

An Automated Single-Pipe Irrigation System

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ABSTRACT

AN automated single-pipe system was developed for both water conveyance and distribution to the field. The pipe has a flexible tube liner inside and is equipped with automated diverter valves. The valves direct water either through the flexible tube for conveyance to downstream pipeline sections or to the outside of the tube for distribution to the field through the pipe gates. The system is well suited for automating multiple-set gated pipe systems for both conventional and surge flow irrigation.

Head loss coefficients were determined for the valves and the pipeline for both the conveyance and distribution modes. Field installation procedures are described. The cost of the single-pipe system is about 60% of that for an automated double pipe system.

INTRODUCTION

Gated irrigation pipe can be used for both water conveyance and water distribution. When a single gated pipeline is used for a number of irrigation sets, one group of gates must be closed and another group opened at each irrigation set change. This requires considerable labor which can be reduced by automating the system. Most automated gated pipe systems use a separate supply pipeline for conveyance. The supply pipe is either buried or placed on the surface and has automated valves attached to risers or outlets located along its length. Each riser with its attached valve(s) serves one or two irrigation sets. The gated pipe is used only for distributing water from the riser to the field surface. This constitutes a double-pipe system.

Attempts have been made to automate the opening and closing of the pipeline gates which comprise one irrigation set so that they can operate as a unit (Haise and Fischbach, 1970). This would allow the pipe to function as a single-pipe system. Cables and rods connected to air cylinders were used to both open and close sliding gates. Frequent adjustments were necessary because temperature-related movement and deflection of the aluminum pipe and the rods or cables changed the gate openings. However, a similar more recent system described by Kessler (1982) apparently operates satisfactorily.

Haise et al. (1980) automated a single-pipe system by pneumatically controlling individual pipe gates. Different configurations of air pillows, pneumatic

cylinders and pillow disc valves were used to automate various types of outlets. Operational problems in the field included erosion at the outlets, insufficient flow adjustment to compensate for variable furrow intake rates, difficulty in changing set size, and movement and twisting of erosion control socks by the wind. These problems were not unique and are often encountered in automating furrow irrigation systems. The cablegation system developed by Kemper et al. (1981) is a single-pipe system which uses a moving plug attached to a cable inside the gated distribution pipe. The plug stops the forward movement of water in the pipe such that the water flows from openings near the top of the pipe into individual furrows upstream from the plug. Water is applied in a continuously moving set across the top of the field.

Reynolds (1968) described a single-pipe system referred to as "miniwai," used to irrigate sugarcane in Hawaii. This system combined both the conveyance and distribution functions into one channel or pipe. The concept was originally applied to an open channel but was extended to include pipelines also. The miniwai pipe or channel had outlets located in its bottom corresponding to irrigation furrow spacings. A flexible rubber membrane liner covered all of the flow openings that comprised one irrigation set. One end of the membrane was attached to the pipe at the downstream end of the set while the upper end was attached to a control rod. When actuated by an operator, such as an air or hydraulic cylinder, the control rod either pressed the rubber membrane down so that water could flow over the top of it or raised the membrane so that water could flow beneath it. During irrigation, water flowed beneath the membrane and was discharged from outlets in the bottom of the pipe. When the membrane was lowered, the outlets were covered and water was conveyed downstream. The pipe for this system was split lengthwise so that the edges of the membrane could be clamped between the two pipe half-sections. The system has not been commercially exploited because of the difficulty of installing the membrane inside a pipe by this means.

Because of the wide diversity in farm irrigation conditions, no one system can satisfy all situations. There is a need for methods to automate gated pipe systems. The objective of this paper is to describe a system which uses the miniwai concept modified to automate gated pipe systems to achieve labor and water savings.

DESCRIPTION AND OPERATION

Instead of splitting a pipe lengthwise to install the membrane liner, as in the original miniwai concept, a thin nylon-reinforced rubber tube is inserted into gated

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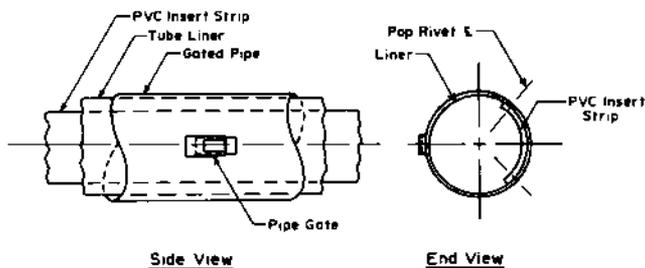


Fig. 1—Schematic drawing of a single-pipe section showing its components.

pipe as illustrated in Fig. 1. Water is diverted either through or to the outside of the tube liner by a diverter valve. In the irrigation mode, water is diverted through the tube to a downstream set or section of pipe, and flow from the gated openings is blocked or shut off by the tube liner. A diverter valve, installed at the upstream end of each set, is controlled by either a timer or an irrigation controller. The tube liner passes continuously through all of the pipe sections of one irrigation set. It is clamped to one side of the pipe opposite the flow openings with a PVC retainer strip inside the tube. This keeps the tube from migrating to the openings and closing them when water flows on the outside of the tube. Furrow stream sizes are adjusted with the outlet gates in the normal manner. Irrigation can proceed in either direction; however, the preferred sequence is to begin with the set at the far end of the pipeline and proceed sequentially upstream set-by-set to the head end of the pipeline.

The complete pipeline system assembly for one irrigation set consists of (1) gated pipe with outlet gates spaced according to local practice, (2) a thin-walled reinforced rubber tube, (3) PVC retainer inserts, (4) tube end clamps, and (5) a diverter valve and controller.

Pipe

Both aluminum and PVC gated pipe were used. One irrigation set will usually consist of several lengths of pipe, wherein the total set width is the same as would be used with regular gated pipe. The set width is usually in even pipe length increments. However, one pipe of a different length can be used in each set to make the set width compatible with the water supply.

Tube Liner

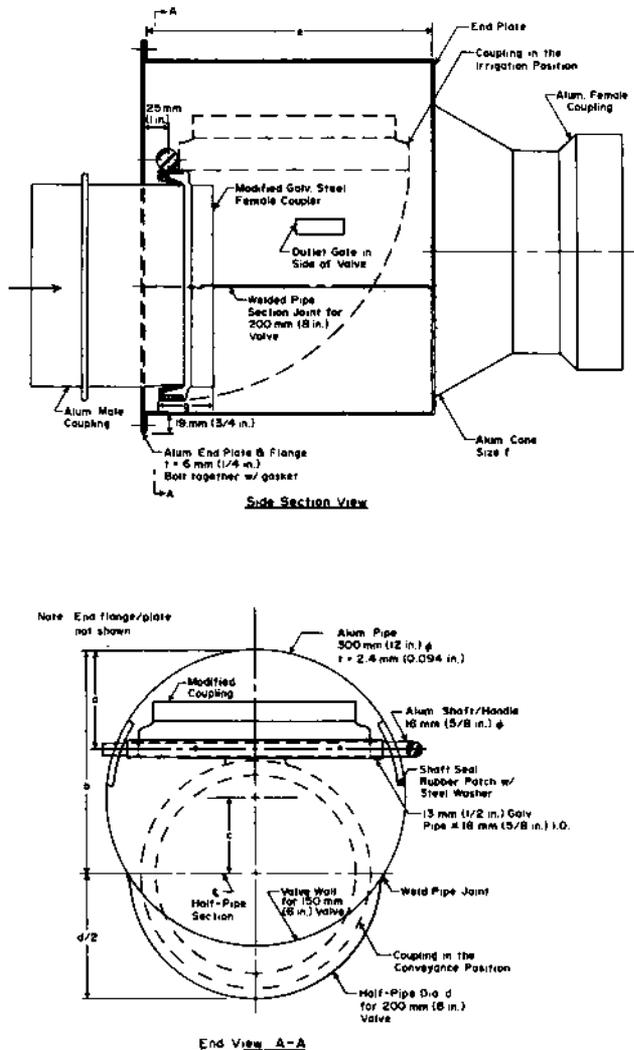
The tube liner was made from a light neoprene fabric material. This 220 g/m² (6.5 oz/yd²) material (approximately 0.2 mm (0.007 in.) thick) consists of a nylon supporting fabric impregnated with neoprene. The tube was formed by sewing the folded edges of a long strip of sheet material cut from a roll. A continuous tube is needed for each set with a length equal to the total length of pipe for one irrigation set plus 1 m (3 ft) extra for attaching the valve.

Retainer Inserts

Retainer insert strips were made by longitudinally cutting 9 m (30 ft) lengths of low pressure PVC pipe into thirds. The lowest cost PVC pipe available was used to minimize cost; thin-wall pipe is satisfactory for this purpose. For 150 and 200 mm (6 and 8 in.) diameters, 345 kPa (50 psi) pipe was the lowest cost. After insertion into the tube liner, both the retainer and liner were fastened to the inside of the pipe with pop rivets.

Diverter Valves

The primary element of the diverter valve is a shortened standard female gated pipe coupling attached to a pivot shaft as shown in Fig. 2 to which the upstream end of the tube is clamped. In the flow-through or conveyance mode, the coupling is positioned so that it fits over a short male pipe stub on the inlet end of the



Dimensions	Valve Size	
	150 mm (6 in.)	200 mm (8 in.)
a	57 (2 1/4 in.)	100 (4 in.)
b	—	230 (9 in.)
c	—	76 (3 in.)
d	—	250 (10 in.)
e	250 (10 in.)	330 (13 in.)
f	150 x 200 (6 x 8 in.)	299 x 259 (8 x 12 in.)
g	54 (2 1/8 in.)	54 (2 1/8 in.)

Fig. 2—Diverter valve showing (a) side view and (b) end view.

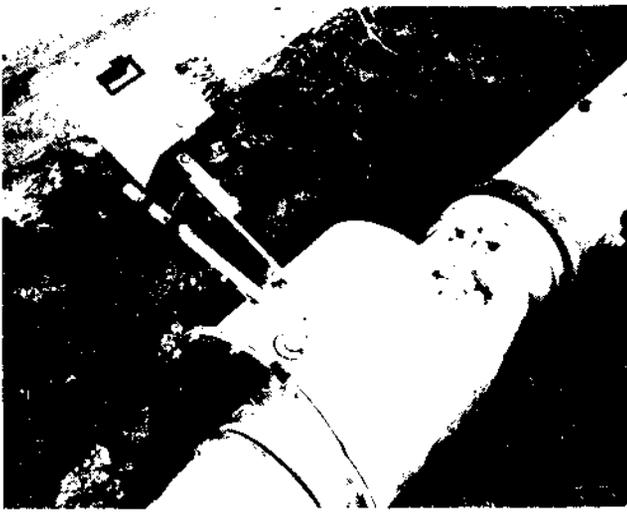


Fig. 3—Diverter valve with an electronic timer and mechanical release.

valve as shown in Fig. 2a. The gasketed joint is the same as that between two lengths of gated pipe. In the irrigation mode, the coupling and shaft are rotated approximately 90 deg so that the female coupling is "folded" to one side of the valve body out of the direct flow path and water is diverted to the outside of the tube liner. In this position, the tube is folded and stretched tight over the end of the female coupling to prevent water from entering the tube. The valve body is constructed, as shown in Fig. 2, from aluminum tubing with a wall thickness of about 2.4 mm (0.094 in.). Although only 150 mm (6 in.) and 200 mm (8 in.) valves have been used, valves for 250 mm (10 in.) systems can be similarly made.

The valve is operated by rotating the pivot shaft approximately 90 deg by either a spring or a pneumatic actuator. The spring, attached to the exterior arm of the shaft, rotates the shaft to its irrigation position when a latch is released. The spring-loaded shaft arm is returned to its latched position manually. When an electronic timer such as that shown in Fig. 3 is used, the latch is released mechanically. An electric solenoid is used to release the latch when an electronic timer like that shown in Fig. 4 is used.

Pneumatic actuators (Humpherys, 1983), such as the air cylinder shown in Fig. 5, rotate the pivot shaft to either position for automatic operation. The air cylinder shown in Fig. 5 is controlled by an electronic timer.

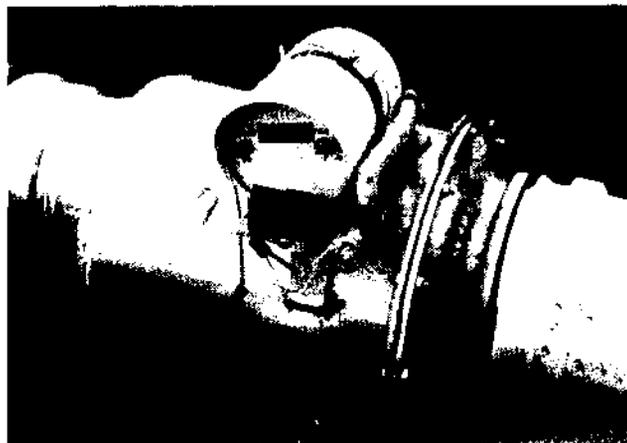


Fig. 4—Solenoid-released latch and electronic timer for a diverter valve.

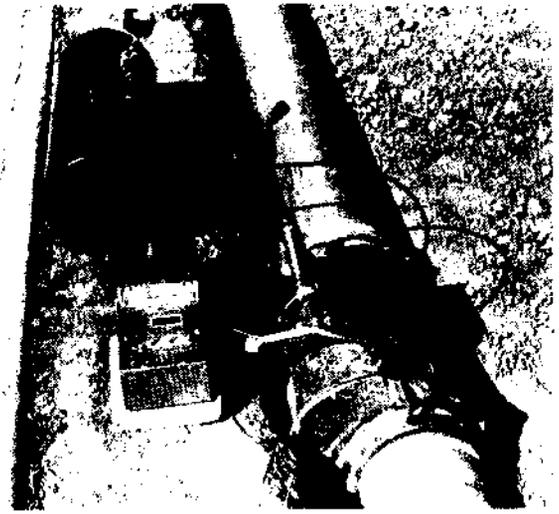


Fig. 5—Air cylinder actuator and electronic timer/controller for surge irrigation.

Clamps

The upstream end of the tub liner is clamped onto a fitting inside the diverter valve with an adjustable stainless steel clamp band.

The downstream end of the tube is clamped inside the end of the furthestmost length of gated pipe in each irrigation set. The ring-shaped clamp, constructed as shown in Fig. 6, fits inside the tube.

LABORATORY TESTS

Model System

Two models of the system were tested in the laboratory with 150 mm (6 in.) diameter 9 m (30 ft) long aluminum and PVC pipes placed in a flume. Each model was the same as a field system except that it was only one pipe length long.

Endurance test: An endurance test was conducted with the aluminum pipe to determine: (1) tube liner durability with repeated cycling and (2) whether the liner would develop leaks near the heads of pop rivets which hold it and the retainer insert in place. The system was cycled 2,140 times before failure occurred using an air cylinder to operate the diverter valve. Failure would have occurred much later except that at about 1,980 cycles,

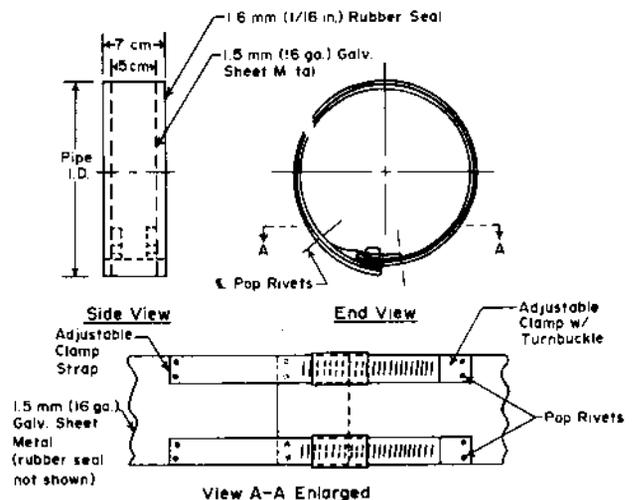


Fig. 6—End clamp for securing the tube liner in the gated distribution pipe.

the test was accelerated to hasten failure by increasing the flow to 38.8 lps (1.37 cfs) with a pressure head of about 76 cm (30 in.). This was an unusually large flow to distribute through the 17 openings in one length of pipe. A strong pressure surge was created at each cycle when the pipe suddenly filled. This would not occur in a full length pipeline in the field. The tube failed by tearing at its downstream end where it was clamped into the pipe. Although the liner was still functioning at its upper end, the neoprene coating had worn from the nylon supporting fabric immediately downstream from the female coupling in the diverter valve. This is where the liner experiences the most flexing. As a result of this test, the tube was folded back to form a double thickness near its end for all subsequent valve installations to minimize wear and extend tube life. There was no evidence of wear on the liner at any other location along its length. Service conditions for the liner inside the pipe are not as severe as those for this material when used for irrigation ditch dams where it has proven durable even though commonly subjected to exposure, temperature extremes and rough handling. Thus, this liner is expected to last about 10 years with the number of irrigation cycles experienced under normal irrigation practice. Liners made from other materials may have an estimated life greater or less than this.

Liner strength test: A pressure test was conducted to estimate the strength of the tube liner. The liner was installed in a short section of 200 mm (8 in.) diameter pipe and pressurized with the tube in the irrigation position such that the liner formed a closure at the downstream end of the pipe. The pipe and liner were subjected to a static hydraulic pressure of about 50 kPa (7.2 psi) for a period of three days without any adverse effects. The pressure was gradually increased to 130 kPa (19 psi) and then to 240 kPa (35 psi) at which point the end clamp was forced out of the pipe. Thus, the liner material easily resisted pressures normally used in gated pipe systems which are usually less than about 50 kPa (7 psi).

Hydraulic Tests

Hydraulic flow tests were conducted to determine the head and friction losses through 150 mm (6 in.) and 200 mm (8 in.) diameter valves and pipes in both the conveyance and irrigation modes.

Diverter valve head loss: The diverter valves were inserted between two lengths of aluminum pipe of corresponding diameters for the tests. Valve losses are usually expressed by a loss coefficient and the mean velocity head as shown in equation [1].

$$H_L = k_v \frac{V^2}{2g} \dots \dots \dots [1]$$

where

- H_L = head loss through the valve, m (ft)
- k_v = coefficient of head loss for a diverter valve
- V = mean flow velocity in the pipe, m/s (ft/s)
- g = acceleration of gravity, m/s² (ft/s²)

The head loss coefficient, k_v , was determined for each size valve in both the conveyance and irrigation modes from the test data using equation [1]. Coefficients for the 150 mm (6 in.) valve were 0.80 and 1.03 in the

conveyance and irrigation modes, respectively. Comparable values for the 200 mm (8 in.) valve were 0.95 and 1.34.

Pipeline loss: Friction losses for gated pipe with and without the tube liner in both the conveyance and distribution modes were determined. Friction losses for turbulent flow in irrigation pipe are commonly determined with the Hazen-Williams formula (American Society of Agricultural Engineers, 1981) which can be written

$$V = CR^{0.63} S^{0.54} \dots \dots \dots [2]$$

where

- V = velocity m/s (ft/s)
- R = hydraulic radius mm (ft)
- S = friction slope m/m (ft/ft)
- C = 0.0109 C_1 for SI units
- C = 1.318 C_1 for English units

where

C_1 = the Hazen-Williams resistance coefficient.

From equation [2], C_1 can be expressed as

$$C_1 = \frac{219.78 V}{D^{0.63} S^{0.54}} \text{ in SI units} \dots \dots \dots [3]$$

or

$$C_1 = \frac{1.817 V}{D^{0.63} S^{0.54}} \text{ in English units} \dots \dots \dots [4]$$

Values of C_1 were determined for the test conditions, which also include one coupling loss for pipe with a rolled end. The coefficient for 50 mm (6 in.) diameter pipe without a liner was 129; with a liner, the coefficients in the conveyance and irrigation modes respectively were 102 and 101. Corresponding values for 200 mm (8 in.) pipe were 125 without the liner and 106 and 104 respectively. Thus, the friction loss with the tube liner inside the pipe is about the same for both modes and pipe sizes and is greater than for a pipe without a liner. The flow capacity is reduced about 16 to 20% with the liner. The increase in friction loss in the irrigation mode, as represented by a decrease in C_1 from 125 to 104 for 200 mm (8 in.) pipe, for example, is not critical. The loss, inversely proportional to $C_1^{1.852}$, would increase about 1.5 times if all of the water were flowing through the full length of the set. However, since water is discharged through succeeding outlet gates along the set, a multiple outlet factor is applied to determine the actual loss. Multiple outlet factors (American Society of Agricultural Engineers, 1981) vary with the number of gates. For example, a system consisting of five pipe lengths with 0.76 m (30 in.) outlet spacings would have 60 outlets. The correction factor for this number of outlets is 0.34; therefore, the total headloss in the irrigation mode with the pipe liner would be 0.34 (1.5) = 0.5 times the head loss in the conveyance mode for unmodified pipe. This will also offset the greater valve loss in the irrigation mode. However, in the conveyance mode, the friction loss is about 1.4 times greater with the liner. Thus, for flows in the higher flow range for each size pipe, the next larger pipe size may be needed where head is limited.

FIELD ASSEMBLY AND INSTALLATION

The single-pipe system is considered a permanent installation and is assembled at the site where it will be used. After assembly, it is difficult to move. A work team of two people is required to assemble the system most efficiently. The field assembly and installation procedures are presented in the Appendix.

FIELD TESTS

A two-set system, 64 m (210 ft) long was installed on an experimental plot to evaluate the concept, test diverted valves, and to determine field assembly procedures.

A second system, 320 m (1050 ft) long, was installed for field testing in 1984. This system, completed in late summer, was successfully used for one irrigation in 1984 and five irrigations in 1985. It consists of seven sets, each of which is 45 m (150 ft) long and composed of five lengths of pipe. PVC pipe was used for one set and aluminum pipe for the other six sets. The aluminum pipe had old-style gates which leaked badly. One reason for using this particular pipe was to reclaim it; the tube liner covers the gates and prevents them from leaking. The seventh or downstream-most set consists of gated pipe only; the pipe liner is not needed because water is not conveyed past the last set. Field assembly was easier and faster with the PVC pipe than with the aluminum pipe, because of the rough edges on the metal couplings in the aluminum pipe.

Six diverter valves are used, one for each of the six uppermost sets. Four of the valves are spring-actuated, while the other two are pneumatically-actuated with air cylinders. The valves are programmed so that irrigation begins at the downstream set and moves progressively upstream. When reset, the valves are in the conveyance or flow-through mode, and when tripped, they are in the irrigation mode. Each valve controls irrigation in the set composed of the five lengths of pipe immediately downstream from it, except that the sixth valve also controls irrigation in the seventh set of regular gated pipe at the end of the line by controlling the water that is conveyed past the sixth set to irrigate the seventh or end set.

Two of the spring-actuated valves are controlled by electronic timers; one with a mechanical trip, Fig. 3, and the other with a solenoid actuated trip, Fig. 4. The other two spring actuated valves are used each as one of a pair with the pneumatically-operated valves which are controlled by electronic surge irrigation timers.

Irrigation can be surged by operating two sets as a pair, controlled by an electronic surge controller, Fig. 5. Water is diverted from one set to another by alternately changing the pneumatically-operated valve at the upper set from one position to the other while the spring-actuated valve in the next downstream set remains in the irrigation position.

Provision to temporarily spill a small part of the flow during set changes may need to be made with some systems since the upstream pipe cannot accept all of the water during the short time that the flow is changing from one side of the tube liner to the other. Most gravity systems can temporarily reject, or not accept, all of the water available, whereas, systems supplied by a pump will need to temporarily spill a small part of the flow for several minutes.

TABLE 1. COSTS PER UNIT LENGTH OF AN AUTOMATED SINGLE-PIPE SYSTEM.

System Component	Cost per unit length (1984)	
	150 mm (6 in.) dia	200 mm (8 in.) dia
	\$/m (ft)	\$/m (ft)
Gated pipe		
Aluminum	\$7.34 (2.24)	\$9.02 (2.75)
PVC	4.76 (1.45)	5.74 (1.75)
Tube liner	2.36 (0.72)	3.12 (0.95)
PVC retainer strips		
345 kPa (50 psi) PVC pipe	0.88 (0.30)	1.35 (0.41)
Labor	0.16 (0.05)	0.16 (0.05)
Pop rivets		
90-100 rivets per pipe length	0.10 (0.03)	0.10 (0.03)
Liner end clamp	0.20 (0.06)	0.21 (0.065)
Diverter valve		
Materials	\$2.30 (0.70)	2.85 (0.87)
Labor	\$3.28 (1.00)	3.28 (1.00)
Total	5.58 (1.70)	6.13 (1.87)
Timers/controllers		
Electronic timer, single function (Fig. 3), \$80 each	1.75 (0.53)	1.75 (0.53)
Electronic surge controller and accessories (Fig. 5) \$500 each	5.47 (1.67)	5.47 (1.67)
Labor		
5.6 man-hour (\$6/h)/45 m (150 ft)	0.74 (0.22)	0.74 (0.22)
TOTAL		
With aluminum gated pipe	\$17.46 (5.32)	\$20.83 (6.35)
With PVC gated pipe, no timer/controller	\$14.88 (4.53)	\$17.55 (5.35)
With electr. timer (Fig. 3)	\$16.63 (5.06)	\$18.30 (5.88)
With surge controller (Fig. 5)	\$20.35 (6.20)	\$23.02 (7.02)

SYSTEM COSTS

Although considerable labor is required to assemble the system, the labor cost per unit length is relatively low and was about 74 cents/m (22 cents/ft) at \$6/h. This is a one-time cost and represents only a small part of the total system cost. The amount of labor required to assemble a 45 m (150 ft) section using PVC pipe with a two-man work team was 5.6 man-hours (2.8 h/person). The time required to install timers or other valve control accessories was not included because this depends upon the type of controllers used. In most cases, these will be attached to the valve and will not require additional time. The labor requirements can be grouped into three general categories: (a) Assemble tube liner assembly and pull through gated pipe, approximately 2 man-hours, (b) attach liner assembly inside the pipe, approximately 2 man-hours, and (c) complete the assembly and connect the sections together, about 1 1/2 man-hours. This amount of labor was for an inexperienced team and should be less for an experienced well-coordinated team. Aluminum pipe with press-on steel fittings required 1/2 man-hour per section to smooth the steel couplings.

The system cost on a unit length basis determined from the cost of materials and labor for the 320 m (1050 ft) long experimental system is shown in Table 1. Costs for the tube liner would likely be less for production runs made specifically for this purpose. The costs shown for the timers and controllers are for those used in the experimental system. Since the pipeline for the set at the downstream end of the system consists only of gated pipe, there are n-1 sets of single-pipe sections, where n = the total number of sets in the system. Thus, the cost of a 365 m (1200 ft) system consisting of eight 45 m (150 ft)

sets of 200 mm (8 in.) PVC pipe (Table 1) would be:

	w/o timers or contr.	w/timer (Fig. 4)	w/surge contr.
1 gated pipe section @ \$5.74/m (\$1.75/ft)	262	262	262
7 single pipe sections	5,618	6,174	7,371
TOTAL	\$5,880	\$6,436	\$7,633

This represents a system cost per unit length of about \$16/m (\$4.90/ft) without timers and controllers, \$17.60/m (\$5.36/ft) with electronic timers and \$20.87 (\$6.36/ft) with surge controllers. The approximate cost of a comparable double-pipe system 365 m (1200 ft) long with four risers; 200 mm (8 in. diameter), 550 kpa (80 psi)* buried PVC mainline; and 200 mm (8 in.) PVC gated pipe without and with automated valves would be:

"Non-automated" double-pipe system cost w/o automated valves or controllers	\$7,240
Cost per unit length	\$19.80/m (\$6.00/ft)
With automated valves (4 @ \$550 ea) but w/o timers or controllers	\$9,440
	\$25.80/m (\$7.90/ft)

For conditions where 345 kpa (50 psi) buried pipe can be used, the cost would be about 95 cents/m (30 cents/ft) less. Costs for commercial controllers currently used in double-pipe systems range from about \$400 for single cycle to \$750 for a 3-cycle surge controller (4 required). A typical equivalent cabling single-pipe system of the same length would cost about \$11.50/m (\$3.50/ft) with similar type gated outlets. However, many cabling systems use different outlets which cost more.

SUMMARY AND CONCLUSIONS

The automated single-pipe system described in this paper allows gated irrigation pipe to be used both for water conveyance and distribution. The system consists of a gated pipeline with a thin-walled flexible membrane tube liner secured inside. A diverter valve at the upper end of each irrigation set diverts water either through the tube liner for downstream conveyance, or to the outside of the liner for distribution to the field through the gated openings. The pipe gates are adjusted at the beginning of the irrigation season with only small follow-up adjustments needed. In the conveyance mode, the gated openings are blocked by the tube liner. The diverter valves can be actuated by either return springs or pneumatic cylinder actuators controlled by timers or irrigation controllers. The system is considered a permanent system.

Laboratory tests were conducted to determine operational and hydraulic characteristics of the system. Flow capacity of the pipe in the conveyance mode with the liner inside was reduced about 16 to 20% for 150 and 200 mm (6 and 8 in.) pipe. With limited available head, a pipe one size larger than would be used for regular gated pipe may be needed in the higher flow ranges.

Assembly labor was a relatively small part of the total system cost. The initial cost of an automated single-pipe system is about 60% of that for automated double-pipe

systems with buried mainlines. A 200 mm (8 in.) diameter system 320 m (1050 ft) long was installed in 1984 near the end of the irrigation season and was successfully used for one irrigation in 1984 and five irrigations during 1985.

This system can be used for automating (a) both new and existing multiple-set gated pipe systems, (b) systems of relatively short length or those having flat or steep slopes which would be either not feasible or more costly to automate with cabling, and (c) single-pipe systems used for surge flow irrigation. It can be used to automate systems which use either aluminum or PVC pipe to conserve both water and energy and to reduce labor. The lack of flexibility in set width can be a disadvantage in some situations and may change from year to year if row spacing changes with a constant water supply.

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APPENDIX

After the materials are delivered to the field site, they are laid out and assembled in the following steps as illustrated in Figs. 7 and 8.

1. Tie the PVC retainer insert strips together with a heavy cord having a tensile strength of about 670 N (150

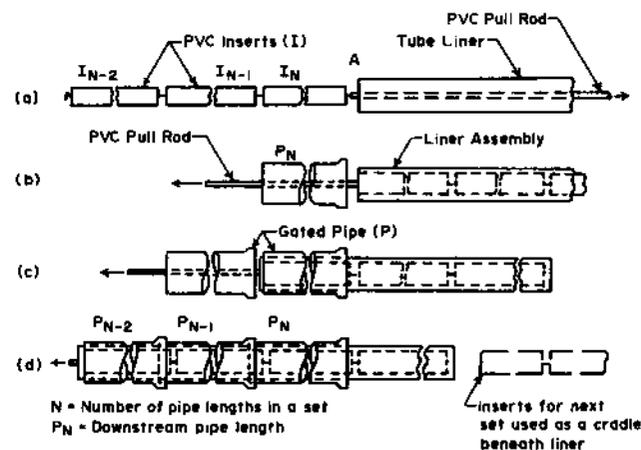


Fig. 7—Schematic drawing to illustrate field layout and assembly of a single-pipe system: (a) PVC insert strips before pulling into tube liner, (b) tube liner assembly ready to pull into the first length of gated pipe, (c) tube liner assembly in first pipe length, and (d) installation of tube liner assembly in the gated pipe.

*This class pipe was used because most contractors install this pipe to avoid the cost and inconvenience of water packing lower pressure pipe during installation as required by ASAE 376.1 and the USDA Soil Conservation Service.



(a)



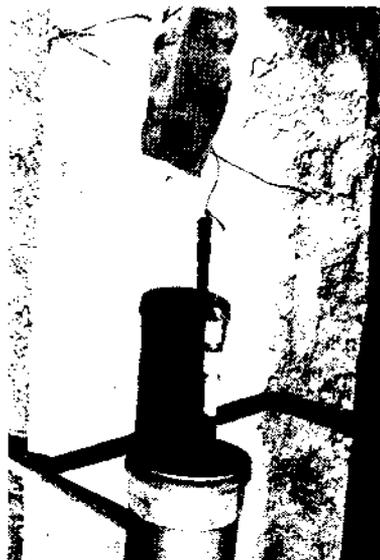
(b)



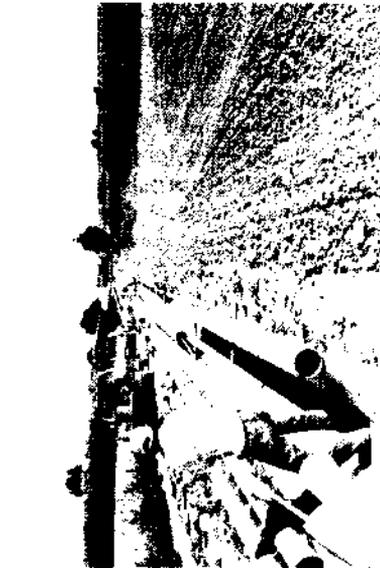
(c)



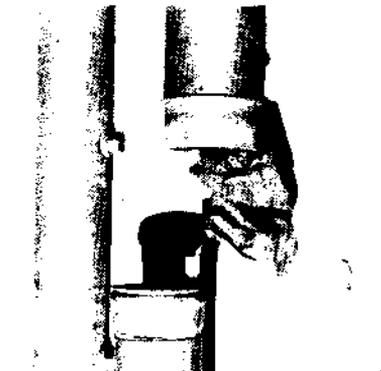
(d)



(e)



(f)



(g)



(h)



(i)

Fig. 8—Photos illustrating the procedures for field assembly of an automated single pipe system: (a) PVC insert strips tied together before system assembly, (b) pull rod inserted into tube liner as liner is unrolled, (c) pull rod inside the tube liner ready to pull inserts into the liner, (d) pulling the insert strips into the tube liner, (e) pull rod attached to liner assembly before entry into first pipe, (f) pulling liner assembly into gated pipe, (g) pull rod attached to liner assembly, (h) drilling holes for pop rivets, and (i) attaching insert and tube liner inside the pipe with pop rivets.

lb) as shown in Figs. 7a and 8a. Leave a space of approximately 40 to 45 cm (16 to 18 in.) between each insert since the inserts do not extend to the ends of the pipe or into the pipe coupling when they are inside the pipeline.

2. Lay the insert strips for the next succeeding set to provide a cradle beneath the tube liner to keep it off the ground. Several lengths of 19 mm (3/4 in.) PVC pipe cemented together is laid on the cradle. This pull rod is about 3 m (10 ft) longer than the irrigation set width and has a threaded cap on its upstream end.

3. Beginning at point A in Fig. 7a, unroll the tube liner and pull it over the pull rod, Fig. 8b.

4. With the tube liner, pull rod and PVC inserts in position, Fig. 8c, pull the interconnected set of inserts into the tube liner, Fig. 8d.

5. Extend a second pull rod, (19 mm (3/4 in.) PVC pipe), approximately 12 m (40 ft) long, through the first (downstream) pipe length and thread it onto a pipe cap attached to the liner assembly, (Fig. 8a). Pull the liner into the first pipe, Figs. 7b and 8f. Take special care to prevent damaging the tube if it is pulled through steel press-on couplings. These fittings sometimes have burrs, sharp edges, and protrusions that must be filed smooth before pulling the tube through them.

6. Insert the pull rod into the next pipe section, Fig. 8g, and pull the liner into the pipe as illustrated in Fig. 7c.

7. Repeat step 6 for each succeeding pipe length until the liner assembly has been drawn through all of the lengths of gated pipe that constitute one set. Extend approximately 1 m (3 ft) of liner material from the last pipe with which to attach the diverter valve.

A system of five or six pipe lengths, 45-55 m (150 to 180 ft) long, is a convenient length to assemble in one unit. The tube liner assembly and pipe must be dry before pulling the liner into the pipe; otherwise, the liner material adheres to the inside of the pipe.

8. Place the pipe with the liner upon wooden or cinder blocks to elevate it for final assembly. Remove every second outlet gate to provide access to the inside of the pipe; orient the pipe so that the outlets are on top. Center the liner assembly lengthwise on the bottom of the upstream-most length of pipe directly opposite the outlets. Attach the liner assembly to the inside wall of the pipe opposite the pipe outlets with 3 mm (1/8 in.) diameter pop rivets. The rivets are either 8 mm (5/16 in.) or 9.5 mm (3/8 in.) long, depending upon the thickness of the PVC retainer and pipe wall. Drill two holes from the outside of the pipe at each location for the pop rivets - one on each side of the pipe near the edges of the PVC insert. Hold the PVC retainer strip in place by a clamp or



(a)



(b)

Fig. 9—Installation of clamp in the downstream end of the pipe and liner: (a) clamp being installed, and (b) clamp installed.



(a)



(b)

Fig. 10—Installation of diverter valve: (a) tube liner folded back before valve is installed, and (b) valve installed and in the divert position.

a hand-held wooden stick while the holes are drilled and the pop rivets installed, Figs. 8h and 8i. A right-angle drive hand drill is convenient to use because of the limited space beneath the pipe. A stop is placed on the drill bit to prevent piercing the top side of the liner. Connect each succeeding pipe to the next upstream pipe with the tube liner assembly centered and pulled taut before riveting. Repeat these steps for each succeeding downstream length of pipe in the set. Take care to prevent relative movement between pipe lengths because this twists the liner. To help prevent this, the pipe joints can be riveted together.

9. Replace the outlet gates and install the tube end clamp in the the last pipe length of the set, Fig. 9. Fold the end of the tube back and to the outside to form a double material thickness before installing the clamp.

10. Attach the tube liner to the shifting collar inside the diverter valve, and install the diverter valve at the

upstream end of the set, Fig. 10. Remove burrs or sharp edges before the tube is clamped to the collar. The valve is easier to install if the pipe is oriented with its outlets on top. The body of the diverter valve must be separated to attach the tube liner. Diverter valves for a given installation, must be designed as "right" or "left" hand, depending upon the pipe/field orientation.

11. Connect the pipe assemblies for each set to one another to complete the installation. The pipe for each set is pushed or "jacked" lengthwise into position so that it can be coupled to the next upstream pipe. It can be pushed from its lower end by using either a crowbar or a hydraulic jack. After installation, the pipe must be plugged on both ends when not in use and the gates closed during the winter to keep rodents from getting inside the pipe. They will damage the tube liner if they have access to it.