extensions of 0, 7.6, 15.2, and 22.9 cm (0, 3, 6, and 9 in) were tested to develop data. The theory behind extensions is that when a fluid such as water is sent through a pipe or tube, there is a certain amount of resistance to flow. This resistance to flow is the frictional forces of the pipe or tube and to any obstructions that are down stream (White 1979).

When a fluid is in a pipe it will have a certain flow characteristic that is in balance with the system and is based on the velocity of the fluid and the frictional forces (Singh 2001). When the fluid in the pipe is redirected due to a fitting such as an elbow, “T”, or valve, the flow after the fitting becomes turbulent due to the hitting forces. The turbulence after the fitting will continue for about 20 pipe diameter before it gets into balance similar to before the fitting (White 1979). In CIP spray devices, the spray head can be considered a “T” fitting that is redirecting the fluid flow and causing turbulence. If a nozzle is installed directly onto the head hub, the redirected fluid is in a turbulent condition immediately before leaving the nozzle. When a fluid leaves a nozzle, it is under the strain of the confinements of the tube and there is an immediate release of pressure and expansion (White 1979). If the fluid flow is released from the nozzle immediately after undergoing the turbulence of a “T’ fitting, the fluid is then subjected to two pressure conditions that may compromise the jet stream condition which has an effect on the cleaning capability at least with respect to impingement energy (Pagcatipunan 2001). With extensions, the turbulence of the redirection is minimized prior to leaving the nozzle so that only the nozzle discharge pressure loss is seen (Pagcatipunan 2001). Smith (1979) suggests a 20-pipe diameter distance after a fitting to maximize the fluid flow condition. In this research, the use of extensions seemed to improve the streams capability and the amount of fluid that was collected at sample sites. At all flow conditions tested, there was an overall significance ($P<0.05$) between 0 cm extensions and all other extensions. This seemed to indicate that extensions are needed to provide the most fluids at most internal tanker locations. In Table 4-13, at 68 Lpm @ 24 bar, the 22.9 cm extensions provided the most fluid to the barrel end and the bulkhead (Sites 2.1 to BHt). Most of these collected volumes were significant ($P<0.05$) from the other extension lengths. The only anomaly was at site 6.40. At certain samples sites (distances away from the CIP device) there were several instances that there was no significant difference between 0 and 7.6 cm extensions for 68 Lpm @ 24 bar, 74 Lpm @ 27.6 bar, and 75.8 Lpm @ 31.0 bar but all sites were significant at 79.5 Lpm @ 34.5 bar. This seemed to indicate that the flow rate had an effect on the extension length. As the flow rate increases, the turbulence increases and the use of extensions may be more beneficial.

Since the extension pipe diameter was 0.64 cm (0.25 in) and using the 20 pipe diameter rule, it was expected that an extension length of 12.8 cm (5 in) would be needed. This was seen in the data since an extension length of 15.2 cm (6 in) appeared to be more beneficial for the collected fluids. Significantly more fluids on average were collected with 15.2 cm extensions than with 0 and 7.6 cm extensions. The difference between 15.2 and 22.9 cm was not as clear as with the other extension lengths since the significance was at $P<0.10$ instead of $P<0.05$. This suggests that the 15.2 cm extension is required.

Pressure effect

Since CIP parameter include fluid pressure as an energy aid for impingement cleaning or to get the fluids to the tanker walls, a series of tests were conducted to determine this effect. Tables 4-17 to 4-21 are these results. The unit's nozzles remained constant for these tests while the fluid pressure was varied. Table 4-17 are the results of a slow rotation speed (4 shaft rpm) and no extensions. As expected as the pressure increased, the fluid that was collected at the tanker's surface increased with the overall differences significant at $P<0.05$. Some differences within a sample site were not significantly different ($P<0.05$) and may be due to the closeness of the device. Significant differences were more apparent the further away from the device. The pressure effect was due to the increased pressure which had a direct effect on the flow rate as Lpm. At 24.1 bar (350 psi) there was a flow volume of 68.1 Lpm whereas at 31.0 bar (450 psi) the flow rate was 75.7 Lpm. Due to the flow rate relationship of pressure and volume, as the pressure increases in a confined space, the flow rate also increases (White 1979) or it can be looked at as in order to obtain the higher pressure, more fluid had to be pumped in the confined space. If the nozzle diameter was increased, it was expected that there would be an increase in volume but a decrease in pressure. CIP pressure is important since at any given nozzle size, a higher pressure would provide more fluid which possibly means better cleaning. This is supported by the various device manufacturers and literature (SSI 2002 Ecolab 2004 Lechler 2006 Gamajet 2006). As stated in literature, increasing volume may be a more significant parameter change then an increase in pressure. However, when operating a CIP device, there is a maximum pressure in which the discharged fluid may have excessive energy (pressure) causing the jet stream to disrupt prematurely. This is the premise of atomizing in which the discharging orifice is small compared to the pressure. When the fluid is discharged, there is a sudden volume enlargement that dissipates the energy quickly (Singh 1999).

During these tests, the rotation speed was also varied to help with determining its effect. The same pressure effect was seen for each rotation speed which again is explained by the increase in fluid volume (Tables 4-17 to 4-21). However, when the rotation speed was increased, the amount of collected fluids at the bulkhead and barrel ends was lower with the higher rotation speeds. Again, this shows that the rotation speed is a major factor in delivery of the fluids and may not be corrected by an increase in pressure or volume.

Pressure and extension effect

Since it was found that pressure and volume have an effect on cleaning potential and that the jet stream was benefited by the use of extensions, the combination was tested. These results are in Table 4-22 to 4-25. Table 4-22 are the results of using a 0030 nozzle with no extensions and a rotation speed of 4 shaft rpm (10 psi air supply). These results again show that as the pressure and volume are increased, the collected volume at each sample site typically increases.

It was expected that the highest collected volumes would occur with 79.5 Lpm @ 34.5 bar (21 gpm @ 500 psi) however this did not occur at the slowest speed (Table 4-22). The highest collected volumes were seen using 75.7 Lpm @ 31.0 bar (20 gpm @ 450 psi) except for 5 sample sites (0, 0.91, 1.52, BHc, and BHt). This may be an anomaly of the system or may be due to an excessive volume/pressure for the nozzle size (SSI PC 2006). Under these conditions, the optimum (term used loosely) operating parameter may be 75.7 Lpm @ 31.0 bar (20 gpm @ 450 psi). Based on the collected surface volumes, the overall significant statistical differences ($P<0.05$) were seen between the 68.1 Lpm and the other conditions while 71.9 and 79.5 Lpm were not significantly different from each other. Operating parameter 75.7 Lpm @ 31.0 bar (20 gpm @ 450 psi) was significantly ($P<0.05$) better than the other three operating parameter when used with no extensions and at a slow shaft speed.

With the installation of extension pieces (7.6, 15.2, and 22.9 cm), the expected outcome was seen (Table 4-23 to 4-25). The highest operating parameter (79.5 Lpm @ 34.5 bar or 21 gpm @ 500 psi) resulted in the highest recoverable surface flow rates for each sample site and extension piece. The overall results were significantly different ($P<0.05$) from the other operating conditions. This seemed to indicate that the extensions were a requirement for the low volume system.

Flow rate effect

The surface collected volume effect based on only flow rate was tested. The results are seen in Table 4-26 for 24.1 bar (350 psi, wash rack defined parameter) and 4-35 for 31.0 bar (450 psi, study defined parameter). The flow pressure was maintained constant but the flow volume was changed by varying the nozzles. Larger orifice nozzles allow more fluid to flow at any given pressure (SSI 2001). Within sampling sites there were some differences seen. There seemed to be no significant differences ($P<0.05$) at the lower flow rates (71.9 and 75.7 Lpm).

Also differences were more apparent the further one moved away from the CIP device. A critical point appears to be at 3.4 m from the device (Site 3.35) in which the collected fluids seem to deviate the most. Typically there was no significant difference between sequential sized nozzles. The use of a 0040 nozzle at 24.1 bar seems to be the start of significant differences. Overall there was no significant different ($P<0.05$) between 0030, 0035, 0040, and 0045 nozzles (volume delivery rate of 71.9, 75.7, 83.3, and 90.8 Lpm). At 24.1 bar, the optimum nozzle for the most amount of water delivered to all sample sites was 0050 which used 94.6 Lpm (29 gpm).

Table 4-27 is the results using the same nozzles but at a higher flow pressure (31.0 bar or 450 psi) that may provide an improvement in cleaning. With these parameters, it was seen that the 0050 nozzle was able to deliver the most fluids to each sample site. The 0050 nozzle is large and delivered 109.8 Lpm or 29 gpm. Unlike 24.1 bar, the 0050 nozzle at 31.0 bar delivered significantly ($P<0.05$) more fluids to the sample sites. Over all there were no significant differences between the other 4 nozzles (0030, 0035, 0040, and 0045). These results seem to indicate that the large nozzle delivers the most fluid to all sample sites. Sample sites furthest away from the device (2.70 to 6.7 m), seemed to benefit the most from the larger nozzle.

Based on these results, it seems the wash rack conditions (71.9 Lpm @ 24.1 bar with no extensions and fast rotation speed – 20 to 22 shaft rpm) may not be ideal for proper washing. Rotation speed and extension length seemed to have the largest impact on tanker surface delivery rates. Flow conditions such as volume and pressure also have an effect but may be less critical if the proper rotation speed and extension length is used.

Nozzle variations – flow volume with constant pressure

CIP device suppliers have equipment that can be used to improve the fluid's jet delivery. These are used to help maintain or improve a jet which increases the potential impingement forces (SSI PC 2006). A typical nozzle has vanes installed into the nozzle in order to help with the flow development (SSI 2004). Without the vanes, the nozzle discharged stream may not fully develop into a jet which may not produce the required fluid reach. This is similar to the flow redevelopment conditions needed when a flow is redirected (see above). Table 4-28 is a comparison of a nozzle with and without the vanes and with a jet stabilizer supplied by the manufacturer. This part of the research is important since during the tanker survey, it was noticed that some CIP device nozzles had variations in the use of vanes. At each sample site there were significant differences (P<0.05) between the units.

The nozzle without the vanes seemed to provide adequate fluids to the walls at 0 to 2.10 m but after this distance, significantly delivered less fluid to the sample sites. Visually this nozzle had a good stream for a short distance (2.5 m) that broke apart at about 3 m becoming misty. This corresponds to the adequate surface fluid collections to 2.10 m. The use of the jet stabilizers provided the most collected fluids from 2.70 to the bulkhead and was a significant improvement to the vane installed nozzle. Interestingly, the jet stabilizer had the lowest surface volumes at 0.91 to 2.10 m that may be an indication that the jet stream was better than the other variables and caused the fluids in this area to deflect more readily, causing the lower collected volumes. Based on this trial set, it appears that the jet stabilizers would be a benefit for washing a tanker.

Considering that the jet stabilizer nozzle is reported to be an improvement over extensions, this aspect of the research was assessed. Table 4-29 and 4-30 show the results at two operating conditions of the jet stabilizer installed as directed compared to a normal nozzle and with added extension pieces. The results indicate that at both conditions there is a significant difference (P<0.05) between the use of the jet stabilizer nozzle and a normally installed nozzle. At 24 bar, there were no significance (P<0.05) between the jet stabilizer nozzle and the normal nozzle with a 3 or 9 in extension but there was with a 6 in extension yet there was not a significant difference between any extension length. At 31 bar, there was a significant difference ($P<0.05$) between the 3 and 9 in extensions and the 6 in that was seen before. The jet stabilizer basically can be used instead of a 3 or 9 in extensions but not to replace a 6 in extension. This finding is similar to the previous extension work in which it was found that the 6 in extension was a significant improvement over no extensions and that the 9 in extension while still effective for some reason was less so than a 6 in extension.

Based on these results, it seems that operating the R-LVHP CIP device, for the maximum amount of cleaning solutions to all internal parts of the tanker, should be operated with at least 15 cm (6 in) extensions at 87 Lpm (23 gpm) at 31 bar (450 psi) and at a 4 rpm rotation speed.

Sd-HVMP

Surface flow rates

The stationary directional high volume medium pressure CIP device is a simpler unit since it does not turn. The directional nozzles are beneficial to ensuring that the bulkheads are properly wetted. This CIP device produced a surface flow pattern quite different than the rotating device (Figure 4-9). Interestingly, this device's surface pattern was almost sigmoidal with the highest flow occurring at the bulkhead (sample Sites BHc and BHt). The pattern was explained by the position of the orifices in the center ball and the directional nozzles. The directional nozzles were highly effective to direct the flow at the bulkheads. Table 4-31 indicates that most of the fluid that contacts the tanker surface is in the bulkhead (Sites BHc and BHt) and then near the device (Sites 0 to 1.5). This is in direct contrast to the R-LVHP device (Table 4-4).

The first evaluation of this unit was to determine the flow rate effect. The results are in Table 4-32. The manufacturer recommended flow conditions of 110 gpm at 65 psi (416 Lpm @

4.5 bar) that under the research system was achieved with 122 gpm @ 65 psi (462 Lpm @ 4.5 bar). These conditions were within the manufacturer's 10% guideline for flow volume dependent on the pumping system (ECO PC 2006). The target pressure is considered the more important parameter. Here we see that a low pressure of 3.1 bar (45 psi) appeared adequate for the fluids to reach all parts of the tankers internal surface. All tested pressures appeared to be adequate for this device. All tested conditions developed their lowest surface flow rates between 3.4 to 4.0 m but the flow rate was still much larger than the R-LVHP unit and mostly above the 1.63 Lpm/m^2 wetting minimum as listed in literature (Ecolab 2001). Surprising the highest device feed flow rate (568 Lpm @ 5.5 bar) developed its lowest surface flow rate at the 6.4 m sample site. This may be because the higher feed rate forces more fluid through the directional nozzles (due to the nozzles larger orifices) causing more fluids to reach the bulkhead. The low flow sites may be a concern for soil removal since there may not be adequate fluid flow to accomplish the cascade cleaning. This observation that fluid feed rate is important may be the reason for the stripes that were seen in tankers during the tanker sanitation survey. Statistically, each flow delivery condition was significant different ($P<0.05$) from each other but what it actually means as it relates to the fluid distribution is not clear. The soil removal test may provide more answers.

Installation orientation – Pitch

The Sd-HVMP is an engineered device with its characteristic for a specific purpose. The device's pitch is significant since the manufacturer designed this for reaching the tanker bulkheads. The pitch is the nozzle's angle variation from horizontal and is measured from the down pipe. It the pitch is too horizontal (closer to 90° angle), the fluid discharged from the nozzles would be directed straight back whereas if the pitch is small (closer to 0° angle), the fluids would be directed straight up. The pitch is engineered for the expected tanker that is to be cleaned (ECO 2006). For a typical tanker of 12.2 to 12.7 m, the pitch angle is 79° (Ecolab 2006). This allows the discharged fluids to hit the top of the barrel, approximately one meter forward of the bulkhead, so that the fluid's momentum carries it the last m and down the bulkhead. Table 4-33 are the results when the pitch angle is adjusted as in the case of a damaged or improperly installed device. When the pitch angle was small (76°) the fluid tended to accumulate near the tanker's center (0 to 5.2 m) with almost no fluid reaching the bulkhead. The surface collected fluid had a peak at 4.6 m due to the direction of the nozzles. From visual observations, the fluid appeared to be directed at around 4 m with the fluid's forward momentum carrying the fluid to 4.6 m and back but not to the barrel end or bulkhead. Under this condition, the barrel end and the bulkhead may not get cleaned properly. If the nozzle pitch has an angle of 82°, the fluid was directed further down the tanker and hit the bulkhead missing a good part of the barrel top. This was seen by the reduced fluid amount collected at the barrel ends (Sites 2.70 to 6.40) and almost no fluid at the bulkhead top site (BHt). Under this condition, the barrel end and the bulkhead top may not get cleaned since the fluid amount was so small.

Both pitch changes were significant with respect to the overall collection of fluids. The pitch change may occur when a device is damaged due to it being dropped. If the damage occurs to only one nozzle, tanker cleaning may be compromised by the damaged nozzle so that only one end of the tanker may be poorly cleaned. If the change in pitch angle is due to improper installation, then both ends of the tanker may be affected with a dirty top barrel on one end and a dirty bulkhead on the other.

Installation orientation – Width centering

Since this device is directional, the installed position may be affected by how well the device is centered in the tanker. The device is engineered to disperse fluids in a straight line with contact at the surface turning to radial dispersion which then flows down the surface wall. The center spray ball also disperses fluids so that the fluid contacts specific areas of the tanker's surface. Altering the direction of this device may affect where the stream finally contacts the surface. How the installation affects where the fluids come in contact with the tanker's surface was observed in the following tables. For Table 4-34, the device was positioned in the C-Thru tanker so that the nozzle was directed to the front left and rear right, directly over the collection sites (Figure 4-9). A 1° turn to the right seemed to shift the fluid slight forward and reduced the fluid to the bulkhead. Statistically based on the collected fluids, each change in installation position was significant at $P<0.05$. Each position shift, or degree change to the right, seemed to move the maximum collected fluids up the tanker's barrel as seen by the collected fluids. This was expected since the nozzles were turning and carry the bulk of the fluid as seen by Table 4-34.

When the device center was shifted to the left, changes were seen with the collected fluids as seen by Table 4-35. The device was facing the tanker's rear left so the fluid was less likely to come in contact with the right rear side. When positioned in this manner, the nozzles were facing the left rear and the right front. When these conditions were tested, no significant difference ($P<0.05$) were seen between 0 (dead-center) and 1° off dead-center but every other off-center angle surface fluid volume was significantly different. At 2.5° and higher, there is a risk that a tanker side may not get adequate fluid volumes to clean properly.

It appears from these trials that installation of this device is critical. Installation has to consider the pitch and centering of the device in order that the nozzles perform as engineered. Flow rate (volume and pressure) may be less critical but may be a factor in cleaning.

Rotating-High Volume Medium Pressure (R-HVMP)

The rotating high volume, medium pressure CIP device (R-HVMP) did not have a visible shaft that could be used to measure the rotation speed. As discussed previously, the rotation speed has a direct impact on the cycle time of rotating CIP devices. As seen in the R-LVHP device, a slower speed produced more flow to the tanker bulkhead and potentially an improved cleaning of the area. The rotation speed of this device was observed by taping a nozzle and timing the rotation time in sec. These devices do not have an external motor and are driven by internal components that required disassembly of the device and the insertion of a new drive impeller which was supplied by the manufacturer. The four rotation speeds were evaluated and the rotation speed in rpm was determined. The results are in Table 4-36. The "normal" impeller developed a rotation speed of 16 rpm which is the typical type for long tanker cleaning (LCS 2006) and would result in a cleaning cycle time of 8 min. The "short" impeller was installed that provided a turning speed of 12 rpm and a cycle time of 11 min. The "long" impellers provide a faster turning speed that should result in a shorter cycle time which was found to be 6.8 and 6.5 min respectively for "long 1" and "long 2". For shorter tankers, the "long" impellers may be used adequately since it is expected that the stream distance would be reduced.

Figure 4-12 are examples of the tanker's surface flow rates. The distribution of the fluids was similar to the R-LVHP CIP device in that a high volume was seen close to the device which got smaller the further one moved from the device. However, unlike the R-LVHP units, the bulkhead volumes saw a very large volume increase. It is thought that this large increase is due to the large feed volume which was about 6 times larger than the low volume device.

Rotation speed

As with the R-LVHP unit, rotation speed may have an effect on fluid dispersion. This was tested with the results in Table 4-37 at 12, 16, and 20 head rpm. For the overall fluid collections, there was not a significant difference ($P<0.05$) between the rotation speeds. It was expected that there would be based on the R-LVHP unit. It was concluded that with the higher flow volumes (these tests were operated at 493 Lpm @ 6.2 bar), the rotation speed may have a smaller impact on the fluid dispersion. This may be expected since the unit mass that is being discharged from the nozzles would be much higher, 247 kg per minute compared to 42 kg per minute for each nozzle. This mass may not be affected by the radial forces and may aid in the discharged fluid's momentum (White 1979). It was interesting that there were significant differences ($P<0.05$) between the rotation speeds at the two sample Sites BHc and BHt. The slower speed (12 rpm) had significantly more fluid collected at these sites than at 16 or 20 rpm. So even though the overall differences were not significant, a slower rotation speed may be needed if the bulkhead is hard to clean.

The fluid velocity, dwell time, and theoretical deliver rate was also calculated for this device based on the calculated circumferences from Table 4-38. The calculated fluid velocities follow a similar pattern as seen with the R-LVHP device. As the rotation speed increases, the fluid velocity increased. This device was operated at higher rotation speeds based on the manufacturer recommendations. These devices may function adequately at the higher rotation speed since the fluid volume is much larger. When reviewing the centripetal force equation, the mass that is being distributed is higher when rotating slow which affects the overall performance of the device.

Table 4-39 is the results of the calculated travel velocity, fluid dwell time, and theoretical volume delivered at the various sample points. Here again it is seen that as the device head speed increases from 12 to 20 rpm, there is an increase in the travel or radial velocity with a decrease in the fluid streams dwell time and delivered fluid volume. Also, under the same head speed there is an increase in the radial velocity which is expected and the subsequent decreases in fluid dwell and delivery. Figure 4-13 shows this data graphically. The delivered volume is much higher than was seen with the R-LVHP device. Also, the high volume systems seem more efficient or may perform better since the delivered volume is proportionally larger than the dwell time. With the R-LVHP device, the delivered volume was proportionally lower through all distances from the device.

In Table 4-40, the surface flow rate was calculated as a percent flow based on the collected fluids. The results show that close to the device, there is a lot of fluid dispersed while as one moves away, the amount of fluid is diminished. The bulkhead volumes did increase dramatically indicating that this device has two peaks, one within 1.5 m of the device and one at the bulkhead. A note of interest is that as the volume and pressure increased, there was a shift in the amount of fluid from the center to the bulkhead. At 416 Lpm and 3.4 bar, 51% of the fluid was within 1.5 m while ~33% was at the bulkhead. When the flow rate was increased to 492 Lpm and 6.2 bar, there was only 35% of the fluid up to 1.5 m and 50% at the bulkhead. This seems to indicate that the increase in volume and pressure was effective to reach the bulkhead better. It is interesting that this pattern was not seen along the barrel. From 3.4 to 6.4 m (Sites 3.4 to 6.4), there was practically no change in the volumes collected when the flow rates increased. This may indicate that the barrel may be harder to clean.

Surface flow rates

Flow volume is one parameter for CIP cleaning. This was tested with the results in Table 4-41 for three volumes at the same pressure (4.5 bar or 65 psi). With the baseline of 416 Lpm, there was not a significant difference ($P<0.05$) between 416 and 454 Lpm or between 454 and 492 Lpm. However, there was a significant difference between the low and high volumes. The differences were noted in various sample sites particularly next to the device and at the bulkhead. At this pressure, the higher volumes appear to provide more fluids to the furthest tanker areas which were expected (GSS 2006 Lechler 2006).

Flow pressure

To determine the pressure effect, the volume had to be increased, so a direct pressure relationship may not be truly seen. Table 4-42 are the results of the pressure testing. The lowest pressure (and volume) was significantly different from the other three variables. This may indicate that this parameter may not clean effectively. The pressures 4.5 and 5.2 were not significantly different from each other but 4.5 and 6.2 was. Also, 5.2 and 6.2 were not significantly different. These differences are similar to the volume differences which may indicate that the pressure is less significant than volume. This finding is similar to that of the device manufacturers (GSS 2006 Lechler 2006 Sellers 2007) and to fluid mechanics literature (White 1979).

Installation depth

Based on literature (Seiberling 1999 Gamajet 2006 Lechler 2006 Sellers 2007) and personal communications with the device manufacturer's (Gamajet 2006 Lechler 2006 Sellers 2007), the installation depth with these sprayers is thought to be significant on the fluid dispersion. A CIP device industry common practice is to place the device at 2/3 the diameter of the vessel (Lechler 2006 Gamajet 2006 Sellers 2007). The closeness of the device to the tankers ceiling impedes the potential fluid flow that reaches the vessels furthest distances. Since the standard tanker's diameter ranges from 160 to 168 cm (63 to 66 in), and average of 109 cm (43 in) was used for the baseline installation. The results of the installation depth tests are seen in Table 4-43 and 4-44. The operating conditions for Table 4-43 were 492 Lpm @ 4.5 bar (130 gpm @ 65 psi) which was the manufacturer's initial suggested parameter while Table 4-44 was operated at 492 Lpm @ 6.2 bar (130 gpm @ 90 psi). The results indicate that overall there was a significant difference ($P<0.05$) between each installed depth for each operating condition. The differences at 492 Lpm @ 4.5 bar were noted for close distances (Sites 0 – 3.35) for 82 and 109 cm depths and further away (Sites 3.96 to BHt) for 109 and 143 cm. At the higher pressure, the differences were significant throughout the tanker. Interestingly, the higher the device was installed, the more fluids were collected in each sample site. This was not expected since it was thought that the higher the device, the more the ceiling would interfere with the fluid reach (LSS 2006 Sellers 2007). Also, the higher the device is installed, the lower the impact angle is to the tankers ends (Table 4-45). It was thought that the better impact angles at the lower depths would be an improvement to the fluid dispersion and therefore the amount of fluid that gets to the surface. The improved impact angle may be the cause of the lower collected fluids since with a better impact angle, more fluid may deflect away from the sampling devices. With the higher depths, the fluid acts more like cascade cleaning and delivers the fluid without deflection. The findings may also be due to the location of the sampling devices that were installed approximately 2/3 into the tanker (1.5 m from top dead center along the circumference). With the CIP device installed high in the tanker, there was more upper tanker coverage of the fluid stream which would get caught by the sampling devices. With a deeper installation, more of the fluid stream may have been below the sampling devices. This explanation may be a detriment of this study.

Significant Observations of Rotating Devices

According to the literature, the rotating devices have 360° coverage of impingement forces (Lechler 2006 Spraying Systems 2002 Gamajet 2006 Sellers 2007). Observations of the devices seemed to contradict this. Using the UF C-Thru model tanker, impingement forces were not seen in many areas with the observed patterns indicated by placing tape pieces at "impingement" contact points along the tanker barrel and bulkhead. Figure 4-14 and 4-15 show the C-Thru tanker with tape indicating the impingement contact points. Figure 4-14 shows the tanker at 10 to 22 ft (tanker markings), with stream contact at around 10 ft, at around 14 ft, just past 18ft, and then at the bulkhead at 22 ft. The tape at 22ft indicates not only the strikes that hit this distance but also those that hit the bulkhead. In Figure 4-15, the strikes were concentrated near the center between 0 and 3 ft mark and then the strikes became less common away from the center. The strike gaps at 0 to 3 ft were 4 to 6 in while from 3 to 10 ft ranged from 9 to 27 in. When the strikes were reaching 10 ft and further, the strikes were about 36 to 48 in part. When following the next nozzle, its strikes hit within 6 in of the first nozzle. This is in direct comparison to the device literature that states the strikes fall between each other equally (Spraying Systems 2006 Gamajet 2006). Figure 4-16 shows the stream pattern based on the visual observations for half a cycle time. The main point of these figures is to realize that unlike literature, the streams will strike the tanker many times during the cycle close to the device while as you move away, the strikes become less frequent. This may have a direct impact on the amount of fluid that is dispensed from the device since the frequency of the strikes has an impact on the fluid rates.

On the bulkhead, the strikes produced the pattern seen in Figure 4-17 and 4-18. Each strike was about 74 cm (29 in) apart leaving a large gap between each impingement strikes. The pattern was seen criss-crossing due to the rotation of the nozzles in that one nozzle had a downward path while the other had an upward path. Figure 4-17 shows the pattern of nozzle A in the downward path while nozzle B is in the upward path. Only 4 direct hits were seen on the bulkhead for this hit cycle which is half the device cycle time (17 min based on rotation speed). Figure 4-18 shows the patterns in the 2nd half of the device cycle time. In this figure, nozzle B is making the downward path while nozzle A is making the upward path. It was seen that each nozzle strike was only about 12 cm (4 to 5 in) away from each other in direct contradiction to the literature which stated that the stream split the distance equally (Spraying Systems 2006 Gamajet

2006). Figure 4-19 shows the pattern of the entire cycle with the gaps that are not be struck by any impingement forces.

In an entire device cycle, only 10 strikes were seen directly hitting the bulkhead which means all cleaning of this area has to be performed within this time frame. Considering that impingement cleaning has a small range (radius of 6 stream diameters – Figure 4-20) around the stream strike, the actual impingement cleaned area (a path of 15.6 cm with a 1.3 cm stream) is small in comparison to the cascade cleaned regions. In the bulkhead, there are areas that potentially receive no impingement forces and rely on cascade force to clean. In these areas, there is a potential of poor cleaning if the cascade action is inadequate. For instance, the gap between strike 1 dotted line and strike 3 solid lines is 76 cm (30 in) and the impingement forces extend only 7.8 cm from the center then this leaves a gap of 60 cm (24 in) that will receive only cascade cleaning forces.

The observed patterns were further defined by using a computer generated diagram (Autodesk Educational Product, San Rafael, CA) operated by Mr. John Henderson (CREC Pilot Plant Manager) based on the observations. The CAD diagram is Figure 4-21 in which the theoretical flow is seen in a circular pattern with a to-scale tanker superimposed onto the circle. The device indexing angle for this diagram is 10°. If the indexing angle is different, the stream patterns would be slightly different. Since the devices discharge water in a spherical pattern (Spraying Systems 2006 Gamajet 2006 Sellers 2007), the diagram is the 2 dimension representation of the discharge. With this view of the stream patterns (which are repeated), the observed tanker surface strikes seem to be better seen. Near the device, there were more frequent wall strikes while as the distance from the center increased, the strikes were less apparent. The 2-D diagram also shows that the bulkhead would receive very few direct hits.

The close strikes of the nozzles can be seen here represented by a dark line for nozzle A and a light line for nozzle B. This pattern was found to be due to the diameter of the CIP device. As one nozzle (A) would hit a bulkhead (front), the other nozzle (B) was hitting the opposite bulkhead (rear) at a parallel point. When the device was half-way through its cycle, nozzle B would hit the front bulkhead with nozzle A hitting the rear. However, since the device was half-way through its cycle, the nozzles were on the other side of the device body (Figure 4-22). This body gap provided the 4-6 in gap distance between the strikes. If the device body was neglected, the strikes would be on top of each other. The body gap was not considered by the CIP device manufacturers when their literature was printed (Lechler PC 2007 Spraying Systems PC 2007).

In further discussions with the manufacturers, it was suggested that one cycle was too short to fully understand how the devices were working. It was explained that the more cycles that were allowed, the streams would close the gaps (Spraying Systems 2006). This was plausible so many cycles were observed. However, the results showed that the strikes repeated the pattern after its full cycle. There was no incremental change to the pattern after each cycle. The only incremental change was seen with the indexing of the nozzles. After much thought, this seemed sensible since the devices are based on a round gear that will repeat the pattern over and over. The only way to shift the pattern (shift the strikes) was to physically shift (rotate) the entire CIP device (Figure 4-23). By physically turning the device, the strike patterns could be shifted around the tanker. This was one possible explanation for surface flow rates that had large standard deviations since at the time, the installation position was not observed. If the device is installed in a certain position, the pattern will be the same each time it is run. If the device is installed in a different position, the pattern shifts. Again this may explain some of the soiled areas that were not consistently in one spot.

Based on these observations, the cycle time is an important aspect of rotating CIP devices cleaning performance. If the device cycle time (example 20 min) is longer than the detergent wash time (for example 15 min minimum), then the entire tanker may not receive adequate detergent washing. The wash time has to consider the device cycle time to ensure that all areas of the tanker will get treated. If the wash time is shorter then the cycle time, there is a possibility that there will be “soiled” areas in the tanker since the detergent was cut short.

Most of the literature shows that the rotating devices discharge fluids in a spherical pattern (Lechler 2006 Spraying Systems 2002 Gamajet 2006 Sellers 2007). However, this is not realistic in a tanker due to its rectangular dimensions. Also, most diagrams show that the top and bottom of the sphere have the streams intersecting. This was seen in the C-Thru tanker since the rotating devices always struck top and bottom at the device. As observed, all the streams would always come to the center making a bent Figure-8 instead of the true Figure-8 of the literature (Gamajet 2006 Sellers 2006). This was a possible reason that the sample sites near the device would have some of the highest surface fluid rates since the streams were always making their way to the center.

While working with one device and discussing the results (Lechler PC 2006), the manufacturer representative devised a new installation method to take advantage of the returning nozzles. Since the device was installed so that the nozzles would always rotate to a straight up and down position, it was conceived that by installing the device 90° from its current position, the straight up and down stream positions would be turned to hit the bulkheads (Figure 4-24 and Figure 4-25). The manufacturer engineered a cradle that when installed in the tanker would allow the nozzles to center around the bulkheads instead of the manway (Figure 4-26). A second device manufacturer designed an entirely different device based on this research (Figure 4-37).

The device when operated in this installation position seemed to provide more fluids to the bulkheads as seen in Table 4-46. The new position overall was significantly different ($P<0.05$) compared to the standard installation. Most of the sample sites also had significant differences detected when the device was installed at 90°. The 90° installation supplied less fluid near the device (0 – 1.52 m Sites) but supplied more fluid further along the barrel (2.10 – 6.40 m Sites) and at the bulkhead (BHc and BHt Sites). The 90° installation position took advantage of the natural rotation pattern of the device, in that the nozzles for each hub revolution would always be in an up and down position when in the standard installation. By turning the device, in each hub revolution the nozzles would always rotate to the bulkheads which meant more strikes at the bulkheads. In the standard installation, it was observed that there were approximately 10 bulkhead strikes during a cycle time but when in the 90° installation, there were approximately 56 strikes in the cycle. The device fluid feed was the same whether in the standard or 90° installation, however it seemed that the fluid was better utilized in the 90° installation based on the bulkhead sample site fluid volume rates (BHc = 3.28 Lpm/100cm^2 at 90° versus 1.32 Lpm/100cm^2 at standard installation).

It was seen with rotating devices that rotation speed is important and may be more important than volume when considering a CIP device. The slower rotation speed delivers more fluid due to the dwell time in a given area. When looking at the difference between the low volume and high volume units, there is not a difference in the dwell time at a given rotation speed (Figure 28A) and not in the velocity (Figure 28B). However, a difference was seen for the volume (Figure 28C). The high volume unit theoretically delivers more fluid to each area but also takes the biggest loss within the first 3 m of the device. The loss with the high volume system is approximately 4.5 times larger than the low volume device when the linear slopes are evaluated in this distance (-0.017 for low and -0.077 for high volume device).

Conclusion

To properly determine wash validation, the CIP device and system have to perform in accordance with its intended purpose. Performance was determined by the ability of the CIP device and system to deliver wash solutions (water, detergent, and sanitizer) to all internal surface areas using a novel approach. This research determined that fluid flow rate (volume and pressure), rotation speed, extensions, and installation orientation are important factors for the CIP device to perform properly. The R-LVHP device was found to deliver adequate fluids to all internal areas at a minimum of 87 Lpm @ 31 bar using 15 to 23 cm extensions and a rotation speed of 4 to 6 rpm while the R-HVMP device was found to deliver adequate fluids to all internal areas at a minimum of 378 Lpm @ 6.2 bar with 13 cm extensions and a rotation speed of 12 to 20 rpm. The Sd-HVMP device was found effective at a minimum of 378 Lpm @ 4.6 bar and installed at the manufacturer's designed pitch (79°) and when centered properly (0° ± 2.5°).

CIP Preliminary Washing Qualifiers – 11Brix OJ

Once CIP devices and their operating parameter were better understood, a set of qualifier tests using orange juice were conducted to weed out system operating parameter that may not be effective. Since the work with riboflavin showed that even parameter that did not supply water to the bulkheads appeared clean, the used of orange juice would ensure that mist or just run down would not cause a misconception of the parameter. Also, these tests were conducted without heat or detergent to determine the effects of impingement and cascade forces. Not using heat or detergent was also a cost effective way of eliminating some operating parameter that may not be effective.

R-LVHP

The data in Table 4-47 and 4-48 are the chemical and visual test results for the R-LVHP CIP device. Six potential parameters were chosen from the surface flow rate experiments were tested. The parameter of 68 Lpm @ 24 bar (treatment 1) were included in these experiments since these conditions were observed and typically used at the wash racks based on the systems manufacturer recommendations (Peacock 2004). Significant differences were detected at $P<0.05$ for each set of conditions except for 87 Lpm @ 31 bar (23 gpm @ 450 psi) and 95 Lpm @ 31 bar (25 gpm @ 450 psi). Individual sites were not evaluated for statistical significance since the entire tanker has to be clean. Based on the surface flow rate data, the operating parameter of 68 Lpm @ 24 bar probably was inadequate since it did not have the extensions to provide flow redevelopment and was rotating too fast. By slowing the device down (treatment 2), a light soil was more easily removed but still had some areas that were considered soiled (Sites 5.8 and 6.4). In the surface flow rate tests, a 15 cm (6 in) extension seemed to provide the most fluid to the far sample sites. The use of a 15 cm (6 in) extension at 87 Lpm and 31 bar still did not provide adequate cleaning solutions. When a 23 cm extension was used with 87 Lpm @ 31 bar, there appeared to be adequate fluids flow to remove soils. By increasing the flow rate by 8 L, there was more fluid collected in the furthest sample sites and there seemed to be more soil removed by statistically there was no cleaning difference by using 87 or 95 Lpm.

Table 4-48 are the visual results of the qualifier tests. These final results were very much the same as the chemical tests. There were some differences between the chemical and visual tests which seemed to show that chemical tests would indicate an area to be cleaner than the visual assessment of the area (Table 4-49). For this research, a chemical test result was considered "clean" or "0" if the residue was below 3 $\mu g/100cm^2$ as determined by lab tests (Appendix C results). It was observed that at a quantity of ~ 3 $\mu g/100cm^2$, a wet stainless steel surface appeared clean but when it dried, there appeared to be soil residue seen as less shiny steel or as a blue or white film.

Based on these results, the R-LVHP device operating conditions to advance to the next phase is 87 Lpm @ 31 bar with 22 cm extensions at 4 rpm rotation speed.

R-HVMP

The results of the water-soluble soiled tanker cleaning are in Tables 4-50 to 4-51. The R-HVMP seems to have a very wide range of operating conditions that may be used for washing. The lowest operating conditions of 435 Lpm @ 4.5 bar was adequate to clean almost all the soils. The only area that soil was detected in by either the chemical or visual assessment was the barrel's end (Sites 5.8 to 6.4) but the bulkhead was clean. All operating conditions proved to sufficiently remove the soils. There were no significant differences ($P<0.05$) in any operating condition (Table 4-52). Even the chemical to visual assessment differences were not significantly different. The operating parameters that were available at the wash rack (378 Lpm @ 6.2 bar) were chosen for use for the next research step since these were easily obtainable at the wash rack without major equipment changes by the wash rack.

Sd-HVMP

The Sd-HVMP CIP device was simpler to evaluate than the R-LVHP device. Flow rate and installation position seemed to be the most important aspects of this device. Based on the surface flow assessments, the installation of this device was maintained at the recommended 79° pitch and placed at 0° dead center for most flow rate tests. However, to aid in the installation position evaluations, qualification tests were also run to determine their impact on cleaning. The results of four flow rate variables are in Tables 4-53 to 4-54 while the installation results are in Tables 4-56 to 4-57. For chemical assessment, the lowest operating parameter (397 Lpm @ 3.1 bar) was found to be statistically different ($P<0.05$) to the other three operating conditions yet there was no significant differences between the highest three operating conditions. The areas of concern for this device were at 3.4 to 4.0 m and then again at 5.8 to 6.4 m for 397 Lpm @ 3.1 bar and 416 Lpm @ 4.5 bar. These areas were also found to have the lowest surface flow rates. The higher flow rate operating conditions of 568 Lpm @ 5.5 bar and 378 Lpm @ 6.2 bar did not seem to have this concern.

For the visual assessment there were significant differences between treatment 1 and the others, also for treatment 2 and the other two but no significant differences between the highest operating pressures. This seemed to indicate that this unit should be operated at the higher pressures with the high volume. As with the other devices, visual soils were more apparent than the chemical residues. As mentioned prior, the chemical assessment has a minimum detection level of 3 $\mu g/100cm^2$ but at this level, if trained and observant, an inspector can detected the residue. Most surfaces appeared clean when wet but once dry, the residue was seen. In standard tanker cleaning, most inspections would occur when the surface is wet so the surface would probably be considered "clean" even if there is a small amount of residue.

Installation position: Based on the flow rate data, only centering positions 0, 1, 2.5 and 5° were tested for qualifying to the next step since the 10° treatment did not distribute fluids to at least one sample site. All the position tests were run at 454 Lpm at 4.7 bar (120 gpm @ 68 psi) to remove flow rate differences. Tables 4-56 and 4-53 are the results of centering the device in the tanker. When the device was pointed to the rear right or towards the sampling devices (centering positions designated with an 'R'), there were no significant differences ($P<0.05$) in the juice removal from the stainless steel based on chemical or visual evaluation even though some residue remained. Based on the fluid flows (Table 4-40) when the nozzle is pointed in this direction there is sufficient fluid to remove water soluble soils. Because of the large volume and the fluids momentum, all areas seemed to be cleaned well. However, when the nozzles were turned to the left (centering positions designated with an 'L'), significance ($P<0.05$) was detected at 5° and at 2.5° for $P<0.10$. These results indicated that when the nozzles were pointed away from an area (barrel side), there is a good chance that the barrel area will not get cleaned due to either low flow or no flow (based on Table 4-43). These results are expected since the device is directional and the directional nozzles have a limited coverage area. The manufacturer primarily designed this device so that the nozzles would clean the bulkheads while also cleaning the entire tanker (Ecolab 2002). When the device is turned, the nozzles turn off center which limited its cleaning range.

Table 4-58 are the combined chemical and visual residues remaining after the rinse if the nozzle was improperly installed. These results reflect the overall cleaning level of the tanker whether it is positioned to the right or left. It is felt that if the nozzles are pointed to the barrel's right side, then the left side would be unclean and vice versa. There was no difference ($P<0.05$) in the cleaning performance if the device was installed up to 2.5° off dead center. The manufacturer suggests placing the device so it is centered but does not indicate how close to center (Ecolab 2006). During the over-the-road food-grade tanker cleaning survey, this device was observed on several occasions to be installed off center that at the time was thought to explain the post-cleaned soiled areas. Based on these results it appears that the overall centering position is vital to cleaning performance.

These devices also have a pitch position that may be important. The pitch of the device is the angle of the nozzles that point to an area in the tanker's front or back. As previously discussed, the device is manufactured to distribute fluids to certain points and allow the fluid's momentum and volume to cascade cleans the surface. The device that was tested had a pitch of

79° and is engineered for a tanker that is 39 to 42 ft long (Ecolab 2002). Tanker dimensions have to be considered when using this device. The pitch is important when considering damaged or improperly installed devices. Table 4-59 and 4-60 are the chemical and visual results of the qualifying tests. For sugar residue by the chemical tests, it was found that there was no overall significant difference at $P<0.05$ but there was at $P<0.10$, if the device was installed at 76, 79, or 82° even though there were significant differences detected at specific sampling sites. As mentioned previously, the sugar residue was not sufficient to be detected by the chemical test so most of these results indicated a clean surface. However, when the device was installed at 76°, the bulkhead area was less clean while at 82°, the center to barrel end was less clean. It was found that at 76°, the bulkhead top was cleaned due to fluid momentum that was then distributed unevenly around the bulkhead. An overall significant difference at $P<0.05$ was detected with visual inspection (Table 4-60). With the visual inspections, residual sugars and pulp were seen particularly when the surface was dry but for some reason were not detected by the AccuClean tests (Neogen Corporation Lansing, MI). This was not expected but may be due to the actual sugar being removed while other juice soils such as pulp and oils remained.

Combining the chemical and visual results (Table 4-61), there was a significant difference ($P<0.05$) between the recommended pitch (79°) and the other tests pitches (76 and 82°) indicating that the pitch seems to be important for proper cleaning performance. The operating parameters that were available at the wash rack (378 Lpm @ 6.2 bar) were chosen for use for the next research step since these were easily obtainable at the wash rack without major equipment changes by the wash rack.

Conclusion

To properly determine wash validation, the CIP device and system have to perform in accordance with its intended purpose. Performance was determined by the ability of the CIP device and system to adequate water volume to all internal surface areas to remove 11°Brix orange juice, a water soluble soil. This research emphasized that fluid flow rate (volume and pressure), rotation speed, extensions, and installation orientation are important factors for the CIP device to perform properly. The R-LVHP device was found to deliver adequate fluids to all internal areas at a minimum of 87 Lpm @ 31 bar using 15 to 23 cm extensions and a rotation speed of 4 to 6 rpm while the R-HVMP device was found to deliver adequate fluids to all internal areas at a minimum of 378 Lpm @ 6.2 bar with 13 cm extensions and a rotation speed of 12 to 20 rpm. The Sd-HVMP device was found effective at a minimum of 378 Lpm @ 4.6 bar and installed at the manufacturer's designed pitch (79°) and when centered properly (0° ± 2.5°).

Table 4-1. Results of CIP device performance validation by manufacturers suggested methods.

Device [1]	Sd-HVMP	R-HVMP	R-LVHP
Flow rate Lpm (gpm) (recorded at pump) [2]	378 (100)	378 (100)	75 (20)
Pressure bar (psi) (recorded at pump) [3]	6.2 (90)	6.9 (100)	41 (600)
Total Fluid Bulkhead Distance m (ft) [4]	9.1 (30)	10.9 (36)	7.6 (25)
Solid Stream Bulkhead Distance m (ft) [5]	9.1 (30)	9.2 (30)	4.8 (16)
Total Fluid Barrel Radius Distance m (ft) [6]	2.4 (8)	10.9 (36)	7.6 (25)

[1]Devices operated at wash rack operating parameters. Sd-HVMP – Stationary, directional – high volume, medium pressure. R-HVMP – Rotating – high volume, medium pressure. R-LVHP – Rotating – low volume, high pressure.
[2]Flow rates (L per minute) recorded at the pump with wash rack equipment. The value in parenthesis is the US units (gallons per minute).
[3]Pressure (bar) recorded at the pump discharge with wash rack equipment. The value in parenthesis is the US units (pounds per square in).
[4]Fluid flow distances to the bulkhead measured visually in meters with 50 ft tape measure on floor. Value in parenthesis is the US units (ft).
[5]Visual assessment of stream distance in meters. Parenthesis is distance in US units (ft).
[6]Visual assessment of fluid path width or stream distance in meters. Parenthesis is distance in US units (ft).

Table 4-2. Visual results of CIP device performance under actual operating conditions in the C-Thru tanker.

Device [1]	Flow rate Lpm (gpm) [2]	Pressure bar (psi) [3]	Fluid reach m (ft) [4]	Comments
Sd-HVMP	378 (100)	6.2 (90)	4.5 (15)	Fluids did not reach the bulkhead. Fluids hit the barrel top too early or not at all due to poor angle. When directional nozzle was directed at bulkhead, fluid hit bulkhead but not barrel. Also found that fluids hit one side of tanker and not the other due to improper installation.
R-HVMP	378 (100)	6.9 (100)	6.1 (20)	Fluids as a stream did reach bulkhead consistently.
R-HVMP	473 (125)	15.5 (225)	5.0 (16)	Fluids as a stream did not reach bulkhead but mist/spray did reach bulkhead. Action was consistent.
R-LVHP	75 (20)	41 (600)	3.4 (11)	Fluids as a stream did not reach bulkhead but some mist/spray did. Solid stream reach to 3.4 m.

[1]Devices operated at wash rack operating parameters. Sd-HVMP – Stationary, directional – high volume, medium pressure. R-HVMP – Rotating – high volume, medium pressure. R-LVHP – Rotating – low volume, high pressure.
[2]Flow rates (L per minute) recorded at the pump with wash rack equipment. Value in parenthesis is the U.S. units (gallons per minute).
[3]Pressure (bar) recorded at the pump discharge with wash rack equipment. Value in parenthesis is the U.S. units (pounds per square in).
[4]Fluid flow distances to the bulkhead measured visually in the C-Thru tanker with 6.7m (22ft) bulkhead. The C-Thru tanker had 1.2 m (4 ft) marked increments. Value in parenthesis is the U.S. units (ft).

Table 4-3. Examples of percent surface flow for R-LVHP CIP device.

Sample Sites	Percent surface flow at delivered flow conditions[1]	
	18 @ 350 & 4 rpm	23 @ 450 & 4 rpm
0	20.3	23.7
0.3	16.1	19.2
0.9	17.1	14.0
1.5	17.0	13.3
2.1	8.4	7.1
2.7	5.7	5.8
3.4	3.1	3.3
4.0	2.5	3.0
4.6	1.7	1.6
5.2	1.3	1.3
5.8	0.9	0.9
6.4	0.4	0.7
BHc[2]	3.6	3.6
BHt[3]	1.8	2.5

[1]Percent flow rate determined by dividing each site by the total fluid collected for each operating condition. Number of samples for each is n = 3. [2]BHc indicates the bulkhead center sampling site at 6.7m from the device. [3]BHt indicates the bulkhead top sampling site at 6.7m from the device.

Table 4-4. Impact force of R-LVHP CIP device using 1G and 5G impact indicators.

Sample Sites [3]	Number of positive reaction at G force detector (n = 3)[1,2]	
	1G	5G
0	3 (0)	3 (0)
0.3	3 (0)	3 (0)
0.9	3 (0)	3 (0)
1.5	2 (0)	1 (0)
2.7	1 (0)	0 (0)
4.6	0 (0)	0 (0)
5.8	0 (0)	0 (0)
6.7	0 (0)	0 (0)

[1]Device operating conditions 87 Lpm @ 32 bar with no extensions and at 4 shaft rpm.
[2]Impact indicators measured at device head level (109 cm from manway) and perpendicular to the device. Results indicate the number of positive reactions (blue arrows) which indicate the specific G force is exceeded. [3]The sample site is the distance in meters from the CIP device that the Teladrop Impact indicator was installed.

Table 4-5. R-LVHP air pressure, rotation speed, and cycle time compared.

Air pressure supply – psi (bar)	Rotation speed (rpm)	Approx. Cycle time (min)
5 (0.34)	3.2	11
7 (0.48)	6.0	6
10 (0.68)	8.2	5

[1]Data from device operating manual (SSI 2006)

Table 4-6. R-LVHP air motor pressure supply related to shaft speed (rpm).

Air motor gauge pressure – bar (psi) [1]	Observed shaft speed (rpm) dry [2]	Observed shaft speed (rpm) wet [3]	Estimated cycle time (min) [4]
0.3 (5)	0	0	Na
0.6 (8)	2.5 ± 0.1	2.3 ± 0.1	15.7
0.7 (10)	4.6 ± 0.2	4.3 ± 0.2	8.4
1.4 (20)	11.0 ± 0.2	10.0 ± 0.2	3.6
2.1 (30)	15.3 ± 0.2	14.2 ± 0.2	2.5
2.8 (40)	22.2 ± 0.4	20.2 ± 0.3	1.8
4.1 (60)	24.5 ± 0.6	22.4 ± 0.3	1.6

[1]Air motor pressure gauge mounted 1.5 m from spray device.
[2]The shaft at the motor was marked to indicate start/stop point. Shaft speed was determined by the time (in seconds) that the mark completed one rotation. Three trials were performed.
[3]Rotation speed determined with 68 Lpm @ 24.1 bar and 79.5 Lpm @ 31.0 bar following the above method. [4]The cycle time is determined by dividing 36 revolutions per cycle by rpm. Cycle time is device specific.

Table 4-7. R-LVHP speed effects at 69 Lpm and 24.1 bar (17.8 gpm and 350 psi at sprayer feed) (wash rack conditions).

Nozzle size	0030	0030	0030	0030	0030
Extension (cm)	0	0	0	0	0
Flow (Lpm)	69	69	69	69	69
Pressure (bar)	24.1	24.1	24.1	24.1	24.1
Air speed	10	20	30	40[1]	60[1]
Sample Sites [2]	Average Flow at rotation speeds L/min/m^2 (std dev) (n = 3)[3]				
0	1.672 (0.031)a	2.041 (0.024)b	2.035 (0.074)b	2.046 (0.009)b	2.170 (0.013)c
0.31	1.318 (0.035)a	1.574 (0.026)b	1.633 (0.012)b	1.611 (0.005)c	1.747 (0.037)d
0.91	1.401 (0.070)a	1.408 (0.016)a	1.396 (0.030)a	1.391 (0.017)a	1.385 (0.014)a
1.52	1.269 (0.025)a	1.379 (0.024)b	1.361 (0.001)a	1.345 (0.013)a	1.325 (0.009)c
2.10	0.577 (0.030)a	0.537 (0.021)b	0.512 (0.027)b	0.499 (0.001)c	0.504 (0.035)c
2.70	0.396 (0.016)a	0.394 (0.022)a	0.376 (0.036)b	0.379 (0.009)b	0.367 (0.003)c
3.35	0.228 (0.020)a	0.229 (0.003)a	0.217 (0.011)b	0.211 (0.004)b	0.181 (0.006)c
3.96	0.188 (0.011)a	0.146 (0.007)b	0.136 (0.003)c	0.129 (0.002)d	0.129 (0.003)d
4.57	0.126 (0.007)a	0.086 (0.005)b	0.076 (0.004)c	0.074 (0.002)c	0.064 (0.006)d
5.18	0.095 (0.006)a	0.063 (0.005)b	0.054 (0.002)c	0.050 (0.000)c	0.047 (0.005)c
5.79	0.064 (0.006)a	0.035 (0.002)b	0.025 (0.005)c	0.021 (0.001)c	0.013 (0.001)d
6.40	0.035 (0.005)a	0.014 (0.002)b	0.009 (0.001)c	0.009 (0.001)c	0.003 (0.001)d
BHc	0.225 (0.022)a	0.192 (0.006)b	0.156 (0.008)c	0.143 (0.010)c	0.148 (0.001)c
BHt	0.080 (0.005)a	0.019 (0.002)b	0.004 (0.002)c	0.000 (0.000)d	0.000 (0.000)d
Statistical difference[4]	1.548 A	2.366 B	2.928 CD	3.208 DE	3.863 E

[1]Standard rotation speeds at wash racks. [2]The sample sites are the collection devices at meter distances from the CIP device. BHc and BHt are the bulkhead center and top sites, respectively at 6.7 m from CIP device. [3]Letters indicate the significant difference (P<0.05) between treatments for each sample site. [4]Values indicate the overall significance by combining the average flow and site differences. Same letters in columns indicate no significant difference (P<0.05).

Table 4-8. R-LVHP speed effects at 74 Lpm and 27.6 bar (19 gpm and 400 psi at sprayer feed).

Nozzle size	0030	0030	0030	0030	0030
Extension (cm)	0	0	0	0	0
Distance(m)	Average Flow at rotation speed $L/min/m^2$ (std dev) (n = 3)[2]				
Air speed	10	20	30	40[1]	60[1]
0	1.709 (0.027)a	2.165 (0.032)b	2.196 (0.005)c	2.230 (0.012)d	2.270 (0.013)e
0.31	1.356 (0.018)a	1.624 (0.032)b	1.632 (0.007)b	1.740 (0.051)b	1.747 (0.037)c
0.91	1.435 (0.072)a	1.468 (0.040)a	1.464 (0.011)a	1.477 (0.009)a	1.467 (0.014)a
1.52	1.430 (0.077)a	1.516 (0.042)a	1.500 (0.019)b	1.563 (0.032)b	1.525 (0.009)b
2.10	0.707 (0.017)a	0.603 (0.015)b	0.573 (0.002)b	0.586 (0.031)c	0.544 (0.005)c
2.70	0.482 (0.017)a	0.453 (0.012)b	0.426 (0.008)b	0.449 (0.034)c	0.448 (0.005)c
3.35	0.259 (0.018)a	0.258 (0.008)a	0.253 (0.007)a	0.257 (0.012)a	0.258 (0.005)a
3.96	0.211 (0.016)a	0.172 (0.009)b	0.166 (0.002)b	0.168 (0.012)c	0.149 (0.003)c
4.57	0.142 (0.010)a	0.100 (0.003)b	0.094 (0.002)c	0.094 (0.002)c	0.085 (0.001)d
5.18	0.109 (0.006)a	0.072 (0.002)b	0.068 (0.001)b	0.070 (0.005)c	0.051 (0.001)d
5.79	0.079 (0.006)a	0.047 (0.003)b	0.038 (0.001)c	0.003 (0.003)c	0.020 (0.000)d
6.40	0.034 (0.002)a	0.025 (0.001)b	0.017 (0.001)c	0.015 (0.002)d	0.007 (0.001)c
BHc	0.299 (0.003)a	0.239 (0.001)b	0.205 (0.003)c	0.168 (0.011)d	0.148 (0.001)d
BHt	0.148 (0.003)a	0.044 (0.004)b	0.016 (0.002)c	0.006 (0.002)d	0.000 (0.000)e
Statistical difference[3]	1.600 A	2.413 B	2.903 C	3.488 D	3.837 D

[1]Standard rotation speeds at wash racks. [2]Letters indicate the significant difference (P<0.05) between treatments for each sample site. [3]Values indicate the overall significance by combining the average flow and site differences. Same letters in columns indicate no significant difference (P<0.05).

Table 4-9. R-LVHP speed effects at 75.8 Lpm and 31.0 bar (20 gpm and 450 psi at sprayer feed).

Nozzle size	0030	0030	0030	0030	0030	0030
Extension (cm)	0	0	0	0	0	0
Distance	Average flow at rotation speed $L/min/m^2$ (std dev) (n = 3)[2]					
(m)	8	10	20	30	40[1]	60[1]
0	1.765 (0.043)a	1.712 (0.051)b	2.214 (0.006)c	2.311 (0.044)c	2.272 (0.016)c	2.321 (0.020)c
0.31	1.387 (0.043)a	1.311 (0.030)a	1.609 (0.009)b	1.737 (0.022)c	1.712 (0.017)c	1.784 (0.010)c
0.91	1.436 (0.070)a	1.386 (0.022)a	1.500 (0.002)b	1.521 (0.008)b	1.528 (0.032)b	1.537 (0.001)b
1.52	1.452 (0.034)a	1.439 (0.008)a	1.632 (0.024)b	1.632 (0.012)b	1.664 (0.043)b	1.665 (0.009)b
2.10	0.799 (0.044)a	0.650 (0.015)b	0.681 (0.015)b	0.636 (0.029)b	0.622 (0.027)b	0.615 (0.014)b
2.70	0.507 (0.020)a	0.418 (0.009)b	0.520 (0.006)b	0.485 (0.016)c	0.482 (0.020)c	0.507 (0.010)c
3.35	0.288 (0.013)a	0.217 (0.009)b	0.295 (0.002)a	0.281 (0.010)b	0.267 (0.003)b	0.273 (0.009)b
3.96	0.233 (0.011)a	0.166 (0.010)b	0.203 (0.004)c	0.186 (0.009)c	0.181 (0.002)c	0.180 (0.005)c
4.57	0.161 (0.010)a	0.107 (0.007)b	0.115 (0.001)c	0.104 (0.004)b	0.109 (0.006)b	0.102 (0.002)b
5.18	0.132 (0.010)a	0.069 (0.001)b	0.086 (0.001)c	0.076 (0.003)c	0.076 (0.005)c	0.065 (0.004)c
5.79	0.091 (0.005)a	0.042 (0.001)b	0.060 (0.002)c	0.045 (0.001)b	0.038 (0.004)b	0.027 (0.002)b
6.40	0.080 (0.002)a	0.032 (0.001)b	0.025 (0.001)c	0.015 (0.002)c	0.017 (0.004)c	0.008 (0.002)c
BHc	0.292 (0.024)a	0.242 (0.004)a	0.276 (0.006)a	0.231 (0.011)a	0.182 (0.021)b	0.157 (0.005)b
BHt	0.138 (0.001)a	0.087 (0.008)b	0.077 (0.003)b	0.028 (0.002)c	0.009 (0.003)c	0.000 (0.000)c
Statistical difference[3]	1.626 A	2.277 A	2.950 B	3.092 C	3.154 D	3.160 E

[1]Standard rotation speeds at wash racks. [2]Letters indicate the significant difference (P<0.05) between treatments for each sample site.
[3]Values indicate the overall significance by combining the average flow and site differences. Same letters in columns indicate no significant difference (P<0.05).

Table 4-10. Calculated circumferences based on potential cleaning distances of a rotating CIP device.

Cleaning diameter in m (nominal ft) [1]	Cleaning radius in m (ft) [2]	Rotating device circumference tip path in m (ft) [3]
1.2 (4)	0.6 (2)	3.8 (12.6)
3.0 (10)	1.5 (5)	9.6 (31.4)
6.0 (20)	3.0 (10)	19.2 (63.8)
9.2 (30)	4.6 (15)	28.7 (94.2)
11.0 (36)	5.5 (18)	34.5 (113.1)
12.2 (40)	6.1 (20)	38.3 (125.7)
13.4 (44)	6.7 (22)	42.1 (138.2)

[1]Cleaning diameter is the diameter of a theoretical spherical tank. [2]Cleaning radius is the radius of the theoretical spherical tank if the device is installed at the tank's center. [3]Circumference determined with formula Pi x D, with Pi = 3.1316. The circumference is the theoretical path that the impinging fluid travels.

Table 4-11. Calculated fluid speeds at various distances based on device head speed (rpm) of R-LVHP device.

			Calculated fluid speed[1] at head rotation speed (rpm)					
		rpm	4		10		20	
		Time per revolution	0.25	15	0.1	6	0.05	3
Diameter (m)	Radius (m)	Circumference (m)	m/min	m/sec	m/min	m/sec	m/min	m/sec
1.2	0.6	3.8	15.3	0.26	38.3	0.64	76.6	1.28
3.0	1.5	9.6	38.3	0.64	95.8	1.60	191.6	3.19
6.0	3.0	19.2	76.6	1.28	191.6	3.19	383.1	6.39
9.2	4.6	28.7	114.9	1.92	287.3	4.79	574.7	9.58
11.0	5.5	34.5	137.9	2.30	344.8	5.75	689.6	11.49
12.2	6.1	38.3	153.3	2.55	383.1	6.39	766.2	12.77
13.4	6.7	42.1	168.6	2.81	421.4	7.02	842.9	14.05

[1] Fluid speed is calculated by dividing the circumference in m by the time (min or sec) for one revolution.

Table 4-12. Theoretical fluid dwell time and fluid delivery at device head speed (rpm) and distance for R-LVHP device.

		Calculated fluid dwell time and delivered volume at head rotation speeds (rpm)								
		4			10			20		
Radius (m)	Circumference (m)	Travel speed m/sec	Dwell sec/10cm[1]	Volume L/10cm[2]	Travel speed m/sec	Dwell sec/10cm[1]	Volume L/10cm[2]	Travel speed m/sec	Dwell sec/10cm[1]	Volume L/10cm[2]
0.6	3.8	0.26	0.376	0.261	0.64	0.157	0.109	1.28	0.078	0.054
1.5	9.6	0.67	0.150	0.101	1.60	0.063	0.043	3.19	0.031	0.022
3.0	19.2	1.33	0.075	0.052	3.19	0.031	0.022	6.39	0.016	0.011
4.6	28.7	2.00	0.050	0.035	4.79	0.021	0.014	9.58	0.010	0.007
5.5	34.5	2.40	0.042	0.029	5.74	0.017	0.012	11.49	0.009	0.006
6.1	38.3	2.66	0.038	0.026	6.39	0.016	0.011	12.77	0.008	0.005
6.7	42.1	2.93	0.034	0.024	7.02	0.014	0.010	14.05	0.007	0.005

[1] Dwell determined by dividing circumference by sec per revolution for each rotation speed (0.25, 0.1, and 0.05 respectively).
[2] L/10cm determined by multiplying 41.6 Lpm per nozzle (83.2 Lpm feed rate) by dwell time divided by 60 sec/minute.

Table 4-13. R-LVHP extension effects 68 Lpm at 24 bar and 10 psi (4 rpm) shaft speed)(18 gpm and 350 psi at sprayer feed).

Nozzle size[1]	0030	0030	0030	0030
Extension size[3]	0 cm (0 in)	7.6 cm (3 in)	15.2 cm (6 in)	22.9 cm (9 in)
Sample Sites [2]	Average Flow at rotation speed L/min/m^2 (std dev) (n = 3)[4]			
0	1.628 (0.003)a	1.875 (0.026)b	2.085 (0.054)b	1.751 (0.040)a
0.31	1.251 (0.006)a	1.513 (0.016)b	1.619 (0.030)b	1.374 (0.031)a
0.91	1.309 (0.030)a	0.988 (0.006)b	0.945 (0.057)b	0.949 (0.033)b
1.52	1.221 (0.018)a	1.040 (0.032)b	1.007 (0.033)b	1.018 (0.044)b
2.10	0.445 (0.008)a	0.462 (0.025)a	0.471 (0.028)a	0.511 (0.016)b
2.70	0.308 (0.023)a	0.374 (0.012)b	0.371 (0.021)b	0.408 (0.008)c
3.35	0.176 (0.014)a	0.202 (0.009)b	0.183 (0.010)b	0.300 (0.011)c
3.96	0.134 (0.012)a	0.163 (0.003)b	0.168 (0.004)b	0.219 (0.002)c
4.57	0.081 (0.008)a	0.097 (0.004)a	0.090 (0.002)a	0.136 (0.001)b
5.18	0.049 (0.006)a	0.070 (0.005)b	0.066 (0.003)c	0.102 (0.003)d
5.79	0.028 (0.004)a	0.046 (0.004)b	0.049 (0.003)b	0.060 (0.002)c
6.40	0.020 (0.002)a	0.037 (0.003)b	0.089 (0.003)c	0.033 (0.001)b
BHc	0.178 (0.012)a	0.176 (0.002)a	0.180 (0.008)a	0.211 (0.013)b
BHt	0.041 (0.003)a	0.108 (0.006)b	0.131 (0.003)b	0.136 (0.013)b
Statistical difference[5]	1.491 A	2.297 B	2.461 C	2.943 D

[1]Size as designated by the manufacturer. [2]Sample sites are the sampling point in m from the device. BHc and BHt are the bulkhead center and top sites respectively at 6.7 m from the device. [3]Extensions were steel pipe ¼ in. NPT fitted into the hub and the nozzles fitted to pipe with coupler. [4]Same letters across columns indicate no significant difference (P<0.05) between treatments at the sample site. [5]Same letters across columns indicate no significance difference (P<0.05) for treatments overall. Determined by analysis of all site flows and site differences. Higher values indicate an overall increase in fluid delivery.

Table 4-14. R-LVHP extension effects at 74 Lpm and 27.6 bar (19 gpm and 400 psi at sprayer feed).

Nozzle size[1]	0030	0030	0030	0030
Extension size[3]	0 cm (0 in)	7.6 cm (3 in)	15.2 cm (6 in)	22.9 cm (9 in)
Sample Sites [2]	Average Flow at rotation speed - L/min/m^2 (std dev) (n = 3)[4]			
0	1.709 (0.027)a	1.982 (0.030)b	1.999 (0.108)b	2.110 (0.060)c
0.31	1.356 (0.018)a	1.575 (0.039)a	1.682 (0.023)b	1.702 (0.019)b
0.91	1.435 (0.072)a	1.137 (0.031)a	0.995 (0.027)b	1.010 (0.032)b
1.52	1.430 (0.077)a	1.215 (0.053)a	1.046 (0.033)a	1.077 (0.062)a
2.10	0.707 (0.017)a	0.723 (0.054)a	0.511 (0.002)b	0.619 (0.052)b
2.70	0.482 (0.017)a	0.561 (0.033)b	0.450 (0.014)c	0.449 (0.046)c
3.35	0.259 (0.018)a	0.293 (0.014)a	0.239 (0.014)b	0.285 (0.035)b
3.96	0.211 (0.016)a	0.251 (0.011)a	0.200 (0.012)a	0.182 (0.022)a
4.57	0.142 (0.010)a	0.152 (0.010)a	0.111 (0.008)b	0.104 (0.015)b
5.18	0.109 (0.006)a	0.129 (0.008)a	0.083 (0.004)b	0.082 (0.013)b
5.79	0.079 (0.006)a	0.092 (0.002)a	0.061 (0.006)b	0.052 (0.007)b
6.40	0.034 (0.002)a	0.040 (0.002)a	0.049 (0.006)b	0.041 (0.004)b
BHc	0.299 (0.003)a	0.268 (0.009)b	0.177 (0.014)c	0.175 (0.018)c
BHt	0.148 (0.003)a	0.190 (0.009)b	0.131 (0.013)c	0.108 (0.012)c
Statistical difference[5]	1.600 A	1.901 B	2.624 C	2.714 C

[1]Size as designated by the manufacturer. [2]Sample site are the sampling point in m from the device. BHc and BHt are the bulkhead center and top sites respectively at 6.7 m from the device. [3]Extensions were steel pipe ¼ in NPT fitted into the hub and the nozzles fitted to pipe with coupler. [4]Same letters across columns indicate no significant difference (P<0.05) between treatments at the sample site. [5]Same letters across columns indicate no significance difference (P<0.05) for treatments overall. Determined by analysis of all site flows and site differences. Higher values indicate an overall increase in fluid delivery.

Table 4-15. R-LVHP extension effects at 75.8 Lpm and 31.0 bar (20 gpm and 450 psi at sprayer feed).

Nozzle size[1]	0030	0030	0030	0030
Extension size[2]	0 cm	7.6 cm (3 in)	15.2 cm (6 in)	22.9 cm (9 in)
Sample Sites [3]	Average Flow at rotation speed - L/min/m^2 (std dev) (n = 3)[4]			
0	1.712 (0.051)a	2.031 (0.073)b	2.280 (0.047)b	2.031 (0.028)c
0.31	1.311 (0.030)a	1.640 (0.051)b	1.755 (0.013)b	1.639 (0.022)b
0.91	1.386 (0.022)a	1.096 (0.035)a	1.001 (0.032)a	1.016 (0.017)a
1.52	1.439 (0.008)a	1.184 (0.038)b	1.084 (0.020)b	1.123 (0.007)b
2.10	0.650 (0.015)a	0.593 (0.033)b	0.573 (0.014)b	0.603 (0.011)b
2.70	0.418 (0.009)a	0.517 (0.035)b	0.500 (0.019)b	0.510 (0.018)b
3.35	0.217 (0.009)a	0.285 (0.032)b	0.264 (0.001)b	0.269 (0.012)b
3.96	0.166 (0.010)a	0.228 (0.029)b	0.230 (0.008)b	0.235 (0.004)b
4.57	0.107 (0.007)a	0.126 (0.010)a	0.116 (0.005)a	0.115 (0.004)a
5.18	0.069 (0.001)a	0.096 (0.012)a	0.089 (0.001)b	0.091 (0.004)b
5.79	0.042 (0.001)a	0.066 (0.011)a	0.066 (0.002)b	0.062 (0.003)b
6.40	0.032 (0.001)a	0.055 (0.012)a	0.061 (0.002)b	0.054 (0.007)b
BHc	0.242 (0.004)a	0.210 (0.027)a	0.213 (0.011)b	0.202 (0.011)b
BHt	0.087 (0.008)a	0.132 (0.016)a	0.146 (0.005)b	0.135 (0.006)c
Statistical difference[5]	1.563 A	2.090 B	2.456 C	2.578 C

[1]Size as designated by the manufacturer. [2]Extensions were steel pipe ¼ in NPT fitted into the hub and the nozzles fitted to pipe with coupler. [3]Sample site are the sampling point in m from the device. BHc is the bulkhead center site and BHt is the bulkhead top site. Bulkhead is 6.7m from device. [4]Same letters across columns indicate no significant difference (P<0.05) between treatments at the sample site. [5]Same letters across columns indicate no significance difference (P<0.05) for treatments overall. Determined by analysis of all site flows and site differences. Higher values indicate an overall increase in fluid delivery.

Table 4-16. R-LVHP extension effects at 79.5 Lpm and 34.5 bar (21 gpm and 500 psi at sprayer feed).

Nozzle size[1]	0030	0030	0030	0030
Extension size[2]	0 cm	7.6 cm (3 in)	15.2 cm (6 in)	22.9 cm (9 in)
Sample Sites [3]	Average Flow at rotation speed - L/min/m^2 (std dev) (n = 3)			
0	1.777 (0.028)a	2.139 (0.008)b	2.294 (0.019)b	1.937 (0.054)c
0.31	1.362 (0.035)a	1.680 (0.015)b	1.773 (0.020)b	1.549 (0.050)c
0.91	1.439 (0.019)a	1.180 (0.007)b	1.028 (0.017)b	1.153 (0.004)c
1.52	1.529 (0.015)a	1.277 (0.010)b	1.130 (0.013)b	1.218 (0.020)c
2.10	0.730 (0.007)a	0.866 (0.008)b	0.646 (0.004)b	0.733 (0.011)c
2.70	0.470 (0.015)a	0.738 (0.017)b	0.555 (0.014)b	0.626 (0.057)a
3.35	0.236 (0.014)a	0.391 (0.005)b	0.283 (0.011)b	0.479 (0.060)c
3.96	0.178 (0.009)a	0.307 (0.009)b	0.249 (0.010)b	0.326 (0.039)a
4.57	0.107 (0.013)a	0.188 (0.006)b	0.126 (0.006)b	0.197 (0.024)c
5.18	0.073 (0.005)a	0.160 (0.003)b	0.100 (0.000)b	0.153 (0.013)b
5.79	0.058 (0.006)a	0.112 (0.007)b	0.077 (0.003)b	0.090 (0.008)b
6.40	0.033 (0.003)a	0.058 (0.002)b	0.136 (0.005)b	0.062 (0.003)c
BHc	0.350 (0.006)a	0.309 (0.003)b	0.261 (0.016)b	0.277 (0.014)c
BHt	0.189 (0.008)a	0.217 (0.005)b	0.193 (0.010)b	0.182 (0.014)b
Statistical difference[5]	1.609 A	2.687 B	2.632 B	3.856 C

[1]Size as designated by the manufacturer. [2]Extensions were steel pipe ¼ in NPT fitted into the hub and the nozzles fitted to pipe with coupler. [3]Sample site are the sampling point in m from the device. BHc and BHt are the bulkhead center top sites respectively at 6.7m from the device. [4]Same letters across columns indicate no significant difference (P<0.05) between treatments at the sample site. [5]Same letters across columns indicate no significance difference (P<0.05) for treatments overall. Determined by analysis of all site flows and site differences. Higher values indicate an overall increase in fluid delivery.

Table 4-17. R-LVHP flow pressure effect 0030 nozzle, no extensions, and 10 psi (4 rpm) air motor speed.

Pressure – bar (psi)	24.1 (350)	27.6 (400)	31 (450)	34.5 (500)
Flow rate - Lpm	68.1	71.9	75.7	79.5
Sample Sites [1]	Average Flow - L/min/m^2 (std dev) at bar (psi) (n = 3)[2]			
0	1.549 (0.011)a	1.628 (0.003)b	1.712 (0.051)b	1.777 (0.028)c
0.31	1.257 (0.018)a	1.251 (0.014)a	1.311 (0.030)b	1.362 (0.035)b
0.91	1.233 (0.048)a	1.309 (0.030)b	1.386 (0.022)b	1.439 (0.019)c
1.52	1.075 (0.055)a	1.221 (0.018)b	1.439 (0.008)c	1.529 (0.015)d
2.10	0.420 (0.003)a	0.445 (0.008)b	0.650 (0.015)c	0.730 (0.015)d
2.70	0.286 (0.009)a	0.308 (0.023)b	0.418 (0.009)c	0.470 (0.015)d
3.35	0.178 (0.009)a	0.176 (0.014)a	0.217 (0.009)b	0.236 (0.014)c
3.96	0.143 (0.009)a	0.134 (0.012)a	0.166 (0.010)b	0.178 (0.009)b
4.57	0.098 (0.006)a	0.081 (0.012)a	0.107 (0.007)a	0.107 (0.013)a
5.18	0.071 (0.049)a	0.049 (0.006)b	0.069 (0.001)a	0.073 (0.005)a
5.79	0.037 (0.003)a	0.028 (0.004)a	0.042 (0.001)b	0.058 (0.006)b
6.40	0.019 (0.010)a	0.020 (0.002)a	0.032 (0.001)b	0.033 (0.003)b
BHc	0.161 (0.010)a	0.178 (0.012)b	0.242 (0.004)c	0.350 (0.006)d
BHt	0.037 (0.003)a	0.041 (0.003)b	0.087 (0.008)c	0.189 (0.008)d
Statistical difference[3]	1.469 A	2.062 B	2.777 C	3.395 C

[1]Sample sites are in m from the CIP device. BHc and BHt are bulkhead center and top sites, respectively at 6.7 m from device. [2]Same letters across columns indicate no significant difference ($P<0.05$) between treatments at the sample site. [3]Same letters across columns indicate no significance difference ($P<0.05$) for treatments overall. Determined by analysis of all site flows and site differences. Higher values indicate an overall increase in fluid delivery.

Table 4-18. R-LVHP flow pressure effect 0030 nozzle, no extensions, and 20 psi (10 rpm) air motor speed.

Pressure – bar (psi)	24.1 (350)	27.6 (400)	31 (450)
Sample sites[1]	Average Flow - L/min/m^2 (std dev) at bar (psi) (n = 3)[2]		
0	2.041 (0.024)a	2.165 (0.032)bc	2.214 (0.006)c
0.31	1.574 (0.026)a	1.624 (0.032)a	1.609 (0.009)a
0.91	1.408 (0.016)a	1.468 (0.040)ab	1.500 (0.002)b
1.52	1.379 (0.024)a	1.516 (0.042)b	1.632 (0.024)c
2.10	0.537 (0.021)a	0.603 (0.015)b	0.681 (0.015)c
2.70	0.394 (0.022)a	0.453 (0.012)b	0.520 (0.006)c
3.35	0.229 (0.003)a	0.258 (0.008)b	0.295 (0.002)c
3.96	0.146 (0.007)a	0.172 (0.009)b	0.203 (0.004)c
4.57	0.086 (0.005)a	0.100 (0.003)b	0.115 (0.001)c
5.18	0.063 (0.005)a	0.072 (0.002)b	0.086 (0.001)c
5.79	0.035 (0.002)a	0.047 (0.003)b	0.060 (0.002)c
6.40	0.014 (0.002)a	0.025 (0.001)b	0.025 (0.001)c
BHc	0.192 (0.006)a	0.239 (0.001)b	0.276 (0.006)c
BHt	0.019 (0.002)a	0.044 (0.004)b	0.077 (0.003)c
Statistical difference[3]	1.580 A	2.485 B	3.450 C

[1]Sample sites are in m from the CIP device. BHc and BHt are bulkhead center and top sites, respectively at 6.7 m from device. [2]Same letters across columns indicate no significant difference (P<0.05) between treatments at the sample site. [3]Same letters across columns indicate no significance difference (P<0.05) for treatments overall. Determined by analysis of all site flows and site differences. Higher values indicate an overall increase in fluid delivery.

Table 4-19. R-LVHP flow rate effect 0030 nozzle, no extensions, and 30 psi (14 rpm) air motor speed.

Pressure – bar (psi)	24.1 (350)	27.6 (400)	31 (450)
Sample Sites [1]	Average Flow - L/min/m^2 (std dev) at bar (psi) (n = 3)[2]		
0	2.035 (0.074)a	2.196 (0.005)a	2.311 (0.044)b
0.31	1.633 (0.012)a	1.632 (0.007)a	1.737 (0.022)b
0.91	1.396 (0.030)a	1.464 (0.011)a	1.521 (0.008)b
1.52	1.361 (0.001)a	1.500 (0.019)b	1.521 (0.008)c
2.10	0.512 (0.027)a	0.573 (0.002)ab	0.636 (0.029)b
2.70	0.376 (0.036)a	0.426 (0.008)a	0.485 (0.016)b
3.35	0.217 (0.011)a	0.253 (0.007)b	0.281 (0.010)c
3.96	0.136 (0.003)a	0.166 (0.002)b	0.186 (0.009)c
4.57	0.076 (0.004)a	0.094 (0.002)b	0.104 (0.004)c
5.18	0.054 (0.002)a	0.068 (0.001)b	0.076 (0.003)b
5.79	0.025 (0.005)a	0.038 (0.000)b	0.045 (0.001)c
6.40	0.009 (0.001)a	0.017 (0.001)b	0.015 (0.002)b
BHc	0.156 (0.008)a	0.205 (0.003)b	0.231 (0.011)b
BHt	0.004 (0.002)a	0.016 (0.002)b	0.028 (0.002)c
Statistical difference[3]	1.571 A	2.332 B	3.084 C

[1]Sample sites are in m from the CIP device. BHc and BHt are bulkhead center and top sites, respectively at 6.7 m from device. [2]Same letters across columns indicate no significant difference (P<0.05) between treatments at the sample site. [3]Same letters across columns indicate no significance difference (P<0.05) for treatments overall. Determined by analysis of all site flows and site differences. Higher values indicate an overall increase in fluid delivery.

Table 4-20. R-LVHP flow pressure effect 0030 nozzle, no extensions, and 40 psi (20 rpm) air motor speed.

Pressure – bar (psi)	24.1 (350)	27.6 (400)	31 (450)
Sample Sites [1]	Average Flow - L/min/m^2 (std dev) at bar (psi) (n = 3)[2]		
0	2.046 (0.009)a	2.230 (0.012)b	2.272 (0.016)b
0.31	1.611 (0.005)a	1.740 (0.051)b	1.712 (0.017)b
0.91	1.391 (0.017)a	1.477 (0.009)b	1.528 (0.032)b
1.52	1.345 (0.013)a	1.563 (0.032)b	1.664 (0.043)b
2.10	0.499 (0.001)a	0.586 (0.031)b	0.622 (0.027)b
2.70	0.379 (0.009)a	0.449 (0.034)ab	0.482 (0.020)b
3.35	0.211 (0.004)a	0.257 (0.012)b	0.267 (0.003)b
3.96	0.129 (0.002)a	0.168 (0.012)b	0.181 (0.002)b
4.57	0.074 (0.002)a	0.094 (0.002)b	0.109 (0.006)c
5.18	0.050 (0.000)a	0.070 (0.005)b	0.076 (0.005)b
5.79	0.021 (0.001)a	0.031 (0.003)b	0.038 (0.004)c
6.40	0.009 (0.001)a	0.015 (0.002)a	0.017 (0.004)a
BHc	0.143 (0.010)a	0.168 (0.011)a	0.182 (0.021)a
BHt	0.000 (0.000)a	0.006 (0.002)b	0.009 (0.003)b
Statistical difference[3]	1.565 A	2.418 B	2.654 C

[1]Sample sites are in m from the CIP device. BHc and BHt are bulkhead center and top sites, respectively at 6.7 m from device. [2]Same letters across columns indicate no significant difference (P<0.05) between treatments at the sample site. [3]Same letters across columns indicate no significance difference (P<0.05) for treatments overall. Determined by analysis of all site flows and site differences. Higher values indicate an overall increase in fluid delivery.

Table 4-21. R-LVHP flow pressure effect 0030 nozzle, no extensions, and 60 psi (22 rpm) air motor speed.

Pressure - bar (psi)	24.1 (350)	27.6 (400)	31 (450)
Sample Sites [1]	Average Flow - L/min/m^2 (std dev) at bar (psi) (n = 3)[2]		
0	2.046 (0.009)a	2.170 (0.013)b	2.321 (0.020)c
0.31	1.611 (0.005)a	1.747 (0.037)b	1.784 (0.010)b
0.91	1.391 (0.017)a	1.467 (0.014)b	1.537 (0.001)c
1.52	1.345 (0.013)a	1.525 (0.009)b	1.665 (0.009)c
2.10	0.499 (0.001)a	0.544 (0.005)b	0.615 (0.014)c
2.70	0.379 (0.009)a	0.448 (0.005)b	0.507 (0.010)c
3.35	0.211 (0.004)a	0.258 (0.005)b	0.273 (0.009)b
3.96	0.129 (0.002)a	0.149 (0.003)b	0.180 (0.005)b
4.57	0.074 (0.002)a	0.085 (0.001)b	0.102 (0.002)c
5.18	0.050 (0.000)a	0.051 (0.001)b	0.065 (0.004)b
5.79	0.021 (0.001)a	0.020 (0.000)b	0.027 (0.002)c
6.40	0.009 (0.001)a	0.007 (0.001)a	0.008 (0.002)a
BHc	0.143 (0.010)a	0.148 (0.001)a	0.157 (0.005)a
BHt	0.000 (0.000)a	0.000 (0.000)a	0.000 (0.000)a
Statistical difference[3]	1.565 A	2.401 B	2.946 C

[1]Sample sites are in m from the CIP device. BHc and BHt are bulkhead center and top sites, respectively at 6.7 m from device. [2]Same letters across columns indicate no significant difference (P<0.05) between treatments at the sample site. [3]Same letters across columns indicate no significance difference (P<0.05) for treatments overall. Determined by analysis of all site flows and site differences. Higher values indicate an overall increase in fluid delivery.

Table 4-22. R-LVHP flow rate with 0030 nozzle, no extensions, and 10 psi (4 rpm) air motor speed.

Lpm (gpm)	68.1 (18)	71.9 (19)	75.7 (20)	79.5 (21)
Bar (psi)	24.1 (350)	27.6 (400)	31.0 (450)	34.5 (500)
Sample Sites [1]	Average Flow - L/min/m^2 (std dev) by operating flow (n = 3)[2]			
0	1.672 (0.031)a	1.709 (0.027)a	1.765 (0.043)b	1.777 (0.028)ab
0.31	1.318 (0.035)a	1.356 (0.018)a	1.387 (0.043)b	1.362 (0.035)ab
0.91	1.401 (0.070)a	1.435 (0.072)a	1.436 (0.070)a	1.439 (0.019)a
1.52	1.269 (0.025)a	1.430 (0.077)b	1.452 (0.034)b	1.529 (0.015)b
2.10	0.577 (0.030)a	0.707 (0.017)b	0.799 (0.044)bc	0.730 (0.007)bc
2.70	0.396 (0.016)a	0.482 (0.017)b	0.507 (0.020)b	0.470 (0.015)c
3.35	0.226 (0.020)a	0.259 (0.018)a	0.288 (0.013)c	0.236 (0.014)c
3.96	0.188 (0.011)a	0.211 (0.016)a	0.233 (0.011)a	0.178 (0.009)a
4.57	0.126 (0.007)a	0.142 (0.010)a	0.161 (0.010)b	0.107 (0.013)b
5.18	0.095 (0.006)a	0.109 (0.006)a	0.132 (0.010)b	0.073 (0.005)a
5.79	0.064 (0.006)a	0.079 (0.006)a	0.091 (0.005)b	0.058 (0.006)a
6.40	0.035 (0.005)a	0.034 (0.002)a	0.080 (0.002)b	0.033 (0.003)a
BHc	0.225 (0.22)a	0.299 (0.003)b	0.292 (0.024)c	0.350 (0.006)c
BHt	0.080 (0.005)a	0.148 (0.003)b	0.138 (0.001)c	0.189 (0.008)d
Statistical difference[3]	1.548 A	1.957 B	2.769 C	2.681 C

[1]Sample sites are in m from the CIP device. BHc and BHt are bulkhead center and top sites, respectively at 6.7 m from device. [2]Same letters across columns indicate no significant difference (P<0.05) between treatments at the sample site. [3]Same letters across columns indicate no significance difference (P<0.05) for treatments overall. Determined by analysis of all site flows and site differences. Higher values indicate an overall increase in fluid delivery.

Table 4-23. R-LVHP flow rate with 0030 nozzle, 3 in. extensions, and 10 psi (4 rpm) air motor speed.

Lpm (gpm)	68.1 (18)	71.9 (19)	75.7 (20)	79.5 (21)
Bar (psi)	24.1 (350)	27.6 (400)	31.0 (450)	34.5 (500)
Sample Sites [1]	Average Flow - L/min/m^2 (std dev) by operating flow (n = 3)[2]			
0	1.875 (0.026)a	1.982 (0.030)a	1.778 (0.303)ab	2.139 (0.008)b
0.31	1.513 (0.016)a	1.575 (0.039)a	1.477 (0.051)ab	1.680 (0.015)b
0.91	0.988 (0.006)a	1.137 (0.031)b	1.148 (0.020)b	1.180 (0.007)b
1.52	1.040 (0.032)a	1.215 (0.053)ab	1.184 (0.052)b	1.277 (0.010)b
2.10	0.462 (0.025)a	0.723 (0.054)b	0.761 (0.036)bc	0.866 (0.008)c
2.70	0.374 (0.012)a	0.561 (0.033)b	0.636 (0.048)bc	0.738 (0.017)c
3.35	0.202 (0.009)a	0.293 (0.014)b	0.355 (0.028)bc	0.391 (0.005)c
3.96	0.163 (0.003)a	0.251 (0.011)b	0.284 (0.021)bc	0.307 (0.009)c
4.57	0.097 (0.004)a	0.152 (0.010)b	0.173 (0.010)bc	0.188 (0.006)c
5.18	0.070 (0.005)a	0.129 (0.008)b	0.150 (0.009)bc	0.160 (0.003)c
5.79	0.046 (0.004)a	0.092 (0.002)b	0.108 (0.006)bc	0.112 (0.007)c
6.40	0.037 (0.003)a	0.040 (0.002)b	0.035 (0.001)b	0.058 (0.002)c
BHc	0.176 (0.002)a	0.268 (0.009)b	0.318 (0.019)c	0.309 (0.003)c
BHt	0.108 (0.006)a	0.190 (0.009)b	0.217 (0.014)bc	0.217 (0.005)c
Statistical difference[3]	1.511 A	2.472 B	3.259 C	3.402 D

[1]Sample sites are in m from the CIP device. BHc and BHt are bulkhead center and top sites, respectively at 6.7 m from device. [2]Same letters across columns indicate no significant difference (P<0.05) between treatments at the sample site. [3]Same letters across columns indicate no significance difference (P<0.05) for treatments overall. Determined by analysis of all site flows and site differences. Higher values indicate an overall increase in fluid delivery.

Table 4-24. R-LVHP flow rate with 0030 nozzle, 6 in. extensions, and 10 psi (4 rpm) air motor speed.

Lpm (gpm)	68.1 (18)	71.9 (19)	75.7 (20)	79.5 (21)
Bar (psi)	24.1 (350)	27.6 (400)	31.0 (450)	34.5 (500)
Sample Sites [1]	Average Flow - L/min/m^2 (std dev) by operating flow (n = 3)[2]			
0	2.093 (0.018)a	1.999 (0.108)a	2.280 (0.047)b	2.109 (0.107)a
0.31	1.612 (0.025)a	1.682 (0.023)a	1.755 (0.013)b	1.599 (0.091)a
0.91	0.926 (0.014)a	0.995 (0.027)a	1.001 (0.032)a	1.052 (0.027)b
1.52	0.999 (0.024)a	1.046 (0.033)a	1.084 (0.020)a	1.132 (0.015)a
2.10	0.461 (0.031)a	0.511 (0.002)a	0.573 (0.014)a	0.596 (0.015)b
2.70	0.374 (0.026)a	0.450 (0.014)b	0.500 (0.019)b	0.540 (0.023)c
3.35	0.184 (0.015)a	0.239 (0.014)b	0.264 (0.001)b	0.307 (0.010)c
3.96	0.171 (0.013)a	0.200 (0.012)b	0.230 (0.008)c	0.278 (0.010)d
4.57	0.090 (0.005)a	0.111 (0.008)b	0.116 (0.005)c	0.140 (0.003)d
5.18	0.067 (0.008)a	0.083 (0.004)b	0.089 (0.001)b	0.113 (0.004)c
5.79	0.049 (0.005)a	0.061 (0.006)b	0.066 (0.002)b	0.085 (0.006)c
6.40	0.041 (0.004)a	0.049 (0.006)b	0.061 (0.002)b	0.074 (0.006)c
BHc	0.165 (0.009)a	0.177 (0.014)a	0.213 (0.011)b	0.275 (0.014)c
BHt	0.111 (0.009)a	0.131 (0.013)b	0.146 (0.005)b	0.184 (0.009)c
Statistical difference[3]	1.525 A	2.124 B	2.527 B	3.177 C

[1]Sample sites are in m from the CIP device. BHc and BHt are bulkhead center and top sites, respectively at 6.7 m from device. [2]Same letters across columns indicate no significant difference (P<0.05) between treatments at the sample site. [3]Same letters across columns indicate no significance difference (P<0.05) for treatments overall. Determined by analysis of all site flows and site differences. Higher values indicate an overall increase in fluid delivery.

Table 4-25. R-LVHP flow rate with 0030 nozzle, 9 in. extensions, and 10 psi (4 rpm) air motor speed.

Lpm (gpm)	68.1 (18)	71.9 (19)	75.7 (20)	79.5 (21)
Bar (psi)	24.1 (350)	27.6 (400)	31.0 (450)	34.5 (500)
Sample Sites [1]	Average Flow - L/min/m^2 (std dev) by operating flow (n = 3)[2]			
0	1.870 (0.039)a	2.110 (0.060)a	2.031 (0.028)b	2.213 (0.086)c
0.31	1.511 (0.012)a	1.702 (0.019)b	1.639 (0.022)c	1.778 (0.097)c
0.91	0.949 (0.029)a	1.010 (0.032)b	1.016 (0.017)b	1.048 (0.058)b
1.52	1.012 (0.043)a	1.077 (0.062)a	1.123 (0.007)a	1.115 (0.082)a
2.10	0.474 (0.029)a	0.619 (0.052)b	0.603 (0.011)b	0.711 (0.035)c
2.70	0.398 (0.038)a	0.449 (0.046)a	0.510 (0.018)b	0.607 (0.062)c
3.35	0.207 (0.011)a	0.285 (0.035)b	0.269 (0.012)b	0.330 (0.047)b
3.96	0.180 (0.013)a	0.182 (0.022)a	0.235 (0.004)b	0.243 (0.028)b
4.57	0.090 (0.004)a	0.104 (0.015)b	0.115 (0.004)b	0.133 (0.013)b
5.18	0.071 (0.005)a	0.082 (0.013)a	0.091 (0.004)b	0.108 (0.013)c
5.79	0.048 (0.006)a	0.052 (0.007)a	0.062 (0.003)b	0.066 (0.010)b
6.40	0.044 (0.007)a	0.041 (0.004)a	0.054 (0.007)a	0.058 (0.009)b
BHc	0.158 (0.007)a	0.175 (0.018)a	0.202 (0.011)b	0.222 (0.035)b
BHt	0.107 (0.006)a	0.108 (0.012)a	0.135 (0.006)b	0.140 (0.014)b
Statistical difference[3]	1.508 A	1.928 B	2.506 C	2.912 D

[1]Sample sites are in m from the CIP device. BHc and BHt are bulkhead center and top sites, respectively at 6.7 m from device. [2]Same letters across columns indicate no significant difference (P<0.05) between treatments at the sample site. [3]Same letters across columns indicate no significance difference (P<0.05) for treatments overall. Determined by analysis of all site flows and site differences. Higher values indicate an overall increase in fluid delivery.

Table 4-26. R-LVHP flow rates at 350 psi with varied nozzles, 9 in. extensions, and 10 psi (4 rpm) air motor speed.

Nozzle size	0030	0035	0040	0045	0050
Lpm (gpm)	71.9 (19)	75.7 (20)	83.3 (22)	90.8 (24)	94.6 (25)
Sample Sites [1]	Average Flow - L/min/m^2 (std dev) by operating flow (n = 3)[2]				
0	1.870 (0.039)a	1.975 (0.024)a	2.379 (0.066)b	2.558 (0.039)c	2.477 (0.062)c
0.31	1.511 (0.012)a	1.618 (0.050)a	1.948 (0.067)b	2.083 (0.034)b	2.062 (0.087)c
0.91	0.949 (0.029)a	1.148 (0.014)b	1.198 (0.045)b	1.273 (0.019)c	1.402 (0.056)d
1.52	1.012 (0.043)a	1.087 (0.039)a	1.231 (0.027)b	1.289 (0.017)c	1.342 (0.071)c
2.10	0.474 (0.029)a	0.485 (0.026)a	0.654 (0.002)b	0.659 (0.027)c	0.662 (0.065)c
2.70	0.398 (0.038)a	0.402 (0.020)a	0.523 (0.016)b	0.572 (0.008)c	0.571 (0.054)c
3.35	0.207 (0.011)a	0.227 (0.015)b	0.273 (0.009)b	0.318 (0.019)c	0.324 (0.032)c
3.96	0.180 (0.013)a	0.207 (0.014)b	0.236 (0.015)c	0.285 (0.014)d	0.309 (0.030)d
4.57	0.090 (0.004)a	0.120 (0.007)b	0.125 (0.008)b	0.147 (0.006)c	0.171 (0.019)c
5.18	0.071 (0.005)a	0.084 (0.006)b	0.093 (0.008)c	0.113 (0.004)d	0.129 (0.015)d
5.79	0.048 (0.006)a	0.060 (0.005)b	0.064 (0.007)b	0.084 (0.004)c	0.095 (0.011)c
6.40	0.044 (0.007)a	0.052 (0.008)a	0.061 (0.009)b	0.070 (0.004)b	0.085 (0.011)c
BHc	0.158 (0.007)a	0.249 (0.020)b	0.234 (0.023)b	0.284 (0.015)c	0.390 (0.044)c
BHt	0.107 (0.006)a	0.154 (0.020)a	0.141 (0.015)b	0.180 (0.012)b	0.227 (0.033)b
Significant difference[3]	1.509 A	2.062 A	2.797 A	3.634 AB	3.875 B

[1]Sample sites are in m from the CIP device. BHc and BHt are bulkhead center and top sites, respectively at 6.7 m from device. [2]Same letters across columns indicate no significant difference (P<0.05) between treatments at the sample site. [3]Same letters across columns indicate no significance difference (P<0.05) for treatments overall. Determined by analysis of all site flows and site differences. Higher values indicate an overall increase in fluid delivery.

Table 4-27. R-LVHP flow rates at 450 psi with varied nozzles, 9 in. extensions, and 10 psi (4 rpm) air motor speed.

Nozzle size	0030	0035	0040	0045	0050
Lpm (gpm)	71.9 (19)	75.7 (20)	83.3 (22)	90.8 (24)	94.6 (25)
Sample Sites [1]	Average Flow - L/min/m^2 (std dev) by operating flow (n = 3)[2]				
0	2.031 (0.028)a	2.152 (0.065)a	2.473 (0.006)b	2.638 (0.058)c	2.925 (0.064)d
0.31	1.639 (0.022)a	1.745 (0.020)a	2.013 (0.019)b	2.128 (0.033)c	2.344 (0.047)d
0.91	1.016 (0.017)a	1.274 (0.023)b	1.263 (0.017)c	1.314 (0.060)c	1.446 (0.067)d
1.52	1.123 (0.007)a	1.210 (0.003)b	1.319 (0.008)c	1.363 (0.077)c	1.497 (0.082)d
2.10	0.603 (0.011)a	0.642 (0.031)a	0.789 (0.020)b	0.805 (0.057)b	0.890 (0.060)c
2.70	0.510 (0.018)a	0.525 (0.033)a	0.731 (0.008)b	0.760 (0.041)b	0.835 (0.044)c
3.35	0.269 (0.012)a	0.303 (0.024)a	0.396 (0.001)b	0.447 (0.034)b	0.492 (0.037)c
3.96	0.235 (0.004)a	0.275 (0.012)b	0.323 (0.010)b	0.374 (0.022)c	0.411 (0.023)d
4.57	0.115 (0.004)a	0.150 (0.001)b	0.166 (0.001)b	0.195 (0.001)c	0.216 (0.001)d
5.18	0.091 (0.004)a	0.114 (0.002)b	0.128 (0.005)b	0.149 (0.008)c	0.165 (0.006)d
5.79	0.062 (0.003)a	0.080 (0.001)b	0.090 (0.001)c	0.111 (0.005)d	0.123 (0.005)e
6.40	0.054 (0.007)a	0.068 (0.001)a	0.082 (0.003)b	0.106 (0.004)c	0.119 (0.003)d
BHc	0.202 (0.011)a	0.324 (0.013)b	0.323 (0.006)b	0.407 (0.016)c	0.451 (0.016)d
BHt	0.135 (0.006)a	0.229 (0.028)b	0.190 (0.008)b	0.266 (0.005)c	0.296 (0.005)d
Significant difference[3]	1.578 A	2.221 A	2.949 A	3.647 A	4.586 B

[1]Sample sites are in m from the CIP device. BHc and BHt are bulkhead center and top sites, respectively at 6.7 m from device. [2]Same letters across columns indicate no significant difference (P<0.05) between treatments at the sample site. [3]Same letters across columns indicate no significance difference (P<0.05) for treatments overall. Determined by analysis of all site flows and site differences. Higher values indicate an overall increase in fluid delivery.

Table 4-28. R-LVHP wall flow rates with nozzle variations.

Sample Sites [3]	Average wall flow rate as L/min/m^2 (std dev) at 87 Lpm and 31 bar feed rate (23 gpm and 450 psi) (n = 3)[1,2]		
	0030 nc	0030 w/o vanes	0030 w jet stabilizer
0	1.71 (0.05)a	1.58 (0.03)b	2.03 (0.02)c
0.31	1.31 (0.03)a	1.26 (0.05)b	1.62 (0.03)c
0.91	1.39 (0.02)a	1.61 (0.11)b	1.14 (0.02)c
1.52	1.44 (0.01)a	1.53 (0.09)b	1.15 (0.06)c
2.10	0.65 (0.02)a	0.72 (0.03)b	0.60 (0.02)c
2.70	0.42 (0.01)a	0.39 (0.05)b	0.44 (0.01)c
3.35	0.22 (0.01)a	0.19 (0.02)b	0.24 (0.01)c
3.96	0.17 (0.01)a	0.12 (0.01)b	0.20 (0.02)c
4.57	0.11 (0.01)a	0.08 (0.01)b	0.11 (0.01)c
5.18	0.07 (0.00)a	0.04 (0.01)b	0.09 (0.01)c
5.79	0.04 (0.00)a	0.02 (0.00)b	0.06 (0.00)c
6.40	0.03 (0.00)a	0.02 (0.00)b	0.05 (0.00)c
BHc	0.24 (0.00)a	0.14 (0.01)b	0.23 (0.02)c
BHt	0.09 (0.01)a	0.02 (0.00)b	0.14 (0.01)c
Significant difference[4]	1.564 A	2.551 B	3.579 C

[1]Device manufacturer details. [2] Same letters in each column indicate no significance P<0.05 at the sample site for treatments. [3]Sample sites are in m from the device. BHc and BHt are bulkhead center and top sites, respectively at 6.7m from device. [4]Same letters in each column indicate no significance P<0.05 for the overall operating conditions.

Table 4-29. R-LVHP flow rates for test nozzle and extensions at 68 Lpm and 24 bar.

Nozzle[2]	0030 JS 0	0030 ST 0	0030 ST 3	0030 ST 6	0030 ST 9
Sample Sites [3]	Average Flow - L/min/m^2 (std dev) (n = 3)[1]				
0	1.89 (0.03)a	1.63 (0.00)b	1.88 (0.03)a	2.09 (0.02)c	1.87 (0.04)a
0.31	1.52 (0.02)a	1.25 (0.01)b	1.51 (0.02)a	1.61 (0.03)a	1.51 (0.01)a
0.91	1.06 (0.03)a	1.31 (0.03)b	0.99 (0.01)a	0.93 (0.01)b	0.95 (0.03)a
1.52	1.08 (0.00)a	1.22 (0.02)b	1.04 (0.03)c	1.00 (0.02)c	1.01 (0.04)c
2.10	0.49 (0.03)a	0.45 (0.01)a	0.46 (0.03)a	0.46 (0.03)a	0.47 (0.03)b
2.70	0.36 (0.01)a	0.31 (0.02)a	0.37 (0.01)b	0.37 (0.03)a	0.40 (0.04)a
3.35	0.20 (0.01)a	0.18 (0.01)a	0.20 (0.01)a	0.18 (0.01)a	0.21 (0.01)a
3.96	0.16 (0.00)a	0.13 (0.01)b	0.16 (0.00)a	0.17 (0.01)a	0.18 (0.01)a
4.57	0.09 (0.00)a	0.08 (0.01)a	0.10 (0.01)a	0.09 (0.01)a	0.09 (0.00)a
5.18	0.07 (0.00)a	0.05 (0.01)b	0.07 (0.01)a	0.07 (0.01)a	0.07 (0.01)a
5.79	0.04 (0.00)a	0.03 (0.00)a	0.05 (0.00)a	0.05 (0.00)a	0.05 (0.01)a
6.40	0.03 (0.00)a	0.02 (0.00)b	0.04 (0.00)a	0.04 (0.00)a	0.04 (0.01)a
BHc	0.19 (0.01)a	0.18 (0.01)b	0.18 (0.01)b	0.16 (0.01)b	0.16 (0.01)b
BHt	0.10 (0.00)a	0.04 (0.00)b	0.11 (0.01)a	0.11 (0.01)a	0.11 (0.01)a
Overall difference[4]	1.520 A	2.134 C	1.797 AB	1.952 B	1.794 AB

[1]Same letters in each column indicate no significant difference ($P<0.05$) at the sample site for each treatment. [2]Nozzle size for each test is 0030 with jet stabilizer no extensions (JS 0), standard nozzle (ST) with extensions (0, 3, 6, or 9 in). [3]Samples sites in m from the device. BHc and BHt are bulkhead center and top sites, respectively at 6.7 m from device. [4]Same letters in each column indicate no significance ($P<0.05$) for nozzle treatment overall.

Table 4-30. R-LVHP flow rates for test nozzle and extensions at 87 Lpm and 31 bar.

Nozzle[2]	0030 JS 0	0030 ST 0	0030 ST 3	0030 ST 6	0030 ST 9
Sample Sites [3]	Average Flow - L/min/m^2 (std dev) (n = 3)[1]				
0	2.03 (0.02)a	1.71 (0.05)b	2.03 (0.07)a	2.28 (0.05)b	2.03 (0.03)a
0.31	1.62 (0.03)a	1.31 (0.03)b	1.64 (0.05)a	1.76 (0.01)b	1.64 (0.02)a
0.91	1.14 (0.02)a	1.39 (0.02)b	1.10 (0.03)a	1.00 (0.03)b	1.02 (0.02)b
1.52	1.15 (0.06)a	1.44 (0.01)b	1.18 (0.04)a	1.08 (0.02)a	1.12 (0.01)a
2.10	0.60 (0.02)a	0.65 (0.02)b	0.59 (0.03)a	0.57 (0.01)a	0.60 (0.01)a
2.70	0.44 (0.01)a	0.42 (0.01)a	0.52 (0.03)a	0.50 (0.02)a	0.51 (0.02)b
3.35	0.24 (0.01)a	0.22 (0.01)a	0.29 (0.03)a	0.26 (0.00)a	0.27 (0.01)a
3.96	0.20 (0.02)a	0.17 (0.01)a	0.23 (0.03)a	0.23 (0.01)a	0.23 (0.00)b
4.57	0.11 (0.01)a	0.11 (0.01)a	0.13 (0.01)a	0.12 (0.01)a	0.12 (0.00)a
5.18	0.09 (0.01)a	0.07 (0.01)b	0.10 (0.01)a	0.09 (0.00)b	0.09 (0.00)a
5.79	0.06 (0.00)a	0.04 (0.00)a	0.07 (0.01)a	0.07 (0.00)b	0.06 (0.00)b
6.40	0.05 (0.00)a	0.03 (0.00)b	0.06 (0.01)a	0.06 (0.00)b	0.05 (0.01)b
BHc	0.23 (0.02)a	0.24 (0.00)a	0.21 (0.03)a	0.21 (0.01)a	0.20 (0.01)a
BHt	0.14 (0.01)a	0.09 (0.01)b	0.13 (0.02)a	0.15 (0.01)a	0.14 (0.01)a
Overall significant difference[4]	1.579 A	2.135 C	1.591 A	2.027 B	1.934 A

[1]Same letters in each column indicate no significant difference (P<0.05) at the distance. [2]Nozzle size for each test is 0030 with jet stabilizer no extensions (JS 0), standard nozzle (ST) with extensions (0, 3, 6, or 9 in). [3]Samples sites in m from the device. BHc and BHt are bulkhead center and top sites, respectively at 6.7 m from device. [4]Same letters in each column indicate no significance (P<0.05) for nozzle treatment overall.

Table 4-31. Percent surface flow for Sd-HVMP CIP device.

	Percent surface flow at delivered flow conditions[1]	
Sample Sites [2]	122 @ 65	150 @ 80
0	8.64	11.03
0.3	8.36	11.66
0.9	4.04	4.65
1.5	4.66	5.84
2.1	3.35	4.98
2.7	1.66	1.82
3.4	1.05	1.69
4.0	1.27	1.40
4.6	2.24	2.62
5.2	3.59	2.71
5.8	1.78	1.63
6.4	2.90	1.08
BHc	30.63	25.94
BHt	25.82	22.95

[1]Percent flow rate determined by dividing each site by the total fluid collected for each operating condition. Number of samples for each is n = 3. [2]Sample sites are the sampling points in m from the device. BHc and BHt are the bulkhead center and top sites, respectively at 6.7m from device.

Table 4-32. Sd-HVMP wall flow rates with varied pump delivery conditions.

Sample Sites [2]	Average wall flow rate - L/min/m^2 (std dev) at pump delivery rate Lpm @ bar (gpm @ psi) (n = 3)[1]		
	397@3.1 (105@45)	462@4.5 (122@65)	568@5.5(150@80)
0	6.02 (0.03)a	9.45 (0.82)b	16.60 (0.35)c
0.31	2.95 (0.05)a	9.14 (0.23)b	17.55 (0.14)c
0.91	2.62 (0.03)a	4.42 (0.24)b	7.00 (0.42)c
1.52	5.10 (0.08)a	5.09 (0.20)b	8.79 (0.03)c
2.10	3.40 (0.06)a	3.66 (0.16)b	7.49 (0.05)c
2.70	2.83 (0.01)a	1.82 (0.10)b	2.74 (0.08)c
3.35	2.86 (0.07)a	1.15 (0.07)b	2.54 (0.01)c
3.96	2.66 (0.04)a	1.39 (0.09)b	2.10 (0.06)c
4.57	6.26 (0.13)a	2.45 (0.11)b	3.94 (0.31)c
5.18	5.69 (0.04)a	3.93 (0.18)b	4.08 (0.22)c
5.79	2.81 (0.06)a	1.95 (0.11)b	2.45 (0.06)c
6.40	4.15 (0.05)a	3.17 (0.45)b	1.62 (0.03)c
BHc	33.34 (0.61)a	33.49 (3.20)b	39.03 (0.89)c
BHt	10.92 (2.74)a	28.23 (2.47)b	34.54 (2.75)c
Overall Difference [3]	7.544 A	9.810 B	13.748 C

[1]Same letters in each column indicate no significant difference P<0.05 at the distance. [2]Sample sites are the sampling point in m from the device. BHc and BHt is the bulkhead center and top sites, respectively at 6.7m from device. [3]Same letters in each column indicate no significance P<0.05 for the overall operating conditions.

Table 4-33. Sd-HVMP wall flow rates with varied installation pitch.

Pitch angle	76	79	82
Sampling Sites [2]	Average wall flow rate L/min/m^2 (std dev)[1] with 568 Lpm and 5.5 bar feed (150 gpm and 80 psi) with varied pitch positions (n= 3)[3]		
0	16.50 (0.30)a	16.60 (0.35)a	16.30 (0.41)a
0.31	18.05 (0.21)a	17.55 (0.14)a	16.25 (0.18)b
0.91	13.30 (0.22)b	7.00 (0.42)a	5.50 (0.02)c
1.52	12.50 (0.03)b	8.79 (0.03)a	6.85 (0.01)c
2.10	11.20 (0.08)b	7.49 (0.05)a	5.38 (0.32)c
2.70	6.00 (0.12)b	2.74 (0.08)a	1.54 (0.04)c
3.35	6.50 (0.72)b	2.54 (0.01)a	1.01 (0.01)c
3.96	8.10 (0.01)b	2.10 (0.06)a	0.83 (0.01)c
4.57	20.00 (1.21)b	3.94 (0.31)a	1.45 (0.03)c
5.18	13.00 (0.81)b	4.08 (0.22)a	1.60 (0.01)c
5.79	0.04 (0.01)b	2.45 (0.06)a	1.20 (0.01)c
6.40	0.01 (0.01)b	1.62 (0.03)a	4.05 (0.27)c
BHc	0.01 (0.01)b	39.03 (0.89)a	42.00 (1.01)c
BHt	2.03 (0.11)b	14.54 (0.75)a	0.01 (0.00)c
Overall Difference[4]	10.945 B	10.319 A	10.212 C

[1]Different letters indicate significant difference ($P<0.05$) for each pitch angle. [2]Sample sites are the sampling point in m from the device. BHc and BHt are the bulkhead center and top sites, respectively at 6.7m from device. [3]Same letters across columns for each sample site indicate no significant difference ($P<0.05$) for treatment. [4]Same letters indicate no significant difference ($P<0.05$) overall for pitch installation.

Table 4-34. Sd-HVMP wall flow rates with varied centering installation.

Degrees off center[2]	0	1R	2.5R	5R	10R
Sample Sites[3]	Average wall flow rate L/min/m^2 (std dev)[1] with 568 Lpm and 5.5 bar feed (150 gpm and 80 psi) with varied centering positions (n= 3)[4]				
0	16.60 (0.35)a	14.79 (0.09)b	15.9 (0.11)c	10.78 (0.25)d	7.96 (0.04)e
0.31	17.55 (0.14)a	13.98 (0.52)b	15.32 (0.22)c	7.32 (0.20)d	8.59 (0.09)e
0.91	7.00 (0.42)a	7.06 (0.22)a	8.80 (0.56)b	5.06 (0.10)c	3.79 (0.07)d
1.52	8.79 (0.03)a	9.46 (0.11)b	9.09 (0.14)c	10.32 (0.16)d	18.62 (0.11)e
2.10	7.49 (0.05)a	7.59 (0.21)a	7.30 (0.06)a	6.45 (0.21)b	5.29 (0.14)c
2.70	2.74 (0.08)a	2.81 (0.04)a	2.81 (0.07)a	6.22 (0.07)b	9.26 (0.02)c
3.35	2.54 (0.01)a	2.39 (0.07)a	2.42 (0.04)a	3.82 (0.03)b	5.68 (0.05)c
3.96	2.10 (0.06)a	3.09 (0.01)b	2.81 (0.02)c	5.52 (0.04)d	31.76 (0.46)e
4.57	3.94 (0.31)a	5.13 (0.01)b	4.88 (0.06)d	16.85 (0.44)d	16.10 (0.37)d
5.18	4.08 (0.22)a	9.69 (0.06)b	7.32 (0.01)c	12.59 (0.60)c	21.40 (0.03)d
5.79	2.45 (0.06)a	3.27 (0.06)b	3.33 (0.05)c	4.31 (0.07)c	3.91 (0.02)e
6.40	1.62 (0.03)a	1.95 (0.06)b	1.78 (0.03)c	2.72 (0.06)d	3.35 (0.02)e
BHc	39.03 (0.89)a	36.97 (0.57)a	33.29 (0.49)b	28.44 (0.02)c	6.73 (0.04)d
BHt	14.54 (0.75)a	6.02 (0.17)b	7.69 (0.40)c	15.71 (0.33)d	1.42 (0.02)e
Overall Difference[5]	10.319 A	10.514 B	11.267 C	13.008 D	14.990 E

[1]Different letters indicate significant difference (P<0.05) for each distance. [2]Device rear nozzle facing right rear. Degrees are measured at manway and 6.7m radius. [3]Sample sites are the sampling point in m from the device. BHc and BHt are the bulkhead center and top sites at 6.7m from device. [4]Same letters across columns for each sample site indicate no significant difference (P<0.05) for treatment. [5]Same letters indicate no significant difference (P<0.05) overall for treatments.

Table 4-35. Sd-HVMP wall flow rates with varied centering installation.

Degrees off center[2]	0	1L	2.5L	5L	10L
Sample Sites [3]	Average wall flow rate L/min/m^2 (std dev)[1] with 568 Lpm and 5.5 bar feed (150 gpm and 80 psi) with varied centering positions (n= 3)[4]				
0	16.60 (0.35)a	18.3 (0.10)b	25.25 (0.34)c	29.28 (0.25)d	33.42 (0.05)e
0.31	17.55 (0.14)a	17.61 (0.15)a	18.29 (0.38)b	17.53 (0.49)c	16.71 (0.08)d
0.91	7.00 (0.42)a	10.18 (0.31)b	10.66 (0.07)c	10.05 (0.50)c	8.56 (0.07)c
1.52	8.79 (0.03)a	8.61 (0.08)a	7.35 (0.14)b	6.50 (0.11)c	4.89 (0.14)d
2.10	7.49 (0.05)a	7.29 (0.20)a	6.33 (0.02)b	5.54 (0.12)c	4.48 (0.14)d
2.70	2.74 (0.08)a	2.81 (0.24)a	3.05 (0.31)b	3.27 (0.16)b	2.45 (0.01)c
3.35	2.54 (0.01)a	2.74 (0.11)a	2.85 (0.09)b	2.14 (0.05)c	2.04 (0.04)d
3.96	2.10 (0.06)a	2.22 (0.06)b	1.53 (0.07)c	1.16 (0.03)d	1.02 (0.09)e
4.57	3.94 (0.31)a	3.98 (0.09)a	1.64 (0.08)b	0.79 (0.07)c	0.41 (0.08)d
5.18	4.08 (0.22)a	4.40 (0.12)a	1.64 (0.11)b	0.69 (0.06)c	0.37 (0.04)d
5.79	2.45 (0.06)a	2.69 (0.05)b	0.98 (0.06)c	0.47 (0.03)d	0.33 (0.03)e
6.40	1.62 (0.03)a	1.48 (0.02)b	0.89 (0.10)c	0.65 (0.05)c	0.37 (0.04)d
BHc	39.03 (0.89)a	38.60 (0.83)b	36.63 (0.24)c	30.34 (0.77)d	6.73 (0.25)e
BHt	14.54 (0.75)a	13.41 (0.60)a	10.49 (0.23)b	4.70 (0.10)c	1.39 (0.11)d
Sig difference[5]	10.319 A	11.023 A	11.541 B	11.294 C	10.084 D

[1]Different letters indicate significant difference (P<0.05) for each distance. [2]Device rear nozzle facing left rear. Degrees are measured at manway and 6.7m radius. [3]Sample sites are the sampling point in m from the device. BHc and BHt are the bulkhead center and top sites, respectively at 6.7m from device. [4]Same letters across columns for each sample site indicate no significant difference (P<0.05) for treatment. [5]Different letters indicate significance (P<0.05) overall for degree installation.

Table 4-36. R-HVMP vane design related to body and hub speed (rpm).

Vane design[1]	Observed shaft speed (rpm)[2] (n = 3)
Long 2	22 ± 0.5
Long 1	20 ± 0.3
Normal	16 ± 0.4
Short	12 ± 0.2

[1] Vane design designations are those of the device manufacturer Lechler Spray Company 2006
[2] Rotation speed based on time for 1 hub revolution.

Table 4-37. R-HVMP wall flow rates with varied rotation speed.

Rotation speed[1] (rpm)	12	16	20
Sample Sites [2]	Average wall flow rate L/min/m^2 (std dev)[3] with 493 Lpm and 6.2 bar feed (130 gpm and 90 psi) with varied rotation speed[2] (n= 3)		
0	7.86 (0.05)a	7.85 (0.08)a	7.68 (0.11)a
0.31	6.15 (0.06)a	6.18 (0.05)a	6.10 (0.02)a
0.91	4.73 (0.00)b	4.68 (0.03)a	4.69 (0.08)a
1.52	5.07 (0.02)a	4.96 (0.07)a	4.99 (0.05)a
2.10	2.63 (0.01)a	2.61 (0.01)a	2.68 (0.05)a
2.70	2.58 (0.03)a	2.57 (0.02)a	2.57 (0.03)a
3.35	1.54 (0.01)a	1.51 (0.01)a	1.54 (0.03)a
3.96	1.30 (0.01)a	1.30 (0.01)a	1.34 (0.03)a
4.57	0.82 (0.01)a	0.83 (0.01)a	0.85 (0.02)a
5.18	0.73 (0.00)a	0.72 (0.01)a	0.76 (0.02)a
5.79	0.51 (0.00)a	0.50 (0.00)a	0.52 (0.02)a
6.40	0.66 (0.01)a	0.68 (0.00)a	0.70 (0.01)a
BHc	48.01 (1.04)b	26.32 (1.10)a	26.91 (0.62)a
BHt	10.76 (0.25)b	6.08 (0.66)a	6.34 (0.42)a
Overall Difference [4]	7.668 A	5.771 A	5.834 A

[1]Rotation speed adjusted by replacing drive impeller. [2]Sample sites are the sampling point in m from the device. BHc and BHt are the bulkhead center and top sites, respectively at 6.7m from device. [3]Different letters in columns indicate significance (P<0.05) for each sample site across treatments. [4]Different letters indicate significance (P<0.05) overall for degree installation.

Table 4-38. Calculated fluid speeds at various distances based on device head speed (rpm) of R-HVMP device.

			Calculated fluid speed[1] at head rotation speed (rpm)					
		rpm	12		16		20	
		Time per revolution	0.083	5	0.063	4	0.05	3
Diameter (m)	Radius (m)	Circumference (m)	m/min	m/sec	m/min	m/sec	m/min	m/sec
1.2	0.6	3.8	46	0.77	61	1.02	77	1.28
3.0	1.5	9.6	115	1.92	153	2.55	192	3.19
6.0	3.0	19.2	230	3.83	307	5.11	383	6.39
9.2	4.6	28.7	345	5.75	460	7.66	575	9.58
11.0	5.5	34.5	414	6.90	552	9.20	690	11.49
12.2	6.1	38.3	460	7.67	613	10.22	766	12.77
13.4	6.7	42.1	506	8.43	674	11.24	843	14.05

[1] Fluid speed is calculated by dividing the circumference in m by the time (min or sec) for one revolution.

Table 4-39. Theoretical fluid dwell time and fluid delivery at device head speed (rpm) and distance for a R-HVMP device.

		Calculated fluid dwell time and delivered volume at head rotation speeds (rpm)								
		12			16			20		
Radius (m)	Circum (m)	Travel speed m/sec	Dwell sec/10cm[1]	L/10cm [2]	Travel speed m/sec	Dwell sec/10cm[1]	L/10cm [2]	Travel speed m/sec	Dwell sec/10cm[1]	L/10cm [2]
0.6	3.8	0.77	0.130	0.412	1.02	0.098	0.309	1.28	0.078	0.247
1.5	9.6	1.92	0.052	0.165	2.55	0.039	0.124	3.19	0.031	0.099
3.0	19.2	3.83	0.026	0.082	5.11	0.020	0.062	6.39	0.016	0.049
4.6	28.7	5.75	0.017	0.055	7.66	0.013	0.041	9.58	0.010	0.033
5.5	34.5	6.90	0.014	0.046	9.20	0.011	0.034	11.49	0.009	0.027
6.1	38.3	7.67	0.013	0.041	10.22	0.010	0.031	12.77	0.008	0.025
6.7	42.1	8.43	0.012	0.037	11.24	0.009	0.028	14.05	0.007	0.022

[1]Dwell determined by dividing circumference by sec per revolution for each rotation speed (0.25, 0.1, and 0.05 respectively).
[2]L/10cm determined by multiplying 41.6 Lpm per nozzle (83.2 Lpm feed rate) by dwell time divided by 60 sec/min.

Table 4-40. Examples of percent surface flow for R-HVMP CIP device.

Flow rate	416 Lpm @ 3.4 bar (110 gpm@49 psi)	454 @ 5.2 bar (120gpm@75psi)	492 Lpm @ 6.2 bar (130gpm@90psi)
Sample Sites [1]	Percent surface flow at delivered flow conditions [2]		
0	16.1	12.3	11.3
0.3	14.3	9.7	9.0
0.9	10.3	7.5	6.9
1.5	10.3	7.9	7.4
2.1	4.4	4.0	4.0
2.7	4.2	3.9	3.8
3.4	2.4	2.3	2.3
4.0	1.9	1.9	2.0
4.6	1.4	1.2	1.3
5.2	1.1	1.1	1.1
5.8	0.8	0.7	0.8
6.4	0.8	1.0	1.0
BHc	28.4	38.8	39.8
BHt	3.7	7.8	9.4

[1]Sample sites are in m from the device. BHc and BHt are bulkhead center and top sample sites respectively at 6.7m from device. [2]Percent flow rates determined by dividing the site flow by the total collected fluid volume.

Table 4-41. R-HVMP wall flow rates with varied flow rates.

	Average wall flow rate L/min/m^2 (std dev)[1] with varied feed flow rate all at 4.5 bar (65 psi) (n= 3)[4]		
Feed flow rate – Lpm [2] (gpm/ft^2)	416 (110)	454 (120)	492 (130)
Sample Sites [3]			
0	6.48 (0.04)a	7.09 (0.29)ab	6.99 (0.22)b
0.31	5.47 (0.05)a	5.55 (0.07)ab	5.62 (0.05)b
0.91	4.44 (0.07)a	4.07 (0.01)b	4.13 (0.11)ab
1.52	4.81 (0.09)a	4.31 (0.06)b	4.49 (0.12)ab
2.10	2.51 (0.04)a	2.15 (0.09)b	2.22 (0.09)b
2.70	2.57 (0.04)a	2.06 (0.10)b	2.01 (0.01)b
3.35	1.67 (0.03)a	1.18 (0.02)b	1.17 (0.04)b
3.96	1.39 (0.04)a	0.93 (0.04)b	0.94 (0.04)b
4.57	0.96 (0.03)a	0.62 (0.02)b	0.65 (0.04)b
5.18	0.81 (0.02)a	0.51 (0.02)b	0.54 (0.02)b
5.79	0.49 (0.00)a	0.36 (0.02)b	0.37 (0.02)b
6.40	0.52 (0.01)a	0.42 (0.03)b	0.44 (0.01)b
BHc	14.70 (0.35)a	17.23 (1.29)ab	17.26 (0.16)b
BHt	2.40 (0.06)a	2.72 (0.54)a	2.56 (0.10)a
Overall Difference[5]	4.52 A	5.34 AB	5.39 B

[1]Different letters indicate significant difference (P<0.05) for each distance. [2]Flow rate adjusted by turning divert valve. [3]Samples sites are in m from the CIP device. BHc and BHt are bulkhead center and top respectively at 6.7 m from device. [4]Same letters across columns indicate no significant difference (P<0.05) for treatments at the sample site. [5]Different letters indicate significance (P<0.05) overall for treatment.

Table 4-42. R-HVMP wall flow rates with varied pressure rates.

Feed pressure – bar and Lpm [2] (psi and gpm)	Average wall flow rate L/min/m^2 (std dev)[1] with variable feed pressure (n= 3)[4]			
	3.4 & 416 (49 & 110)	4.5 & 435 (65 & 115)	5.2 & 454 (75 & 120)	6.2 & 492 (90 & 130)
Sample Sites [3]				
0	6.18 (0.28)a	6.79 (0.38)a	7.15 (0.06)b	7.68 (0.11)c
0.31	5.48 (0.52)a	5.51 (0.07)a	5.63 (0.06)b	6.10 (0.02)b
0.91	3.94 (0.26)a	4.26 (0.21)a	4.34 (0.06)b	4.69 (0.06)b
1.52	3.95 (0..25)a	4.56 (0.28)b	4.57 (0.02)c	4.99 (0.05)d
2.10	1.70 (0.07)a	2.33 (0.20)b	2.33 (0.01)c	2.68 (0.05)d
2.70	1.61 (0.08)a	2.31 (0.29)b	2.24 (0.02)c	2.57 (0.03)d
3.35	0.92 (0.06)a	1.43 (0.27)b	1.32 (0.03)c	1.54 (0.03)d
3.96	0.72 (0.05)a	1.16 (0.25)b	1.11 (0.01)c	1.34 (0.03)d
4.57	0.52 (0.02)a	0.79 (0.19)b	0.72 (0.01)c	0.85 (0.02)d
5.18	0.44 (0.01)a	0.66 (0.17)b	0.61 (0.01)c	0.76 (0.02)d
5.79	0.31 (0.01)a	0.42 (0.07)b	0.41 (0.00)c	0.52 (0.02)d
6.40	0.31 (0.02)a	0.47 (0.06)b	0.56 (0.02)c	0.70 (0.01)d
BHc	10.93 (0.73)a	15.97 (1.62)b	22.55 (0.56)c	26.91 (0.62)d
BHt	1.42 (0.19)a	2.56 (0.39)b	4.51 (0.56)c	6.34 (0.42)c
Overall Difference[5]	3.75 A	5.30 B	6.93 BC	8.41 C

[1]Values are the average flow rates with standard deviation in parentheses. Different letters indicate significance (P<0.05) for a given sample site. [2]Flow rate adjusted by turning divert valve. [3] Samples sites are in m from the CIP device. BHc and BHt are bulkhead center and top respectively at 6.7 m from device. [4]Same letters across columns indicate no significant difference (P<0.05) for treatments at the sample site. [5]Different letters indicate significance (P<0.05) overall for treatment.

Table 4-43. R-HVMP wall flow rates with varied installation depth at 4.5 bar.

	Average wall flow rate L/min/m^2 (std dev)[1] with varied installation depth at 492 Lpm and 4.5 bar (130 gpm and 65 psi) (n= 3)[4]		
Installed depth – cm (in)[2]	82 (33)	109 (43)	143 (56)
Sample Sites [3]			
0	9.44 (0.14)a	6.99 (0.22)b	6.75 (0.41)b
0.31	6.76 (0.06)a	5.62 (0.05)b	5.18 (0.26)b
0.91	4.82 (0.11)a	4.13 (0.11)b	3.87 (0.13)b
1.52	4.82 (0.09)a	4.49 (0.12)a	4.07 (0.04)b
2.10	2.27 (0.04)a	2.22 (0.09)a	2.22 (0.01)a
2.70	2.23 (0.05)a	2.01 (0.01)b	1.95 (0.04)b
3.35	1.42 (0.01)a	1.17 (0.04)b	1.08 (0.00)b
3.96	1.08 (0.02)a	0.94 (0.04)a	0.90 (0.01)b
4.57	0.73 (0.01)a	0.65 (0.04)a	0.58 (0.00)b
5.18	0.61 (0.02)a	0.54 (0.02)a	0.47 (0.01)b
5.79	0.40 (0.01)a	0.37 (0.02)a	0.33 (0.00)b
6.40	0.50 (0.02)a	0.44 (0.01)a	0.41 (0.01)b
BHc	21.43 (0.08)a	17.26 (0.16)b	16.51 (0.26)b
BHt	2.86 (0.19)a	2.56 (0.10)a	3.34 (0.23)b
Overall Difference [5]	5.24 A	4.96 B	5.33 C

[1]Different letters across row indicate significant difference (P<0.05) for a given sample site. [2]Depth adjusted by removing or installing appropriately sized spool pieces. [3]Samples sites are in m from the CIP device. BHc and BHt are bulkhead center and top respectively at 6.7 m from device. [4]Same letters across columns indicate no significant difference (P<0.05) for treatments at the sample site. [5]Different letters indicate significance (P<0.05) overall for treatment.

Table 4-44. R-HVMP wall flow rates with varied installation depth at 6.2 bar.

	Average wall flow rate L/min/m^2 (std dev)[1] with varied installation depth at 492 Lpm and 6.2 bar (130 gpm and 90 psi) (n= 3)[4]		
Installed depth – cm (in) [2]	82 (33)	109 (43)	143 (56)
Sample Sites [3]			
0	11.11 (0.57)a	7.68 (0.11)b	6.83 (0.08)c
0.31	8.10 (0.34)a	6.10 (0.02)b	4.91 (0.02)c
0.91	6.02 (0.14)a	4.69 (0.08)b	4.42 (0.01)c
1.52	5.57 (0.15)a	4.99 (0.05)b	4.61 (0.01)c
2.10	3.64 (0.07)a	2.68 (0.05)b	3.03 (0.04)c
2.70	3.03 (0.03)a	2.57 (0.03)b	2.62 (0.02)c
3.35	2.22 (0.04)a	1.54 (0.03)b	1.89 (0.02)c
3.96	2.10 (0.13)a	1.34 (0.03)b	1.44 (0.02)c
4.57	1.59 (0.07)a	0.85 (0.02)b	0.88 (0.02)c
5.18	1.45 (0.14)a	0.76 (0.02)b	0.73 (0.02)b
5.79	0.89 (0.03)a	0.52 (0.02)b	0.47 (0.01)b
6.40	0.99 (0.06)a	0.70 (0.01)b	0.86 (0.00)c
BHc	28.46 (0.94)a	26.91 (0.62)b	20.83 (0.06)c
BHt	2.71 (0.34)a	6.34 (0.42)b	4.37 (0.01)c
Overall Difference [5]	6.56 A	6.83 B	6.99 C

[1]Different letters across row indicate significant difference (P<0.05) for a given sample site. [2]Depth adjusted by removing or installing appropriately sized spool pieces. [3]Samples sites are in m from the CIP device. BHc and BHt are bulkhead center and top respectively at 6.7 m from device. [4]Same letters across columns indicate no significant difference (P<0.05) for treatments at the sample site. [5]Different letters indicate significance (P<0.05) overall for treatment.

Table 4-45. Impact angles at varied installation depths.

Installed depth – cm (in) Sample Sites [2]	Impact angles[1] 82 (33)	109 (43)	143 (56)
0	90.0	90.0	90.0
0.31	70.6	74.7	77.4
0.91	43.4	50.7	56.3
1.52	29.5	36.3	42.0
2.10	22.0	27.7	32.8
2.70	17.5	22.2	26.6
3.35	14.4	18.4	22.3
3.96	12.3	15.8	19.1
4.57	10.7	13.7	16.7
5.18	9.5	12.2	14.8
5.79	8.5	10.9	13.3
6.40	7.7	9.9	12.1
BHc	90.0	90.0	90.0
BHt	9.0	9.5	11.5

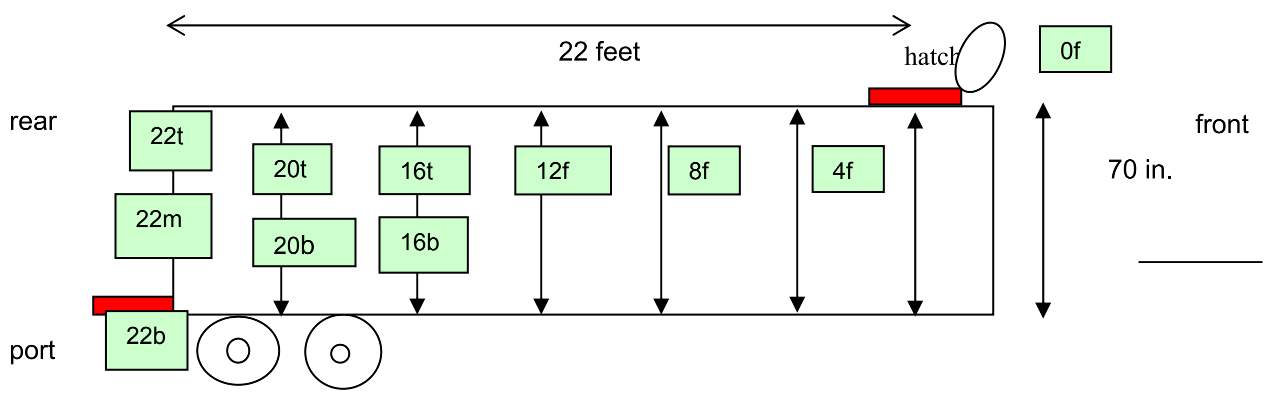
[1]Impact angle is the angle the fluid hits the stainless steel at the distance. The angle is measure at the depth of the device at the barrel wall. [2]Samples sites are in m from the CIP device. BHc and BHt are bulkhead center and top respectively at 6.7 m from device.

Table 4-46. Rotating device installation position – standard versus 90°.

Sample site[1]	Lpm/m^2 by device installation position (n = 3)[2] Standard	90 degree
0	6.07 (0.20)a	5.29 (0.02)b
0.31	4.88 (0.13)a	4.66 (0.17)b
0.91	3.63 (0.07)a	3.19 (0.05)b
1.52	3.31 (0.04)a	3.20 (0.01)a
2.10	1.63 (0.02)a	1.74 (0.05b
2.70	1.47 (0.03)a	1.67 (0.06)b
3.35	0.81 (0.04)a	1.14 (0.05)b
3.96	0.63 (0.03)a	1.05 (0.04)b
4.57	0.35 (0.03)a	0.69 (0.05)b
5.18	0.28 (0.02)a	0.58 (0.03)b
5.79	0.20 (0.02)a	0.45 (0.02)b
6.40	0.23 (0.02)a	0.71 (0.01)b
BHc	1.32 (0.09)a	3.28 (0.21)b
BHt	0.50 (0.05)a	1.36 (0.11)b
Overall difference[3]	2.81 A	4.00 B

[1]Sample sites are the collection points in m from the device. BHc and BHt are bulkhead center and top sites, respectively at 6.7m from device. [2]Same letters across columns indicate no significant difference (P<0.05) for treatments at the sample site. [3]Same letters across columns indicate no significant difference (P<0.05) overall for treatment.

Figure 4-1. Picture of the UF C-Thru tanker showing sluice, funnels and tubes.



Note: Dimensions are not to scale

Figure 4-2. UF C-Thru Model tanker dimensions and sampling sites.

Figure 4-3. UF C-Thru Model Tanker. (Winniczuk 2006)

Figure 4-4. UF C-Thru Model Tanker with CIP device. (Winniczuk 2006)

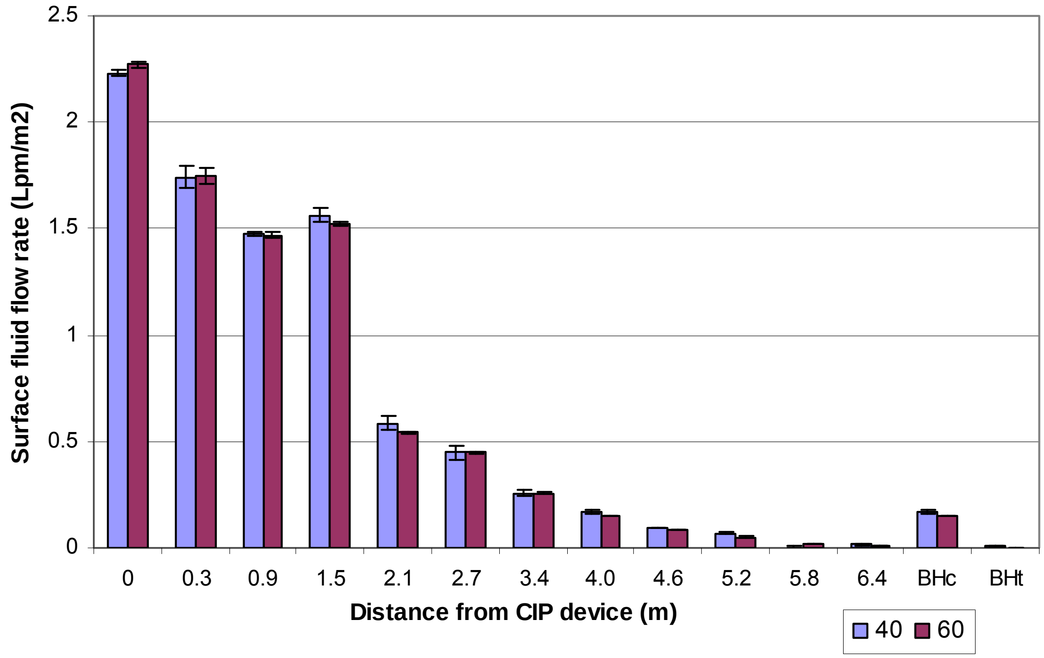


Figure 4-5. Graph of surface flow pattern for R-LVHP CIP device for 2 rotation speeds (40 and 60 psi supply). The x-axis is the sampling device location in m from the CIP device. BHc and BHt are the bulkhead center and top sites respectively at 6.7 m from the device. The y-axis is the calculated surface fluid flow rate based on the collected flow mass for each sampling site.

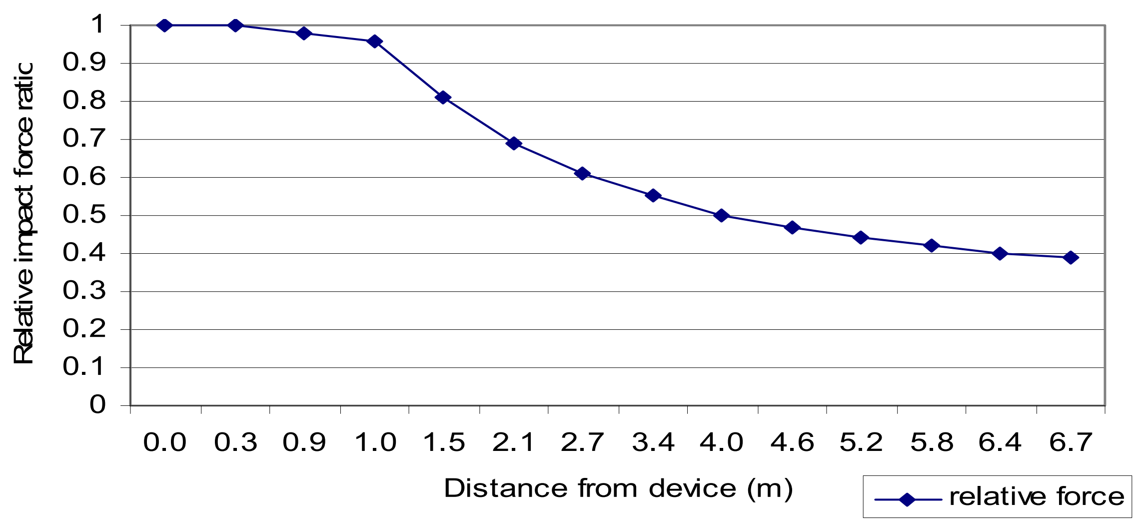


Figure 4-6. Relative impact force for R-LVHP device with 0035 nozzles. The x-axis is the distance from the device in meters. The y-axis is the relative force ratio of the impact region at the distance perpendicular to the device. The relative force ratio is the ratio of the force at distances from the device compared to the force at 0m. There are no units for the ratio.

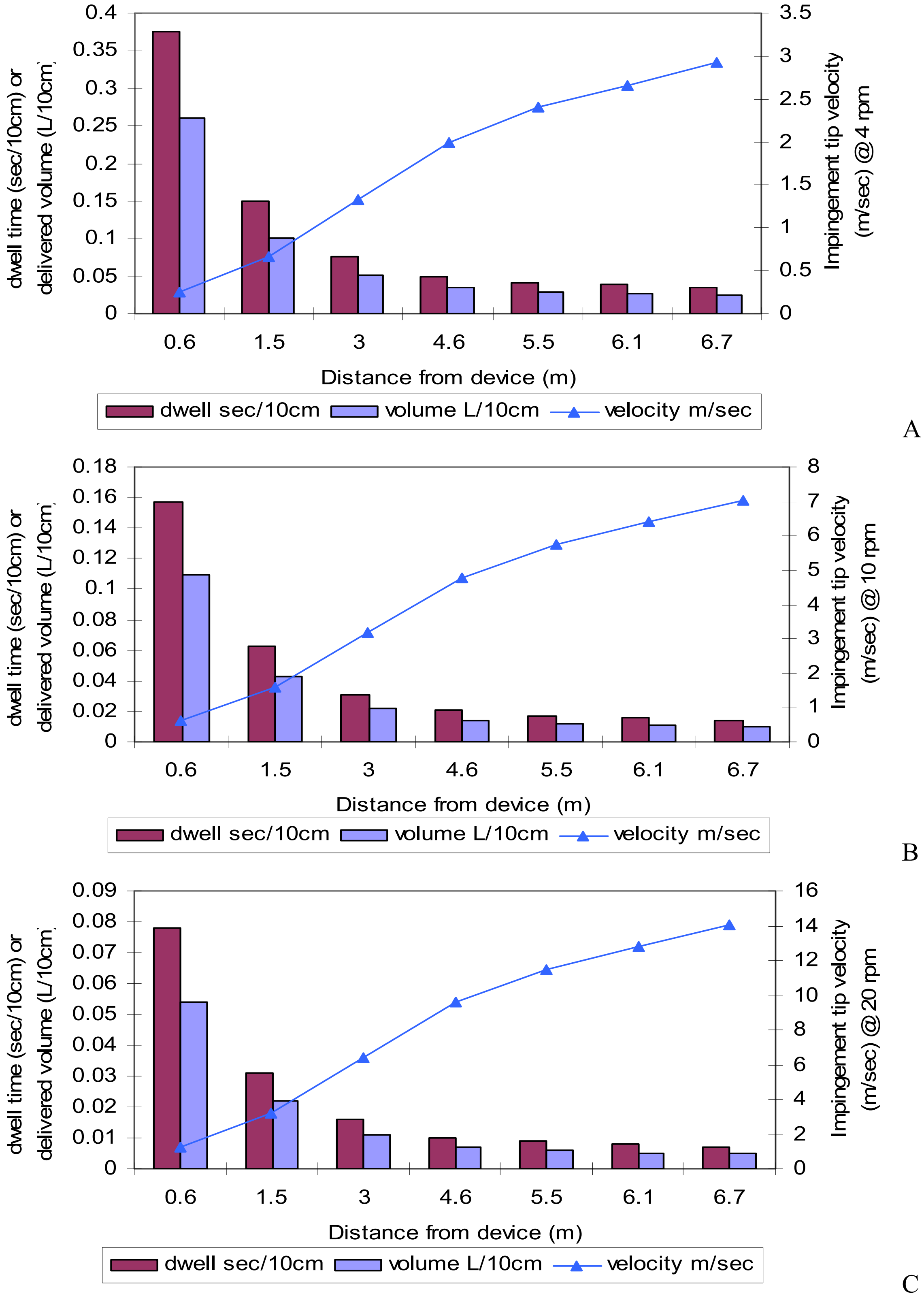


Figure 4-7. R-LVHP stream tip impingement velocity, stream dwell time, and delivered fluid comparison. A is 4 rpm, B is 10 rpm, and C is 20 rpm. Please note the z scale (velocity) change from A to B and C.

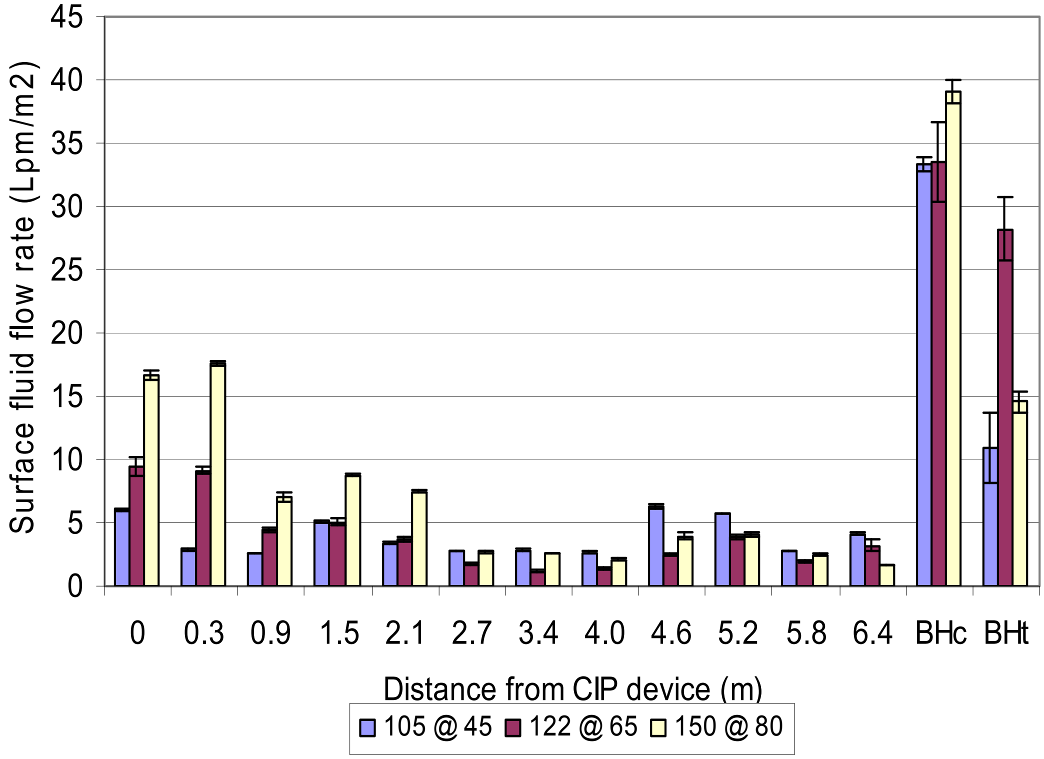


Figure 4-8. Graph of surface flow pattern for a Sd-HVMP CIP device.
The x-axis is the distance in m of the sample sites from the device. BHc and BHt are bulkhead center and top sites, respectively at 6.7 m from device. The y-axis is the determined surface fluid flow rate based on the collected fluid mass for each site. Please note that some error bars are not visible due to the scale.

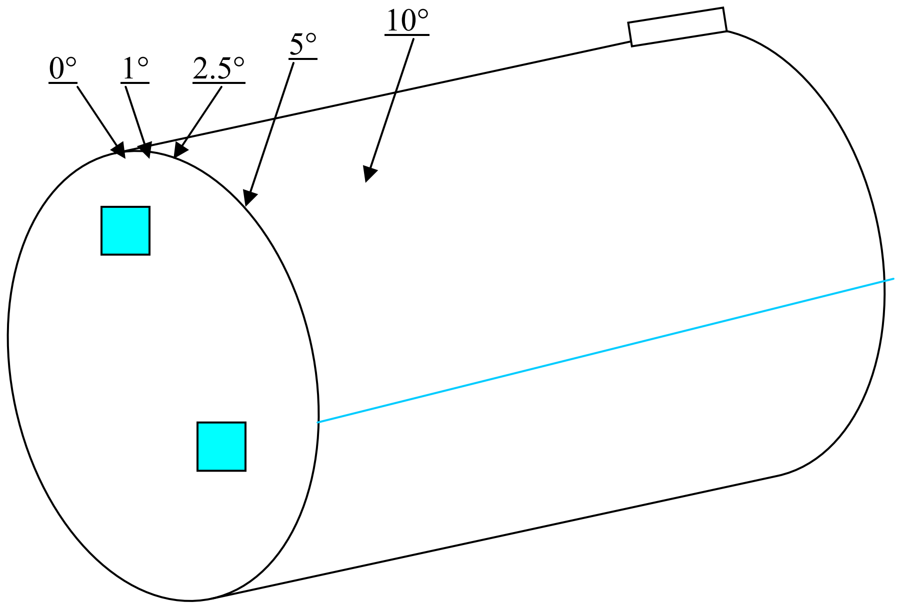


Figure 4-9. Bulkhead view of the Sd-HVMP CIP device's center stream strike positions on the bulkhead in degrees off-center. 10° did not strike bulkhead but struck barrel at 4 m from device. Blue squares are the bulkhead sample sluices. The blue line is the top of the sluices on the barrel.

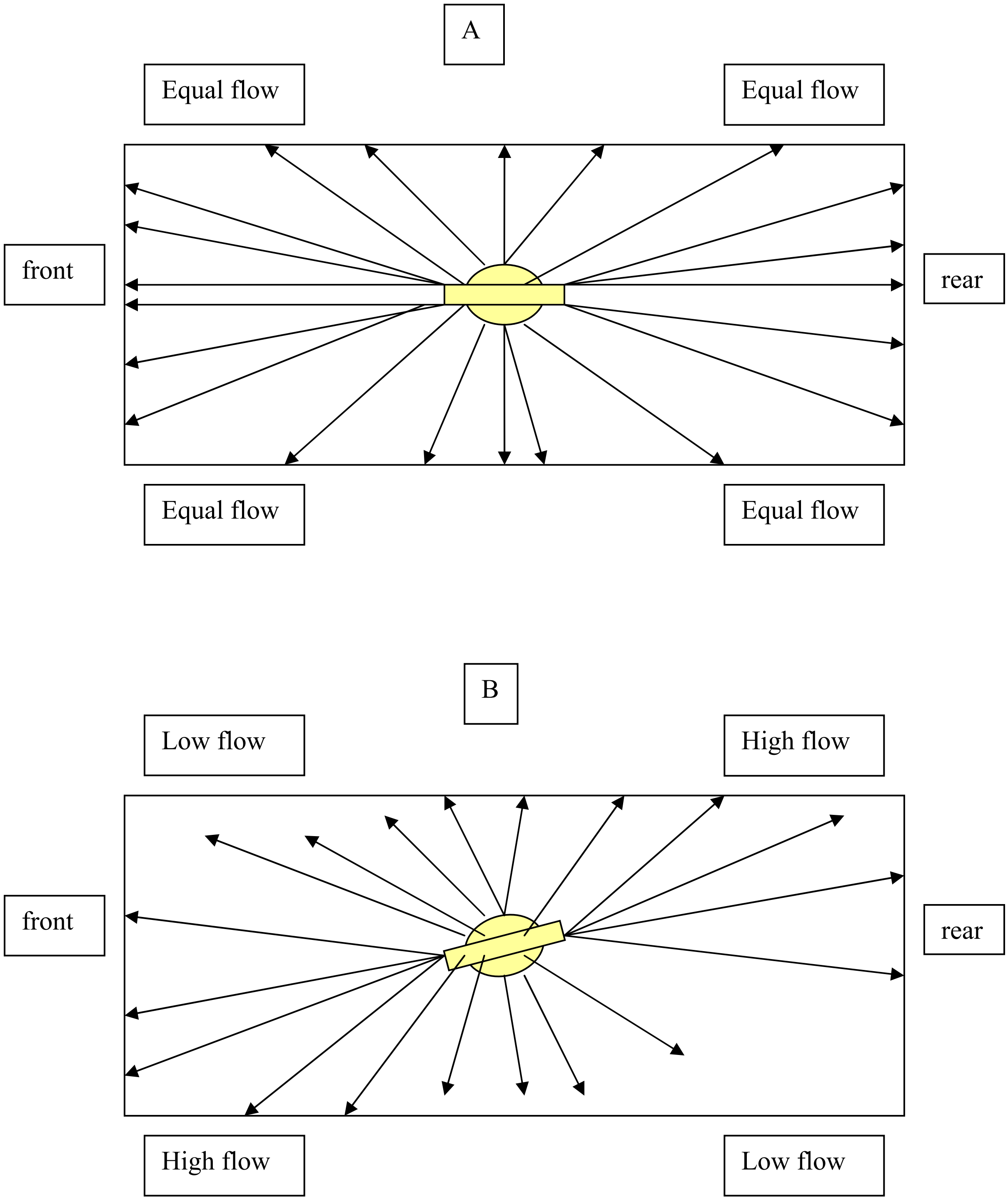


Figure 4-10. The Sd-HVMP device stream flow when installed correctly, A) Nozzles (rectangle) point to the center of bulkheads or incorrectly B) Nozzles (rectangle) point away from the center of the bulkheads).

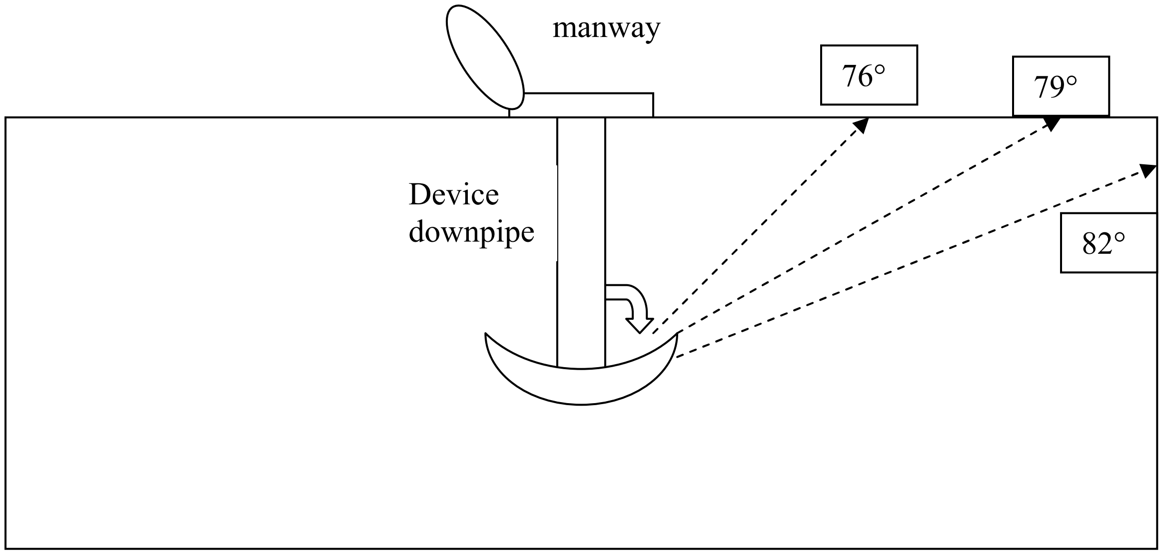


Figure 4-11. An Sd-HVMP device pitch installation. Angles are measured from the down pipe.

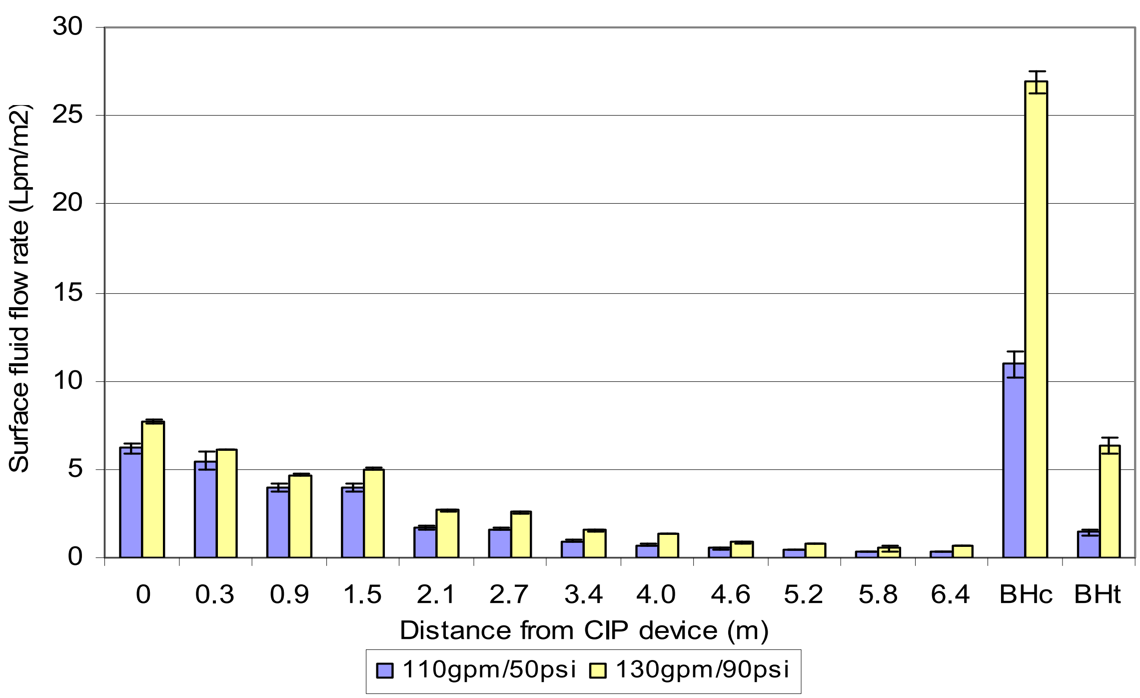


Figure 4-12. Examples of surface flow volumes for R-HVMP installation. The x-axis is the sample site in m from device. BHc and BHt are bulkhead center and top sites, respectively at 6.7m from device. Please note that some error bars are not visible due to the scale and the small standard deviation.

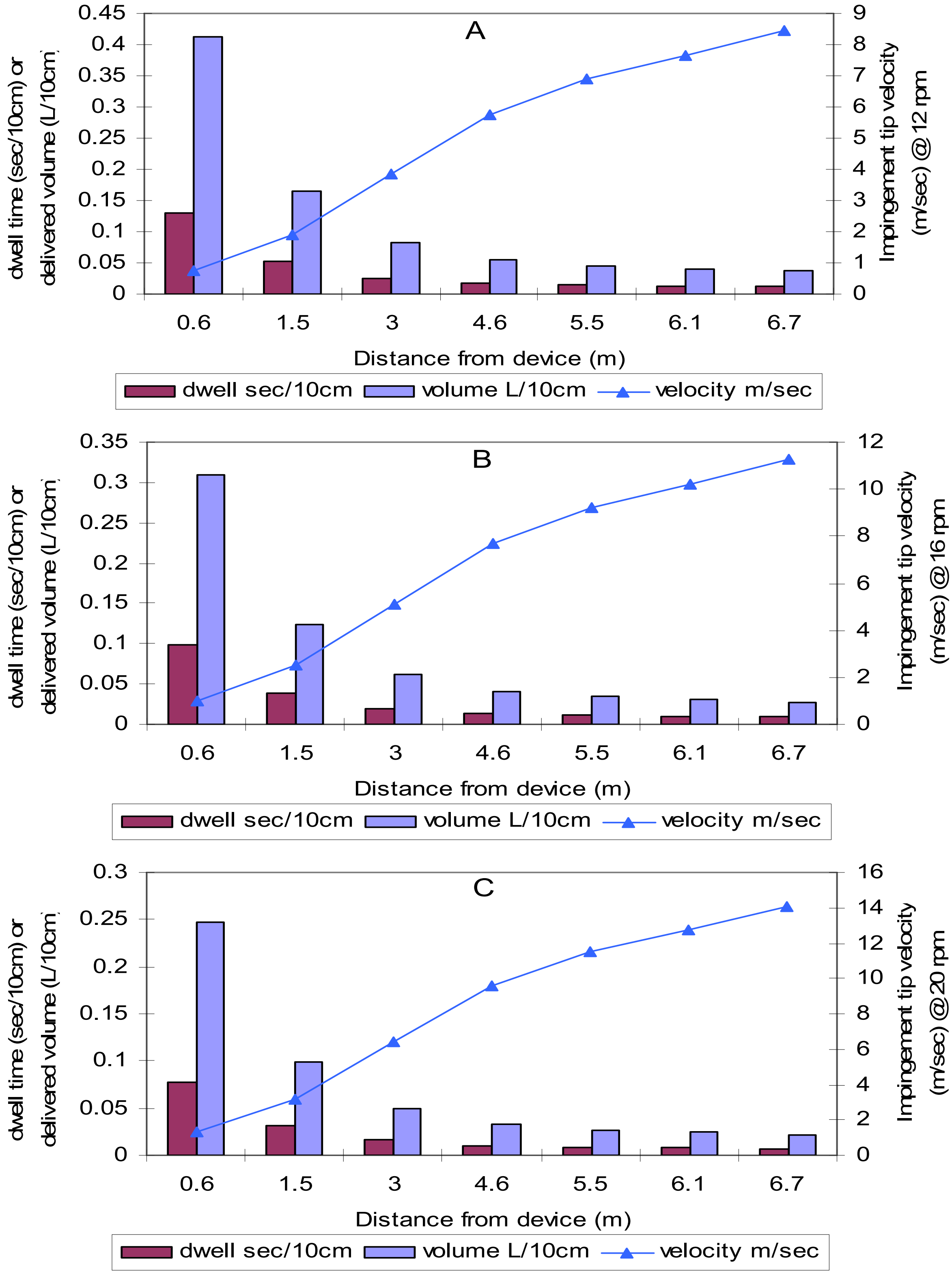


Figure 4-13. R-HVMP stream velocity, stream dwell time, and delivered fluid comparison. A)12 rpm, B) 16 rpm, and C) 20 rpm. Please note the z scale changes from A to B and C.

Figure 4-14. Impingement contact points 10-22 ft (tape). Blue arrows highlight the tape. The numbers on the tanker 2x4 are in ft from the spray device.

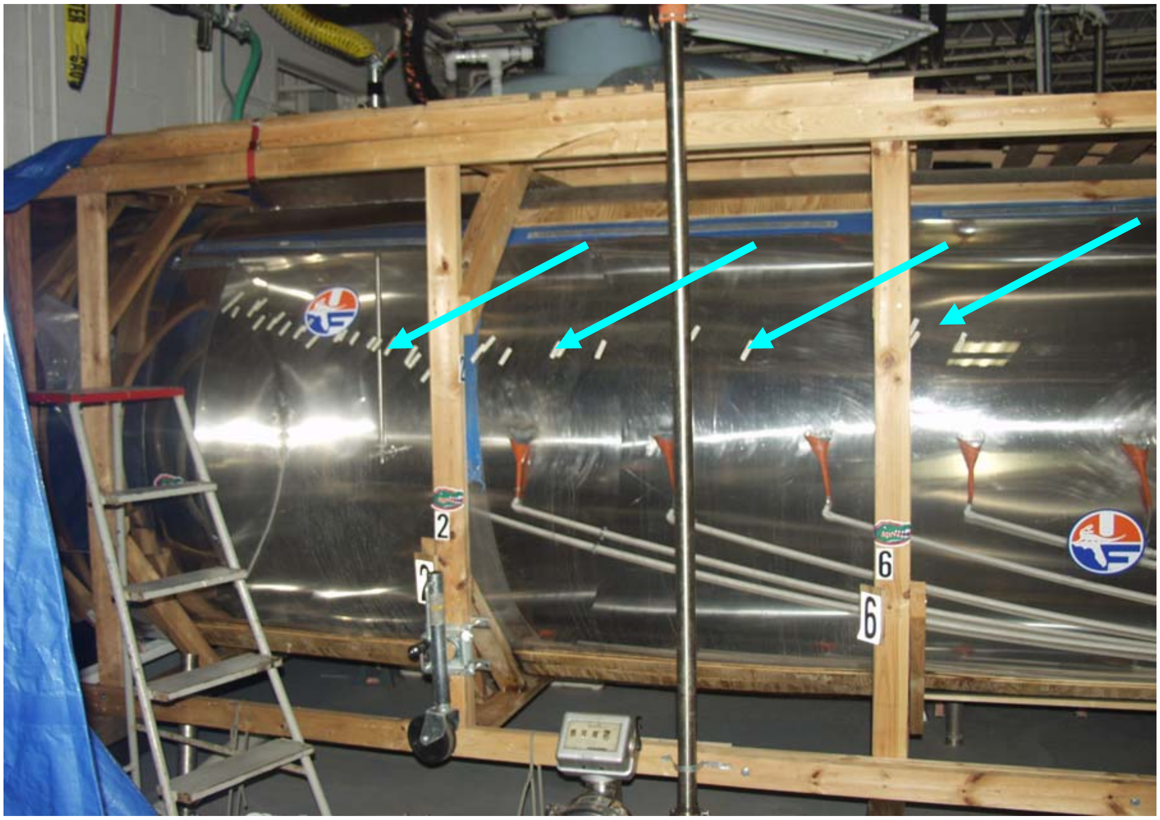


Figure 4-15. Impingement contact points 14-18 ft. Blue arrows highlight the tape. The numbers on the tanker 2x4 are in ft from the spray device.

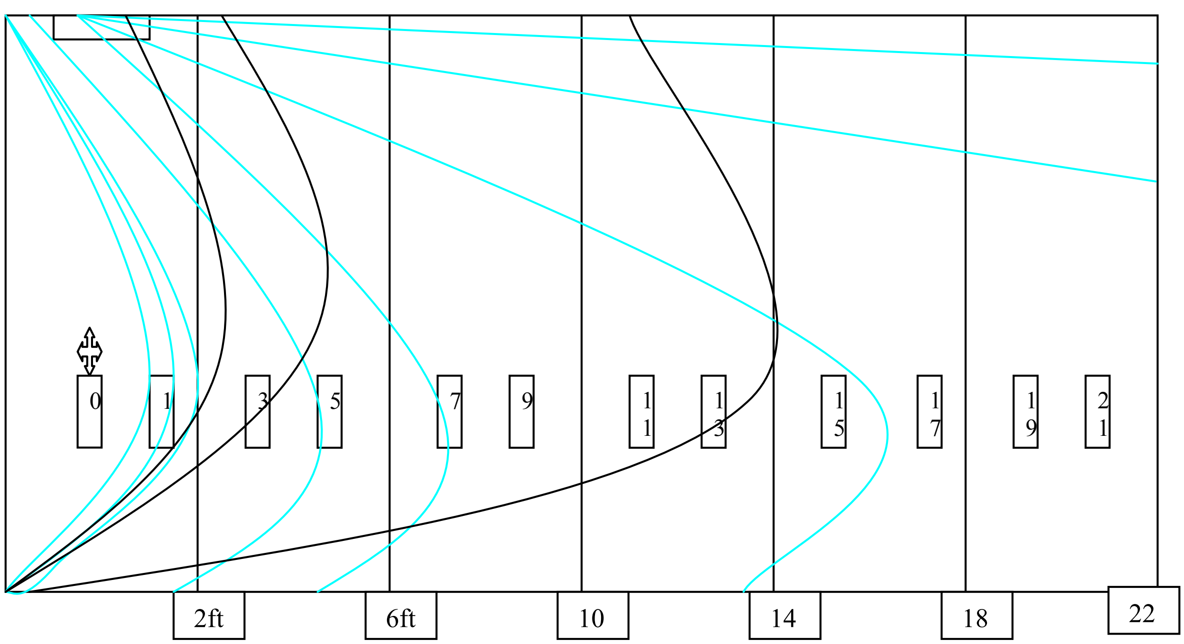


Figure 4-16. Rotating device patterns downward (blue) and upward (black) streams from 0 to 22 ft.

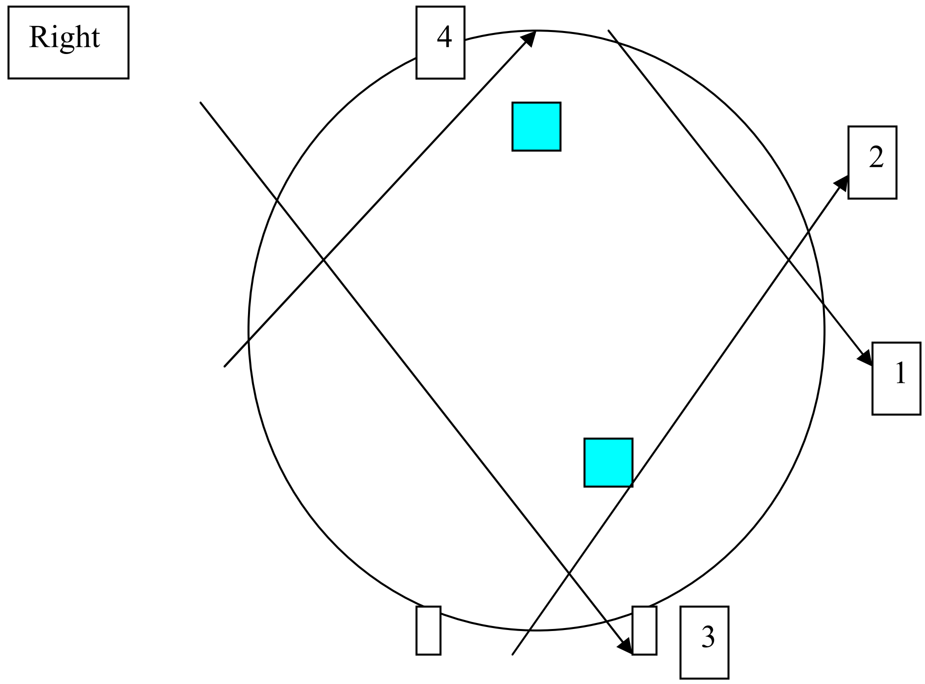


Figure 4-17. Pattern 1 (first nozzle) for the bulkhead direct stream strikes. Blue squares are the sampling sites. No1 is the pattern of the 1st strike followed by 2, etc. The downward strike No5 hit at 13ft with spray hitting right bulkhead while upwards strike No6 hit at 13ft with spray to right bulkhead. Downward strike No. 7 hits at 7ft with no spray hitting bulkhead and upward strike No. 8 hits at 7ft with spray hitting right bulkhead.

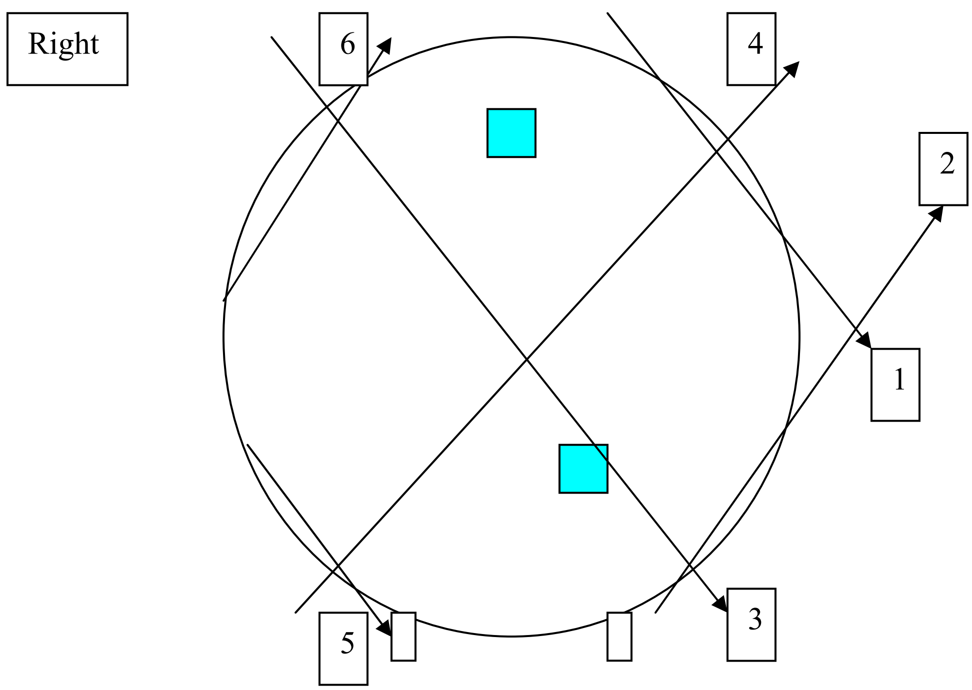


Figure 4-18. Pattern 2 (sec nozzle) for the bulkhead direct stream strikes. Blue squares are the sampling sites. Downward strike No7 hits at 13ft funnel. Upward strike No. 8 hits at 14ft.

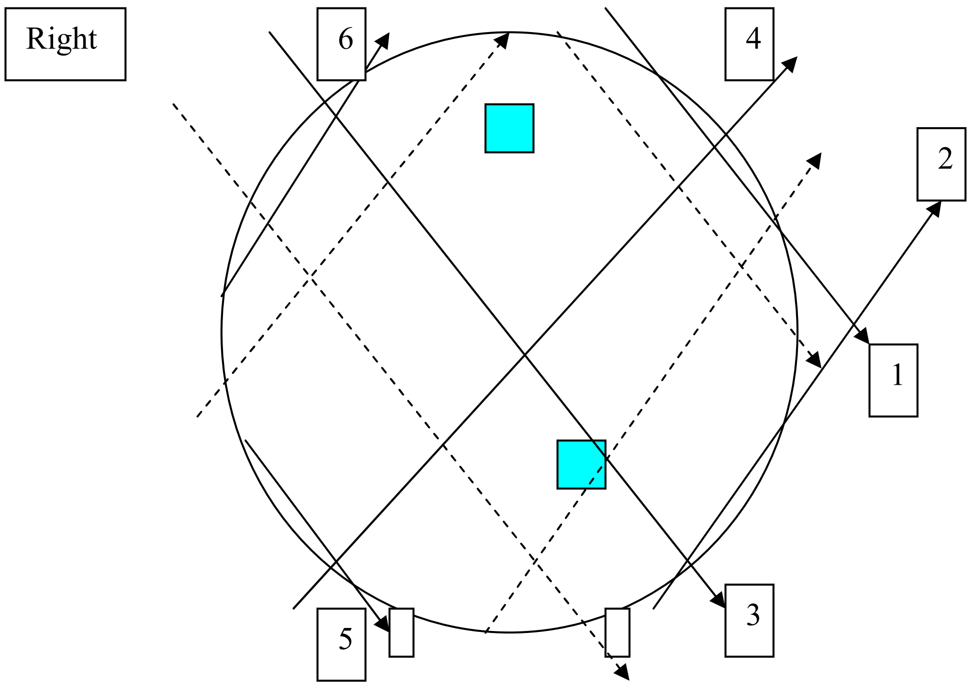


Figure 4-19. Diagram of strikes for entire cycle time. Solid lines are nozzle A and dashed lines are nozzle B. The numbers indicate the observed strike time pattern where 1 is the first strike.

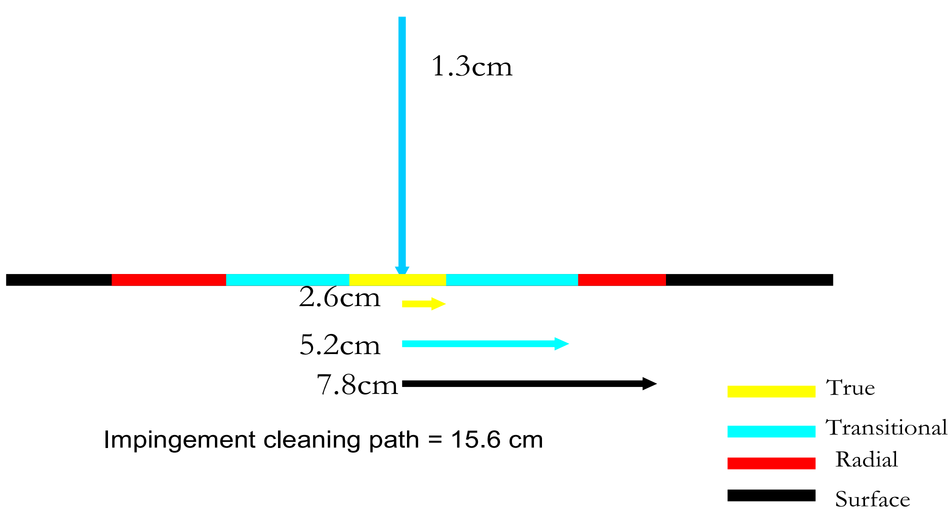


Figure 4-20. Impingement path dimensions. The yellow region is the true impingement force while the blue is the transitional impingement force and red is the radial force. Black is the surface.

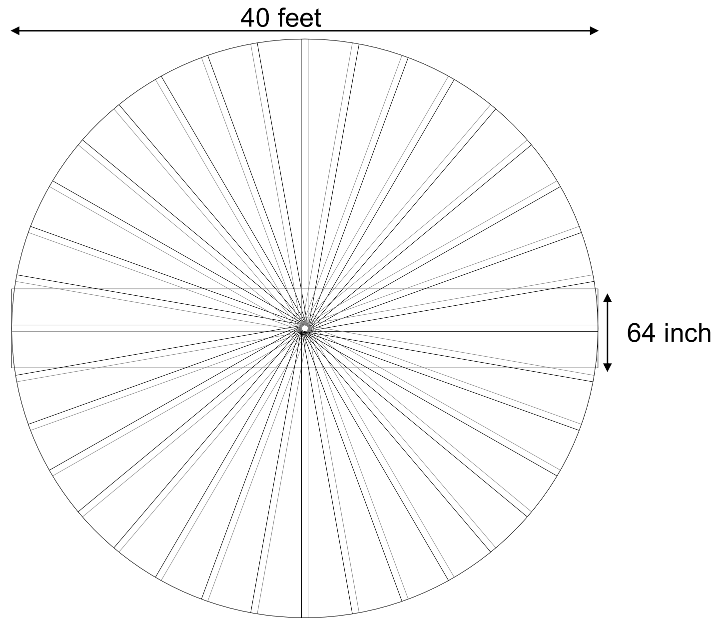


Diagram source: Mr. John Henderson,
Plant Manager, UF CREC

Figure 4-21. CIP device circular pattern imposed on a tanker, drawn to scale. Dark line emanating from center is one nozzle while light line is the other nozzle.

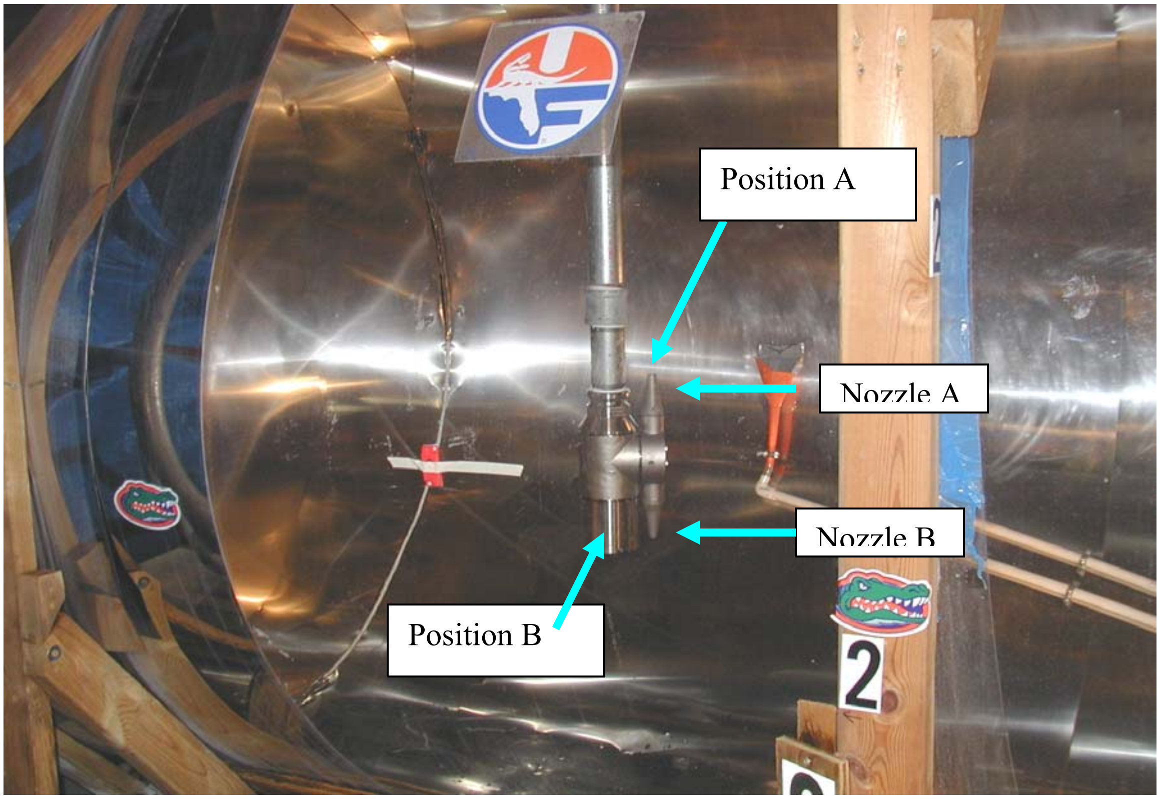


Figure 4-22. CIP device with body hub in position A (blue arrow). Position B is position of the hub on the opposite side of the body. During the cycle, the hub would travel around the body to position B with the nozzle A facing down.

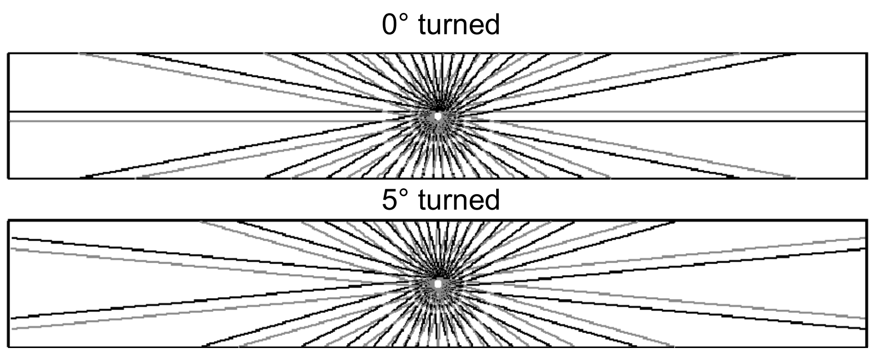


Diagram source: Mr. John Henderson
Pilot Plant Manager, UF CREC

Figure 4-23. Rotating device installation position. The fluid impact would be at the indicated line patterns for 0° and 5° turned installations.

Figure 4-24. R-HVMP device installed with 90° elbow

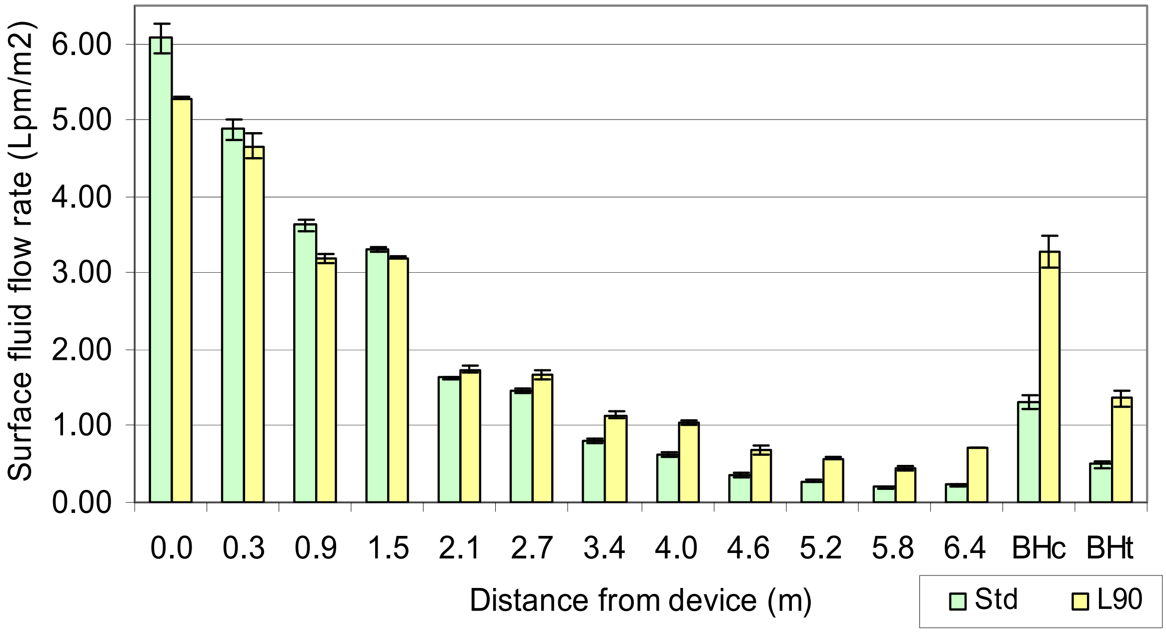


Figure 4-25. Installation position of rotating device. Std indicates the standard installation as manufacturer designed. L90 indicates the installation at 90° from standard installation.

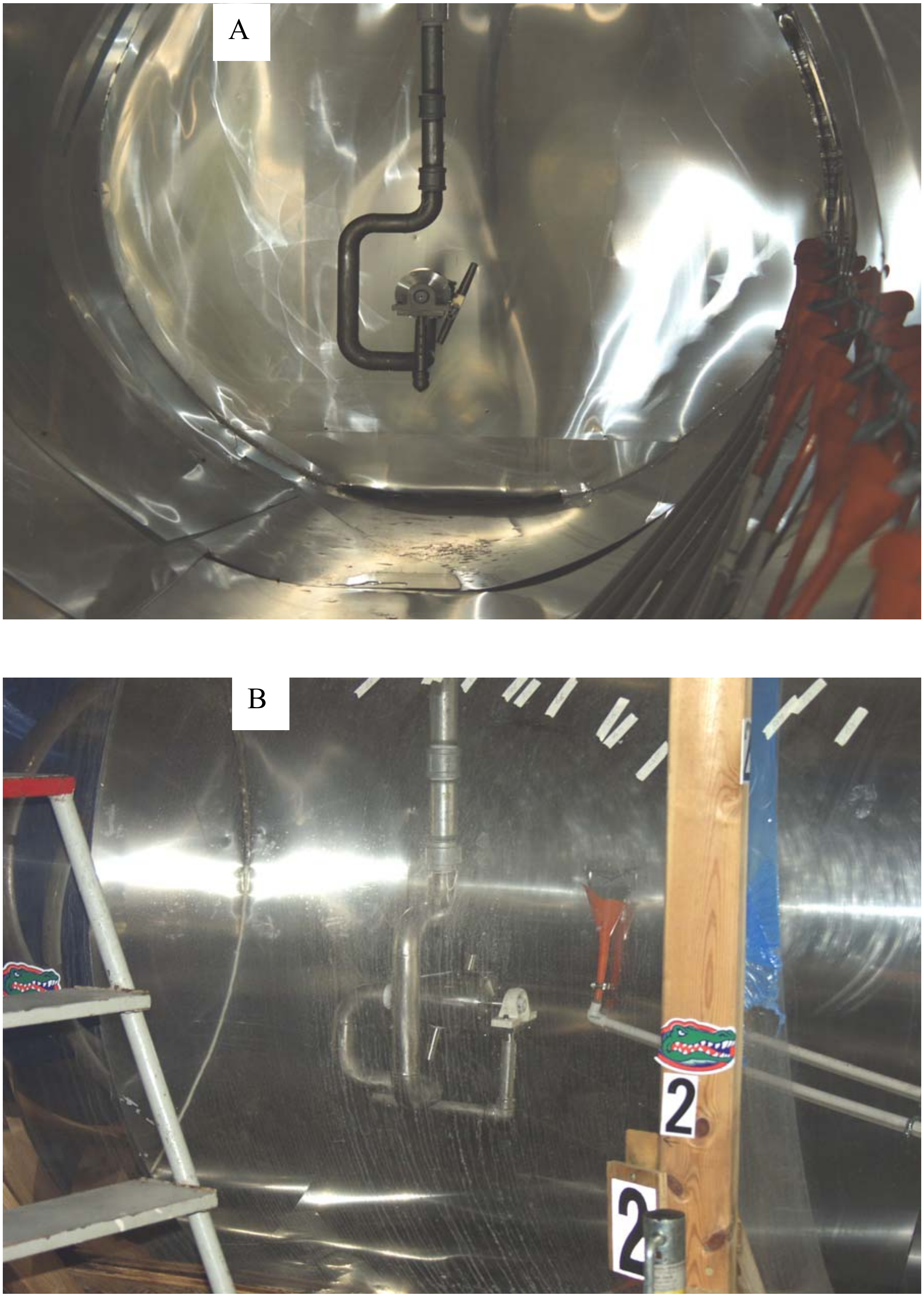


Figure 4-26. Lechler CIP 90° cradle device A bulkhead view B lateral view at 2 ft (Device by Lechler Spray Company).

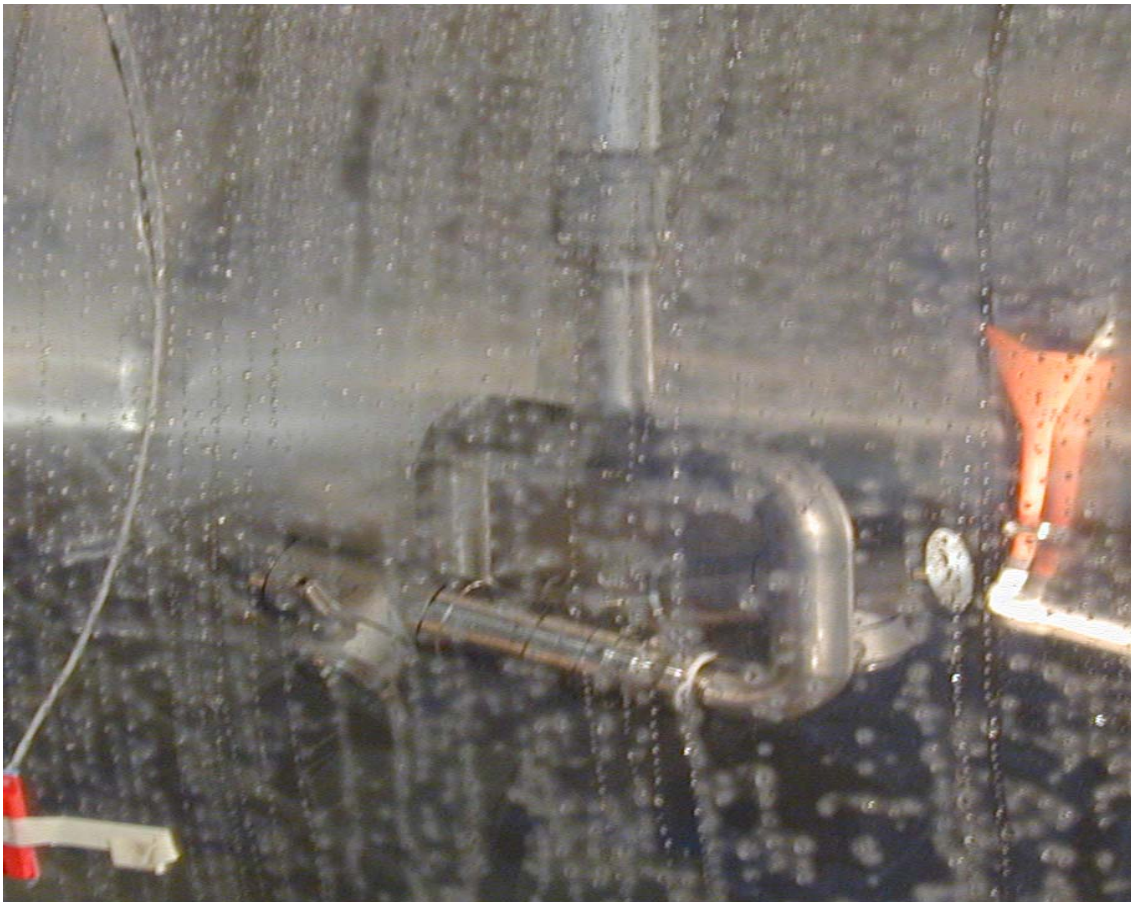


Figure 4-27. CIP device cradle (Model GJ-88) designed by Gamajet to hold two CIP devices (Model EZ-8).

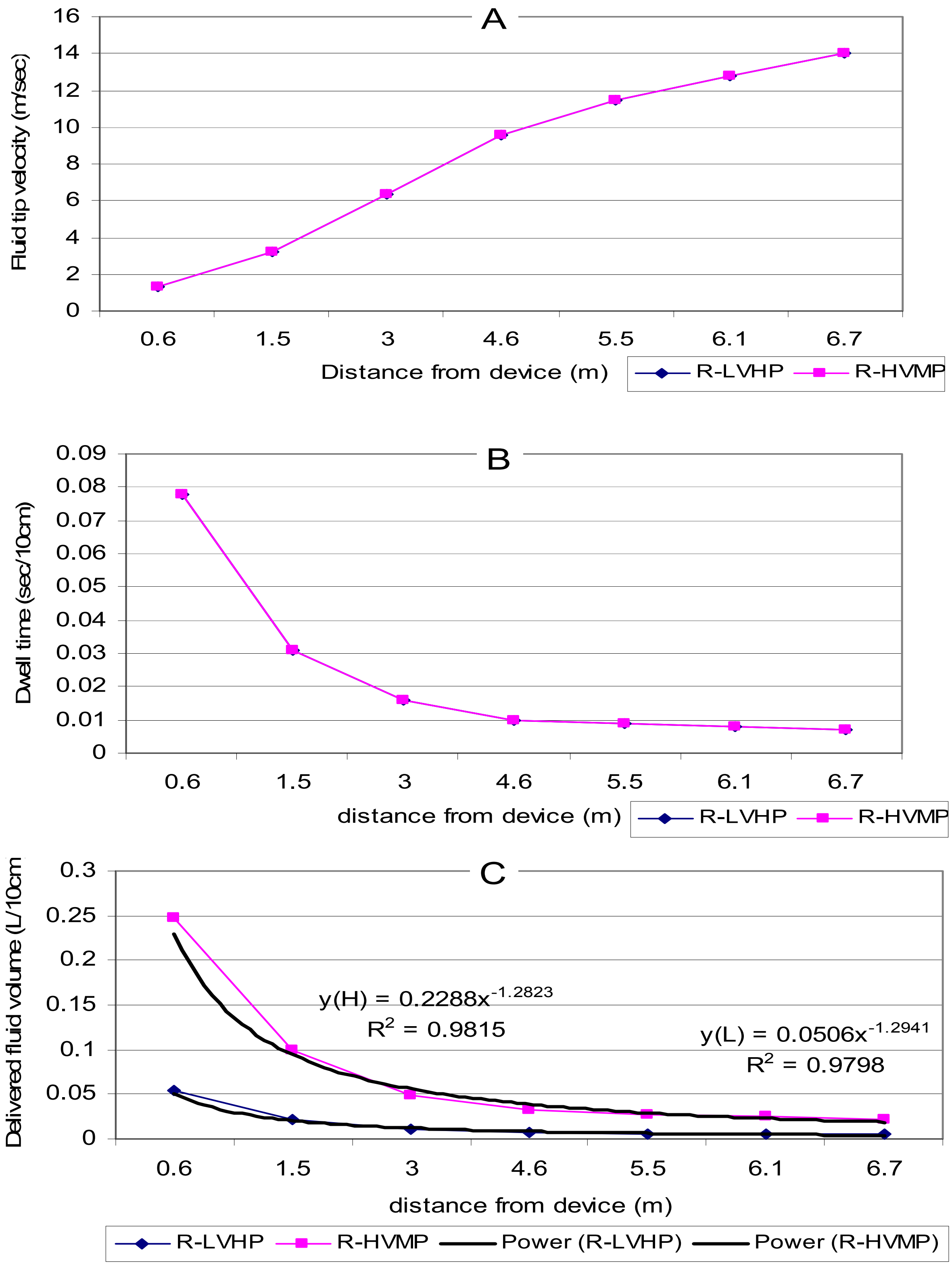


Figure 4-28. Comparison of low versus high volume rotating device at the same rotation speed (20 rpm) with respect to A) dwell time, B) fluid velocity, and C) delivered volume. X axis is the sampling point as distance from device.

Table 4-47. Chemical residue tests for R-LVHP operating parameter qualification

	Chemical residue at operating parameter (n = 3)[1]					
Lpm/m^2@bar	68 @ 24[2]	68 @ 24	87 @ 24	87 @ 31	87 @ 31	95 @ 31
Gpm/ft^2@psi	18 @ 350	18 @ 350	23 @ 350	23 @ 450	23 @ 450	25 @ 450
Extension(cm)	0	0	22	15	22	22
Speed(rpm)	20	4	4	4	4	4
Sample Sites[3]						
0 (0)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
0.3 (1)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.11 (0.19)	0.10 (0.19)
0.9 (3)	0.00 (0.00)	0.22 (0.38)	0.22 (0.19)	0.22 (0.38)	0.22 (0.38)	0.10 (0.19)
1.5 (5)	0.00 (0.00)	0.22 (0.19)	0.44 (0.19)	0.22 (0.38)	0.22 (0.38)	0.10 (0.19)
2.1 (7)	0.00 (0.00)	0.22 (0.19)	0.22 (0.38)	0.67 (0.33)	0.00 (0.00)	0.00 (0.00)
2.7 (9)	0.89 (0.19)	0.00 (0.00)	0.00 (0.00)	0.78 (0.51)	0.00 (0.00)	0.00 (0.00)
3.4 (11)	1.22 (0.19)	0.22 (0.19)	0.00 (0.00)	0.89 (0.19)	0.11 (0.19)	0.10 (0.19)
4.0 (13)	1.22 (0.19)	0.00 (0.00)	0.00 (0.00)	0.44 (0.19)	0.11 (0.19)	0.20 (0.38)
4.6 (15)	2.22 (0.19)	0.33 (0.00)	0.33 (0.58)	0.67 (0.00)	0.11 (0.19)	0.00 (0.00)
5.2 (17)	2.56 (0.19)	0.44 (0.38)	0.78 (0.38)	1.44 (0.19)	0.11 (0.19)	0.00 (0.00)
5.8 (19)	3.00 (0.00)	1.00 (0.33)	1.33 (0.00)	1.89 (0.51)	0.49 (0.51)	0.67 (0.33)
6.4 (21)	3.00 (0.00)	1.89 (0.19)	1.78 (0.19)	2.11 (0.19)	1.00 (0.58)	0.67 (0.58)
BH	2.33 (0.67)	0.11 (0.19)	0.56 (0.38)	0.67 (0.33)	0.11 (0.19)	0.00 (0.00)
Ave score and sig diff[4]	1.26 A	0.36 B	0.44 C	0.77 D	0.20 E	0.15 E

[1]Residue based on visual 4 point Hedonic scale. 0 = clean (green - <3 μg/100cm^2); 1 = slightly soiled (gray); 2 = more soiled (first purple color); 3 = dirty (initial inoculation level). [2]Variable tested for comparison only. Wash rack parameter. [3]Sample site is the site in m from the CIP device. BH is the bulkhead at 6.7m. [4]Values with different letters are significant at P<0.05 for the entire tanker. High values indicate a dirtier tanker.

Table 4-48. Visual residue tests for R-LVHP operating parameter qualification

	Visual residue score at operating parameter (n = 3)					
Lpm/m^2@bar	68 @ 24[2]	68 @ 24	87 @ 24	87 @ 31	87 @ 31	95 @ 31
Extension(cm)	0	0	22	15	22	22
Speed(rpm)	20	4	4	4	4	4
Sample Sites[3]						
0 (0)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
0.3 (1)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
0.9 (3)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
1.5 (5)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
2.1 (7)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
2.7 (9)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
3.4 (11)	0.44 (0.51)	0.00 (0.00)	0.00 (0.00)	0.11 (0.19)	0.00 (0.00)	0.00 (0.00)
4.0 (13)	2.11 (0.19)	0.00 (0.00)	0.00 (0.00)	0.33 (0.33)	0.00 (0.00)	0.00 (0.00)
4.6 (15)	2.78 (0.19)	0.89 (0.38)	0.33 (0.58)	0.89 (0.19)	0.00 (0.00)	0.00 (0.00)
5.2 (17)	2.78 (0.38)	1.56 (0.51)	1.56 (0.51)	1.67 (0.33)	1.00 (0.67)	0.67 (0.67)
5.8 (19)	3.00 (0.00)	2.00 (0.00)	2.00 (0.00)	1.89 (0.19)	0.67 (0.33)	1.33 (0.33)
6.4 (21)	3.00 (0.00)	2.11 (0.19)	2.00 (0.00)	2.11 (0.38)	0.53 (0.38)	1.44 (0.38)
BH	1.78 (1.17)	0.33 (0.33)	0.11 (0.19)	0.33 (0.00)	0.00 (0.00)	0.00 (0.00)
Ave score and sig diff[4]	1.22 A	0.53 B	0.46 C	0.56 D	0.17 E	0.27 E

[1]Residue based on visual 4 point Hedonic scale. 0 = clean (green - <3 µg/100cm^2); 1 = slightly soiled (gray); 2 = more soiled (first purple color); 3 = dirty (initial inoculation level). [2]Variable tested for comparison only. Wash rack parameter. [3]Sample site is the site in m from the CIP device. BH is the bulkhead at 6.7m. [4]Values with different letters are significant at P<0.05 for the entire tanker. High value indicates a dirtier tanker.

Table 4-49. Residue tests for R-LVHP operating parameter qualification

	Residue analysis at operating parameter (n = 3)											
Lpm/m²@bar	68 @ 24[2]		68 @ 24		87 @ 24		87 @31		87 @ 31		95 @ 31	
Extension(cm)	0		0		22		15		22		22	
Speed(rpm)	20		4		4		4		4		4	
Sample sites	C	V	C	V	C	V	C	V	C	V	C	V
0 (0)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3 (1)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.10	0.00
0.9 (3)	0.00	0.00	0.22	0.00	0.22	0.00	0.22	0.00	0.22	0.00	0.10	0.00
1.5 (5)	0.00	0.00	0.22	0.00	0.44	0.00	0.22	0.00	0.22	0.00	0.10	0.00
2.1 (7)	0.00	0.00	0.22	0.00	0.22	0.00	0.67	0.00	0.00	0.00	0.00	0.00
2.7 (9)	0.89	0.00	0.00	0.00	0.00	0.00	0.78	0.00	0.00	0.00	0.00	0.00
3.4 (11)	1.22	0.44	0.22	0.00	0.00	0.00	0.89	0.11	0.11	0.00	0.10	0.00
4.0 (13)	1.22	2.11	0.00	0.00	0.00	0.00	0.44	0.33	0.11	0.00	0.20	0.00
4.6 (15)	2.22	2.78	0.33	0.89	0.33	0.33	0.67	0.89	0.11	0.00	0.00	0.00
5.2 (17)	2.56	2.78	0.44	1.56	0.78	1.56	1.44	1.67	0.11	1.00	0.00	0.67
5.8 (19)	3.00	3.00	1.00	2.00	1.33	2.00	1.89	1.89	0.49	0.67	0.67	1.33
6.4 (21)	3.00	3.00	1.89	2.11	1.78	2.00	2.11	2.11	1.00	0.53	0.67	1.44
BH	2.33	1.78	0.11	0.33	0.56	0.11	0.67	0.33	0.11	0.00	0.00	0.00
Sig diff[3]	A	A	B	B	C	C	D	D	E	E	E	E
Ave score and sig diff [4,5]	2.49 A		0.89 B		0.90 C		1.33 D		0.37 E		0.41 E	

[1]Chemical residue based on visual 4 point Hedonic scale. 0 = clean (green - <3 µg/100cm²); 1 = slightly soiled (gray); 2 = more soiled (first purple color); 3 = dirty (initial inoculation level). Visual residue based on visual 4 point Hedonic scale. 0 = clean (no residue wet or dry; 1 = residue wet; 2 = more soiled (pulp, juice); 3 = dirty (initial inoculation level). A value of 0.5 was given when residue seen when dry. [2]Variable tested for comparison only to wash rack parameters. [3]Significant differences (P<0.05) determined between chemical and visual assays for entire tanker. [4]Average score combines visual and chemical Hedonic scores. 0 = clean; 1 = slightly soiled; 2 = more soiled; 3 = dirty (initial inoculation level). [5]Significance (P<0.05) determined between operating parameter with combined chemical and visual clean assessment.

Table 4-50. Chemical residue tests for R-HVMP operating parameter qualification

	Chemical assessment at operating parameter (n = 3)[1]			
Lpm/m^2@bar	435 @ 4.5[2]	454 @ 5.2[2]	492 @ 6.2	378 @ 6.2[3]
Gpm/ft^2@psi	110 @ 50	120 @ 75	130 @ 90	100 @ 90
Center	5	5	5	5
Pitch	16	16	16	16
Sample Sites[4]				
0 (0)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
0.3 (1)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
0.9 (3)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
1.5 (5)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
2.1 (7)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
2.7 (9)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
3.4 (11)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
4.0 (13)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
4.6 (15)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
5.2 (17)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
5.8 (19)	0.17 (0.29)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
6.4 (21)	0.33 (0.29)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
BH	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Ave score and sig diff[5]	0.04 A	0.00 A	0.00 A	0.00 A

[1]Residue based on chemical 4 point Hedonic scale. 0 = clean (green - <3 $\mu g/100cm^2$); 1 = slightly soiled (gray); 2 = more soiled (first purple color); 3 = dirty (initial inoculation level). [2]Manufacturer recommended parameter. [3]Available wash rack parameter. [4]Sample site is the site in m from the CIP device. BH is the bulkhead at 6.7m. [5]Values with different letters are significant at P<0.05 for the entire tanker. High value indicates a dirtier tanker.

Table 4-51. Visual residue tests for R-HVMP operating parameter qualification

	Visual assessment at operating parameter (n = 3)[1]			
Lpm/m^2@bar	435 @ 4.5[2]	454 @ 5.2[2]	492 @ 6.2	378 @ 6.2[3]
Gpm/ft^2@psi	110 @ 50	120 @ 75	130 @ 90	100 @ 90
Center	5	5	5	5
Pitch	16	16	16	16
Sample Sites [4]				
0 (0)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
0.3 (1)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
0.9 (3)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
1.5 (5)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
2.1 (7)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
2.7 (9)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
3.4 (11)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
4.0 (13)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
4.6 (15)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
5.2 (17)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
5.8 (19)	0.17 (0.29)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
6.4 (21)	0.17 (0.29)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
BH	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Ave score and sig diff [5]	0.03 A	0.00 A	0.00 A	0.00 A

[1]Residue based on visual 4 point Hedonic scale. 0 = clean (no residue); 1 = slightly soiled; 2 = more soiled; 3 = dirty (initial inoculation level). [2]Manufacturer recommended parameter. [3]Available wash rack parameter. [4]Sample site is the site in m from the CIP device. BH is the bulkhead at 6.7m. [5]Values with different letters are significantly different at $P<0.05$ for the entire tanker. High value indicates a dirtier tanker.

Table 4-52. Residue tests for R-HVMP operating parameter qualification

	Combined residues at operating parameter (n = 3)							
Lpm/m^2@bar	435 @ 4.5		454 @ 5.2		492 @ 6.2		378 @ 6.2	
Extension(cm)	5		5		5		5	
Speed(rpm)	16		16		16		16	
Sample Sites [3]	C[1]	V[2]	C	V	C	V	C	V
0 (0)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3 (1)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.9 (3)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.5 (5)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.1 (7)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.7 (9)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.4 (11)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.0 (13)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.6 (15)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.2 (17)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.8 (19)	0.17	0.17	0.00	0.00	0.00	0.00	0.00	0.00
6.4 (21)	0.33	0.17	0.00	0.00	0.00	0.00	0.00	0.00
BH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sig diff	A	A	A	A	A	A	A	A
Ave score and sig diff [4]	0.06 A		0.00 A		0.00 A		0.00 A	

[1]Residue based on chemical 4 point Hedonic scale. 0 = clean (green - <3 μg/100cm^2); 1 = slightly soiled (gray); 2 = more soiled (first purple color); 3 = dirty (initial inoculation level) [2]Residue based on visual 4 point Hedonic scale. 0 = clean (no residue); 1 = slightly soiled; 2 = more soiled; 3 = dirty (initial inoculation level). [3]Sample site is the site in m from the CIP device. BH is the bulkhead at 6.7m. [4]Values with different letters are significantly different at P<0.05 for the entire tanker. High value indicates a dirtier tanker.

Table 4-53. Chemical residue tests for Sd-HVMP operating parameter qualification

	Chemical residue at operating parameter (n = 3)[1]			
Lpm/m^2@bar	397 @ 3.1[2]	416 @ 4.5[2]	568 @ 5.5	378 @ 6.2[3]
Gpm/ft^2@psi	105 @ 45	110 @ 65	150 @ 80	100 @ 90
Center	0	0	0	0
Pitch	79	79	79	79
Sample Sites [4]				
0 (0)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
0.3 (1)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
0.9 (3)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
1.5 (5)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
2.1 (7)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
2.7 (9)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
3.4 (11)	1.33 (0.87)	0.78 (0.67)	0.00 (0.00)	0.00 (0.00)
4.0 (13)	1.78 (0.44)	1.11 (0.33)	0.00 (0.00)	0.00 (0.00)
4.6 (15)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
5.2 (17)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
5.8 (19)	1.00 (0.00)	0.89 (0.33)	0.00 (0.00)	0.00 (0.00)
6.4 (21)	1.89 (0.33)	0.33 (0.50)	0.00 (0.00)	0.00 (0.00)
BH	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Ave score and sig diff [5]	0.46 A	0.24 B	0.00 B	0.00 B

[1]Residue based on chemical 4 point Hedonic scale. 0 = clean (green - <3 μg/100cm^2); 1 = slightly soiled (gray); 2 = more soiled (first purple color); 3 = dirty (initial inoculation level). [2]System manufacturer suggested parameter. [3]Wash rack parameter. [4]Sample site is the site in m from the CIP device. BH is the bulkhead at 6.7m. [5]Values with different letters are significantly different at $P<0.05$ for the entire tanker. High value indicates a dirtier tanker.

Table 4-54. Visual residue tests for Sd-HVMP operating parameter qualification

	Visual residue at operating parameter (n = 3)[1]			
Lpm/m^2@bar	397 @ 3.1[2]	416 @ 4.5[2]	568 @ 5.5	378 @ 6.2
Gpm/ft^2@psi	105 @ 45	110 @ 65	150 @ 80	100 @ 90
Center	0	0	0	0
Pitch	79	79	79	79
Sample Sites [3]				
0 (0)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
0.3 (1)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
0.9 (3)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
1.5 (5)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
2.1 (7)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
2.7 (9)	0.11 (0.33)	0.11 (0.33)	0.00 (0.00)	0.00 (0.00)
3.4 (11)	2.00 (0.00)	0.78 (0.67)	0.22 (0.44)	0.00 (0.00)
4.0 (13)	2.00 (0.00)	1.11 (0.33)	0.22 (0.44)	0.44 (0.53)
4.6 (15)	0.22 (0.44)	0.22 (0.44)	0.11 (0.33)	0.00 (0.00)
5.2 (17)	0.11 (0.33)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
5.8 (19)	2.00 (0.00)	0.89 (0.33)	0.22 (0.44)	0.00 (0.00)
6.4 (21)	1.56 (0.73)	0.78 (0.44)	0.56 (0.53)	0.22 (0.44)
BH	0.06 (0.24)	0.06 (0.24)	0.00 (0.00)	0.00 (0.00)
Ave score and sig diff [4]	0.62 A	0.30 B	0.10 C	0.05 C

[1]Residue based on visual 4 point Hedonic scale. 0 = clean (no residue); 1 = slightly soiled; 2 = more soiled; 3 = dirty (initial inoculation level). [2]Manufacturer recommended parameter. [3]Sample site is the site in m from the CIP device. BH is the bulkhead at 6.7m. [4]Values with different letters are significantly different at $P<0.05$ for the entire tanker. High value indicates a dirtier tanker.

Table 4-55. Residue tests for Sd-HVMP operating parameter qualification

	Residue assayed at operating parameter (n = 3)							
Lpm/m^2@bar	397 @ 3.1		416 @ 4.5		568 @ 5.5		378 @ 6.2	
Centered	0		0		0		0	
Pitch	79		79		79		79	
Sample Sites [3]	C[1]	V[2]	C	V	C	V	C	V
0 (0)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3 (1)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.9 (3)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.5 (5)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.1 (7)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.7 (9)	0.00	0.11	0.00	0.11	0.00	0.00	0.00	0.00
3.4 (11)	1.33	2.00	0.78	0.78	0.00	0.22	0.00	0.00
4.0 (13)	1.78	2.00	1.11	1.11	0.00	0.22	0.00	0.44
4.6 (15)	0.00	0.22	0.00	0.22	0.00	0.11	0.00	0.00
5.2 (17)	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00
5.8 (19)	1.00	2.00	0.89	0.89	0.00	0.22	0.00	0.00
6.4 (21)	1.89	1.56	0.33	0.78	0.00	0.56	0.00	0.22
BH	0.00	0.06	0.00	0.06	0.00	0.00	0.00	0.00
Statistical diff [4]	A	A	A	A	A	A	A	A
Ave score and sig diff [5]	1.08 A		0.54 B		0.10 C		0.05 C	

[1]Residue based on chemical 4 point Hedonic scale. 0 = clean (green - <3 µg/100cm^2); 1 = slightly soiled (gray); 2 = more soiled (first purple color); 3 = dirty (initial inoculation level) [2]Residue based on visual 4 point Hedonic scale. 0 = clean (no residue); 1 = slightly soiled; 2 = more soiled; 3 = dirty (initial inoculation level). [3]Sample site is the site in m from the CIP device. BH is the bulkhead at 6.7m. [4]Values with different letters are significantly different at P<0.05 between parameters for chemical or visual residues. [5]Values with different letters are significantly different at P<0.05 for the entire tanker. High value indicates a dirtier tanker.

Table 4-56. Chemical residue tests for Sd-HVMP installation position qualification

	Chemical assay at operating parameter (n = 3)[1]						
Lpm/m²@bar	454@4.7	454@4.7	454@4.7	454@4.7	454@4.7	454@4.7	454@4.7
Gpm/ft²@psi	120@68	120@68	120@68	120@ 68	120@ 68	120@68	120@68
Center	5L	2.5L	1L	0[2]	1R	2.5R	5R
Pitch	79	79	79	79[2]	79	79	79
Sample Sites [3]							
0 (0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
0.3 (1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
0.9 (3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1.5 (5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
2.1 (7)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
2.7 (9)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
3.4 (11)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
4.0 (13)	0.0 (0.0)	0.2 (0.3)	0.0 (0.0)	0.2 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
4.6 (15)	0.0 (0.0)	0.2 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
5.2 (17)	1.3 (0.6)	0.2 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
5.8 (19)	2.0 (0.0)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
6.4 (21)	0.8 (0.3)	0.5 (0.5)	0.2 (0.3)	0.2 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
BH	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Ave score and sig diff [4]	0.32 B	0.11 A	0.02 A	0.03 A	0.00 A	0.00 A	0.00 A

[1]Residue based on visual 4 point Hedonic scale of device. 0 = clean (green - <3 μg/100cm²); 1 = slightly soiled (gray); 2 = more soiled (first purple color); 3 = dirty (initial inoculation level) [2]System manufacturer suggested parameter. [3]Sample site is the site in m from the CIP device. BH is the bulkhead at 6.7m. [4]Values with different letters are significant at P<0.05 for the entire tanker. High value indicates a dirtier tanker.

Table 4-57. Visual residue tests for Sd-HVMP installation position qualification

	Visual assay at operating parameter (n = 3)[1]						
Lpm/m^2@bar	454@4.7	454@4.7	454@4.7	454@4.7	454@4.7	454@4.7	454@4.7
Gpm/ft^2@psi	120@68	120@68	120@68	120@ 68	120@ 68	120@68	120@68
Center	5L	2.5L	1L	0[2]	1R	2.5R	5R
Pitch	79	79	79	79[2]	79	79	79
Sample Sites [3]							
0 (0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
0.3 (1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
0.9 (3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1.5 (5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
2.1 (7)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
2.7 (9)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
3.4 (11)	0.5 (0.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
4.0 (13)	1.0 (0.0)	0.2 (0.3)	0.2 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
4.6 (15)	1.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
5.2 (17)	2.0 (0.0)	0.5 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
5.8 (19)	2.0 (0.0)	1.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
6.4 (21)	2.0 (0.0)	1.3 (0.6)	0.5 (0.0)	0.3 (0.3)	0.2 (0.3)	0.0 (0.0)	0.0 (0.0)
BH	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Ave score and sig diff [4]	0.65 B	0.23 A	0.05 A	0.02 A	0.02 A	0.00 A	0.00 A

[1]Residue based on visual 4 point Hedonic scale of the device. 0 = clean (no residue); 1 = slightly soiled; 2 = more soiled; 3 = dirty (initial inoculation level). [2]System manufacturer suggested parameter. [3]Sample site is the site in m from the CIP device. BH is the bulkhead at 6.7m. [4]Values with different letters are significantly different at $P<0.05$ for the entire tanker. High value indicates a dirtier tanker.

Table 4-58. Residue tests for Sd-HVMP installation positions qualification

	Combined residue assay at operating parameter (n = 3)							
Lpm/m^2@bar	454 @ 4.7		454 @ 4.7		454 @ 4.7		454 @ 4.7	
Centered (°)[1]	0		1		2.5		5	
Pitch (°)	79		79		79		79	
Sample Sites[2]	C	V	C	V	C	V	C	V
0 (0)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.3 (1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.9 (3)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.5 (5)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.1 (7)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.7 (9)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.4 (11)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
4.0 (13)	0.2	0.0	0.0	0.2	0.2	0.2	0.0	1.0
4.6 (15)	0.0	0.0	0.0	0.0	0.2	0.0	0.0	1.0
5.2 (17)	0.0	0.0	0.0	0.0	0.2	0.5	1.3	2.0
5.8 (19)	0.0	0.0	0.0	0.0	0.3	1.0	2.0	2.0
6.4 (21)	0.2	0.3	0.2	0.5	0.5	1.3	0.8	2.0
BH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Overall score and sig diff[3]	0.05 A		0.07 A		0.34 A		0.97 B	

[1]Values are worse case of either left or right. If pointing left, then the right side is unclean. If pointing right, then the left side is unclean. [2]Sample site is the site in m from the CIP device. BH is the bulkhead at 6.7m. [3]Values with different letters are significantly different at $P<0.05$ for the entire tanker. High value indicates a dirtier tanker.

Table 4-59. Chemical residue tests for Sd-HVMP installation pitch qualification

	Chemical assay at operating parameter (n = 3)[1]		
Lpm/m^2@bar	454@4.7	454@4.7	454@4.7
Gpm/ft^2@psi	120@68	120@68	120@68
Center	0	0[2]	0
Pitch	76	79[2]	82
Sample Sites [3]			
0 (0)	0.0 (0.0)a	0.0 (0.0)a	0.0 (0.0)a
0.3 (1)	0.0 (0.0)a	0.0 (0.0)a	0.0 (0.0)a
0.9 (3)	0.0 (0.0)a	0.0 (0.0)a	0.0 (0.0)a
1.5 (5)	0.0 (0.0)a	0.0 (0.0)a	0.0 (0.0)a
2.1 (7)	0.0 (0.0)a	0.0 (0.0)a	0.0 (0.0)a
2.7 (9)	0.0 (0.0)a	0.0 (0.0)a	0.3 (0.6)b
3.4 (11)	0.0 (0.0)a	0.0 (0.0)a	0.3 (0.6)b
4.0 (13)	0.0 (0.0)a	0.2 (0.3)a	0.7 (0.6)a
4.6 (15)	0.0 (0.0)a	0.0 (0.0)a	0.3 (0.6)b
5.2 (17)	0.0 (0.0)a	0.0 (0.0)a	0.3 (0.6)b
5.8 (19)	2.7 (0.6)b	0.0 (0.0)a	0.7 (0.6)c
6.4 (21)	3.0 (0.0)b	0.2 (0.3)a	0.0 (0.0)a
BH[4]	0.3 (0.6)a	0.0 (0.0)a	1.7 (0.6)b
	3.0 (0.0)b	0.0 (0.0)a	0.0 (0.0)a
Ave score and sig diff P<0.05[5]	0.64 A	0.03 A	0.31 A
Ave score and sig diff P<0.10 [6]	0.64 B	0.03 A	0.31 B

[1]Residue based on visual 4 point Hedonic scale of the device. 0 = clean (green - <3 µg/100cm^2); 1 = slightly soiled (gray); 2 = more soiled (first purple color); 3 = dirty (initial inoculation level) [2]System manufacturer suggested parameter. [3]Sample site is the site in m from the CIP device. BH is the bulkhead at 6.7m. [4]Bulkhead separated by top and center respectively. [5]Values with different letters are significantly different at P<0.05 for the entire tanker. [6]Values with different letters are significantly different at P<0.10 for the entire tanker.

Table 4-60. Visual residue tests for Sd-HVMP installation pitch qualification

	Operating parameter (n = 3) [1]		
Lpm/m^2@bar	454@4.7	454@4.7	454@4.7
Gpm/ft^2@psi	120@68	120@68	120@68
Center	0	0 [2]	0
Pitch	76	79 [2]	82
Sample Sites [3]			
0 (0)	0.0 (0.0)a	0.0 (0.0)a	0.0 (0.0)a
0.3 (1)	0.0 (0.0)a	0.0 (0.0)a	0.0 (0.0)a
0.9 (3)	0.0 (0.0)a	0.0 (0.0)a	0.0 (0.0)a
1.5 (5)	0.0 (0.0)a	0.0 (0.0)a	0.0 (0.0)a
2.1 (7)	0.0 (0.0)a	0.0 (0.0)a	0.0 (0.0)a
2.7 (9)	0.2 (0.3)a	0.0 (0.0)a	0.7 (0.6)a
3.4 (11)	0.0 (0.0)a	0.0 (0.0)a	2.0 (0.0)b
4.0 (13)	0.0 (0.0)a	0.0 (0.0)a	2.3 (0.6)a
4.6 (15)	0.0 (0.0)a	0.0 (0.0)a	2.0 (0.0)b
5.2 (17)	0.0 (0.0)a	0.0 (0.0)a	2.0 (0.0)b
5.8 (19)	3.0 (0.0)b	0.0 (0.0)a	1.7 (0.6)c
6.4 (21)	3.0 (0.0)b	0.3 (0.3)a	0.0 (0.0)a
BH [4]	2.0 (0.0)b	0.0 (0.0)a	2.0 (1.0)b
	2.7 (0.6)b	0.0 (0.0)a	0.0 (0.0)a
Ave score and sig diff P<0.05 [5]	0.78 B	0.02 A	0.91 B

[1]Residue based on visual 4 point Hedonic scale of the device. 0 = clean (green - <3 µg/100cm^2); 1 = slightly soiled (gray); 2 = more soiled (first purple color); 3 = dirty (initial inoculation level) [2]System manufacturer suggested parameter. [3]Sample site is the site in m from the CIP device. BH is the bulkhead at 6.7m. [4]Bulkhead separated by top and center respectively. [5]Values with different letters are significantly different at P<0.05 for the entire tanker.

Table 4-61. Residue test summary for Sd-HVMP installation pitch qualification

	Combined residue assay at operating parameter (n = 3)[1]					
Lpm/m^2@bar	454 @ 4.7		454 @ 4.7		454 @ 4.7	
Centered (degrees)	0		0		0	
Pitch (degrees)	76		79		82	
Sample Sites [3]	C[1]	V[2]	C	V	C	V
0 (0)	0.0	0.0	0.0	0.0	0.0	0.0
0.3 (1)	0.0	0.0	0.0	0.0	0.0	0.0
0.9 (3)	0.0	0.0	0.0	0.0	0.0	0.0
1.5 (5)	0.0	0.0	0.0	0.0	0.0	0.0
2.1 (7)	0.0	0.0	0.0	0.0	0.0	0.0
2.7 (9)	0.0	0.0	0.0	0.2	0.3	0.7
3.4 (11)	0.0	0.0	0.0	0.0	0.3	2.0
4.0 (13)	0.2	0.0	0.0	0.0	0.7	2.3
4.6 (15)	0.0	0.0	0.0	0.0	0.3	2.0
5.2 (17)	0.0	0.0	0.0	0.0	0.3	2.0
5.8 (19)	0.0	0.0	2.7	3.0	0.7	1.7
6.4 (21)	0.2	0.3	3.0	3.0	0.0	0.0
BHc	0.0	0.0	3.0	2.7	0.0	0.0
BHt	0.0	0.0	0.3	2.0	1.7	2.0
Overall score and sig diff $P<0.05$ [4]	0.05 B		1.42 A		1.21 B	

[1]Residue based on chemical 4 point Hedonic scale of the device. 0 = clean (green - <3 μg/100cm^2); 1 = slightly soiled (gray); 2 = more soiled (first purple color); 3 = dirty (initial inoculation level). [2]Residue based on visual 4 point Hedonic scale of the device. 0 = clean (no visual residue); 1 = slightly soiled; 2 = more soiled; 3 = dirty (initial inoculation level). [3]Sample site is the site in m from the CIP device. BH is the bulkhead at 6.7m. [4]Values with different letters are significantly different at P<0.05 for the entire tanker.

CHAPTER 5
WASH PROTOCOL VALIDATION

Introduction

In Part 1 of this study, the baseline results indicated that food-grade tankers may not be adequately cleaned due to at least one wash parameter (detergent concentration, wash temperature, wash action). It was observed in Part 1 that the CIP device may be performing poorly and thus the primary cause of poor cleaning. Based on observations, it was determined that the wash action was the primary cause of inadequate washing. In Part 2, the CIP systems were evaluated and adequate wash system parameters were determined. With these wash system parameters, the tanker wash validation was re-commenced. To fully understand the effect of detergent concentration and wash temperature, these were also evaluated.

Materials and Methods

Tankers

Every effort was made to use the C-Thru Model tanker for all wash validation work (Figure 5-1) and in the UF CREC Pilot Plant. However, due to the lack heating capacity for the large volume systems, tankers were obtained from cooperating wash-rack (Indian River Transport for Sd-HVMP and R-HVMP devices). Prior to tanker surface inoculation, the same surface preparation process was completed for all tankers. All manual cleaning was conducted by the researcher. The manual wash protocol that was found to remove all residues was as follows;

- Rinse surfaces with ambient temperature water.
- Wash surface with warm water (43°C) and Dawn dishwashing detergent (Proctor and Gamble, Cincinnati OH) (3 fl oz per 1 gallon water) using a green scrubby (3M Industries, Minneapolis, MN).
- Rinse with ambient temperature water.

- Wash surface with warm water (43°C) and Fisherbrand Sparkleen 1 for manual washing (Fisher Scientific, Pittsbugh PA) (1 oz per gallon water) using a new green scrubby.
- Rinse surfaces well with ambient temperature water.
- Allow the tanker to dry for 24 hours.

For this study, 12 sample sites were designated in the tankers for inoculation (Figure 5-2). These sites were used whether the wash was in the C-Thru Model tanker or the wash company tanker.

CIP Devices

Three representative devices were evaluated (CIP device brand names and models should be held confidential and are only used for example purposes):

1. **Rotating, Low Volume, High pressure (R-LVHP):** The Spraying Systems AA190 supplied by the manufacturer was used with the appropriate modifications. Operating parameters were 87 Lpm @ 31 bar (23 gpm at 450 psi) with 23 cm (9 in) extensions and rotating at 4 rpm.
2. **Rotating, High Volume, Medium Pressure (R-HVMP):** The unit used is the Sellers 360, supplied by the wash rack, operated at 360 Lpm at 6.8 bar (100 gpm at 100 psi) rotating at 16 rpm using the wash rack facility) and a turret speed based on flow.
3. **Static, High Volume, Medium Pressure (S-HVMP):** The unit used was supplied by the manufacturer and operated at the wash rack. Operating parameters were 530 Lpm at 4.7 bar (140 gpm at 68 psi) installed dead center (0° based on bulkhead center) and with the manufacturers pitch (79).

Soil Slurry Production

Microorganisms used were the same as in Part 1 however preparation for the soil type were modified as discussed below. *B. megaterium* ATCC 14581 was used as the heat resistant spore-former in lieu of the *Alicyclobacillus* species which are known spoilage microorganisms of orange and other juices (Parish 1995). *S. cerevisiae* (ATCC 2601) was used as a general heat labile juice spoilage microorganism (Parish 2000) while a generic *E. coli* (ATCC 23522) was used for the HACCP pertinent safety microorganism (FDA 2001).

Type 2 Wash

Soils for the Type 2 wash were 55°Brix Valencia orange juice with 10% sinking pulp produced at the CREC (June 20-21, 2006) and stored at -23°C (-10°F). The concentrate was diluted to 30°Brix with deionized water as confirmed with a digital refractometer (Model 10450 A.O. ABBE). Soils were prepared in 400 gram batches at 30°Brix concentrate and were autoclaved at 121°C for 10 min for sterility. Bacteria (*B. megaterium* and *E. coli*) were grown in TSB for 1 day at 35°C and then transferred to acidified (pH 5.0) TSB for 2 days at 35°C. Yeast (*S. cerevisiae*) was incubated in TSB at 30°C for 2 days. TSB growth was transferred to centrifuge tubes (120x15 mm 16 ml) and centrifuged at 3,000 rpm for 30 min using an International Clinical Centrifuge Model CL33726M-1 (International Equipment Company, Needham Heights, Mass.). Supernatants were removed from the tubes and the pellets were transferred to the orange juice by rinsing the tubes with fresh 30°Brix orange juice, three times. Total soil volume for adequate surface application was 320 grams with a 3.9 pH. Juice and microorganisms were shaken well for 2 min and sprayed onto the tanker surface at the designated sites. The average juice inoculation was expected to be 1 gram per 100 cm2. This was determined by the mass difference of the slurry in the spray bottle divided by the inoculated surface area. Microbial populations were estimated to be 1,000,000 cfu/100cm^2 for each microorganism. Soil residue as sugar was expected to be 3 on the 4 point Hedonic scale (0 to 3) while the ATP readings were 5.1 RLU (Relative Light Units) as determined with a Lightning Bioluminescence reader (BioControl Systems).

Type 4 Wash

The Type 4 soil was an equal blend of pasteurized whole milk (Publix brand, Lakeland FL), pasteurized egg whites (Papetti's Liquid Egg, Elizabeth NJ), and commercial peanut butter (Publix Creamy brand, Lakeland FL). Bacteria (*B. megaterium* and *E. coli*) were grown in TSB for 2 days at 35°C while the yeast (*S. cerevisiae*) was incubated in TSB at 30°C for 2 days. TSB was transferred to centrifuge tubes (120x15 mm 16 ml) and centrifuged at 3,000 rpm for 30 min using an International Clinical Centrifuge Model CL33726M-1 (International Equipment Company, Needham Heights, Mass.). Supernatants were removed from the tubes and the pellets were transferred to the allergen food slurry by rinsing with fresh milk. Total soil slurry required for adequate surface application was 320 grams with a 6.2 pH. Allergen slurry and microorganisms were blended well for 2 min at speed 7 using an Oster blender Model Osterizer Galaxie 14 (John Oster Manufacturing Company, Milwaukee, WI). The slurry was sprayed onto the tanker surface at the designated sites using a sweeping motion. The average inoculation was expected to be 1 gram per 100 cm^2 resulting in a microbial population of 1000000 cfu/100cm^2 for each microorganism and allergen concentrations were estimated to be 8000, 22000, and 29000 µg/100cm^2 respectively for milk, egg, and peanut allergens. Allergen concentrations were estimated from nutritional analysis data of the products and confirmed in the slurry after serial dilutions in sterile phosphate water. The slurry when dry had a sugar residue based on the AccuClean method (Neogen Corporation) of 3 points on a 4 point Hedonic scale and ATP reading was 5.3 RLU (Relative Light Units) with a Lightning Bioluminescence reader (BioControl Systems).

Surface Inoculation

The appropriate soil was spray applied on the sample sites (Figure 5-2) using a manually operated spray bottle. Application rate was estimated at 1 gm/100cm^2 which would represent an empty drained tanker. When spraying, a sweeping motion was used to apply the soil evenly. Soils were allowed to dry for 24 hours at ambient conditions.

Washes

All washes followed the guidelines of the JPA Model Tanker Wash Guidelines (JPA 2006) for the Fruit Juice Industry for Type 2 and 4 washes. Same detergents and sanitizers used at wash facilities were used for this study. Detergent and sanitizer solutions were prepared according to the manufacturer directions and were evaluated for concentration before washing using manufacturer supplied test kits.

To assess detergent effect, a set of Type 4 washes using the R-LVHP device were conducted with three detergent concentrations ranges (100 to 150, 450 to 550, and 900 to 1000 ppm active alkalinity). Wash time and temperature followed the JPA guidelines for the Type 4 wash.

To assess temperature effect, Type 2 and 4 washes were conducted with the feed temperature at 71°C (160°F) measured at the device infeed. The tested feed temperature was chosen based on detergent suppliers' recommendations (Ecolab PC 2007 Zep PC 2007 Chemical Systems 2007) and food protein (allergen) cleaning literature (Katsuyama 1999 Schumacher 2003 Marriott 2006).

Visual Assessment

Visual assessment of cleaning was completed prior to swabbing an area. Visual assessment of cleaning was accomplished by using the guidelines of Kulkarni (1974) and Richter (1975). Visual observations were not limited to the swabbed 100 cm^2 but encompassed larger areas and areas that were not swabbed. After-cleaning, observations were performed prior to sampling the food contact surface. A hand-held (MagLight Model 2-D cell, Mag Instruments) and a head-mounted flashlight (Eveready Model KE, Eveready Industries) were used for the internal observations. Areas were touched by hand to feel for certain surface qualities after swabbing. This was useful for pits, rust spots, cracks, residual soils, and other abnormalities.

Visual clean assessment was determined immediately after cleaning for a “wet” clean assay and after drying for 20 min for a “dry” clean assay. Wet clean was useful to determine gross cleaning inadequacies while the dry clean assay was useful for the residual minute soils that stained the stainless steel. Examples of what was expected for an unclean surface are; pulp, residual carbohydrates, fat spots (greasy areas due to fats or oils), blue stains (proteins), white stains (milk stone), any color particulates (pipe scale, sand, detergent residue), and water droplet adhesion (indicative of thin film soils).

Microbiology

Tankers were sampled before and after cleaning for comparison purposes. Sample sites are seen in Figure 5-2 for all washes. Spongesicle® with 10 ml neutralizing broth (International BioProducts, Bothell, WA) was used for all swab samples. Before-cleaning sample sites were aseptically sampled by swabbing a 100 cm^2 (2 ½ by 2 ½ swipes of Spongesicle®) of tanker surface. Spongesicles were returned to the labeled bag and placed in a cooler with ice packs for the trip to the lab. After cleaning, all parts were replaced onto the tanker and the tanker was closed but not sealed. After-cleaning samples were taken after the tanker was re-opened. After-cleaning samples were taken near the before-cleaning areas ensuring that the before-cleaning site was not re-sampled. All Spongesicles® were returned to their labeled bags and placed in a cooler with ice packs for the trip to the lab.

Water and sanitizer solutions were collected in a Spongesicle® with the sponge removed but the neutralizing broth retained. Samples were taken before the tanker at appropriate sampling ports if available. Samples taken after the tanker were collected from the rear port after 5 min of flow. Cleaning solutions were collected in sterile Whirlpak® bags with a neutralizing solution (0.5% sodium thiosulfate) (Fisher Scientific). If collected solutions were hot (detergent solutions or hot rinse water), these were cooled in running tap water prior to placing in the cooler. Additional samples of inside food-contact or outside tanker surfaces were taken as needed to help understand some of the results. All samples were placed in the cooler and transported to the laboratory at the University of Florida Citrus Research and Education Center, Lake Alfred, FL for analytical testing.

All samples were plated the same day they were obtained. Aliquots (90 ml) of pre-warmed (45°C) 0.1% buffered peptone water (BPW) (International BioProducts) were aseptically transferred to each surface swab Spongesicle® sample bag. The sponge of the Spongesicle® was massaged well for at least 60 sec to release adhered bacteria into the BPW solution. For each liquid sample, no pre-dilutions were deemed unnecessary other than for enumerations. All sponge and liquid BPW samples were then serially diluted to -3 and plated in the following manner;

1. *B. megaterium* populations: Samples were plated on PCA and incubated for 48 hours at 35°C. After determining the total population, the *E. coli* and yeast counts were subtracted to yield the total Bacillus count. Confirmation of the bacteria was by microscopic evaluation.

2. Generic *E. coli* populations: Follow methods as outlined for *E.coli*/Coliform Count Petrifilm® (3M, St. Paul, MN). A confirmation test on presumptive positive colonies was performed by aseptically transferring suspect colonies to 9ml tubes of EC-MUG broth (Difco) with an inverted Durham tube and incubated at 44.5°C for 24 hours. Growth, gas, and fluorescence were indicative of a positive result.

3. Presence of *E. coli*: Follow method as outlined by the Ecolite® (Charm Sciences, Lawrence, MA) all-in-one rapid test method using 20 ml of undiluted Spongesicle® sample and 80 ml of 45°C sterile DI water for dilution. Confirmation on presumptive positive samples was as above for populations.

4. *S. cerevisiae* populations: Samples were plated on potato dextrose agar acidified with 10% tartaric acid to pH 3.5 +/- 0.2. Plates were incubated at 32°C for up to 5 days. Full counts were typically available at 3 days.

All microbiological analyses were performed in duplicate except for the Ecolite® test that was performed only once per sample. Positive and negative controls were included in each set of sample sets for all protocols as a control for the method. Raw ingredients (juice, milk, eggs, and peanut butter) were also evaluated by these procedures to determine residual contributions.

Allergens

From the same SpongeSicle bag used for microbiology analysis and after removing the required amount for the microbiology testing, aliquots of the SpongeSicle BPW were removed for allergen testing. Before-wash samples were serially diluted to -5 in order to be in the range of the test kits. Five mL each of dilutions -3 to -5 were placed in pre-labeled 6x9 inch sterile plastic bags (Fisherbrand, Pittsburg, PA). For all post-wash samples, 5 mL aliquots were removed directly from the SpongeSicle BPW samples or the liquid samples and placed in pre-labeled 6x9 in sterile plastic bags (Fisherbrand, Pittsburg, PA). All bags were refrigerated until tested.

Prior to testing, allergen sample bags were removed from the refrigerator and warmed to 40°C and massaged and shaken well for 60 sec. Procedures were followed for each allergen using a commercially available allergen test kit (Alert Allergen Test Kits, Neogen Corporation, Lansing, Mich.) for each allergen (Total Milk No. 8471, Egg No. 8451, and Peanut No. 8431). A micro-well reader (Stat Fax Model 321 Plus, Neogen Corporation, Lansing, Mich.) was used to read allergen levels in the wells to eliminate subjective color evaluations of the wells (colorimetric evaluation). All wells were read at 650 nm at 24°C according to the manufacturer's specification. Allergen tests were conducted once per sample but read three times within 2 min and averaged. Standard curves were determined using the positive controls of the test kit.

Residual Microbial and Soil Analysis with ATP

Microorganisms and soil residue as ATP were determined by direct swab of an inoculated area with a Lightning MVP® swab after SpongeSicle sampling and near the SpongeSicle site ensuring that the same spots were not sampled. Swabs were placed in the ice cooler until returned to the lab. At the lab, prior to testing, the swabs were warmed to room temperature, activated, and ATP residues were read with a Lightning Model 04 Bioluminometer (BioControl, Bothell, WA). ATP residue was recorded as Relative Light Units (RLU) per 100cm^2. Swabs and instruments were used according to the manufacturer directions. A standard calibration set supplied by the manufacturer (BioControl Bothell, WA) was used to calibrate the Bioluminometer before each set of samples.

Residual Soils

To determine residual sugars and proteins, the AccuClean Simple Sanitation test swabs were used (Neogen Corporation Lansing MI). All AccuClean sampling was conducted after the microbiology samples and every effort was made not to sample an area that was sampled by the SpongeSicle or the ATP swabs. Manufacturer procedures were followed using only 3 drops of wetting solution on the test swab.

Statistical Analysis

The overall tanker wash validation was statistically analyzed with SAS 9.1 (SAS Institute Inc., Cary NC May 2007). Paired comparisons were completed using the Student t-test function of Microsoft Office Excel 2003 (Microsoft Corp. Bellevue, WA April 2006).

Results and Discussion

Detergent Concentration

Detergent concentration results are in Table 5-1 for the R-LVHP and Table 5-2 for Sd-HVMP device. Detergent concentration tests were conducted with these devices as representative of there respective types. R-LVHP results may also be the more critical unit since this device operates at the lowest volume and runs the risk of barrel end temperature issues. Type 4 soil was used to determine the detergent's effective allergen/protein removal. Devices were operated according to the parameter determined previously and using the 71°C discharge temperature suggested by the wash regime unless otherwise directed by the detergent's manufacturer (JPA 2005).

In the tanker wash survey (Winniczuk unpublished), it was found that a chlorinated alkaline cleaner was used by wash facilities at an average concentration of 150 ppm active alkalinity with 10 ppm chlorine at 10.5 pH. This concentration was used as the baseline for comparisons. Further detergent analyses are in Appendix B.

Test results indicated that there were no overall significant differences ($P<0.05$) between the detergent concentrations when either device was operated at their respective hydraulic conditions. There was some residue on the surface for each detergent concentration but in general were below the target limit of 1 $\mu g/100cm^2$ which was below the methods detection limit. Results below the methods detection limit may have resulted in large standard deviations which may be the reason for the lack of significant difference. Even though there were no significant differences overall, the R-LVHP device did have a determined significant difference between 150 ppm active alkalinity and the other two higher concentrations at the bulkhead which may mean that 150 ppm is too low for this device. This was not seen with the Sd-HVMP device which distributed much more fluid during its cleaning cycle.

Another aspect of the alkaline cleaners used is the added chlorine that is used to peptize proteins and to reduce milk stone deposits (Katsuyama 1993). At 150 ppm active alkalinity, the average free chlorine concentration was 10 ppm while at 500 and 1000 ppm active alkaline, it was 60 and 100 ppm free chlorine respectively. Whereas the active alkalinity is used to remove fatty soils and some proteins, the chlorine is used to remove tenacious soils that may adhere to the stainless steel due to the warm high humid conditions of the wash (Katsuyama 1993 Mabesa

1979 Bigalke 1978). Under these conditions, the increased chlorine concentration may be more important to the protein removal then the actual active alkalinity.

Pre-CIP handling of the tanker may be instrumental particularly with the low volume system. Since the milk fats (or lipids of other products) may protect the proteins from water cleaning, a manual water wash that is higher than the melt point of the fat may be needed (Mabesa 1979). All manual washing/rinsing was conducted with 25 to 28°C water. Typically a temperature, 3°C (5°F) higher than the fat's melt point would aid in removing the lipid without affecting the protein (Katsuyama 1993 Schmidt 2003). If the R-LVHP device is used, it may have to be operated with a higher detergent concentration to ensure adequate chemical activity in all parts of the tanker.

Temperature

Wash temperature is another factor that may have had an effect on the tanker washing effectiveness. This factor was assessed by running washes at 2 different temperatures, one at the standard 71°C discharge minimum and the other at a 71°C feed temperature. Other researchers (Bigalke 1978 Mabesa 1979) have found that high temperatures (>50°C) may be detrimental to removing milk and other proteinaceous soils. Also, high temperatures (>37°C) in combination with high humidity (>80-100%) can lead to the formation of a tenacious soil (Mabesa 1979). Tankers are a perfect vessel for combining high temperature and high humidity during the wash cycle. Results of this assessment are in Table 5-3. These results indicate that there was no significant difference ($P<0.05$) overall between the temperature regimes at the tested conditions. The lack of significance may be due to the large standard deviations that were seen which may be due to the allergen detection methods limitations. There was a significant difference at the bulkhead which might be expected since the fluid volume was low in this area. With the low volume of the R-LVHP device, the use of the 71°C discharge temperature may be detrimental since the steel temperature can reach protein cook-on or lipid polymerization temperatures long before the wash solution can get to the area (Figure 3-3) (Mabesa 1979). To obtain the 71°C discharge temperature, a feed temperature of 85 to 91°C was needed which was similar to observed feed temperatures of the tanker survey (Winniczuk unpublished). This high temperature can heat up the stainless steel before the nozzles are oriented properly to clean the bulkhead. A 71°C feed temperature provided a discharge temperature of 54°C which is above the suggested discharge temperature for milk cleaning (Bigalke 1978 Wilkins 1993) and for egg cleaning (NEB 2004). These results may have been observed in this study since the milk residue, as an allergen (even though below the target limit), was lower close to the device (Sites 0 to 3.7 m) but higher further away (4.9 to BH). The exact starting position of the rotating device was not monitored which also may explain the results since the starting point of the device may influence the soils removal during the cycle time. For example, if the wash was started when the nozzles were facing the bulkheads, these would receive the detergent first which would remove soils before the tanker steel heated to temperatures that produce protein cook-on. If the wash started with the nozzles facing the tanker's center (0 m from the device), the steel may heat up long before the nozzles and the wash fluid get to the bulkhead since the device has to go through its cycle.

The detergent concentration used (150 ppm active alkalinity) was also the wash facilities observed average that may be too low for proper washing which combined with temperature and low volume rates, may be the cause of the lack of protein removal at the bulkhead. However, since there appears to be no statistically significant difference between a 71°C feed or discharge temperature, it is felt that temperature has little bearing on the washes.

Type 2 Wash

Rotating-low volume, high pressure device (R-LVHP)

Wash validations were commenced with an assessment of the wash rack conditions as a baseline for comparison even though the surface flow rate and qualification data indicated that the wash rack conditions are not acceptable. Table 5-4 are the results of the R-LVHP Type 2 wash following the wash rack conditions of 68 Lpm @ 24 bar with no extensions and a rotation speed of 20 rpm. The minimum discharge temperature of 71°C was used for all tests per JPA guidelines. The column headed “Flow rate” is the nearest surface flow rate for the inoculated area and is for example purposes. Soil residues (visual, ATP, and sugar results) indicate that this device as operated was inadequate to properly clean the tanker. Flow rates appear to be adequate to clean near the device (Sites 0 to 3.7) but are very low further away (Sites 4.9 to BHt). At the bulkhead top (Site BHt) there was no flow detected. This soil was a simple juice solution that should be cleaned with adequate water flow combined with the detergent.

Only one sample site (Site 0) was above the literature flow rate of 1.63 Lpm/m^2 minimum for surface wetting which may be the reason for the lack of cleaning (Ecolab 2002). However, Sites 1.2 to 3.7 were below this minimum but seemed to adequately clean the surface. Literature flow rates are based on cascade cleaning equipment which may explain this difference (Ecolab 2002 Lechler 2004). On the other hand, when the surface flow rates were very low as in Sites 4.9 to the bulkhead, the cleaning was not accomplished. Interestingly, the BHc that was soiled, had a surface flow rate of 0.079 Lpm/m^2 that was similar to the value at Site 3.7, which was relatively clean. It is felt that even though the flow rate a BHc was equivalent to Site 3.7, how the fluids are dispersed to this site may be significantly different than at 3.7. Visually, the stream at BHc was mist with practically no impingement forces so the cleaning at the bulkhead would rely strictly on cascade cleaning of the mist. Fluid amounts from the mist were low.

With respect to the microorganism reduction, the *S. cerevisiae* and *E. coli* were effectively removed or inactivated during the wash. Since practically no fluid reached the bulkhead top region (Site BHt), these microorganisms were probably not removed but inactivated due to the temperature (heat inactivation) (Jay 2001). The temperature profile of the tanker (Figure 4-4) indicated that the bulkhead top region did heat to a minimum lethal temperature of 55°C for a sufficient time (approximately 28 min) to inactivate the microorganisms (Jay 2001). However, this time and temperature were not sufficient to inactivate the *Bacillus* and more specifically the *Bacillus* spores (Jay 2001). Since vegetative *Bacillus* is not known to be heat resistant, these may have been inactivated while the spores that were either in the slurry or developed during the drying process, would survive the heat process. The recovery method did not take this into account.

Based on these results combined with the observations of the previous work, it appears that this device as operated is not effective to wash the tanker.

R-LVHP study determined rotation speed

To rule out the rotation speed effect, a test set was conducted using the rotation speed variable only. These results are in Table 5-5. Flow rates were improved compared to the faster rotation speed with fluid collected at the bulkhead top (Site BHt). By using a slow rotation speed, it was expected to see more cleaned areas. Soil removal was improved but the Sites 4.9, 6.1, and the bulkhead (BHt) still had visual, ATP, or sugar soils. Microorganism results were similar to the previous trial in that *S. cerevisiae* and *E. coli* were effectively reduced but the *B. megaterium* was at relatively high levels. Reducing the rotation speed appears to not be the only factor for effective cleaning with this device.

R-LVHP study determined extension length

The extension lengths of 15 and 22 cm (6 and 9 in) were tested since both extensions seem to provide adequate flow and were not found to be significantly different for fluid dispersion. These results are in Table 5-6 and 5-7 respectively for 15 and 22 cm extensions. The 15 cm extension was seen to significantly improve the fluid distribution in the surface flow rate tests. Flow rates were improved to each sample site with an improvement (as compared to the operating parameter of Table 5-4) in the soil residues as detected by visual, ATP, and sugar analysis. Areas that did not appear to be cleaned well were at the barrel end at 6.1 m. Residual soil was more noticeable when the stainless steel was dry not when wet. This may be expected due to solubility of the soil (Richter 1975). *S. cerevisiae* and *E. coli* results were not recovered as expected while a minimum 5 log reduction was seen with *B. megaterium*. While not fully removing the *B. megaterium* inoculation, the reduction appeared significant (6.1 log to -0.67 log). This seemed to indicate that a Type 2 wash can effectively clean a tanker with 68 Lpm @ 24 bar with a 15 cm (6 in) extensions and at 4 rpm rotation speed. However, since the barrel end was still above the soiled minimum another various needs to be tested.

Based on the previous qualification results, the 22 cm (9 in) extension was thought to be more effective under washing conditions while a low flow rate was important to the wash facilities (Bynum Transport PC 2005; Clewiston Tank Wash PC 2005; USA Tank Wash PC 2005; Oakley Transport PC 2006; Sterling Tank Wash PC 2006). The purpose of the next test was to confirm this combination. This test was conducted at 68 Lpm @ 24 bar with a 22 cm extension with the results are in Table 5-7. These results indicate that the soil was effectively removed up to 3.7 m while the Sites 4.9 to 6.1 (barrel end) still had residues (visual and sugar) above the target minimum. All microorganisms were effectively and significantly removed (6 log units initial to ~0 log units final). Due to the residues in the barrel, these operating conditions could not be validation to effectively clean the tanker.

R-LVHP study determined flow rate

Since the lowest flow rate appeared to be ineffective with the improvements of rotation speed and extension length, the flow rate was increased to 75.7 Lpm @ 31 bar which the previous research seemed to indicate this trend. Under these conditions, the tanker could be effectively cleaned (Table 5-8). All soils and microorganisms were reduced to acceptable levels while the results may not be ideal, these conditions did meet the “clean” requirements as determined early in the research. R-LVHP CIP device when operated under the conditions of 75.7 Lpm @ 31 bar with a 4 rpm rotation speed and 22 cm (9 in) extensions were validated to effectively clean a tanker.

A further increase to 83 Lpm @ 31 bar as indicated by the results of the qualification tests are in Table 5-9. A rotation speed of 4 rpm and the 22 cm extensions were also used since these seem to be significant for proper cleaning. Under these operating conditions, all areas were effectively cleaned with the barrel end (Site 6.1) also cleaned to non-recoverable levels.

Based on these results, when using the R-LVHP CIP device, effective Type 2 cleaning can be achieved at a minimum of 75.7 Lpm @ 31 bar with a rotation speed of 4 rpm and fitted with 22 cm (9 in) extensions with a 71°C discharge temperature. Based on improved cleaning results, 83 Lpm @ 31 bar with a rotation speed of 4 rpm and fitted with 22 cm (9 in) extensions with a 71°C discharge temperature is recommended for the R-LVHP CIP devices. Compared to the wash rack operating parameters, increasing the fluid volume and pressure combined with a decrease in the rotation speed and the installation of extensions for flow development are important.

Rotating–high volume, medium pressure device (R-HVMP)

All qualified operating conditions of the R-HVMP device seem adequate for a Type 2 washed tanker. Wash results for operating parameter 416 Lpm @ 4.5 bar, 492 Lpm @ 5.5 bar, or 378 Lpm @ 6.2 bar are in Tables 5-10, 5-11, and 5-12. Soil residues (visual, ATP, and sugar) were all within the research guidelines as were the microbial results. However, visual residue was seen at the barrel end particularly when it was dry at 416 @ 4.5 bar and 378 @ 6.2 bar but not at 492 @ 5.5 bar. The inoculation material was 30° Brix orange juice solution with an estimated 300,000 µg. This sugar solution was effectively reduced to below the methods detection limit of 3 µg with 378 Lpm @ 6.2 bar and 492 Lpm @ 5.5 bar but not at 416 Lpm @ 4.5 bar. Visual residue may be the small sugar residue or a product of the sugar and the heat or detergent. No microorganisms were recovered for any wash operating condition which indicates each parameter is effective to reduce and/or eliminate microorganisms from the tanker. Proper manual washing was extremely important at the manway while all other tanker areas relied on the manual rinse and the CIP wash.

Stationary directional–high volume, medium pressure device (Sd-HVMP)

Four operating conditions were used for the Sd-HVMP device with 454 Lpm @ 3.1 bar and 416 Lpm @ 4.5 bar suggested by the manufacturers (Ecolab 2006 Sani-Matic 2006). Both of these operating parameters were effective to reduce soil and microorganisms to very low levels that met the studies guideline (Tables 5-13 and 5-14). Both operating conditions had some residue between 1.2 to 3.7 m (Sites 1.2, 2.4, and 3.7) which may be due to this units reduced fluid flow at this location. Combinations of flow and pressure were seen as the main reason for the residue. Operating conditions of 492 Lpm @ 5.5 bar and 378 Lpm @ 6.2 bar were seen at the wash rack and were highly effective for soil and microorganism removal (Tables 5-15 and 5-16). Lower volume and higher pressure appeared to be more effective since no visual or sugar residue was detected when the unit was operated properly. Residues at 492 Lpm @ 5.5 bar did meet the studies guidelines.

This device was tested for installation position since it was observed that this parameter may be significant to its proper performance. Results of these trials are in Tables 5-17 to 5-21 for off center installation and Tables 5-22 to 5-23 for pitch installation. For off center trials, testing was only completed on the device when it was installed so that the nozzles were facing away from the inoculated sites. Based on the flow rate and qualification results, it was deemed appropriate to only test this since this would be the worse case area to be cleaned. When the device is pointed toward the inoculated sites, it was felt that cleaning would be accomplished since the fluids were adequate. These results indicate that as the installation angle is increased, there is a greater chance of not properly cleaning the low fluid side (the area that the nozzles are not pointing at).

The angle comparison of these results are seen in Table 5-21 with the statistical analysis based solely on the soil removal since the microbial residues (non-recoverable) were of limited value. When evaluating the residual soils, a significant difference ($P<0.05$) was seen when the device was installed at 5° off dead center compared to when installed at 0° dead center and was significantly different compared to 1 and 2.5°, indicating that this device should be used for a Type 2 wash with it installed at 0° ± 2.5° from dead center.

Further trials were run with this device for the pitch that seemed to be significant based on surface fluid volumes and the qualification tests. Table 5-22 is the results when the device was installed with a 76° pitch (as measured from the devices down-shaft to the linear part of the nozzles). When installed in this way, the end of the tanker (barrel end and bulkhead) was more soiled than the control of 0°. However, no or very few microorganisms were present probably due to the temperature and the flow that was sufficient to remove microorganisms but not fully remove the soil. The device was next tested at 82° pitch (Table 5-23) again with no recovery of microorganisms but some recovery of soils. Soiled areas had shifted up the barrel to the 2.4 to 4.7 m region which was the lowest flow rates when this device was installed. Tanker ends were cleaned better except at the bulkhead top. One reason this may have occurred is that the stream was not directed onto the barrel but below the bulkhead's top so that the fluid may not been able to cascade up to clean this area. A statistical analysis of the pitch is seen in Table 5-24 indicating that the 3° deviation from the manufacturer's design and recommendation is adequate to reduce the cleaning performance of this device. Further testing should be conducted with smaller deviations.

Type 2 Wash Conclusions

Tables 5-25 to 5-29 are the statistical analysis data for each device for a Type 2 wash. Analysis is based on averaging the soils and microbiology residues. R-LVHP device was operated at the parameter (68 Lpm @ 24 bar with 0 cm extensions and 20 rpm rotation speed) observed at the wash facilities as a baseline and for comparison purposes (Table 5-25). Utilizing the studies determined parameter (flow conditions, rotation speed, and extensions), it was seen that by slowing the rotation speed, the microorganisms were significantly ($P<0.05$) reduced while the extensions were a significant aid to reducing the soils. Reduction of microorganisms seemed to be less affected by the device parameter since operating at 68 Lpm @ 24 bar at 4 rpm with 15 or 22 cm extensions was not significantly different ($P<0.05$) from 76 Lpm @ 31 bar or 83 Lpm @ 31 bar.

The combination of both rotation speed and extensions with an increased flow rate resulted in significant differences in how the unit was operated. Ideally, for a Type 2 wash, the parameter of 83 Lpm @ 31 bar with 22 cm extensions and a 4 rpm rotation speed were significant for soil and microorganism removal.

Table 5-26 are the summarized results for the R-HVMP device. The tested operating parameters were not significantly different for the reduction of microorganisms. Microorganisms were either removed or inactivated by the flow or heat. Differences were seen for the soils with no significant difference ($P<0.05$) between 416 @ 4.5 and 378 @ 6.8 but both being significantly different and higher than the 492 Lpm @ 5.5 bar operating condition. Main differences were noted at the barrel ends.

When installed correctly (0° dead center and 79° pitch), the Sd-HVMP device did not have significant differences for soils or microorganisms (Table 5-27). Sufficient fluid flow and heat was achieved to remove or inactivate the microorganisms and to remove the soils. This device was tested for installation position also since this condition was observed many times during the tanker survey. Table 5-28 shows that when the position was at 5° off dead center, there was a significant difference in the cleaning performance as seen by residual soils. This deviation from center was large enough to result in low flow areas that were incapable of adequately cleaning the area. The device's pitch was also tested with a 3° deviation from the manufacturer's design, sufficient to reduce the cleaning performance (Table 5-29). Both installation variations should be minimized.

Type 4 Wash

Type 4 wash is directed at cleaning allergen soils which are perceived to be hard to remove (JPA 2005). Each device was subjected to the Type 4 wash with a complimentary soil. Again, CIP devices were tested at the parameter observed at the wash racks for a baseline result for comparisons.

Rotating–low volume, high pressure device

Results of the wash rack operating parameter of 68 Lpm @ 24 bar with 20 rpm rotation speed and no extensions are in Table 5-30. Results indicate that these operating conditions were not sufficient to properly clean a tanker. Soils, microorganisms, and allergens were not effectively removed. However, it was found that heat sensitive microorganisms (*S. cerevisiae* and *E. coli*) were effectively reduced while the heat resistant microorganisms, such as *B. megaterium* were able to survive. It is hypothesized that the *B. megaterium* survived due to spore production either in the slurry or after it was applied, since vegetative cells are reported to be sensitive to the heat (Jay 1999). Allergens were recovered in many sample sites. It was observed that the lack of cleaning fluid was a direct cause of the lack of removal.

Increasing the flow rate (to 76 Lpm @ 31 bar) and installing 22 cm (9 in) extensions with a reduced rotation speed (4 rpm) were effective to reduce or eliminate most of the soils (Table 5-31). Increased fluid rate effectively increased the fluid that reached all internal areas of the tanker. This fluid increase seems to be very important to clean the tanker. This finding may be similar to previous findings that an increase in volume is more important than an increase in pressure (Marriott 1999). Visual and detectable soils were removed more than when operated at 68 Lpm @ 24 bar with the barrel end being effectively cleaned. Reduction in *S. cerevisiae* and *E. coli* was expected due to the temperature while most of the *B. megaterium* was removed except for the barrel end (Site 6.1) which means that the fluid flow to this area may still be inadequate. Allergens were not detected up to ~3.0 m (Sites 0 to 2.4) while beyond 3 m there was some recovery but at very low levels (< 0 log µg or <1 µg) which was the target limit of this study. Increasing the flow rate to 83 Lpm @ 31 bar did reduce the visible and sugar soils but not the allergen residue (Table 5-32).

Based on these results, it seems that this device should be operated with 22 cm (9 in) extensions at a slow rotation speed (4 shaft rpm) and at a minimum of 76 Lpm @ 31 bar. A food grade tanker can be effectively cleaned with this wash protocol.

Rotating–high volume, medium pressure device

The minimum suggested operating parameter (416 Lpm @ 4.5 bar) of this device was sufficient to reduce visual and detectable soils to low levels (Table 5-33). Residue when visible was usually when the surface was dry indicating a very low level. This low level was below the detection limit of the ATP test while residual sugar was detected only at the barrel ends. All microorganisms were effectively removed or inactivated by this operating parameter while allergens were also mostly removed. Soil residues were similar when this device was operated at 378 Lpm @ 6.2 bar or at 492 Lpm @ 5.5 bar (Tables 5-34 and 5-35). It was expected that the higher flow rate (492 Lpm @ 5.5 bar) would be more effective but this was not seen since the allergen residues were basically the same as with 416 Lpm @ 4.5 bar (Gamajet PC 2007) The lowest volume (378 Lpm @ 6.2 bar) did seem to have more allergens residues possibly substantiating the volume versus pressure contention (Marriott 1999) but all were within the studies guidelines. When operated at this low volume, *B. megaterium* was found close to the device (Sites 0 and 1.2) which was surprising since this area was expected to be have to best cleaning pressures and volume. The two samples that were positive were probably due to poor manual cleaning of the manway, to the devices impingement gap, or to possible post-process contamination.

Stationary directional–high volume, medium pressure device

The Sd-HVMP device was affected by flow rate with the lowest pressure condition (454 Lpm @ 3.1 bar) leaving residues (Table 5-36) that were not seen with a Type 2 wash. These operating conditions were suggested by one of the device manufacturers (Sani-Matic 2006).

Flow volumes were high for this device with the bulkhead receiving most of the fluids. Visual soils were detected in more sample sites than other operating parameter but all were below the studies target. Residues were seen mainly when the surface was dry indicating a possible lack of flow or some other condition such as a reaction of heat with the soils. ATP residues were acceptable throughout all sample sites with the residual sugar only in the lowest surface flow area (Site 3.7). As seen in the surface flow rate data, this area is a common low flow zone that is due to the position of the orifices. No microorganisms were recovered at this operating condition but allergens were detected at the low flow zones and at the barrel end. Bulkheads were well cleaned.

Another suggestion by the device manufacturer was to operate the device at a minimum pressure of 4.5 bar (65 psi) with no specified volume rate. Table 5-37 is the results of the device when operated to achieve 4.5 bar (65 psi) using 416 Lpm (110 gpm) (Ecolab 2006). This flow parameter seemed to be more effective than the lower pressure (3.1 bar). Higher flow parameter with a properly centered and pitched CIP device was sufficient to clean all inoculated sites in the tanker.

The wash facilities used flow parameters that were different from the device manufacturer's suggestion for this research. Wash facilities were using parameters that were determined by the pump systems that they had. These parameters were however in the range of the manufacturer's recommendation (Ecolab PC 2006 IRT PC 2006) since CIP operating parameters can be a range in which the proper combination of flow volume and pressure (hydraulics) work together to produce the cleaning (Ecolab 2006). When operated at the wash facility parameters (378 Lpm @ 6.2 bar or 492 Lpm @ 5.5 bar in Tables 5-38 and 5-39 respectively) the tanker was adequately cleaned based on the studies analyses. No residues were detected with 378 Lpm @ 6.2 bar while one washed tanker had egg residue in sample Site 3.7 (3.7 m from device) for 492 Lpm @ 5.5 bar. This was the lowest surface flow rate that may explain this. Surface flow volume is critical for cascade cleaning. Even though this parameter used more fluid (492 Lpm) it was not distributed as well as the 378 Lpm since the 378 Lpm seemed to deliver more fluids at the low volume zone. This is probably due to the pressure effect.

Installation tests were repeated for the Type 4 wash with the results seen in Tables 5-40 to 5-47. Operating this device at dead center appears to be ideal with no more than a 1° deviation from the center (Table 5-41). At 2.5° there were more sites that had recoverable soils (Table 5-42) indicating a lack of cleaning ability at this installation position and when at 5° (Table 5-43), much more soil was recovered on the tanker surfaces. Statistical analysis of the combined soils and allergens was determined with the results in Table 5-44. For a Type 4 soil, there was no significant difference ($P<0.05$) between installing this device at 0 or 1° from dead center but a difference was detected at 2.5 and 5°. With the Type 4 soil, the device's installation position appears to be more stringent in order to properly clean the tanker.

Type 4 Wash Conclusions

Summary of the Type 4 wash validation study is in Tables 5-45 to 5-46. Statistical analysis of the R-LVHP device (Table 5-45) indicates that the results of washing with 68 Lpm @ 24 bar with no extensions and a rotation speed of 20 rpm is significantly different ($P<0.05$) as compared to when this device is operated at 76 Lpm @ 31 bar or at 83 Lpm @ 31 bar. As previously surmised, the fast rotation speed increases the tangential velocity of the low mass (volume) fluid which allows only a small radius (Singh 2001). Also with no extensions, proper fluid flow development does not occur so the discharged fluid leaves the nozzle with high energy which dissipates rapidly when it leaves the nozzle with a sudden expansion that allows a short throw distance (White 1977 Singh 2001). Residual soils, microorganisms and allergens were recovered at significantly higher levels with this operating parameter than the larger volume operating parameter. There was no significant difference between the flow rates at 31 bar for microorganisms or allergens but there was for the remaining soils. Soil residues were mostly visual indicating a lack of cleaning with the 76 Lpm @ 31 bar. Effective cleaning was seen with the 83 Lpm @ 31 bar with 22cm extensions and a slow 4 shaft rpm.

R-HVMP device analysis is in Table 5-46 with no significant difference ($P<0.05$) in soil removal for any operating condition. Based on the surface fluid flows and literature, the volume of the cleaning fluid may be more important for cleaning foods than the pressure (Gamajet 2006 Katsuyama 1993). For some reason, soils were present for all operating parameters that may indicate that a tenacious soil does exist which may need lower wash temperature or higher detergent concentration to be fully removed (Mabesa 1979). Wash temperatures that were used were chosen based on the minimum discharge requirement of JPA (JPA 2005) and the temperature evaluation part of this study that indicated very little temperature effect but with further testing, may prove to be a significant factor. Detergent concentrations used were based on the detergent evaluation discussed earlier and on the observations at the wash racks that used the lowest recommended detergent concentration. A higher detergent concentration may be more effective but in this study was not observed. Microorganisms were effectively removed by all three operating conditions while allergen residue was significantly higher when operated at 378 Lpm @ 6.2 bar however the allergen residues were below the studies target maximum of 0 log $\mu g/100\ cm^2$ or 1 $\mu g/100\ cm^2$. This CIP device seemed to be a very good choice for cleaning tankers.

The statistical evaluation of the Sd-HVMP cleaning results are in Table 5-47. For soil removal, there was a significant difference ($P<0.05$) found between the 454 Lpm @ 3.1 bar treatment compared to the three other operating conditions. Even though the wash volume was higher than two other treatments, the lower pressure may have caused inadequate fluid volumes to reach the tanker walls (Richter 1975). Soils that were seen after the 454 Lpm @ 3.1 bar treatment were seen when the tanker surface was dry. This may mean a lack of sufficient water to flush down the surfaces. There were no significant differences ($P<0.05$) between the other 3 parameter treatments. With micro and allergens, no operating parameter treatment was statistically different from the others. All microorganisms were effectively and completely removed while small amounts of allergen were found in two treatments. However, the residues were below the studies target maximum. Since this CIP device relies on massive amounts of fluid flow across a surface to clean, it appears to be effective for this purpose. Also, based on the installation position tests, this device should be installed as close to dead center as possible with no deviations of the manufacturer's pitch recommendation.

Table 5-1. Detergent concentration effect for R-LVHP JPA Type 4 wash.

Detergent concentration [2] (ppm active alkalinity)	Milk allergen residue - μg/100cm² (std dev)[1] (n = 3)		
	150	500	1000
Sample Sites [3]			
0	0.0 (0.0)a	0.0 (0.0)a	0.0 (0.0)a
1.2	0.3 (0.0)a	0.4 (0.1)a	0.4 (0.2)a
2.4	0.5 (0.1)a	0.4 (0.1)a	0.4 (0.3)a
3.7	0.8 (0.0)a	0.7 (0.0)a	0.5 (0.1)a
4.9	1.1 (0.2)a	0.9 (0.3)a	1.0 (0.2)a
6.1	0.9 (0.3)a	0.8 (0.3)a	0.9 (0.4)a
BH	0.6 (0.1)a	0.2 (0.1)b	0.3 (0.1)b
Overall Sig Diff [4]	0.60 A	0.49 A	0.50 A

[1] Type 4 wash with R-LVHP operated at 87 Lpm @ 31 bar with 22 cm extensions and 4 rpm and 71°C discharge temperature (feed temperature range 85 – 91°C). Values are the average milk allergen with standard deviation in parenthesis. Same letters across rows indicate no significant difference P<0.05 for the sample site for wash parameter.
[2] Concentration determined by active alkalinity titration with 0.1N sulfuric acid to pH 8.3.
[3] Sample site is the site in m from the CIP device. BH is the bulkhead at 6.7m.
[4] Values with different letters are significantly different at P<0.05 for the entire tanker.

Table 5-2. Detergent concentration effect for Sd-HVMP JPA Type 4 wash.

Detergent concentration (ppm active alkalinity)	Milk allergen residue - μg/100cm² (std dev)[1,2] (n = 3)		
	150	450	900
Sample Sites [3]			
0	0.0 (0.0)a	0.0 (0.0)a	0.0 (0.0)a
1.2	0.0 (0.0)a	0.0 (0.0)a	0.0 (0.0)a
2.4	0.1 (0.1)a	0.0 (0.0)a	0.0 (0.0)a
3.7	0.2 (0.0)a	0.1 (0.0)a	0.3 (0.1)a
4.9	0.2 (0.2)a	0.0 (0.0)a	0.1 (0.1)a
6.1	0.3 (0.3)a	0.1 (0.1)a	0.1 (0.1)a
BH	0.0 (0.0)a	0.1 (0.1)a	0.0 (0.0)a
Overall Sig Diff [4]	0.11 A	0.04 A	0.07 A

[1] Type 4 wash with Sd-HVMP operated at 378 Lpm @ 6.5 bar with 0° centering, 79° pitch and 71°C discharge temperature (feed temperature range 85 – 89°C). Values are the average milk allergen with standard deviation in parenthesis. Same letters across rows indicate no significant difference P<0.05 for the sample site for wash parameter.
[2] Detergent concentrations as delivered at the cooperating wash rack. Determined by active alkalinity titration with 0.1N sulfuric acid to pH 8.3.
[3] Sample site is the site in m from the CIP device. BH is the bulkhead at 6.7m.
[4] Values with different letters are significantly different at P<0.05 for the entire tanker.

Table 5-3. Temperature effect for JPA Type 4 wash.

Temperature (°C) Sample Sites [2]	Milk allergen residue - µg (std dev) [1] (n = 3) 71°C discharge	71°C feed
0	0.0 (0.0)a	0.0 (0.0)a
1.2	0.3 (0.3)a	1.0 (0.6)a
2.4	0.6 (0.3)a	0.8 (0.7)a
3.7	0.3 (0.2)a	0.7 (0.8)a
4.9	1.1 (0.1)a	0.7 (0.3)a
6.1	0.9 (0.4)a	0.0 (0.0)a
BH	0.6 (0.5)a	0.2 (0.2)b
Overall Sig Diff [3]	0.54 A	0.49 A

[1] Type 4 wash with R-LVHP operated at 87 Lpm @ 31 bar with 22 cm extensions and 4 rpm and 150 ppm active alkalinity. Values are the average milk allergen of 3 trials with standard deviation in parenthesis. Same letters across rows indicate no significant difference (P<0.05).
[2] Sample site is the site in m from the CIP device. BH is the bulkhead at 6.7m.
[3] Values with different letters are significantly different at P<0.05 for the entire tanker.

Table 5-4. Type 2 wash results for R-LVHP validation at 68.1 Lpm @ 24.1 bar, 20 rpm, no extensions, and 71°C minimum discharge temperature.

		Sampling results (n = 3) [1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	3.5(0.1)	3(0)	6.03(0.1)	6.07(0.10)	6.12(0.05)
Sample Sites [2]	Flow rate[3] (Lpm/m^2)	Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli
0	2.06(0.008)	0.7(0.6)	1.7(0.1)	1.0(0)	-1 (0)	1.1 (0.2)	-1 (0)
1.2	1.27(0.008)	0.0(0)	1.8(0.1)	0.0(0)	-1 (0)	-1 (0)	-1 (0)
2.4	0.27(0.003)	0.0(0)	1.8(0.1)	0.0(0)	-1 (0)	-1 (0)	-1 (0)
3.7	0.08(0.003)	1.0(1.0)	2.5(0.1)	0.3(0.3)	-1 (0)	2.0 (0)	-1 (0)
4.9	0.019(0.001)	2.7(0.6)	3.2(0.1)	2.0(0)	-1 (0)	5.0 (0.3)	-1 (0)
6.1	0.001(0.001)	3.0(0)	3.2(0)	3.0(0)	-1 (0)	5.3 (0)	-1 (0)
BHc	0.079(0.003)	2.0(0)	3.0(0)	2.7(0.6)	-1 (0)	5.8 (0)	-1 (0)
BHt	0.00(0.00)	3.0(0)	3.3(0)	3.0(0)	-1 (0)	5.3 (0)	-1 (0)

[1] Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2] Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m.
[3] Flow rate from nearest surface flow sample device for example purposes only.
[4] Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5] ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty.
[6] Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).

Table 5-5. Type 2 wash results for R-LVHP validation at 68.1 Lpm @ 24.1 bar, no extensions, 4 rpm and 71°C minimum discharge temperature.

		Sampling results (n = 3) [1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	3.5 (0.2)	3 (0)	5.96 (0.2)	5.97 (0.05)	6.01 (0.03)
Sample Sites [2]	Flow rate[3] (Lpm/m^2)	Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli
0	1.58 (0.006)	0 (0)	1.8 (0)	0.0 (0)	-1 (0)	1.1 (0.17)	-1 (0)
1.2	1.29 (0.025)	0 (0)	1.7 (0.1)	0.4 (0.3)	-1 (0)	-1 (0)	-1 (0)
2.4	0.32 (0.012)	0 (0)	1.7 (0.1)	0.8 (0.8)	-1 (0)	-1 (0)	-1 (0)
3.7	0.13 (0.012)	0.3 (0.2)	2.5 (0.1)	0.7 (0.7)	-1 (0)	1.47 (0.06)	-1 (0)
4.9	0.005 (0.007)	1.8 (0.4)	3.0 (0.1)	1.7 (0.8)	-1 (0)	2.73 (0.02)	-1 (0)
6.1	0.02 (0.002)	2.6 (0.1)	3.4 (0)	2.8 (0.1)	-1 (0)	4.99 (0.01)	-1 (0)
BHc	0.19 (0.009)	0.3 (0.6)	3.0 (0)	0.8 (1.0)	-1 (0)	4.99 (0.01)	-1 (0)
BHt	0.05 (0.004)	0.7 (0.6)	3.5 (0.1)	1.3 (0.6)	-1 (0)	4.99 (0.01)	-1 (0)

[1] Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2] Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m.
[3] Flow rate from nearest surface flow sample device for example purposes only.
[4] Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5] ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty.
[6] Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).

Table 5-6. Type 2 wash results for R-LVHP validation at 68.1 Lpm @ 24.1 bar, 4 rpm, 6 in extensions and 71°C discharge temperature.

		Sampling results (n = 3) [1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	3.8 (0.2)	3 (0)	5.98 (0.15)	6.12 (0.07)	6.22 (0.21)
Sample Sites [2]	Flow rate [3] (Lpm/m^2)	Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli
0	2.09 (0.025)	0 (0)	1.8 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	1.00 (0.016)	0 (0)	1.7 (0.1)	0.1 (0.2)	-1 (0)	-1 (0)	-1 (0)
2.4	0.37 (0.011)	0 (0)	1.7 (0)	0.2 (0.2)	-1 (0)	-1 (0)	-1 (0)
3.7	0.17 (0.005)	0 (0)	1.8 (0.1)	0.2 (0.2)	-1 (0)	-1 (0)	-1 (0)
4.9	0.07 (0.001)	0.8 (0)	1.8 (0.1)	0.3 (0.1)	-1 (0)	-1 (0)	-1 (0)
6.1	0.04 (0.001)	1.8 (0.3)	2.3 (0.1)	1.8 (0.1)	-1 (0)	-0.67 (0.58)	-1 (0)
BHc	0.16 (0.092)	0 (0)	1.9 (0.1)	0.7 (0.6)	-1 (0)	-0.67(0.58)	-1 (0)
BHt	0.11 (0.082)	0.2 (0.3)	2.0 (0.2)	1.3 (1.2)	-1 (0)	-0.33 (0.58)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).

Table 5-7. Type 2 wash results for R-LVHP validation at 68.1 Lpm @ 24.1 bar, 4 rpm, 9 in extensions and 71°C discharge temperature.

		Sampling results (n = 3) [1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	3.4 (0.2)	3 (0)	6.03 (0.03)	6.05 (0.02)	6.05 (0.03)
Sample Sites [2]	Flow rate[3] (Lpm/m^2)	Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli
0	2.00 (0.025)	0 (0)	1.8 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	1.07 (0.016)	0.1 (0.2)	1.8 (0.1)	0.2 (0.2)	-1 (0)	-1 (0)	-1 (0)
2.4	0.45 (0.011)	0 (0)	1.7 (0.1)	0.1 (0.1)	-1 (0)	-1 (0)	-1 (0)
3.7	0.22 (0.005)	0 (0)	1.8 (0.1)	0.2 (0.1)	-1 (0)	-1 (0)	-1 (0)
4.9	0.09 (0.001)	1.1 (0.3)	2.0 (0.1)	0.3 (0.1)	-1 (0)	-1 (0)	-1 (0)
6.1	0.05 (0.001)	2.1 (0.1)	2.1 (0.1)	1.8 (0.3)	-1 (0)	-1 (0)	-1 (0)
BHc	0.22 (0.029)	0.2 (0.3)	1.9 (0.1)	0.3 (0.6)	-1 (0)	-1 (0)	-1 (0)
BHt	0.13 (0.015)	0.7 (0.6)	2.0 (0.4)	0.8 (1.0)	-1 (0)	0.10 (0.17)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).

Table 5-8. Type 2 wash results for R-LVHP validation at 75.7 Lpm @ 31.0 bar (20 gpm @ 450 psi), 4 rpm, 22 cm (9 in) extensions and 71°C discharge temperature.

		Sampling results (n = 3) [1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	3.4 (0.2)	3 (0)	6.01 (0.03)	6.01 (0.03)	6.07 (0.03)
Sample Sites [2]	Flow rate[3] (Lpm/m^2)	Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli
0	1.94 (0.025)	0 (0)	1.8 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	1.11 (0.016)	0 (0)	1.7 (0.1)	0.1 (0.2)	-1 (0)	-1 (0)	-1 (0)
2.4	0.56 (0.011)	0 (0)	1.8 (0.1)	0.2 (0.2)	-1 (0)	-1 (0)	-1 (0)
3.7	0.24 (0.005)	0.1 (0.1)	1.8 (0.1)	0.2 (0.2)	-1 (0)	-1 (0)	-1 (0)
4.9	0.09 (0.001)	1.0 (0.3)	2.0 (0.1)	0.3 (0.1)	-1 (0)	-1 (0)	-1 (0)
6.1	0.05 (0.001)	1.4 (0.5)	2.1 (0.1)	1.8 (0.1)	-1 (0)	-1 (0)	-1 (0)
BHc	0.24 (0.010)	0.3 (0.6)	1.9 (0.1)	0.7 (0.6)	-1 (0)	-1 (0)	-1 (0)
BHt	0.14 (0.009)	0.7 (0.6)	2.4 (0.3)	1.3 (1.2)	-1 (0)	-0.67 (0.58)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).

Table 5-9. Type 2 wash results for R-LVHP validation at 83.3 Lpm @ 31.0 bar (22 gpm @ 450 psi), 4 rpm, 22 cm (9 in) extensions and 71°C discharge temperature.

		Sampling results (n = 3) [1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	3.8 (0.2)	3 (0)	6.17 (0.45)	6.04 (0.09)	6.00 (0.47)
Sampling Sites [2]	Flow rate[3] (Lpm/m^2)	Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli
0	2.32 (0.079)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	1.23 (0.041)	0.1 (0.2)	1.5 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	0.66 (0.034)	0 (0)	1.4 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	0.31 (0.012)	0 (0)	1.7 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
4.9	0.12 (0.007)	0 (0)	1.7 (0.3)	0 (0)	-1 (0)	-1 (0)	-1 (0)
6.1	0.08 (0.005)	0.4 (0.5)	1.7 (0.2)	0.6 (0.4)	-1 (0)	-1 (0)	-1 (0)
BHc	0.29 (0.014)	0 (0)	1.7 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	0.16 (0.017)	0 (0)	1.7 (0.1)	0.2 (0.3)	-1 (0)	0 (1.00)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).

Table 5-10. Type 2 wash results for R-HVMP validation at 416 Lpm @ 4.5 bar (110 gpm @ 65 psi), 16 rpm, 12 cm (5 in) extensions and 71°C discharge temperature.

		Sampling results (n = 3) [1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	3.8 (0.2)	3 (0)	6.17 (0.45)	6.04 (0.09)	6.00 (0.47)
Sampling Sites [2]	Flow rate[3] (Lpm/m^2)	Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli
0	4.65 (0.145)	0 (0)	1.7 (0)	0 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	2.99 (0.080)	0 (0)	1.7 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	1.34 (0.008)	0 (0)	1.7 (0)	0 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	0.63 (0.030)	0 (0)	1.8 (0)	0 (0)	-1 (0)	-1 (0)	-1 (0)
4.9	0.36 (0.014)	0.3 (0.6)	1.8 (0.2)	0 (0)	-1 (0)	-1 (0)	-1 (0)
6.1	0.29 (0.008)	0.8 (0.3)	2.2 (0.2)	0.5 (0.3)	-1 (0)	-1 (0)	-1 (0)
BHc	1.88 (0.017)	0 (0)	1.9 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	0.28 (0.011)	0 (0)	1.8 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).

Table 5-11. Type 2 wash results for R-HVMP validation at 378 Lpm @ 6.2 bar (100 gpm @ 90 psi), 16 rpm, 12 cm (5 in) extensions and 71°C discharge temperature.

		Sampling results (n = 3) [1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	3.8 (0)	3 (0)	6.05 (0.02)	6.05 (0.02)	6.08 (0.04)
Sampling Sites [2]	Flow rate[3] (Lpm/m^2)	Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli
0	6.04 (0.130)	0 (0)	1.7 (0)	0 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	3.19 (0.086)	0 (0)	1.7 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	1.39 (0.043)	0 (0)	1.7 (0)	0 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	0.65 (0.007)	0 (0)	1.8 (0)	0 (0)	-1 (0)	-1 (0)	-1 (0)
4.9	0.29 (0.004)	0.3 (0.6)	1.8 (0.2)	0 (0)	-1 (0)	-1 (0)	-1 (0)
6.1	0.23 (0.008)	0.8 (0.3)	2.0 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHc	1.31 (0.081)	0 (0)	1.9 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	0.61 (0.049)	0 (0)	1.8 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).

Table 5-12. Type 2 wash results for R-HVMP validation at 492 Lpm @ 5.5 bar (130 gpm @ 80 psi), 16 rpm, 12 cm (5 in) extensions and 71°C discharge temperature.

		Sampling results (n = 3)[1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	3.8 (0.2)	3 (0)	6.06 (0.04)	6.05 (0.05)	6.05 (0.04)
Sampling Sites [2]	Flow rate[3] (Lpm/m^2)	Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli
0	8.52 (0.032)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	5.52 (0.038)	0 (0)	1.5 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	2.69 (0.020)	0 (0)	1.4 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	1.32 (0.006)	0 (0)	1.7 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
4.9	0.74 (0.008)	0 (0)	1.7 (0.3)	0 (0)	-1 (0)	-1 (0)	-1 (0)
6.1	0.64 (0.010)	0 (0)	1.7 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHc	4.43 (0.043)	0 (0)	1.8 (0)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	0.81 (0.027)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).

Table 5-13. Type 2 wash results for Sd-HVMP validation at 454 Lpm @ 3.1 bar (120 gpm @ 45 psi), 0° centered, 79° pitch and 71°C discharge temperature.

		Sampling results (n = 3)[1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	3.8 (0.3)	3 (0)	6.09 (0.03)	6.05 (0.02)	6.05 (0.05)
Sampling Sites [2]	Flow rate[3] (Lpm/m^2)	Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli
0	3.83 (0.039)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	1.61 (0.041)	0.1 (0.2)	1.9 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	1.89 (0.020)	0.1 (0.1)	1.9 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	1.88 (0.023)	0.1 (0.1)	2.0 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
4.9	4.02 (0.059)	0 (0)	1.7 (0.3)	0 (0)	-1 (0)	-1 (0)	-1 (0)
6.1	2.38 (0.043)	0 (0)	1.7 (0.2)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHc	25.70 (0.168)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	15.00 (0.177)	0 (0)	1.7 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).

Table 5-14. Type 2 wash results for Sd-HVMP validation at 416 Lpm @ 4.5 bar (110 gpm @ 65 psi), 0°C, 79° pitch and 71°C discharge temperature.

		Sampling results (n = 3) [1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	5.0 (0.4)	3 (0)	6.08 (0.04)	6.04 (0.10)	6.05 (0.04)
Sampling Sites [2]	Flow rate[3] (Lpm/m^2)	Visual[4]	ATP[3]	Sugar[4]	Sacc	Bac	Ecoli
0	2.11 (0.111)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	3.34 (0.112)	0 (0)	1.5 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	1.18 (0.065)	0.4 (0.3)	2.0 (0.2)	0.6 (0.3)	-1 (0)	-1 (0)	-1 (0)
3.7	0.95 (0.025)	0.3 (0.2)	2.2 (0.1)	0.5 (0.3)	-1 (0)	-1 (0)	-1 (0)
4.9	2.69 (0.108)	0 (0)	1.7 (0.3)	0 (0)	-1 (0)	-1 (0)	-1 (0)
6.1	2.29 (0.164)	0 (0)	1.7 (0.2)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHc	20.66 (1.199)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	18.68 (0.279)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).

Table 5-15. Type 2 wash results for Sd-HVMP validation at 378 Lpm @ 6.2 bar (100 gpm @ 90 psi), 0°C, 79° pitch and 71°C discharge temperature.

		Sampling results (n = 3)[1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	5.0 (0.4)	3 (0)	6.05 (0.02)	6.05 (0.04)	6.06 (0.05)
Sampling Sites [2]	Flow rate[3] (Lpm/m^2)	Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli
0	3.09 (0.459)	0 (0)	1.5 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	4.30 (0.210)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	1.32 (0.062)	0 (0)	1.4 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	1.24 (0.070)	0 (0)	1.7 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
4.9	3.15 (0.152)	0 (0)	1.7 (0.3)	0 (0)	-1 (0)	-1 (0)	-1 (0)
6.1	2.95 (0.030)	0 (0)	1.5 (0.2)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHc	32.77 (0.271)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	29.04 (0.432)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).

Table 5-16. Type 2 wash results for Sd-HVMP validation at 492 Lpm @ 5.5 bar (130 gpm @ 80 psi), 0°C, 79° pitch and 71°C discharge temperature.

		Sampling results (n = 3)[1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	5.0 (0.4)	3 (0)	6.00 (0.01)	6.04 (0.04)	6.05 (0.05)
Sampling Sites [2]	Flow rate[3] (Lpm/m^2)	Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli
0	11.05 (0.230)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	5.85 (0.021)	0 (0)	1.5 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	1.82 (0.052)	0 (0)	1.4 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	1.40 (0.038)	0.2 (0.1)	1.9 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
4.9	2.71 (0.147)	0 (0)	1.7 (0.3)	0 (0)	-1 (0)	-1 (0)	-1 (0)
6.1	1.08 (0.022)	0.1 (0)	2.2 (0.2)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHc	25.98 (0.592)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	9.68 (0.500)	0 (0)	1.6 (0.0)	0 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).

Table 5-17. Type 2 wash results for Sd-HVMP validation at 454 Lpm @ 4.7 bar (120 gpm @ 68 psi), 0°C, 79° pitch and 71°C discharge temperature.

		Sampling results (n = 3)[1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	5.0 (0.4)	3 (0)	6.00 (0.01)	6.04 (0.04)	6.05 (0.05)
Sampling Sites [2]	Flow rate[3] (Lpm/m^2)	Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli
0	13.28 (0.30)	0 (0)	1.5 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	7.03 (0.03)	0 (0)	1.5 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	2.19 (0.08)	0 (0)	1.4 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	1.68 (0.06)	0.2 (0.1)	1.9 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
4.9	3.26 (0.22)	0 (0)	1.8 (0.3)	0 (0)	-1 (0)	-1 (0)	-1 (0)
6.1	1.30 (0.03)	0.2 (0.3)	1.9 (0.2)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHc	31.22 (0.88)	0 (0)	1.7 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	11.63 (0.71)	0 (0)	1.7 (0.0)	0 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).

Table 5-18. Type 2 wash results for Sd-HVMP validation at 454 Lpm @ 4.7 bar (120 gpm @ 68 psi), 1°LC, 79° pitch and 71°C discharge temperature.

		Sampling results (n = 3)[1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	5.0 (0.4)	3 (0)	6.00 (0.01)	6.04 (0.04)	6.05 (0.05)
Sampling Sites [2]	Flow rate[3] (Lpm/m^2)	Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli
0	14.64 (0.10)	0 (0)	1.7 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	6.89 (0.08)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	2.25 (0.24)	0 (0)	1.5 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	1.78 (0.06)	0 (0)	1.9 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
4.9	3.52 (0.12)	0 (0)	1.7 (0.3)	0 (0)	-1 (0)	-1 (0)	-1 (0)
6.1	1.19 (0.02)	0.2 (0.3)	2.0 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHc	30.88 (0.83)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	10.73 (0.60)	0 (0)	1.6 (0.0)	0 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).

Table 5-19. Type 2 wash results for Sd-HVMP validation at 454 Lpm @ 4.7 bar (120 gpm @ 68 psi), 2.5°LC, 79° pitch and 71°C discharge temperature.

		Sampling results (n = 3)[1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	5.0 (0.4)	3 (0)	6.00 (0.01)	6.04 (0.04)	6.05 (0.05)
Sampling Sites [2]	Flow rate[3] (Lpm/m^2)	Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli
0	20.20 (0.34)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	5.88 (0.14)	0 (0)	1.5 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	2.44 (0.31)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	1.22 (0.07)	0 (0)	1.9 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
4.9	1.31 (0.11)	0.2 (0.3)	1.8 (0.3)	0 (0)	-1 (0)	-1 (0)	-1 (0)
6.1	0.71 (0.10)	0.5 (0.5)	2.1 (0.2)	0.1 (0.1)	-1 (0)	-1 (0)	-1 (0)
BHc	29.30 (0.24)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	8.39 (0.23)	0 (0)	1.7 (0.0)	0 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).

Table 5-20. Type 2 wash results for Sd-HVMP validation at 454 Lpm @ 4.7 bar (120 gpm @ 68 psi), 5°LC, 79° pitch and 71°C discharge temperature.

		Sampling results (n = 3)[1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	5.0 (0.4)	3 (0)	6.00 (0.01)	6.04 (0.04)	6.05 (0.05)
Sampling Sites [2]	Flow rate[3] (Lpm/m^2)	Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli
0	23.43 (0.26)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	5.20 (0.11)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	2.61 (0.16)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	0.93 (0.03)	0 (0)	2.0 (0.1)	0.1 (0.1)	-1 (0)	-1 (0)	-1 (0)
4.9	0.55 (0.06)	0.9 (0.4)	2.1 (0.3)	0.1 (0.1)	-1 (0)	-1 (0)	-1 (0)
6.1	0.52 (0.05)	0.8 (0.3)	2.3 (0.2)	0.2 (0.1)	-1 (0)	-1 (0)	-1 (0)
BHc	24.27 (0.77)	0 (0)	1.6 (0.0)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	3.76 (0.10)	0 (0)	1.8 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).

Table 5-21. Wash results stats for Sd-HVMP off center installation for worse case situation.

	Operating parameter (n = 3)[1]			
Lpm/m²-bar	454 @ 4.7	454 @ 4.7	454 @ 4.7	454 @ 4.7
Centered (°)[1]	0	1	2.5	5
Pitch (°)	79	79	79	79
Sample Sites [3]	Combined clean analysis rating[2]			
0	0.50	0.57	0.53	0.53
1.2	0.50	0.53	0.50	0.53
2.4	0.47	0.50	0.53	0.53
3.7	0.70	0.63	0.63	0.70
4.9	0.60	0.57	0.67	1.03
6.1	0.70	0.73	0.90	1.10
BHc	0.57	0.53	0.53	0.53
BHt	0.57	0.53	0.57	0.60
Overall sig diff [4]	0.58 A	0.58 AB	0.61 AB	0.70 BC

[1]All trials when devices pointed away from sample sites, which is the worse case for installation. Values are the average of 3 trials of combined cleaned residue. [2]Micro results not included in statistical analysis since it did not contribute to analysis. [3]Sample site is the area in m from the CIP device. BHc and BHt are the bulkhead center and top areas, respectively at 6.7 m. [4]Values with the same letter are not significantly different at P<0.05.

Table 5-22. Type 2 wash results for Sd-HVMP validation at 454 Lpm @ 4.7 bar (120 gpm @ 68 psi), 0°C, 76° pitch and 71°C discharge temperature.

		Sampling results (n = 3)[1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	5.0 (0.4)	3 (0)	6.00 (0.01)	6.04 (0.04)	6.05 (0.05)
Sampling Sites [2]	Flow rate[3] (Lpm/m^2)	Visual[4]	ATP[3]	Sugar[4]	Sacc	Bac	Ecoli
0	16.50 (0.30)	0 (0)	1.7 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	12.50 (0.03)	0 (0)	1.7 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	6.00 (0.12)	0 (0)	1.6 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	8.10 (0.01)	0.2 (0.1)	1.9 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
4.9	13.00 (0.81)	0 (0)	1.8 (0.3)	0 (0)	-1 (0)	-1 (0)	-1 (0)
6.1	0.01 (0.01)	3.0 (0)	3.1 (0.6)	3.0 (0)	-1 (0)	0.5 (0.3)	-1 (0)
BHc	0.01 (0.01)	2.7 (0.5)	2.1 (0.3)	0.3 (0.6)	-1 (0)	1 (0)	-1 (0)
BHt	2.03 (0.11)	2.0 (0)	3.2 (0.6)	2.5 (1.0)	-1 (0)	1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = E. coli (generic).

Table 5-23. Type 2 wash results for Sd-HVMP validation at 454 Lpm @ 4.7 bar (120 gpm @ 68 psi), 0°C, 82° pitch and 71°C discharge temperature.

		Sampling results (n = 3)[1]					
		Soils			Microbiology[6] (log)		
Before wash values		3 (0)	5.0 (0.4)	3 (0)	6.00 (0.01)	6.04 (0.04)	6.05 (0.05)
Sampling Sites[2]	Flow rate[3] (Lpm/m^2)	Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli
0	16.30 (0.41)	0 (0)	1.8 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	6.85 (0.01)	0 (0)	1.7 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	1.54 (0.04)	0.6 (0.7)	1.7 (0.1)	0.3 (0.6)	-1 (0)	-1 (0)	-1 (0)
3.7	0.83 (0.01)	2.2 (0.6)	2.4 (0.3)	0.7 (0.6)	-1 (0)	1 (0.5)	-1 (0)
4.9	1.60 (0.01)	2.0 (0)	2.6 (0.1)	0.3 (0.6)	-1 (0)	-1 (0)	-1 (0)
6.1	4.05 (0.27)	0.0 (0)	1.9 (0.2)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHc	42.00 (1.01)	0 (0)	1.8 (0.1)	0 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	0.02 (0.00)	2.0 (1.0)	2.6 (0.3)	1.7 (0.6)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).

Table 5-24. Wash results for Sd-HVMP installation pitch position

	Operating parameter (n = 3)[1]		
Lpm/m^2-bar	454 @ 4.7	454 @ 4.7	454 @ 4.7
Centered (°)	0	0	0
Pitch (°)[2]	79	76	82
Sample Sites [3]	Combined clean analysis rating[4]		
0	0.50	0.57	0.60
1.2	0.50	0.57	0.57
2.4	0.47	0.50	0.53
3.7	0.70	0.70	1.77
4.9	0.60	0.60	1.63
6.1	0.70	3.03	0.63
BHc	0.57	1.70	0.60
BHt	0.57	2.57	2.10
Overall sig diff [5]	0.58 A	1.28 B	1.10 B

[1]Sampling results are the average of 3 trials.
[2]Pitch determined by adjusting manway cover.
[3]Sample site is the area in m from the CIP device. BHc and BHt are the bulkhead center and top areas, respectively at 6.7 m.
[4]Micro results not included in statistical analysis since it did not contribute to analysis.
[5]Lower values mean less soils indicating an improved clean. Values with the same letter are not significant at $P<0.05$.

Table 5-25. R-LVHP operating parameter differences for Type 2 wash

	Operating parameter statistical analysis					
Lpm @ bar	68 @ 24	68 @ 24	68 @ 24	68 @ 24	76 @ 31	83 @ 31
Rotation speed (rpm)	20	4	4	4	4	4
Extension (cm)	0	0	15	22	22	22
Average soils [1]	1.87 A	1.45 A	0.93 B	0.96 C	0.98 C	0.60 D
Average micro [2]	4.67 A	4.09 B	-0.90 C	-0.86 C	-0.98 C	-0.86 C

[1]The value is the average of all soil determinations. Lower values mean less recovered soils indicating an improved clean. Values with the same letter are not significant at $P<0.05$.
[2]The value is the average of all microorganism determinations. Lower values mean less microbial recovery indicating an improved clean. Values with the same letter are not significant at $P<0.05$.

Table 5-26. R-HVMP operating parameter differences for Type 2 wash

	Operating parameter statistical analysis		
Lpm @ bar	416 @ 4.5	378 @ 6.2	492 @ 5.5
Rotation speed (rpm)	16	16	16
Extension (cm)	12	12	12
Average soils [1]	0.68 A	0.65 A	0.54 B
Average micro [2]	0.1 A	0.1 A	0.1 A

[1]The value is the average of all soil determinations. Lower values mean less recovered soil indicating an improved clean. Values with the same letter are not significant at P<0.05.
[2]The value is the average of all microorganism determinations. Lower values mean less recovered microbes indicating an improved clean. Values with the same letter are not significant at P<0.05.

Table 5-27. Sd-HVMP operating parameter differences for Type 2 wash

	Operating parameter statistical analysis			
Lpm @ bar	454 @ 3.1	416 @ 4.5	378 @ 6.2	492 @ 5.5
Centering (° from dead center)	0	0	0	0
Pitch (degrees)	79	79	79	79
Average soils [1]	0.60 A	0.65 A	0.53 A	0.58 A
Average micro [2]	0.1 A	0.1 A	0.1 A	0.1 A

[1]The value is the average of all soil determinations. Lower values mean less recovered soil indicating an improved clean. Values with the same letter are not significant at P<0.05.
[2]The value is the average of all microorganism determinations. Lower values mean less recovered microbes indicating an improved clean. Values with the same letter are not significant at P<0.05.

Table 5-28. Sd-HVMP operating parameter differences for Type 2 wash

	Operating parameter statistical analysis			
Lpm @ bar	454 @ 4.7	454 @ 4.7	454 @ 4.7	454 @ 4.7
Centering (° from dead center)	0	1	2.5	5
Pitch (degrees)	79	79	79	79
Average soils [1]	0.58 A	0.58 A	0.61 A	0.70 B
Average micro [2]	0.1 A	0.1 A	0.1 A	0.1 A

[1]The value is the average of all soil determinations. Lower values mean less recovered soil indicating an improved clean. Values with the same letter are not significant at P<0.05.
[2]The value is the average of all microorganism determinations. Lower values mean less recovered microbes indicating an improved clean. Values with the same letter are not significant at P<0.05.

Table 5-29. Sd-HVMP operating parameter differences for Type 2 wash

	Operating parameter statistical analysis		
Lpm @ bar	454 @ 4.7	454 @ 4.7	454 @ 4.7
Centering (° from dead center)	0	0	0
Pitch (degrees)	76	79	82
Average soils[1]	1.28 B	0.58 A	1.10 B
Average micro[2]	0.1 A	0.1 A	0.2 A

[1]The value is the average of all soil determinations. Lower values mean less recovered soil indicating an improved clean. Values with the same letter are not significant at P<0.05.
[2]The value is the average of all microorganism determinations. Lower values mean less recovered microbes indicating an improved clean. Values with the same letter are not significant at P<0.05.

Table 5-30. Type 4 wash results for R-LVHP validation at 68.1 Lpm @ 24.1 bar (18 gpm @ 350 psi), 20 rpm, no extensions, and 71°C minimum discharge temperature.

		Sampling results (n = 3)[1]								
		Soils			Micro (log)[6]			Allergen (log µg)[7]		
		Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli	Milk	Egg	Peanut
Before wash values		3 (0)	4.1 (0.1)	3 (0)	5.81 (0.1)	6.10 (0.10)	6.12 (0.05)	3.70 (0.20)	4.38 (0.16)	4.41 (0.12)
Sampling Sites[2]	Flow rate [3] (Lpm/m^2)									
0	2.05 (0.008)	0.0 (0)	2.0(0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	1.21 (0.008)	0.0 (0)	1.9(0.1)	1.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	0.37 (0.003)	0.0 (0)	2.7(0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-0.4 (0.3)	0.70 (0.5)	-1 (0)
3.7	0.13 (0.003)	2.3 (1.0)	3.0(0.1)	2.3 (0.3)	-1 (0)	1.0 (1)	-1 (0)	0 (1)	0.70 (0.5)	0.70 (1.0)
4.9	0.05 (0.001)	3.0 (0)	3.5(0.1)	2.0 (0)	-1 (0)	1.0 (0.5)	-1 (0)	1.75 (0.5)	2.0 (1.0)	1.90 (0.6)
6.1	0.00 (0.001)	3.0 (0)	3.5(0)	3.0 (0)	-1 (0)	3.04 (0.4)	-1 (0)	3.54 (1.5)	3.85 (0.15)	3.0 (1.0)
BHc	0.01 (0.003)	3.0 (0)	3.5(0)	3.0 (0)	-1 (0)	3.0 (0.5)	-1 (0)	3.54 (1.0)	3.75 (0.22)	3.11 (0.8)
BHt	0.00 (0.00)	3.0 (0)	3.5(0)	3.0 (0)	-1 (0)	3.10 (0.2)	-1 (0)	3.60 (1.5)	4.28(0.21)	3.81 (1.1)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m.
[3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty.
[6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).
[7]Results are log values of µg/100cm^2. -1 log is used for <1 or no recovery.

Table 5-31. Type 4 wash results for R-LVHP validation at 76 Lpm @ 31 bar (20 gpm @ 450 psi), 4 rpm, 22cm extensions, and 71°C minimum discharge temperature.

		Sampling results (n = 3)[1]								
		Soils			Micro (log)[6]			Allergen (log)[7]		
		Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli	Milk	Egg	Peanut
Before wash values		3 (0)	5.2 (0.1)	3 (0)	5.88 (0.22)	6.35 (0.41)	6.17 (0.45)	3.84 (0.31)	4.35 (0.16)	4.15 (0.12)
Sampling Sites[2]	Flow rate[3] (Lpm/m^2)									
0	2.03 (0.028)	0.0 (0.6)	1.7 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	1.12 (0.007)	0.0 (0)	1.8 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	0.51 (0.018)	0.0 (0)	1.8 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	0.24 (0.004)	0.0 (0)	1.9 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-0.47 (0.59)	-1 (0)
4.9	0.091 (0.004)	0.5 (0.6)	2.0 (0.1)	0.3 (0.29)	-1 (0)	-1 (0)	-1 (0)	-0.84 (0.14)	-0.62 (0.66)	-0.80 (0.35)
6.1	0.054 (0.007)	0.8 (0.2)	2.3 (0)	0.3 (0.29)	-1 (0)	-0.33 (0.59)	-1 (0)	-0.84 (0.28)	-0.63 (0.59)	-0.80 (0.35)
BHc	0.202 (0.007)	0.0 (0)	1.9 (0)	0 (0)	-1 (0)	-1 (0)	-1 (0)	-0.67 (0.19)	-1 (0)	-0.80 (0.35)
BHt	0.14 (0.006)	0.0 (0)	2.0 (0.1)	0.3 (0.29)	-1 (0)	-1 (0)	-1 (0)	-0.33 (0.19)	-0.67 (0.19)	-0.34 (0.19)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m.
[3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty.
[6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).
[7]Results are log values of µg/100cm^2. -1 log is used for <1 or no recovery.

Table 5-32. Type 4 wash results for R-LVHP validation at 83 Lpm @ 31 bar (22 gpm @ 450 psi), 4 rpm, 22cm extensions, and 71°C minimum discharge temperature.

		Sampling results (n = 3)[1]								
		Soils			Micro (log /100cm²)[6]			Allergen (log µg/100cm²)[7]		
		Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli	Milk	Egg	Peanut
Before wash values		3 (0)	4.1 (0.1)	3 (0)	5.78 (0.42)	6.35 (0.45)	6.22 (0.32)	3.86 (0.34)	4.39 (0.16)	4.41 (0.12)
Sampling Sites[2]	Flow rate[3] (Lpm/m²)									
0	2.157 (0.08)	0.0 (0)	1.6 (0.1)	0.0(0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	1.221 (0.08)	0.0 (0)	1.7 (0.1)	0.0(0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	0.529 (0.03)	0.0 (0)	1.7 (0.1)	0.0(0)	-1 (0)	-1 (0)	-1 (0)	-0.83 (0.35)	-0.47 (0.67)	-0.80 (0.35)
3.7	0.285 (0.03)	0.0 (1.0)	2.0 (0.1)	0.0(0)	-1 (0)	-0.67 (0.58)	-1 (0)	-0.56 (0.42)	-0.45 (0.59)	-0.80 (0.35)
4.9	0.122 (0.01)	0.2 (0.1)	2.0 (0.1)	0.0(0)	-1 (0)	-1 (0)	-1 (0)	-0.13 (0.15)	-0.62 (0.66)	-0.38 (0.54)
6.1	0.081 (0.01)	0.2 (0.1)	2.0 (0)	0.1(0.1)	-1 (0)	-1 (0)	-1 (0)	-0.16 (0.12)	-0.60 (0.70)	-0.72 (0.49)
BHc	0.244 (0.03)	0.3 (0.1)	2.0 (0)	0.0(0)	-1 (0)	-1 (0)	-1 (0)	-0.33 (0.19)	-0.63 (0.64)	-1 (0)
BHt	0.326 (0.02)	0.5 (0.2)	1.7 (0.1)	0.1(0.1)	-1 (0)	-1 (0)	-1 (0)	-0.33 (0.19)	-0.63 (0.64)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m.
[3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty.
[6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).
[7]Results are log values of µg/100cm². -1 log is used for <1 or no recovery.

Table 5-33. Type 4 wash results for R-HVMP validation at 416 Lpm @ 4.5 bar (110 gpm @ 65 psi), 16 rpm, 12 cm extensions, and 71°C minimum discharge temperature.

		Sampling results (n = 3)[1]								
		Soils			Micro (log)[6]			Allergen (log µg)[7]		
		Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli	Milk	Egg	Peanut
Before wash values		3 (0)	3.5 (0.1)	3 (0)	6.03 (0.1)	6.07 (0.10)	6.12 (0.05)	4.25 (0.0)	4.30 (0.02)	29×10^3
Sampling Sites[2]	Flow rate[3] (Lpm/m^2)									
0	7.09 (0.29)	0.7 (0.6)	1.7 (0.1)	0.0(0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	4.31 (0.06)	0.0 (0)	1.8 (0.1)	0.0(0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	2.06 (0.11)	0.0 (0)	1.8 (0.1)	0.0(0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	0.93 (0.04)	0.0 (0)	1.7 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	0.1 (0.1)	-1 (0)	-1 (0)
4.9	0.51 (0.02)	0.5 (0.3)	1.7 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-0.56 (0.42)	-1 (0)	-1 (0)
6.1	0.42 (0.04)	0.5 (0.3)	1.6 (0.1)	0.2 (0.3)	-1 (0)	-1 (0)	-1 (0)	-0.74 (0.54)	-1 (0)	-1 (0)
BHc	17.23 (1.29)	0.0 (0)	1.7 (0)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	2.72 (0.54)	0.0 (0)	1.8 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m.
[3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty.
[6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).
[7]Results are log values of $\mu g/100cm^2$. -1 log is used for <1 or no recovery.

Table 5-34. Type 4 wash results for R-HVMP validation at 378 Lpm @ 6.2 bar (100 gpm @ 90 psi), 16 rpm, 12 cm extensions, and 71°C minimum discharge temperature.

		Sampling results (n = 3)[1]								
			Soils			Micro (log)[6]			Allergen (log µg)[7]	
		Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli	Milk	Egg	Peanut
Before wash values		3 (0)	5.2 (0)	3 (0)	6.08 (0.43)	6.50 (0.42)	5.95 (0.19)	4.12 (0.30)	4.45 (0.24)	4.26 (0.17)
Sampling Sites[2]	Flow rate[3] (Lpm/m^2)									
0	6.02 (0.20)	0.0 (0)	1.5 (0.1)	0.0 (0)	-1 (0)	-0.13 (0.8)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	3.30 (0.04)	0.0 (0)	1.5 (0.2)	0.0 (0)	-1 (0)	-0.67 (0.58)	-1 (0)	-0.13 (0.40)	-0.90 (0.17)	-0.90 (0.17)
2.4	1.47 (0.04)	0.0 (0)	1.5 (0.2)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-0.10 (0.40)	-0.80 (0.17)	-0.50 (0.63)
3.7	0.61 (0.04)	0.2 (0.3)	1.5 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-0.46 (0.58)	-1 (0)	-0.50 (0.63)
4.9	0.28 (0.04)	0.5 (0.5)	1.5 (0.2)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-0.90 (0.17)	-0.9 (0.17)
6.1	0.24 (0.04)	0.5 (0)	1.5 (0.2)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-0.9 (0.17)
BHc	0.49 (0.08)	0.0 (0)	1.8 (0.3)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-0.84 (0.28)	-0.90 (0.17)	-0.9 (0.17)
BHt	1.30 (0.08)	0.5 (0)	1.7 (0.2)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-0.84 (0.28)	-0.90 (0.17)	-0.9 (0.17)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m.
[3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty.
[6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).
[7]Results are log values of µg/100cm^2. -1 log is used for <1 or no recovery.

Table 5-35. Type 4 wash results for R-HVMP validation at 492 Lpm @ 5.5 bar (130 gpm @ 80 psi), 16 rpm, 12 cm extensions, and 71°C minimum discharge temperature.

		Sampling results (n = 3)[1]								
		Soils (per 100cm^2)			Micro (log)[6]			Allergen (log µg)[7]		
		Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli	Milk	Egg	Peanut
Before wash values		3 (0)	3.5 (0.1)	3 (0)	6.03 (0.1)	6.53 (0.10)	6.12 (0.05)	4.15 (0.30)	4.30 (0.21)	4.25 (0.11)
Sampling Sites[2]	Flow rate[3] (Lpm/m^2)									
0	2.06 (0.008)	0.0 (0)	1.7 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	1.27 (0.008)	0.0 (0)	1.8 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	0.27 (0.003)	0.0 (0)	1.8 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	0.08 (0.003)	0.0 (0)	1.8 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-0.90 (0.17)	-1 (0)	-1 (0)
4.9	0.019 (0.001)	0.0 (0)	1.7 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-0.90 (0.17)	-1 (0)	-1 (0)
6.1	0.001 (0.001)	0.0 (0)	1.7 (0)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-0.90 (0.28)	-1 (0)	-0.9 (0.17)
BHc	0.079 (0.003)	0.0 (0)	1.6 (0)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-0.90 (0.17)	-1 (0)	-1 (0)
BHt	0.00 (0.00)	0.0 (0)	1.7 (0)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-0.50 (0.28)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m.
[3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty.
[6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).
[7]Results are log values of µg/100cm^2. -1 log is used for <1 or no recovery.

Table 5-36. Type 4 wash results for Sd-HVMP validation at 454 Lpm @ 3.1 bar (120 gpm @ 45 psi), 0° centered, 79° pitch, and 71°C minimum discharge temperature.

		Sampling results (n = 3)[1]								
			Soils		Micro (log)[6]			Allergen (log µg)[7]		
		Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli	Milk	Egg	Peanut
Before wash values		3 (0)	5.0 (0.4)	3 (0)	6.40 (0.50)	6.62 (0.17)	5.94 (0.60)	3.70 (0.11)	4.30 (0.10)	4.01 (0.03)
Sampling Sites[2]	Flow rate[3] (Lpm/m^2)									
0	4.64 (0.69)	0.0 (0)	1.6 (0.2)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	6.43 (0.32)	0.6 (0.4)	1.8 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	1.99 (0.08)	0.5 (0.5)	1.8 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-0.84 (0.28)
3.7	1.87 (0.12)	0.5 (0.5)	1.9 (0.5)	0.5 (0.3)	-1 (0)	-1 (0)	-1 (0)	-0.84 (0.28)	-0.9 (0.17)	-0.84 (0.28)
4.9	4.72 (0.24)	0.7 (0.3)	1.8 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-0.74 (0.45)
6.1	4.44 (0.04)	0.7 (0.3)	1.9 (0.2)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-0.74 (0.45)
BHc	49.08 (0.41)	0.1 (0)	2.0 (0.5)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	43.51 (0.65)	0.2 (0.3)	1.9 (0.3)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation.
[2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m.
[3]Flow rate from nearest surface flow sample device for example purposes only.
[4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty.
[5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty.
[6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic).
[7]Results are log values of $\mu g/100cm^2$. -1 log is used for <1 or no recovery.

Table 5-37. Type 4 wash results for Sd-HVMP validation at 416 Lpm @ 4.5 bar (110 gpm @ 65 psi), 0° centered, 79° pitch, and 71°C minimum discharge temperature.

		Sampling results (n = 3)[1]								
		Soils			Micro (log)[6]			Allergen (log µg)[7]		
		Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli	Milk	Egg	Peanut
Before wash values		3 (0)	3.5 (0.1)	3 (0)	6.35 (0.2)	6.47 (0.10)	6.13 (0.05)	3.92 (0.13)	4.25 (0.15)	4.05 (0.21)
Sampling Sites[2]	Flow rate[3] (Lpm/m^2)									
0	3.17 (0.17)	0.0 (0)	1.7 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	5.00 (0.17)	0.0 (0)	1.8 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	1.78 (0.10)	0.0 (0)	1.8 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	1.43 (0.04)	0.5 (0.3)	1.8 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
4.9	4.03 (0.16)	0.0 (0)	1.8 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
6.1	3.44 (0.25)	0.2 (0.1)	2.0 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
BHc	30.95 (1.80)	0.0 (0)	1.7 (0)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	27.97 (0.42)	0.0 (0)	1.8 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation. [2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only. [4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty. [5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic). [7]Results are log values of $\mu g/100cm^2$. -1 log is used for <1 or no recovery.

Table 5-38. Type 4 wash results for Sd-HVMP validation at 378 Lpm @ 6.2 bar (100 gpm @ 90 psi), 0° centered, 79° pitch, and 71°C minimum discharge temperature.

		Sampling results (n = 3)[1]								
			Soils		Micro (log)[6]			Allergen (log µg)[7]		
		Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli	Milk	Egg	Peanut
Before wash values		3 (0)	5.2 (0.1)	3 (0)	5.98 (0.15)	6.45 (0.23)	6.51 (0.25)	3.94 (0.05)	4.33 (0.14)	4.18 (0.05)
Sampling Sites[2]	Flow rate[3] (Lpm/m²)									
0	5.99 (0.05)	0.0 (0)	1.7 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	5.15 (0.03)	0.0 (0)	1.8 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	2.82 (0.02)	0.0 (0)	1.8 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	2.69 (0.02)	0.0 (0)	1.7 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
4.9	5.67 (0.13)	0.0 (0)	1.7 (0)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
6.1	4.11 (0.08)	0.0 (0)	1.7 (0)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
BHc	33.77 (0.29)	0.0 (0)	1.6 (0)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	13.37 (0.47)	0.0 (0)	1.6 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation. [2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only. [4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty. [5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic). [7]Results are log values of µg/100cm². -1 log is used for <1 or no recovery.

Table 5-39. Type 4 wash results for Sd-HVMP validation at 492 Lpm @ 5.5 bar (130 gpm @ 80 psi), 0° centered, 79° pitch, and 71°C minimum discharge temperature.

		Sampling results (n = 3)[1]								
			Soils			Micro (log)[6]			Allergen (log µg)[7]	
		Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli	Milk	Egg	Peanut
Before wash values		3 (0)	5.3 (0.3)	3 (0)	6.43 (0.50)	6.62 (0.18)	5.99 (0.60)	3.86 (0.30)	4.35 (0.16)	4.17 (0.03)
Sampling Sites[2]	Flow rate[3] (Lpm/m^2)									
0	4.64 (0.70)	0.0 (0)	1.7 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	6.43 (0.33)	0.0 (0)	1.8 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	2.08 (0.08)	0.0 (0)	1.7 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	1.87 (0.08)	0.0 (0)	2.0 (0.1)	0.0 (0)	-1 (0)	-1.0 (0)	-1 (0)	-1 (0)	-0.9 (0.17)	-1 (0)
4.9	4.72 (0.24)	0.0 (0)	1.8 (0)	0.0 (0)	-1 (0)	-1.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
6.1	2.48 (0.17)	0.0 (0)	2.1 (0.2)	0.0 (0)	-1 (0)	-1.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
BHc	49.25 (0.41)	0.0 (0)	1.7 (0)	0.0 (0)	-1 (0)	-1.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	43.58 (0.81)	0.0 (0)	1.7 (0.1)	0.0 (0)	-1 (0)	-1.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation. [2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only. [4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty. [5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic). [7]Results are log values of µg/100cm^2. -1 log is used for <1 or no recovery.

Table 5-40. Type 4 wash results for Sd-HVMP validation at 454 Lpm @ 4.7 bar (120 gpm @ 68 psi), 0° centered, 79° pitch, and 71°C minimum discharge temperature.

		Sampling results (n = 3)[1]								
		Soils			Micro (log)[6]			Allergen (log µg)[7]		
		Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli	Milk	Egg	Peanut
Before wash values		3 (0)	5.3 (0.3)	3 (0)	6.43 (0.50)	6.62 (0.18)	5.99 (0.60)	3.86 (0.30)	4.35 (0.16)	4.17 (0.03)
Sampling Sites[2]	Flow rate[3] (Lpm/m^2)									
0	13.28 (0.30)	0.0 (0)	1.7 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	7.03 (0.03)	0.0 (0)	1.7 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	2.19 (0.08)	0.0 (0)	1.7 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	1.68 (0.06)	0.1 (0.2)	2.2 (0.2)	0.0 (0)	-1 (0)	-1.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
4.9	3.26 (0.22)	0.0 (0)	1.8 (0)	0.0 (0)	-1 (0)	-1.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
6.1	1.30 (0.03)	0.5 (0.5)	2.5 (0.3)	0.3(0.3)	-1 (0)	0.5 (0.3)	-1 (0)	-0.5 (0.17)	-0.9 (0.29)	-1 (0)
BHc	31.22 (0.88)	0.0 (0)	1.8 (0)	0.0 (0)	-1 (0)	-1.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	11.63 (0.71)	0.0 (0)	1.7 (0.1)	0.0 (0)	-1 (0)	-1.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation. [2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only. [4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty. [5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic). [7]Results are log values of µg/100cm^2. -1 log is used for <1 or no recovery.

Table 5-41. Type 4 wash results for Sd-HVMP validation at 454 Lpm @ 4.7 bar (120 gpm @ 68 psi), 1° centered, 79° pitch, and 71°C minimum discharge temperature.

		Sampling results (n = 3)[1]								
			Soils			Micro (log)[6]			Allergen (log µg)[7]	
		Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli	Milk	Egg	Peanut
Before wash values		3 (0)	5.3 (0.3)	3 (0)	6.43 (0.50)	6.62 (0.18)	5.99 (0.60)	3.86 (0.30)	4.35 (0.16)	4.17 (0.03)
Sampling Sites[2]	Flow rate[3] (Lpm/m^2)									
0	14.64 (0.10)	0.0 (0)	1.7 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	6.89 (0.08)	0.0 (0)	1.6 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	2.25 (0.24)	0.0 (0)	1.7 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	1.78 (0.06)	0.0 (0)	1.9 (0.1)	0.0 (0)	-1 (0)	-0.5 (0)	-1 (0)	-0.5 (0.17)	-1 (0)	-1 (0)
4.9	3.52 (0.12)	0.0 (0)	1.8 (0)	0.0 (0)	-1 (0)	-1.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
6.1	1.19 (0.02)	0.7 (0.5)	2.4 (0.2)	0.5(0.3)	-1 (0)	0.7 (0.6)	-1 (0)	-0.5 (0.17)	-0.3 (0.17)	-1 (0)
BHc	30.88 (0.83)	0.0 (0)	1.8 (0)	0.0 (0)	-1 (0)	-1.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	10.73 (0.60)	0.0 (0)	1.8 (0)	0.0 (0)	-1 (0)	-1.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation. [2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only. [4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty. [5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic). [7]Results are log values of µg/100cm^2. -1 log is used for <1 or no recovery.

Table 5-42. Type 4 wash results for Sd-HVMP validation at 454 Lpm @ 4.7 bar (120 gpm @ 68 psi), 2.5° centered, 79° pitch, and 71°C minimum discharge temperature.

		Sampling results (n = 3)[1]								
			Soils			Micro (log)[6]			Allergen (log µg)[7]	
		Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli	Milk	Egg	Peanut
Before wash values		3 (0)	5.3 (0.3)	3 (0)	6.43 (0.50)	6.62 (0.18)	5.99 (0.60)	3.86 (0.30)	4.35 (0.16)	4.17 (0.03)
Sampling Sites[2]	Flow rate[3] (Lpm/m^2)									
0	20.20 (0.34)	0.0 (0)	1.6 (0)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	5.88 (0.14)	0.0 (0)	1.6 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	2.44 (0.31)	0.0 (0)	1.7 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	1.22 (0.07)	1.0 (0.5)	2.6 (0.1)	0.3 (0.3)	-1 (0)	-0.5 (0)	-1 (0)	-0.5 (0.17)	-1 (0)	-1 (0)
4.9	1.31 (0.11)	0.5 (1.0)	2.4 (0.2)	0.5 (0.3)	-1 (0)	-1.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
6.1	0.71 (0.10)	1.33 (0.5)	2.6 (0.2)	0.8 (0.3)	-1 (0)	0.7 (0.6)	-1 (0)	-0.5 (0.17)	-0.3 (0.17)	-1 (0)
BHc	29.30 (0.24)	0.0 (0)	1.8 (0)	0.0 (0)	-1 (0)	-1.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	8.39 (0.23)	0.0 (0)	1.9 (0.1)	0.0 (0)	-1 (0)	-1.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation. [2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only. [4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty. [5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = *S. cerevisiae* Bac = *B. megaterium* Ecoli = *E. coli* (generic). [7]Results are log values of µg/100cm^2. -1 log is used for <1 or no recovery.

Table 5-43. Type 4 wash results for Sd-HVMP validation at 454 Lpm @ 4.7 bar (120 gpm @ 68 psi), 5° centered, 79° pitch, and 71°C minimum discharge temperature.

		Sampling results (n=2)[1]								
		Soils			Micro (log)[6]			Allergen (log µg)[7]		
		Visual[4]	ATP[5]	Sugar[4]	Sacc	Bac	Ecoli	Milk	Egg	Peanut
Before wash values		3 (0)	5.3 (0.3)	3 (0)	6.43 (0.50)	6.62 (0.18)	5.99 (0.60)	3.86 (0.30)	4.35 (0.16)	4.17 (0.03)
Sampling Sites[2]	Flow rate[3] (Lpm/m^2)									
0	23.43 (0.26)	0.0 (0)	1.7 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
1.2	5.20 (0.11)	0.0 (0)	1.7 (0)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
2.4	2.61 (0.16)	0.0 (0)	1.9 (0.1)	0.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
3.7	0.93 (0.03)	1.3 (0.3)	2.7 (0.2)	1 (0)	-1 (0)	-0.5 (0)	-1 (0)	-0.1 (0.2)	-1 (0)	-1 (0)
4.9	0.55 (0.06)	1.7 (0.3)	2.8 (0.2)	0.8 (0.3)	-1 (0)	-1.0 (0)	-1 (0)	0 (0.2)	-1 (0)	-1 (0)
6.1	0.52 (0.05)	1.7 (0.3)	2.8 (0.2)	1.0 (0)	-1 (0)	0.7 (0.6)	-1 (0)	0.35 (1.0)	-0.3 (0.17)	-0.1 (0.5)
BHc	24.27 (0.77)	0.0 (0)	1.8 (0.1)	0.0 (0)	-1 (0)	-1.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)
BHt	3.76 (0.10)	0.3 (0.3)	2.0 (0.1)	0.0 (0)	-1 (0)	-1.0 (0)	-1 (0)	-1 (0)	-1 (0)	-1 (0)

[1]Sampling results are the average of 3 trials. Value in parenthesis is the standard deviation. [2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Flow rate from nearest surface flow sample device for example purposes only. [4]Visual and sugar assessment on a 4 point Hedonic scale. 0 = clean. 3 = dirty. [5]ATP results are Relative Light Units as determined by reader. RLU: < 2.5 = clean. RLU: 2.5 – 3.0 = slightly soiled. RLU: >3.0 = dirty. [6]Results are log values. -1 log is used for <1 or no recovery. Sacc = S. cerevisiae Bac = B. megaterium Ecoli = E. coli (generic). [7]Results are log values of µg/100cm^2. -1 log is used for <1 or no recovery.

Table 5-44. Type 4 wash combined results and stats for Sd-HVMP worse case installation position.

	Operating parameter (n = 3)			
Lpm @ bar	454 @ 4.7	454 @ 4.7	454 @ 4.7	454 @ 4.7
Centered (°)[1]	0	1	2.5	5[3]
Pitch (°)	79	79	79	79
Sample Sites[2]	Combined clean analysis rating[3]			
0	-0.22	-0.22	-0.23	-0.22
1.2	-0.22	-0.23	-0.23	-0.22
2.4	-0.22	-0.22	-0.22	-0.18
3.7	-0.12	-0.10	0.23	-.48
4.9	-0.20	-0.20	0.07	0.56
6.1	0.15	0.30	0.48	0.91
BHc	-0.20	-0.20	-0.20	-0.20
BHt	-0.22	-0.20	-0.18	-0.12
Overall sig diff [4]	-0.15 A	-0.13 A	-0.04 B	0.13 C

[1]All trials when devices pointed away from sample sites, which is the worse case for installation. [2]Sample site is the site in m from the CIP device. BHc and BHt are the bulkhead center and top sites at 6.7m. [3]Results included visual, ATP, soils and allergen results. Does not include micro results. Results are average of 3 trials. [4]Values are the average of all data. Same letters indicate no significance at P<0.05 across treatments.

Table 5-45. R-LVHP operating parameter differences for Type 4 wash.

	Operating parameter statistical analysis		
Lpm @ bar	68 @ 24	76 @ 31	83 @ 31
Rotation speed (rpm)	20	4	4
Extension (cm)	0	22	22
Average soils [1]	2.18 A	1.17 B	0.67 C
Average micro [2]	0.46 A	0.01 B	-0.03 B
Average allergen [3]	1.66 A	-0.33 B	-0.35 B

[1]The value is the average of all soil determinations. Lower values indicate less residual soil. Values with the same letter are not significantly different at P<0.05.
[2]The value is the average of all microorganism determinations. Lower values indicate lower microbial residue. Values with the same letter are not significantly different at P<0.05.
[3]The value is the average of all allergen determinations. Lower values indicate less residual allergen. Values with the same letter are not significantly different at P<0.05.

Table 5-46. R-HVMP operating parameter differences for Type 4 wash.

	Operating parameter statistical analysis		
Lpm @ bar	416 @ 4.5	378 @ 6.2	492 @ 5.5
Rotation speed (rpm)	16	16	16
Extension (cm)	12	12	12
Average soils [1]	0.65 A	0.59 A	0.58 A
Average micro [2]	0.0 A	-0.03 A	0.0 A
Average allergen [3]	-0.05 A	-0.5 B	-0.21 A

[1]The value is the average of all soil determinations. Lower values indicate less residual soil. Values with the same letter are not significantly different at P<0.05.
[2]The value is the average of all microorganism determinations. Lower values indicate lower microbial residue. Values with the same letter are not significantly different at P<0.05.
[3]The value is the average of all allergen determinations. Lower values indicate less residual allergen. Values with the same letter are not significantly different at P<0.05.

Table 5-47. Sd-HVMP operating parameter differences for Type 4 wash.

	Operating parameter statistical analysis			
Lpm @ bar	454 @ 3.1	416 @ 4.5	378 @ 6.2	492 @ 5.5
Centering (° from dead center)	0	0	0	0
Pitch (degrees)	79	79	79	79
Average soils [1]	0.77 A	0.63 B	0.57 B	0.60 B
Average micro [2]	0.0 A	0.0 A	0.0 A	0.0 A
Average allergen [3]	-0.20 A	0.0 A	0.0 A	-0.04 A

[1]The value is the average of all soil determinations. Lower values indicate less residual soil. Values with the same letter are not significantly different at P<0.05.
[2]The value is the average of all microorganism determinations. Lower values indicate lower microbial residue. Values with the same letter are not significantly different at P<0.05.
[3]The value is the average of all allergen determinations. Lower values indicate less residual allergen. Values with the same letter are not significantly different at P<0.05.

Figure 5-1. UF C-Thru model tanker showing sluices, funnels, and tubes. (Winniczuk 2007)

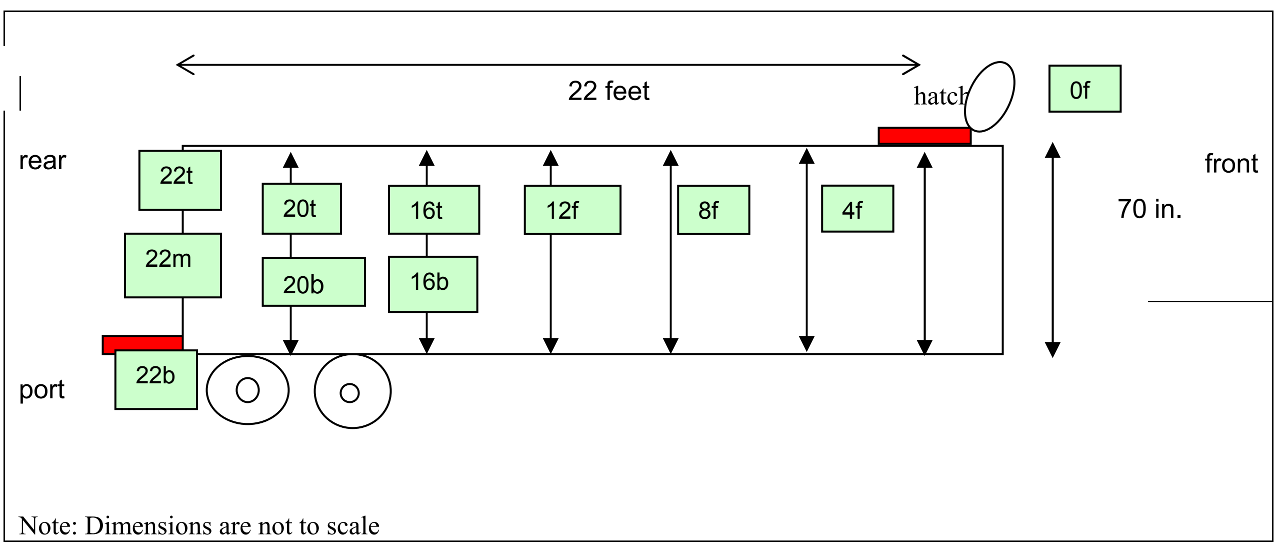


Figure 5-2. UF C-Thru Model tanker dimensions and sampling sites. (Winniczuk 2006)

CHAPTER 6
RESEARCH CONCLUSION

Many liquid products are hauled by over-the-road tankers. These over-the-road tankers need to be cleaned to a level to provide assurance that the product they carry will not cause any illness in the next product prepared from it. Ideally, the sanitation program should reduce or eliminate any potential microbial, chemical, or physical contamination. Where many physical hazards can be reduced by proper handling procedures or product filtering to ensure that physical contamination does not occur, reduction of microbial and chemical contamination has to be accomplished through the washing and sanitizing steps and post-wash handling procedures. Tankers can be contaminated by microorganisms (pathogens) as a result of residues that were not cleaned out or by re-contamination by post-wash handling practices. These microorganisms can increase in population while the tanker is in transport for its next load, if the tanker does not have adequate protective residues (residual sanitizer). Chemical contamination can occur by improper cleaning and by improper rinsing of detergents and sanitizers. Improper cleaning can leave the previous product in the tanker and if the previous product is considered to have toxicological effects (such as an allergen) it can contaminate the next product. Improper rinsing of detergents and sanitizers can also lead to chemical contamination of the next product. In both cases, increases in the chemical contamination are not likely to occur so the residue level is the amount to contaminate the next product. With chemical contamination, the dilution effect of the next product may provide relief from intoxication. However, regulatory guidelines indicate that the next product would be adulterated. Also, the residue amount in a tanker is not well defined. Depending on the residue, small amounts can cause toxicological effects to certain populations. Complete removal of offending chemical residue is required.

Over-the-road tankers are typically cleaned by a clean-in-place (CIP) process. As with any cleaning, there are five factors that need to be considered for cleaning, 1) soil type, 2) temperature, 3) time, 4) chemical concentration, and 5) cleaning action. Cleaning processes entail the use of a CIP device that utilizes the five cleaning factors in certain combinations to accomplish a clean tanker. Soil type will depend on the previous product and may not be controllable so the other factors have to compensate to ensure the tanker is cleaned well. Typically, cleaning consists of using detergent at the proper concentration, at the proper temperature, for the appropriate amount of time with the proper cleaning action for the soil removal. Any deviation of a factor can lead to improper cleaning.

This research evaluated two tanker cleaning protocols (JPA Type 2 and Type 4) for removal of microbial, soil, and chemical (allergen) residues. In Part 1 (research baseline), many results exceeded "clean" residue levels which may have been due to a high cleaning temperature, a low detergent concentration, or cleaning actions (cascade or impingement) that were too low. These baseline conclusions were based on the recovery of chemical residues (allergens) without the recovery of microbial residues. High temperatures are effective for microorganism inactivation and in most situations is the main process for pathogen reduction. However, allergens are proteins that can be negatively affected by high temperatures. Also, the detergent concentration used may be too low, thereby not allowing adequate solubilization of the soils. Also, soil removal may not be achieved if the cleaning action (cascade or impingement depending on the device) is too low. Further observations of Part 1 of the study found that the cleaning action was a main point of contention for non-removal of the soil. The primary cleaning action for tanker cleaning is supplied by the CIP device.

To achieve the wash process validation goals, Part 2 of the research evaluated the operating parameters of three CIP devices typically used at wash facilities. This was accomplished by collecting the wash fluid dispersed from the CIP devices at various points along a model tanker's internal stainless steel surface. Collection of the fluids allowed an objective determination of the CIP device operating conditions. It was determined that some CIP device operating parameters that were being used at tanker wash facilities were in fact not effectively cleaning the tankers, particularly in the bulkhead regions. Residues that were recovered in these regions were calculated to be high enough (>10 $\mu g/100cm^2$) to cause potential toxicological effects in consumers of the next product. It was found that some operating parameter combinations of rotating devices (flow rate and pressure, rotation speed, extension length) were unable to provide any fluids to at least 1 sample site in the tanker particularly in the barrel ends (4.6 to 6.7 m from device) and the bulkhead (6.4 to 6.7 m from device). Also, if a directional device was not installed correctly, fluids were not collected in the barrel from 3.0 to 6.0 m from the device and the bulkhead. It was found that if CIP devices were operated at less than effective volume, pressure, rotation speeds, flow development, or installation orientation, soil residues can be left on a tanker surface. Various qualification tests were conducted to determine the device factors that can deliver wash fluids to all parts of the tanker. Results indicated that when using a rotating-low volume, high pressure CIP device (R-LVHP), a slow rotation speed (4 to 6 shaft rpm) with at least 15 cm flow development tubes were needed with a flow rate of at least 76 Lpm at 31 bar pressure for adequate surface flows. R-LVHP device did not perform well when the rotation speed and pressure were excessive since either factor seemed to decrease the cleaning radius. When using a rotating-high volume, medium pressure device, operating parameter were less limiting with an effective usage range of 303 to 492 Lpm, 4.5 to 6.2 bar, and rotation speed of 15 to 20 rpm and extension range of 12 to 15 cm. It was observed that with the R-HVMP device that rotation speed had less affect on the cleaning radius but that excessive pressure (>13 bar) would reduce the cleaning radius. With both rotating devices, excessive pressure caused atomization of the fluid stream with reduced droplet size while excessive rotation speed caused increased radial momentum of the fluid stream. The stationary-directional high volume, medium pressure device was effective at 378 to 492 Lpm range and 4.5 to 6.2 bar however, the installation position was critical. Sd-HVMP device pitch had a 3° range from the manufacturer's engineered position (as tested). Also, the centering of this device in the tanker was critical with an approximate off center range of 1°.

In Part 3 of this study, tests were conducted to determine the device's factors and cleaning factors (detergent concentration and temperature) that could be used to effectively clean a tanker with two wash protocols for the juice industry (JPA Type 2 and Type 4 washes). It was found that using either wash type when a CIP device was operated effectively, a clean and sanitary tanker can be achieved that will not cause a transfer of potentially harmful microbial or chemical residues. Microorganisms were effectively reduced by removal with the wash fluids or inactivation by the temperature or the chemical sanitizer. Allergens were also reduced by removal with the wash fluids.

CHAPTER 7
FUTURE WORK

Based on conversations with industry personnel, cleaning with low water volume is very important. Water is a valuable and limited resource so continued work with low volume CIP systems is important particularly with respect to other food industries such as the dairy industry. Also, with respect to valuable resources, further research should look into the use of lower wash temperatures such as 60 to 65°C (140 to 149°F) feed with a discharge of ≥ 48°C (118°F). The lower temperature may be beneficial for allergen removal while still removing microorganisms and be more cost effective. In this study, theoretical allergen residue values were based on previous literature indicating that a no recovery level or below the method's detection limit should be the target as indicated by FDA. Future work needs to be conducted to determine the actual allergen residue that remains on a surface after cleaning that may be detrimental to the next product. A defined allergen target would be important for developing proper cleaning guidelines. This research used a blended allergen soil to determine multiple allergen residues after a cleaning. Combining foods may have had a negative effect for some of the soil removal. Future work should evaluate the soils separately or at least fully investigate the possible soil interaction effects. Tankers haul products other than food in particularly some high dollar value chemicals. The transport industry has interest in the proper cleaning of these transports so that the chemical products are not contaminated. Based on observations in this study, an investigation into the manual wash practices may be important particularly with the wash facilities that practice this. In particular is how the manual wash high pressure wand is used, how close the wand needs to be to the surface to remove soils, and the use of warm water (38°C or 100°F) instead of ambient water (20 to 26°C or 68 to 78°F).

APPENDIX A
JUICE PRODUCTS ASSOCIATION FOOD COMMODITY AND WASH TYPE LIST

Table A-1. JPA food commodity and wash type list

▲Indicates a product with high allergen potential. **Food Commodity**	Tanker Wash **Types**
Alcohol Products, All Types (food grade)	2
Apple Juice- Concentrated and Single Strength	2
Aromatic Chemicals- **Food Grade Only** (GRAS, FCC Certified)	3
Beverage Bases	2
Blood	Not Permitted
Canola Oil	3
Caramel Color	2
Chemicals and Cleaning Agents- Non-Food Grade	Not Permitted
Cherry Juice- Concentrate and Single Strength	2
▲Chocolate	4
Citric Acid Solution	2
Citrisol- Non-food Grade Cleaning Solvent from Citrus Oils	Not Permitted
Citrus Fruit Aroma and Essence- Aqueous	2
Citrus Fruit Terpenes	3
Citrus Punch- Concentrate and Single Strength	2
Cocoa	Not Permitted
Colors, Artificial and Vegetable Based- **Food Grade Only**	Not Permitted
Corn Oil	3
Corn Sweeteners	2
Corn Syrup	2
Cranberry Juice- Concentrate and Single Strength	2
D-Limonene Oil, **Food Grade**	3
D-Limonene Oil, Non-Food Grade	Not Permitted
▲Dairy Products, Pasteurized- Cream, Milk, Milk Balancer	4
▲Dairy Products, Unpasteurized- Cream, Milk, Milk Balancer	4
Dyes, Inks and Pigments- Non-Food Grade	Not Permitted
▲Eggs and Egg Based Products	4
Essential Oils	3
Fats- Product is solid at 70°F (21°C)	Not Permitted
Fats, Rendered	Not Permitted
Fish Oils	Not Permitted
Flavors, Natural and Artificial	3
Fruit Juice- Concentrates and single strength (including raw or fresh)	2
Fruit Punch and beverage bases	2
Glycerin, Food Grade	3
Glycerin, Unpasteurized- Non-Food Grade	Not Permitted
Grape Juice, All Types- Concentrate and Single Strength	2

▲Indicates a product with high allergen potential.	Tanker Wash
Food Commodity	**Types**
Grapefruit Juice- Concentrate and Single Strength (including fresh)	2
High Fructose Corn Syrup	2
Honey	2
Hydrogenated Vegetable Oils- Product is solid at 70°F (21°C)	Not Permitted
Iso-sweet	2
Kiwi Juice- Concentrate and Single Strength (including fresh)	2
Lecithin (emulsifier)	Not Permitted
Lysine (recovered cooking oils)	Not Permitted
Lemon Juice- Concentrate and Single Strength (including fresh)	2
Malt	3
Mineral Oil	3
Mineral Salts (i.e.: Epsom Salt)	Not Permitted
Molasses (food grade)	2
Molasses (non food grade)	Not Permitted
Non-Citrus Fruit Aroma and Essence- Aqueous	2
▲Nut Products	4
Orange Concentrate- OM	2
Orange Juice- Concentrated and Single Strength	2
Paraffin Wax	Not Permitted
Peach Juice- Concentrate and Single Strength (including fresh)	2
▲Peanut Based Products (other than Oil)	4
▲Peanut Oil	4
Pear Juice- Concentrate and Single Strength (including fresh)	2
Pepper or Plant Mash	4
Pharmaceuticals (non food grade)	Not Permitted
Pharmaceuticals (food grade)	3
Pineapple Juice- Concentrate and Single Strength	2
Propylene Glycol (food grade)	3
Prune Juice- Concentrate and Single Strength	2
Raspberry Juice- Concentrate and Single Strength	2
Sorbitol - Food Grade	2
Sorbitol, Non-food Grade	Not Permitted
▲Soy based products	4
▲Soybean Oil	4
Strawberry Juice- Concentrate and Single Strength	2
Sugar, Liquid	2
Sunflower Oil	3
Sweeteners	2
Syrups	2
Vegetable Oils- Product Liquid at 70°F (21°C)	3
Vinegar	2
Water (food grade)	2
Watermelon Juice- Concentrate and Single Strength	2

▲Indicates a product with high allergen potential.	Tanker Wash
Food Commodity	**Types**
Waxes	Not Permitted
▲Whey, Pasteurized	4
▲Whey, raw	4
Witch Hazel (food grade)	2
▲Yeast- Active and Inactive	4

Accessible at www.juiceproducts.org

APPENDIX B
DETERGENT DILUTION RATES AND ASSOCIATED CHEMICAL ANALYSES

Table B-1. Detergent dilution rates and chemical and physical analyses

Dilution rate (oz detergent/gal water)	% rate	Average ppm as active alkalinity (std)[1,2]	Average pH[1]	Average chlorine (ppm)[1,3]
1 / 6	0.130	157 (50)	10.3	<10
1 / 5	0.156	233 (58)	10.6	10
1 / 4	0.195	367 (58)	11.3	20
1 / 3	0.260	467 (58)	11.4	60
1 / 2	0.391	667 (58)	11.6	90
1 / 1	0.781	1267 (150)	12.0	100
1.28 / 1	1	1433 (58)	12.1	130

[1]Average based on 6 individual determinations (n = 6)
[2]Active alkalinity determined Alkalinity test kit (Chemical Systems of Florida, Zellwood FL) using 0.1N Sulfuric acid and titrated to pH 8.3
[3]Free chlorine measured by orthotolidine test kit (Hach Industries, Loveland, CO)

APPENDIX C
CALCULATION OF INSIDE TANKER SURFACE AREA OF A 12.2 M (40FT) TANKER

Table C-1. Calculation of internal surface area

Barrel surface	Dimension
Diameter (d)	160.0 cm
Length (L)	1219.2 cm
Circumference (Π*d)	502.7 cm
Surface Area (Π*d*L)	612913.4 cm^2
Number of blocks on barrel surface	6129.1
Bulkhead surface	
Diameter (d)	160.0 cm
Radius (r)	80.0 cm
Surface areas ($\Pi * r^2$)	20106.2 cm^2
Number of blocks on bulkhead surface	201.1
2 bulkheads	402.1
Total internal surface area (barrel + bulkheads)	653125.8 cm^2
Total number of blocks in tanker	6531.3

APPENDIX D
DETERMINATION OF DETECTION LIMIT WITH ACCUCLEAN SWAB

Table D-1. Determining detection limit of AccuClean swabs

			Serial dilutions[3]								
	start	Pre diln	0	-1	-2	-3	-4	-5	-6	-7
Orange juice μg	$3x10^5$	0	300000	30000	3000	300	30	3	0.3	0.03
n = 8			B2	B2	B2	B2	B2	B2	Gr	Gn
Milk μg	33000	0	33000	3300	330	33	3.3	0.3	0.03	0.003
n = 6			B2	B2	B2	B2	B2	Gr	Gn	Gn

[1]AccuClean is a product of Neogen Company, Lansing, MI
[2]AccuClean results were based on the color card
Gn = Green - clean
Gr = Gray – questionable, needs recleaning
B1 = Blue level 1 – dirty, needs recleaning
B2 = Blue level 2 – very dirty, needs recleaning
[3]Serial dilutions prepared with sterile deionized water.

APPENDIX E
DETERMINATION OF ALLERGEN DETECTION LIMIT WITH ALERT TEST KIT

Table E-1. Determination of detection limit for allergen test kits.

Allergen	Estimated start µg	Pre diln	Allergen results at serial dilutions[3] 0	-1	-2	-3	-4	-5	-6
Milk µg	33000	0[1]	33000	3300	330	33	3	0.3	0.03
n = 6			Pos	Pos	Pos	Pos	Pos	Neg	Neg
Egg µg	30000	0[1]	30000	3000	300	30	3	0.3	0.03
n = 6			Pos	Pos	Pos	Pos	Pos	Neg	Neg
Peanut µg	60000	0[1]	60000	6000	600	60	6	0.6	0.06
n = 6			Pos	Pos	Pos	Pos	Pos	Pos	Neg
Milk µg	33000	1/3[2]	11000	1100	110	11	1	0.1	0.01
n = 9			Pos	Pos	Pos	Pos	Pos	Neg	Neg
Egg µg	30000	1/3[2]	10000	1000	100	10	1	0.1	0.01
n = 9			Pos	Pos	Pos	Pos	Pos	Neg	Neg
Peanut µg	60000	1/3[2]	20000	2000	200	20	2	0.2	0.02
n = 9			Pos	Pos	Pos	Pos	Pos	Neg	Neg

[1]The 0 dilution was the slurry material each analyzed independently by serial dilutions. [2]The 1/3 dilution was the prepared slurry material without microorganisms and serial diluted. [3]Serial dilutions were with sterile deionized water. The serial dilution concentrations were confirmed by Alert analysis and wells were read with the well reader.

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BIOGRAPHICAL SKETCH

Polikarp (Paul) Pfeofil Winniczuk is the son of Ukrainian immigrant farmers. He has been working with foods since his youth on his parent's farm in New York's southern tier where he first learned "food science" from his parents. Since then, he has worked in various food fields in slaughterhouses, meat processing, fluid milk and cheese processing, aseptic fluid processing, orange and other juice processing, and meal replacement and nutritional supplement products. He received a BS degree in food science from Purdue University in 1986 and an MS degree in food science from the University of Florida in 1994. He has worked in the citrus industry for at least 10 years in quality assurance and microbiology. He was recently an assistant research scientist for the University of Florida at the Citrus Research and Education Center in Lake Alfred, FL. He is currently finishing the over-the-road tanker sanitation project and a PhD in food science with an emphasis in food microbiology and sanitation. Future plans are to be self-employed.