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Energy Efficient Main Pipelines for Drip-Irrigated Tomato Production [1]

A.G. Smajstrla, G.A. Clark and F.S. Zazueta[2]

The main pipeline in an irrigation system is the pipeline that carries water from the irrigation pump to the distribution pipelines in the field. The purpose of the main pipeline is to efficiently deliver the flow rate and pressure required to irrigate the subunits or zones. Energy losses can be minimized by properly selecting and installing components so that friction losses will be low and the pipelines will work properly throughout the life of the irrigation system.

For drip-irrigated tomato production, a field is normally divided into several zones, and one zone is irrigated at a time. This allows the mainline (and pumping system) to be as small as possible because it needs only enough capacity for the largest zone. Sometimes, however, more than one zone or the entire field is irrigated at once. In those cases, the main pipeline must have sufficient capacity for the largest area irrigated at one time.

Selection Procedures

Main pipelines are selected on the basis of both economic and hydraulic considerations. Selection based on economic considerations means that the pipeline will have the lowest annual cost for the entire life of the irrigation system compared with both the next larger and the next smaller available pipe diameters. Selection based on hydraulic considerations means that the velocity of flow will be low enough to minimize surge pressures (water hammer) and that the pipe will have a pressure rating adequate to withstand both expected static and surge pressures. When these economic and hydraulic considerations produce different results, the larger (more conservative) pipe size must be chosen.

Economic Considerations

When main pipelines are selected on the basis of economic considerations, a detailed economic analysis is required. In this analysis, the initial pipe and installation cost for various commercially available pipe sizes (amortized over the expected life of the system at current interest rates) is compared with the annual pumping cost for each of the commercially available pipe sizes. When the amortized initial cost is added to the annual operating cost, the pipeline with the lowest total cost is shown to be the most economical for the buyer. This is the pipe size that should be selected.

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2. A.G. Smajstrla, professor; G.A. Clark, associate professor, Gulf Coast Research and Education Center, Bradenton FL; and F.S. Zazueta, professor, Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, 32611.

For small pipe sizes, the initial cost is low but the pumping cost is high because friction losses are higher in smaller pipe sizes. Conversely, the initial cost is high for large pipe sizes, but the pumping cost is low because friction losses are lower in larger pipes. The actual pipe size selected depends on the pipeline length, the intended flow rate, the initial cost of the pipe and installation and the estimated hours of operation and cost of pumping throughout the life of the system.

When drip systems are used to irrigate annual crops with a relatively short growing season, such as vegetable crops in Florida, the annual hours of operation are comparatively low. This is because drip-irrigated tomatoes rarely require more than 2 to 3 hours of irrigation per day, even under peak water use conditions, and growing seasons are relatively short (normally about 100 days per season). Under these conditions, a detailed economic analysis favors the selection of smaller pipe sizes than does a hydraulic analysis. Thus, the hydraulic analysis almost always controls the pipe size selected.

The reader is advised to make an initial selection of the mainline pipe size using the hydraulic considerations given in the following sections of this publication. The annual operating cost for the mainline pipe size selected can then be calculated. Only if the annual pumping cost is high with respect to the amortized initial cost will it be necessary to compare the total annual cost with that of the next larger pipe size to determine which of these pipe sizes should be selected. For more information on how to conduct a detailed economic analysis of a main pipeline, see the IFAS Agricultural Engineering Extension Report entitled *Selection of Main Irrigation Pipelines: Economic Analysis.*

Hydraulic Considerations

One hydraulics question must be answered: Is the water velocity low enough to avoid hydraulic shocks (water hammer) that could damage the pipeline? This is actually a two-part question. To answer it, both the pipe size and the pressure rating must be specified.

Pipe Size

In general, the diameter of the mainline pipe should be large enough to limit the velocity of water flow to 5 feet per second (fps). This velocity will minimize friction losses and will prevent water hammer problems if the pipe has an adequate pressure rating and is properly installed.

Table 1 gives the maximum flow rates that can be carried in Class 160 PVC irrigation pipe and in aluminum irrigation pipe so that the 5 fps velocity is not exceeded. To use Table 1, determine the flow rate required for the largest irrigation zone (or zones, if more than one zone will be operated at once), then select the pipe diameter that can carry this flow rate. For example, if the irrigation system requires 180 gallons per minute (gpm), a 4-inch PVC or aluminum pipeline will be adequate because the 4-inch PVC pipe can carry up to 211 gpm and the 4-inch aluminum pipe up to 187 gpm before the 5 fps velocity is exceeded. As another example, if the irrigation system requires 700 gpm, 8-inch PVC or aluminum pipelines can be used.

If more than one zone will be operated at the same time, their flow rates must be added to select the required mainline pipe size. For example, if two zones, each requiring 160 gpm, will be operated at the same time, the mainline size must be based on the total flow rate of 320 gpm. In this case, 6-inch PVC or aluminum pipelines would be required.

Notice that the capacities of the PVC and aluminum pipes in Table 1 are slightly different for pipes of the same nominal diameter. This is because the capacity is based on the inside pipe diameter (I.D.) and the inside diameters for PVC pipes are slightly different than for aluminum pipes. The blank lines in Table 1 indicate that 5- and 7-inch PVC and 2.5-inch aluminum irrigation pipe are not commercially available.

Pressure Rating

Class 160 PVC pipe refers to plastic irrigation pipe with a pressure rating of 160 pounds per square inch (psi). Aluminum irrigation pipe has a pressure rating of 145 to 150 psi. These pressure ratings will normally be adequate for mainlines in drip irrigation

systems. In some cases, pipe with higher pressure ratings may be required or lower pressure ratings may be adequate, as discussed in the following paragraphs.

The pressure rating of a main pipeline must be considerably greater than the normal system operating (static) pressure so that the mainline will be safe and functional for the life of the irrigation system. The mainline must be able to withstand the pump discharge pressure during normal operating conditions and the potentially destructive pressures generated by water hammer. In addition, PVC pipe pressure ratings must be de-rated (decreased) for water temperatures above 73.4°F. This de-rating is necessary because the strength of plastic pipe is reduced at high temperatures. The pressure rating stamped on the pipe is determined at the standard temperature of 73.4°F.

Water Hammer

Water hammer pressures are the pressure surges that occur because of sudden stoppage or reduction in flow, or because of a change in direction of flow. These pressure surges occur when valves close quickly, when air is suddenly released from a pipeline or when water changes direction at a tee, elbow or other pipe fitting. Although water hammer pressure surges last for only a brief moment, they can be large enough to burst pipelines. Damage from water hammer typically occurs at fittings, particularly if the fittings are not properly installed.

In irrigation pipes, the actual water hammer pressure depends on pipe material, wall thickness, velocity of flow and other factors, such as how quickly a valve closes or how abruptly the water changes direction. A detailed surge pressure analysis must be made to estimate the amount of surge pressure that will be developed in a specific pipeline. Procedures for conducting a detailed surge analysis are given in IFAS Extension Circular 828, " *Water Hammer in Irrigation Systems"*.

ASAE (1991a) and FIS (1991) irrigation design standards state that water hammer in irrigation pipelines can be minimized by limiting the velocity of flow to 5 fps. The small surge pressures that can occur at this velocity will not cause damage if the working pressure in the pipeline is limited to 72 percent of the pressure rating stamped on the pipe. This limits the working pressure of Class 160 PVC pipe to 115 psi (0.72 x 160 psi = 115 psi).

Temperature Effects

Pressure ratings of PVC pipe are determined at the standard temperature of 73.4°F (23°C). A temperature increase above 73.4°F reduces the strength of PVC pipes, a factor that must be considered when PVC pipes are selected. For Class 160 PVC pipe, the amount of reduction is approximately 20 psi for each 10°F elevation in temperature. The actual reductions are shown in Table 2 .

When water is pumped from an underground aquifer, its temperature is normally in the range of 70 to 75°F; such temperatures will have little effect on the pressure rating of the pipe. Water pumped from ponds is considerably warmer during summer months. Summertime pond water temperatures may reach 90°F or more. When this is the case, the pipe pressure rating will be reduced, as shown in Table 2 . For example, the pressure rating of Class 160 PVC pipe will be 141 psi when the water temperature is 80°F. The rating will be only 120 psi when the water temperature is 90°F.

Pipe Size Selection Example

A mainline pipe diameter is selected on the basis of both the maximum allowable velocity of 5 fps and a pressure rating adequate for the normal operating pressure plus surge pressures, after the pressure rating has been adjusted for temperature. The following example illustrates the selection procedure.

Assume that a mainline pipe is to be selected to carry 400 gpm, and that PVC pipe will be used. As shown in Table 1 , a 6-inch Class 160 PVC pipe will keep the velocity of flow below 5 fps. (Note that the 6-inch pipe can carry 458 gpm at a 5 fps velocity.) Assume that the water source is a pond and that the maximum expected water temperature is 90°F. Then, as indicated in Table 2, the Class 160 pipe pressure rating must be decreased to 120 psi. Finally, to avoid damage from water hammer, the operating pressure should not be allowed to exceed 72 percent

times the available pressure rating of 120 psi, or 86 psi. Thus, a 6-inch, Class 160 PVC pipeline will be adequate if the normal operating pressure in the pipeline does not exceed 86 psi.

The pressure rating for aluminum pipe is not sensitive to temperature. Thus, the 145 to 150 psi pressure rating of aluminum irrigation pipes would be adequate for most drip irrigation systems. Using the same example, a 6-inch aluminum irrigation pipeline would be adequate to carry 400 gpm at a velocity of less than 5 fps.

Other Considerations

An irrigation pipeline must be properly installed to function effectively. This publication has addressed only pipe sizing and selection. The buyer must be certain that the pipeline is properly installed and that air and pressure relief valves are installed as needed. See ASAE (1991a,b) or FIS (1991) irrigation standards for more information on proper pipeline installation.

Summary

Main pipelines are selected on the basis of both economic and hydraulic considerations. When these two criteria produce different results, the larger (more conservative) pipe size should be chosen. For annual crops requiring relatively few hours of pump operation per year, hydraulic considerations almost always control the pipe size selected by limiting the velocity of flow to 5 fps. Pipe pressure ratings must be adequate to withstand the normal operating pressure plus surge pressures. PVC pipe pressure ratings must be decreased for water temperatures above 73.4°F. Normally, the pressure ratings of Class 160 PVC or aluminum irrigation pipe are adequate for main pipelines in drip irrigation systems.

References

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Table 1.

Table 1. Flow rates that limit velocities to 5 fps for Class 160 PVC and aluminum irrigation pipe.

	Class 160 PVC		Aluminum Irr. Pipe	
Nominal Diameter (inches)	Inside Diameter (in.)	Flow Rate (gpm)	Inside Diameter (in.)	Flow Rate (gpm)
2	2.193	59	1.900	44
2.5	2.655	86	N/A[1]	N/A
3	3.230	128	2.914	104
4	4.154	211	3.906	187
5	N/A	N/A	4.896	294
6	6.115	458	5.884	424
7	N/A	N/A	6.872	579
8	7.961	777	7.856	756
10	9.924	1207	9.818	1181
12	11.770	1698	11.872	1727

[1]N/A: Not available in this size

Table 2.

Table 2. Temperature effects on PVC pipe pressure ratings.

Temperature Degrees F	PVC Pipe Derating Factor (multiplier)	Class 160 PVC Pipe Pressure Rating (psi)
73.4	1.00	160
80	0.88	141
90	0.75	120
100	0.62	99
110	0.50	80
120	0.40	64