Dual-Conduit Layflat Tubing for Water Conveyance and Distribution

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Abstract

Layflat tubing, or flexible pipe, is used for both distribution and conveyance of irrigation water and has many of the advantages of rigid surface irrigation pipe. The tubing described in this article is uniquely constructed with an interior membrane so as to form a dual-conduit tube. This permits the tube to be used both for water conveyance and distribution. Manual, semi-automatic, and fully automatic diverter valves were developed to direct water flow either to one side of the membrane for distribution through outlets in the side of the tube, or to the opposite side of the membrane for water conveyance to the next irrigation set(s). In the conveyance mode, the membrane covers the distribution outlets or gates in the side of the tube. To change irrigation sets manually, the irrigator either pulls or pushes a handle on a diverter valve to change the tube's operating mode. This eliminates manually opening individual gates for the next succeeding set and closing all of the gates of the previous set. Valve and coupler fittings were designed to be easily assembled and disassembled. The tubing system was satisfactorily tested and evaluated on three farms. The tubing was also tested for surge irrigation by controlling an automatic diverter valve with a surge controller. **Keywords.** Irrigation, Flexible pipe, Diverter valves.

Introduction

Layflat tubing has been used for a number of years for irrigation. Some of the first tests for this use were conducted at Utah State University (Hansen, 1954; Lauritzen, 1957; Humpherys and Lauritzen, 1964). The tubing has been fabricated from various materials such as canvas, vinyl, polyethylene, butyl, polypropylene, and each material laminated with a supporting fabric. Subsequent research on the hydraulics of layflat tubing, or flexible pipes as it is sometimes referred to in other countries, was conducted in Romania by Iconescu et al. (1965) and in Hungary by Bertok (1982). Most layflat tubing presently used in the United States is a low-cost, thin-wall, non-reinforced tubing with a one-year approximate life expectancy.

Layflat tubing is used both for water conveyance and, when equipped with irrigation outlets, for water distribution to individual furrows. It has many of the advantages of rigid surface irrigation pipe and can be used as a low-cost alternative to surface pipe in most situations. It is well-suited to divide fields with long lengths of run into shorter irrigation lengths. The tubing described in this paper is uniquely constructed with an interior membrane so as to form a dual-conduit tube which can serve two functions — water conveyance and distribution. When a single-conduit gated pipeline or length of tubing is used for a number of consecutive irrigation sets, one group of gates must be manually closed and another group opened at each irrigation set change; or, if irrigating from a ditch, siphon tubes must be moved and reset. This requires considerable labor which can be almost eliminated by using the tubing described in this article.

Reynolds (1968) described a unique system, referred to as "miniwai", for irrigating sugar cane in Hawaii. The system utilized a flexible membrane installed in an irrigation conduit — either an open channel or a rigid pipe. This allowed the conduit to serve both conveyance and irrigation functions (Redditt, III, 1969; Gibson, 1969). In the distribution or irrigation mode, water passed beneath the membrane and was discharged into furrows through flow openings in the bottom of the conduit. In the conveyance mode, water flowed on top of the membrane to the next irrigation set and pressed the membrane tightly over the flow openings to close them. Thus, by merely raising or lowering the upstream end of the membrane, irrigation could be automatically changed from one set to another without having to manually open and close the outlet gates. The pipe used in the Hawaiian system was split lengthwise so that the edges of the membrane could be clamped between the two reassembled pipe half-sections. The system has not been accepted or commercially exploited because of the difficulty of installing a membrane inside of a pipe. In an attempt to solve this problem, Humpherys (1986) devised a means of installing a flexible tube inside of a pipe. However, at present, the most practical and economically feasible method of utilizing the miniwai concept is to use layflat, dual-conduit, flexible tubing such as that described (Humpherys and Oest, 1990).

The purpose of this article is to describe dual-conduit tubing, its valves and accessories, field evaluation tests, and operational characteristics when used as a labor-saving system for irrigation.

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System Description

A typical field layout of a dual-conduit layflat tubing system is shown schematically in figure 1. The system can be served by any low-pressure water supply from a ditch, reservoir, or pump. Since this is a low pressure system, the normal supply pressure at the inlet should not exceed about 2 m (7 ft) of head or 20 kpa (3 psi). The system is normally installed such that the field slope provides all or part of the tube's hydraulic friction loss. Unless the water supply is clean, such as that from a well or reservoir, a trash/weed screen should be used to remove all debris that could plug the outlets or otherwise damage the tubing if it got inside. The system is installed similar to that for gated pipe such that the outlet spacings correspond to field furrow spacings as shown in figure 2. A diverter valve is required for each irrigation set except for the set at the downstream end of the line. Thus, where the number of irrigation sets is n, the number of valves required is n – 1. Diverter valves are used to change the operating mode of the system from conveyance to distribution or vice versa. As in the Hawaiian miniwai system, the tubing outlets are covered by the tube's interior membrane when in the conveyance mode. In the distribution or irrigation mode, water flows on the other side of the membrane and pushes the membrane to the far side of the tube so water can flow from the tubing outlets into individual furrows.

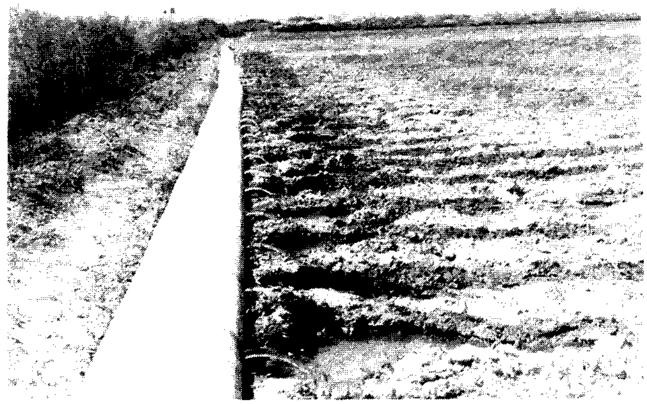

Figure 2–Photo of 300 mm (12 in.) diameter dual-conduit tubing in the distribution mode. The tubing replaced siphon tubes and the ditch seen on the left.

Tubing

While any suitable tubing material can be used, vinyl with a polyester or nylon reinforcing fabric is presently used. Other materials are also being tested to determine which would be the best for this application. The material contains an ultraviolet inhibitor to give the tubing an expected exposure life of approximately 5 to 8 years. The unique feature of the tubing is its fabrication. It is fabricated from one or two long, narrow sheets or strips of material whose edges are heat-sealed longitudinally so as to form a tube with one of the sheets forming an interior membrane as illustrated in figure 3. The tubing can be fabricated in any length; however, lengths exceeding about 46 m (150 ft) are difficult to handle, particularly with tubing 300 mm (12 in.) or larger in diameter. Tubing has been fabricated in diameters of 200 mm (8 in.), 250 mm (10 in.), 300 mm (12 in.), and 380 mm (15 in.) for field testing. The 380 mm (15 in.) diameter tubing is perhaps the largest feasible size for ease of handling and valve construction.

Flow outlets are located on one side of the tube as shown in figure 3. Those currently used are adjustable gates commonly used with thin-wall tubing. The original outlets consisted of a flow-regulating slide in a mating pocket which was sealed to the tubing. A round orifice or flow opening was punched through both the pocket and the tube. The slide was cut from a semi-rigid sheet of 1 to 1.5 mm (0.04 to 0.06 in.) thick polyethylene or similar material with a common plumbing gasket cemented to one side. The gasket formed a seat around the orifice when the slide was fully inserted into the pocket. This type of outlet was used during the first two years of testing to reduce the bulkiness of the tubing when rolled up for storage. However, the outlets leaked at some pressures and were not always sufficiently watertight. The tubing is currently folded in layers for storage and transport with the gates staggered between successive layers so that tubing bulkiness is not objectionable. The tubing is also easier to lay out in the field when folded rather than from a roll. Therefore, commercial outlet gates similar to that shown in figure 4 are used in lieu of the slide-type gates. Plain holes or orifices in the wall of the tube can be used for outlets in some cases where flow adjustment is not needed. However, it is usually necessary to adjust furrow flows to

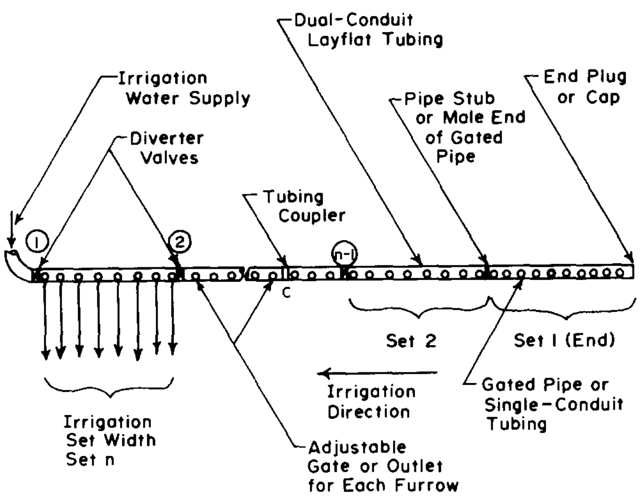

Figure 1–Diagram of a dual-conduit layflat tubing system field layout.

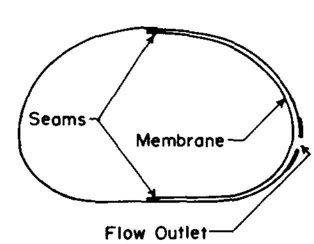

Figure 3–Cross-section diagram of layflat tubing illustrating its fabrication with an internal membrane.

Figure 4–Flow outlet with an adjustable gate.

accommodate different soil intake rates that occur from the first irrigation to the last and also the variations between tractor wheel-traveled and non-travelled furrows.

The tubing can withstand pressures greater than those normally used during irrigation. The preferred operating pressure head for irrigating with layflat tubing ranges from about 25 cm (10 in.) to 50 cm (20 in.). Pressures greater than this cause high velocity streams to be emitted from the tubing outlets; these streams cause erosion at the head of the furrows where water strikes the soil surface. Therefore, this is a low-head system wherein the tubing is not normally required to withstand pressures greater than about 20 kPa (3 psi). One length of 250 mm (10 in.) diameter tubing was temporarily subjected to about 70 kPa (10 psi) of pressure without damage and a 300 mm (12 in.) tube was used for three seasons with an operating pressure of about 14 kPa (2 psi).

Additional research is needed to obtain information for the hydraulic design of the tubing. At present, the tubing is designed with a Manning n of 0.014 to 0.015 or a Hazen-Williams coefficient of 100 to 95. Since the tubing is not fully round, the hydraulic radius rather than the tube diameter is used for design purposes. The cross-sectional area of the tube can be determined from the head/diameter ratio, H/D, by using figure 5 which was taken from USDA Technical Bulletin No. 1309 (Humpherys and Lauritzen, 1964). The value of this ratio will usually range from approximately 1 to 2.5 for which the corresponding tube area, a, varies from about 0.9 to 0.98 times the full-round area, A.

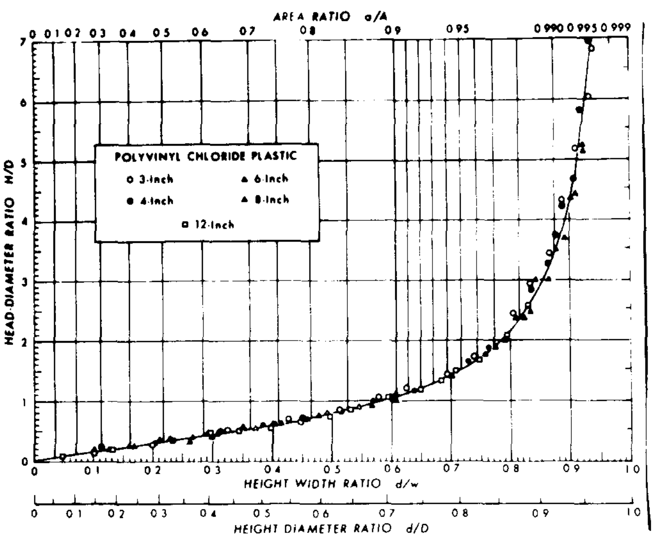

Figure 5–Area ratio for layflat tubing related to hydrostatic head, and tube height and width (taken from fig. 4, USDA Technical Bulletin No. 1309).

The cost of the tubing and its accessories is comparable to a gated pipe system of similar size constructed of aluminum or PVC.

Couplers

Couplers are used to connect two lengths of tubing, including the interior membrane. Diverter valves serve as couplers since they are installed in the system between the two lengths of tubing that constitute two irrigation sets. The tubing is usually fabricated, or cut to the required lengths which correspond to individual irrigation set widths, so that couplers (other than the diverter valves) are not normally needed. However, a coupler may occasionally be needed to connect two odd lengths of tubing where a valve is not needed or to splice a length of tubing that has been cut or separated to repair a damaged section.

A tubing coupler, figure 6, consists of a section of aluminum or PVC surface pipe about 0.3 m (12 in.) long with an interior membrane whose edges are cemented to the inside walls of the pipe on each side. Thus, when the membrane inside the coupler is attached to the corresponding tubing membranes at each end by fasteners, a continuous membrane, which extends through two lengths of tubing, is constituted. To facilitate dismantling or moving the semi-permanent tubing system, connections to the valve and couplers are designed so that the fittings can be easily disconnected from the tubing.

Velcro-like fabric fasteners are used to connect the interior membrane of the tubing to that of the coupler or valve. One matched fastener piece is attached to the end of the membrane inside of the tube while its mating fastener is attached to the corresponding membrane inside of the coupler or valve, as illustrated in views B and C-C of figure 7. The velcro fasteners are attached to the membranes by a superior quality super weatherstrip (Part No. 8, Master Chemical Corporation, Memphis,

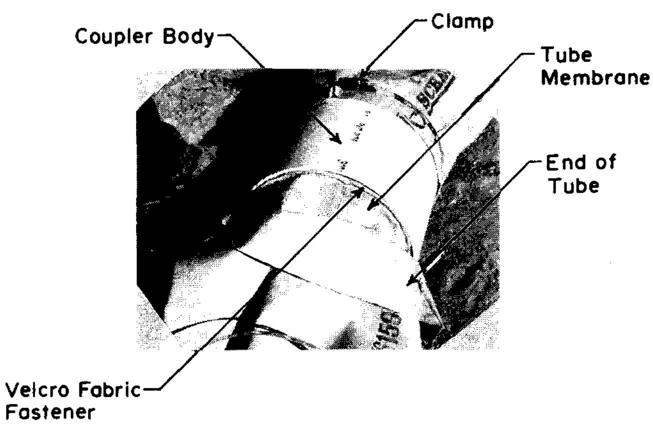

Figure 6–Interior membrane of a tube connected to that of a coupler with a Velcro-type fastener.

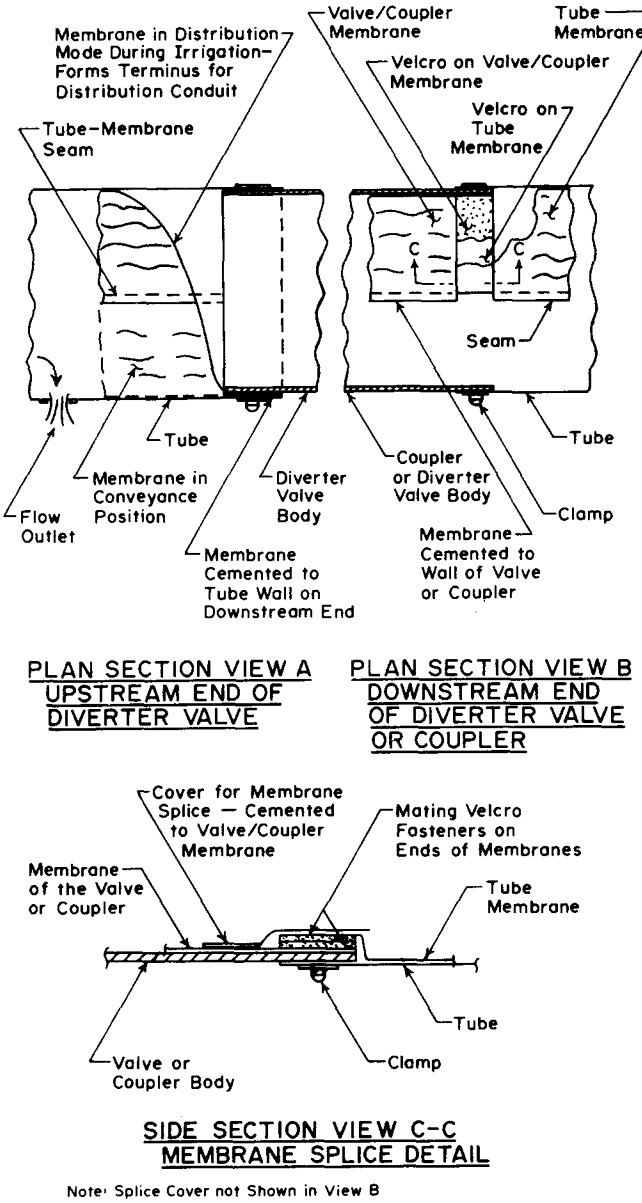

Figure 7–Diagram showing tubing connections to a coupler and diverter valve, and membrane connections using Velcro-type fabric fasteners.

Tennessee) adhesive which is allowed to fully cure for about two weeks before use or by both cementing and stitching with a non-rotting synthetic thread. The tube membranes are connected as shown at both ends of a coupler and at the downstream end of each valve. The end of the tubing membrane, with the fastener material attached, is cut away from the tube wall on each side so as to form a tongue-like membrane segment which extends about 5 cm (2 in.) into the end of the coupler or valve body. The end of the tube is folded back to allow the membrane segment to extend into the pipe section where the two mating fasteners are connected as shown in figure 6. The end of the tube is then unfolded and slipped over the coupler or valve pipe section and clamped. A strip of tubing material cemented to the coupler or valve membrane forms a flap or cover over the fastener connection as shown in view C-C of figure 7. Zipper connectors can also be used, but they are not as convenient.

VALVES

As noted previously, diverter valves are used to change the tube's operating mode from conveyance to distribution or vice versa. As shown in figure 1, a valve is needed for each irrigation set to redirect water from the field segment being irrigated to the next set or field segment to be irrigated. This is accomplished by diverting the flow of water inside the valve from one side of the interior membrane to the other. In the conveyance mode, water is conveyed to the downstream end of a given set or length of tubing, for example set n (fig. 1), where it enters the next downstream diverter valve, 2. Depending upon the position of valve 2, water is either conveyed past set n-1 to set n-2 downstream or is diverted to the furrows of set n-1. When all of the valves in the system are in the conveyance mode, water is conveyed past each set consecutively to the very end or furthest downstream set where it is discharged through outlets to the field. The end set is a single conduit used for distribution only. When a given valve is changed to the distribution or irrigation mode, water is diverted from the conveyance side of the membrane to the distribution side in the tubing immediately downstream from the valve. Thus, irrigation of that set begins and irrigation of the previous downstream set is terminated. Irrigation in the upstream direction from the far end of the line, as described above, is the preferred method rather than irrigating in the downstream direction. The tubing is attached to the upstream end of each valve so as to form a terminus for the tube's irrigation conduit which extends upstream from the valve as shown in view A of figure 7. This is done by cementing the downstream end of the tube's interior membrane to the discharge side of the tube (the side with the flow outlets). The tube is then slipped over and clamped to the upstream end of the valve body. The tubing is attached to the downstream end of each valve in the same manner as that described for couplers (views B and C-C, fig. 7).

Two different styles of diverter valves which accomplish the same function were tested. The valve bodies for both are made from short sections of aluminum tubing about 0.6 m (2 ft) long which have the same outside diameter as surface irrigation pipe and a wall thickness of about 2.5 mm (0.1 in.). The valves can also be made from PVC pipe containing U.V. inhibitor. The edges of the valve's interior membrane, of one-half circumference net width, are cemented to the inside walls of the downstream portion of each valve body with a superior quality super weatherstrip adhesive.

Most of the valves tested were manually operated and most systems will likely use this type valve (fig. 8). However, semiautomated and automated valves were tested as alternatives to manual valves where their use may be desirable and to evaluate design methods for constructing them.

Style 1 valve. The upstream end of the membrane inside this valve is attached to a flat stainless steel spring band mounted inside of the valve body with its ends diametrically opposite each other as illustrated in figure 9. The ends of the spring band are attached to stainless steel hinges which are mounted in anchor blocks attached to the

Figure 8–Photo of manual valve with a pull-push handle to change irrigation sets.

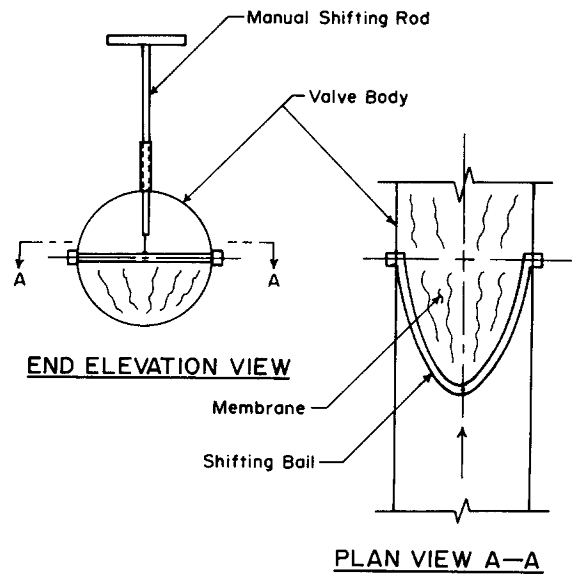

Figure 10–Schematic diagram (plan view) of a hoop-shaped bail shifter for style 2 diverter valve.

wall of the pipe. A shifting rod attached to the center of the steel band moves the band from one side of the valve to the other. The band becomes S-shaped as it moves from side to side, but at each end of its travel, it becomes straight again and conforms to the inside wall of the valve body. Thus, the end of the membrane, which is attached to the band, is moved from side-to-side to divert water from one side of the membrane to the other. A 9.5 mm (3/8 in.) diameter stainless steel pipe is used for the shifting rod. This slides over a 6 mm (1/4 in.) diameter brass guide rod which has its lower end attached to one side of the valve body (fig. 9). This style valve was used in the field only during the first year. Their construction requires close tolerances in fitting the spring band inside of the valve body, and facilities for maintaining these tolerances were not available. Consequently, some of the experimental valves leaked internally.

Style 2 valve. As shown in figure 10, the second style valve uses a bail in a hoop or alligator-jaw configuration to shift the membrane. One manual version uses an 11 mm (7/16 in.) diameter brass shifting rod to move the bail. Because the outer end of the bail swings in an arc, it is not aligned straight with the axis or line-of-motion of the shift rod throughout its entire travel path as can be seen in figure 11. Therefore, a 2.4 mm (3/32 in.) diameter, stainless steel spring wire attached to the end of the shift rod and to the bail accommodates the lateral movement of the bail along the arc of its travel path. Since the spring sometimes pulled out of the rod when it was held by set screws, it was subsequently silver soldered into a thin brass sleeve which was then threaded into the end of the shifting rod. The bail consists of two flat pieces of aluminum riveted together with the tubing membrane and rubber seals clamped in-between. The shape of the bail conforms approximately to one-half of an ellipse and makes an angle of 25° with the side of the valve body at both ends of its travel path.

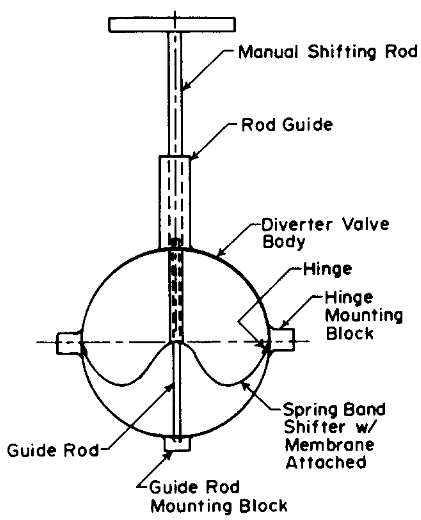

Figure 9–Cross-section diagram of a style 1 diverter valve with a stainless steel, spring-band shifter.

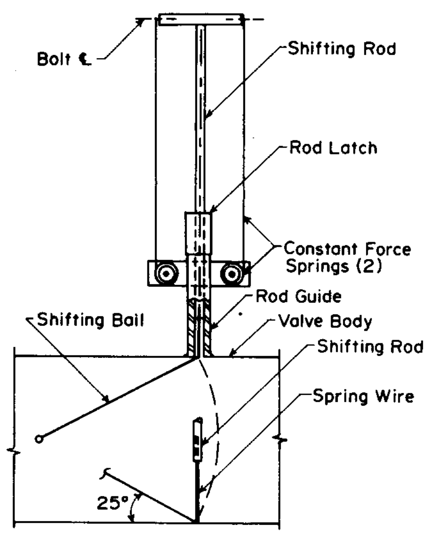

Figure 11–Cross-section diagram of a style 2 semi-automated diverter valve.

The second version uses either a manually operated arm or a 12 V DC gearmotor connected by reducing gears to the bail shaft on one side of the valve where the shaft extends through the wall of the valve body. For this version, the bail is designed stronger so as to withstand the shifting torque which is applied to only one side of the bail by the gearmotor. This version of the style 2 valve is preferred for all of the manual and semiautomated valves as well as the automated valves.

Semiautomated valves. Manual valves of both styles can be semiautomated by adding return springs, latch, and an electric solenoid operator to release a shifting rod or an arm from their manually-reset, extended conveyance position. One way that this was done is shown schematically in figure 11. A shift rod latch through which the shifting rod travels consists of a modified quick-connect air hose coupling. Small steel balls fit into a detent groove on the shifting rod to hold the rod in its extended position. A sliding collar on the air hose coupler is moved about 3 mm (1/8 in.) by an electric solenoid (not shown in fig. 11) to release the shift rod. The shift rod is moved to its distribution position by two constant-force springs attached to the rod handle as illustrated in the figure. The latch mechanism must be covered to keep it free from sand and debris. The intermittent duty solenoid can be controlled by any timer/controller which provides the appropriate energizing current. The valve is manually reset to its bypass or conveyance position prior to an irrigation. When energized by a timer/controller, the solenoid releases the latch and the shift rod is pulled to its distribution position by the springs to begin irrigation of the set immediately downstream from the valve. The valves can also be operated semiautomatically when driven by an electric motor as described in the next paragraph. Because labor requirements to operate this system are so small, the only time, in most cases, that semiautomated valves are needed is when set changes are made during the night.

Automated valves. Both style valves can be fully automated by using a 1.2 mm (3/64 in.) diameter, 7×19 stranded, stainless steel cable instead of shifting rods to move the membrane. The cable is pulled from side-to-side by a 12 V DC gearmotor. Number 25 roller chain attached to the ends of the shifting cable is driven by a sprocket on the motor's output shaft. The motor's rotational direction is determined by the controller.

The preferred method for automating the style 2 valves is to attach the gearmotor directly to one side of the bail shaft as noted previously. The type of controller used determines whether the valve will be operated semi-automatically or automatically. Motor-driven valves controlled automatically with surge controllers are being tested.

The automated valves are suited for intermittent or surge irrigation and this is the only application for which they have been used. Because the labor requirements for operating this tubing system are so small, the only justifiable reason, in most cases, to use fully automated valves is to utilize the surge concept.

Controllers

The semiautomated diverter valves tested were controlled by mechanical timers which are also used to control irrigation gates (Humpherys and Fisher, 1987; Humpherys, 1988). These timers are equipped with electrical switch contacts such that when they are manually reset, a 22 000 μ fd capacitor is charged from a 12 V battery. At the end of the set time period, the timer activates a switch to discharge the capacitor. The capacitor's electrical discharge energizes an electric solenoid which in turn releases a latch on the valve and allows the valve to change positions. Any timer or controller can be used which provides the appropriate energizing current for the solenoids.

The automated, motorized valves being tested are controlled by experimental electronic controllers previously developed for surge irrigation (Fisher and Humpherys, 1983). Since these particular controllers were designed to operate solenoids, a latching relay is used to interface a controller to the motor which operates the diverter valve. For test purposes, one automated valve is controlled by a commercial surge controller which also uses a 12 V electric motor to operate the valve.

Field Tests

The layflat tubing system was tested on two farmer fields in Idaho and currently (1991) on a 4-ha (10-ac) field near Firebaugh, California.

Farm I. The tubing on this Idaho farm consists of 98 m (325 ft) of 300 mm (12 in.) diameter and 182 m (600 ft) of 250 mm (10 in.) diameter tubing in six irrigation sets (fig. 2). The average set width is 47 m (154 ft) with an average slope of 0.0013. Water is supplied from a reuse pond with an available head of about 1.4 m (4.6 ft). The average flow rate is about 50 L/s (1.76 cfs). This first field test of the system replaced an open ditch and siphon tubes. Both manual and automated valves were used. The system in general performed satisfactorily during the first year except for first season start-up problems.

Some of the tubing cement failed after being immersed in water for a time, and the first valves leaked. Style 2 valves with a bail-type diverter mechanism were used the second and third years. After the first year's use, the farmer's confidence in the system was such that he filled the ditch formerly used to irrigate the field. Instead of moving and setting 50-mm (2-in.) siphon tubes many times during an irrigation, the irrigator now just pulls a handle on the manual valves to change an irrigation set (fig. 8) or programs the desired irrigation on an automated valve controller. This saves the irrigator considerable time and labor.

Farm II. Tubing for this test was 200 mm (8 in.) diameter and 137 m (450 ft) long with three manual valves and four irrigation sets. The set width was 46 m (150 ft). The relatively steep slope, approximately 1.5%, was somewhat greater than the optimum. This tended to cause nonuniform distribution from the outlets but was compensated for by individual adjustment of the outlet flows. The style 1 valves were replaced for the second year's tests. The basic concept of the dual-conduit tubing was shown to be satisfactory.

Farm III. Three 27 m (90 ft) lengths of 380 mm (15 in.) diameter tubing are being tested on a 4-ha (10-ac) field in California during 1991. This system uses two manual valves and is supplied with water from a farm reservoir at a pressure head of about 0.6 m (2 ft). This is the largest diameter tubing tested and is about the largest feasible size considering its ease of handling. The tubing was fabricated from two different reinforced vinyl materials from two manufacturers. One material has a polyester supporting fabric while the other has nylon. These will be observed under the high temperature conditions of the site for several years to determine if there are significant differences in the two materials for this application.

General Observations and System Operating Criteria

The velcro-type fasteners performed satisfactorily as a means of connecting the membrane of the tubing to that of a valve or coupler. No significant problems developed when the tubing was dismantled for winter storage and reassembled the following year. A very small amount of leakage occurs at the ends of the fastener, but this is not usually significant.

The adjustable slide-type outlets used originally were only satisfactory when the pressure head in the tube was about one diameter or more. At this pressure, the tube assumes a somewhat rounded, oval shape with a cross-section area of about 0.9 of the full-round area and the slides were easy to use and sealed fairly well. However, at lower pressures, the tubing became more flat and the slides (being near or on the sharp curvature at the edge of the tube) were difficult to adjust and leaked. Consequently, the slide-type outlets were replaced with commercial gates commonly used in thin-wall tubing; these are more satisfactory for low-head use.

Water must be admitted into the full length of the tubing at the time it is laid out in the field to hold it in place against wind. This naturally occurs if irrigation begins at the downstream set immediately following installation. Enough water usually remains in the tubing after an irrigation to prevent movement by the wind. The tubing needs to be placed in a shallow depression or furrow to prevent it from rolling. A bed with a uniform slope, desirable to prevent head and flow variations, can be prepared by using a radio-controlled trencher (Kincaid and Fisher, 1991).

Since the interior membrane is not needed for the irrigation set at the downstream end of a line, conventional gated pipe or single-conduit tubing can be used for this set. If tubing is used, its end can be closed by raising it to a height greater than the hydraulic grade line of water in the tube or by clamping it onto a pipe plug.

As with gated pipe, the tubing system performs best when used on relatively flat or mild slopes. Fields with considerable side slope cause the tubing to flow only partially full with shallow flow depths in upstream sections of tubing and excessive pressure in downstream sections. Thus, it is difficult to adjust the outlets to obtain uniform stream sizes. With layflat tubing on steep slopes, this problem can be handled by placing a log, short pipe, or similar means under the tubing to create a step at intervals to "stair-step" the flow downhill and thus maintain a more uniform head in the tubing. Uniform distribution from gated pipe is also difficult to achieve under these conditions.

In operation, when irrigation proceeds in the downstream direction, the tubing of the set being irrigated is shifted from the distribution mode to the conveyance or bypass mode. There is a time lag for this change to occur because the distribution conduit of the tube must be completely emptied through the flow outlets before water can pass through the conveyance or bypass side of the tube. This requires about 1 to 3 minutes or longer depending on the tube, stream, and flow opening sizes. This time lag does not occur during the opposite sequence change, as when irrigating in the upstream direction from the downstream end of the line, where the shift is from conveyance to the distribution mode. Therefore, operationally, sequencing set changes from the downstream set to the upstream set is preferred. The lag time will not be a problem where the tubing is supplied directly from a reservoir or canal such that the inflow can vary. However, it must be considered when operating motorized valves for intermittent applications where irrigation is alternated between two sets and the supply flow is fixed or cannot be temporarily rejected. Provision can often be made in the supply system to spill part of the flow, if necessary, during the short 1 to 3 minute time-period required to make the change.

Sediment accumulation in the tubing could be a problem in some cases where the irrigation water supply contains sediment. This usually occurs where canals and laterals receive irrigation runoff from upstream farms. Limited field experience to date indicates that this should not be a significant problem if the tubing is flushed before picking it up. Shifting the water alternately from one side of the membrane to the other during irrigation tends to keep sediment from accumulating; this can also be done just prior to picking up the tubing to flush remaining sediment from the tube. The tubing can also be rolled over to put the outlets on the bottom of the tube prior to flushing if large amounts of sediment have accumulated.

Summary and Conclusions

Layflat tubing was fabricated with an interior membrane and distribution outlets along one side so that the tubing can perform as a dual conduit to serve two functions — water conveyance and distribution. Diverter valves were developed to divert the flow of water from one side of the membrane to the other to change the tube's operating mode from conveyance to distribution or vice versa. In the distribution or irrigation mode, water is distributed through gated outlets to individual furrows, while in the conveyance mode, the interior membrane covers the outlets so as to shut a group of them off at one time. Once the outlet gates are adjusted, the only manual operating labor required is that to push or pull a handle on a valve to change irrigation sets from one field segment to another.

A dual-conduit layflat tubing system consisting of multiple sets or sections of tubing, each with a diverter valve, was successfully tested on three farm fields. The following conclusions are based on these tests:

1. The dual-conduit concept using layflat tubing is feasible and can be used as an alternative to open ditches with siphon tubes, gated pipe, and single-conduit tubing for irrigation.
2. Once installed, the system can eliminate most irrigation labor such as moving and setting siphon tubes and opening and closing outlet gates on gated pipe.

3. Diverter valves with a bail or alligator-jaw design performed satisfactorily to change the tube's operating mode.
4. Velcro-type fabric fasteners were satisfactory as a means of connecting two lengths of tubing membrane for assembly and disassembly of system components.
5. Sufficient water to secure the tubing against wind should be admitted into the tubing as soon as possible after field layout.
6. The tubing system should not be used or connected to a water supply source which has a static pressure greater than about 20 kpa (3 psi). To minimize erosion, operating pressure head in the tube should be less than about 50 cm (20 in.).
7. The system works best if irrigation begins at the downstream end of the line and progresses upstream.
8. The system can be used for surge irrigation if the supply flow can be interrupted or spilled during the valve change from distribution to the conveyance mode and the static pressure does not exceed the recommended operating pressure head, 50 cm (20 in.).
9. Where irrigation water contains sediment, the tubing should be flushed to remove accumulated sediment.
10. Commercial, adjustable outlet gates made for thin-wall tubing performed satisfactorily, whereas, the slide-type gate outlets used at first were not always satisfactory.
11. The system works best on relatively flat or mild slopes. Uniform distribution becomes more difficult to achieve as slopes exceed about 1.5%.

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