AUTOMATED SINGLE-PIPE SYSTEMS FOR CONVEYANCE AND WATER DISTRIBUTION

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Introduction

An advantage of gated pipe for irrigation is that it can be used both for water conveyance and water distribution. A single gated pipeline is normally used for a number of irrigation sets and this requires that one group of gates be closed and another opened at each irrigation set change. Since this requires considerable labor, different methods of automation are being developed to minimize the labor requirement. In most automated gated pipe systems, a separate pipeline is used for conveyance while the gated pipe is used only for distributing water to the field. The supply pipe is either buried or placed on the surface and has automated valves attached to risers or outlets located along its length. This constitutes a double-pipe system.

Several attempts have been made to automate the opening and closing of a group of gates of one irrigation set so that the gated pipe can be used as a single-pipe system. Fischbach (1) used both cables and rods connected to air cylinders to open and close sliding gates in four 30-foot lengths of 8-inch diameter aluminum pipe. When tested in the field, it was necessary to make frequent adjustments because movement caused by temperature related expansion, contraction and deflection of the aluminum pipe and the rods or cables changed the gate openings. A separate cylinder for each 12 gates and again for each 3 gates still did not prove satisfactory. He concluded that each gate or opening must be individually controlled rather than tieing them together mechanically.

Reynolds (7) described a single-pipe system, referred to as "miniwai," which was used to irrigate sugarcane in Hawaii. This system combined both the conveyance and distribution functions in one channel or pipe. The concept was originally applied to an open channel but was extended to include pipelines also. The pipe or channel had outlets located in its bottom corresponding to irrigation furrow spacings. A flexible rubber membrane was used to cover all of the flow openings that comprise one irrigation set. The downstream 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 at the upstream end of the set. 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 it so that water could flow beneath it. During irrigation, water flowed beneath the membrane and out of the outlets in the bottom of the pipe. When the membrane was lowered, it covered the outlets and water was conveyed to the next downstream set. The pipe used in this system was split lengthwise so that the membrane could be installed by clamping its side edges between the two pipe half-sections. The sides of the membrane were attached to the top of the channel in an open channel system. This was an effective means of automating a single-pipe system but has not been commercially exploited because of the difficulty of installing the membrane inside the pipe.

Pneumatically controlled outlets for a single-pipe system were used by Haise et al. (2). One such system used a metal transition box containing a miniature air pillow or bladder to control the flow from an Epp-Fly[1] type gated opening. When the pillow was inflated, it seated against the outside of the gate to stop the flow of water.

Another pneumatic valve developed by Payne (2) was installed on gated pipe in place of conventional manually operated gates. The valve used a miniature hydraulic cylinder and a spring-loaded disc type closure and seat. It extended into the pipeline and opened when the pressurized air cylinder pushed the disc from its seat. This normally closed valve used a spring to return the disc to its seat when the air cylinder was depressurized. These valves were also installed in a reinforced butyl rubber flexible pipe or tube but neither installation was entirely satisfactory. Perhaps the most successful automated outlet was a pillow-disc valve which was installed at each gated pipe opening. This valve consisted of a miniature pneumatic pillow which, when inflated, forced a disc against the valve seat to close the valve. The valve was a normally open valve and automatically opened when the pneumatic pillow was depressurized. Operational problems in the field included erosion at the outlets, insufficient flow adjustment to compensate for variable furrow intake rates, inability to change set size and movement and twisting of erosion control socks by the wind. Most of these and other problems associated with all of the systems that have been tested are inherent in automating a furrow irrigation system.

Some of the problems associated with automating gated pipe systems are overcome by the recent development of the cablegation single-pipe system by Kemper et al. (5). This system is described in another paper to be presented at this conference.

Equipment and controls are now becoming more readily available for automating existing double-pipe systems having buried pipeline equipped with risers. However, there is a need and a large potential use for a simple

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[1]Company and trade names are shown for the benefit of the reader and do not imply endorsement or preferential treatment of the company or products noted.

low cost means of automating both existing and new single-line gated pipe systems. The three systems described in this paper are further attempts to automate single-pipe irrigation systems.

Flo-Thru Gated Pipe System

Improvements in irrigation systems are being made in the Grand Valley of Colorado as one component of the Colorado River Basin salinity control project. These improvements include the semiautomation of on-farm irrigation systems. One system used quite extensively since 1979 is the "flow-thru" gated pipe system. This is a single-pipe system designed by technicians of the Soil Conservation Service (6,8). The concept, applied to gated pipe, is an extension of the concrete-lined ported ditch system which is installed on a "stair-step" grade.

System Description

The flo-thru gated pipe system consists of a single gated pipeline installed in a series of sections on a stair-step grade at the upper end of a field as shown in Figure 1. Each section comprises one irrigation set and has a stair-step drop at its lower end. A semiautomatic valve is located downstream from the drop. During irrigation, water flows as pipe flow from openings in a downstream operating section, and as open channel or free surface flow in all of the upstream pipe sections or sets.

Design and Operation

Pipe size and slope vary with the field cross slope, available water supply and furrow stream size. The range of field slopes within which the system can be used is approximately 0.004 to 0.02. A minimum slope of about 0.004 is necessary to provide the required amount of drop at the end of each section. Drop heights are standardized at 0.4 foot as much as possible. However, drops of 0.3 foot are sometimes used with small streams. The flow range for most systems varies from about 0.5 to 1.5 cfs. Systems can be designed for flows smaller than 0.5 cfs, but farm stream sizes are usually larger than this. Flows larger than 1.5 cfs require larger pipes and steeper field slopes than are usually available.

A program has been developed for a TI-59 calculator to simplify system design (8). Input parameters include supply stream size, furrow stream size, total length, and total head or elevation difference. The pipe is designed so that the free surface flow occupies about 60 to 75% of the pipe cross sectional area. The pipe is placed in the field with the gates approximately 30 degrees from vertical so that the water flows beneath the openings as free surface flow for all downstream sets. This requires approximately one increment larger pipe size than would be used for a conventional gated pipe system. With the aid of the programmed calculator, the required pipe diameter and slope and the number of sets are determined for the given field conditions.

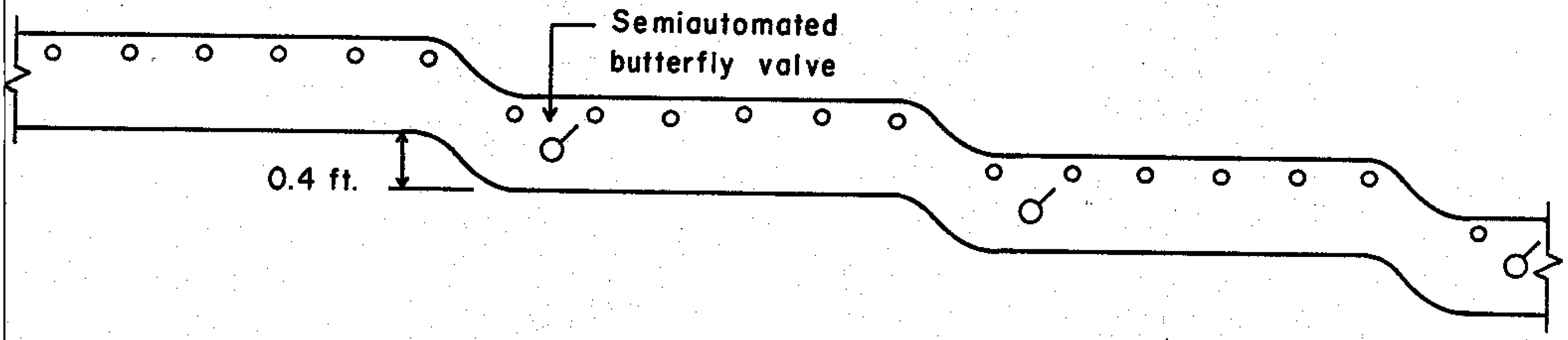

Figure 1 - Schematic diagram of semiautomatic "flo-thru" gated pipe irrigation system.

The valve located at each drop either opens or closes to allow irrigation to proceed to the next set in the sequence. The irrigation sequence proceeds in the downstream direction when the valve is of the normally open type which releases water downstream at the end of its timed period. Irrigation proceeds in the upstream direction if the valve is a normally closed type that "checks" the water in the pipeline when it closes at the end of its timed period. Irrigation in the downstream direction with a normally open butterfly valve is preferred. Some of the earlier systems used a normally closed check valve which created undesirable pressure surges in the pipeline and caused pipe movement when it closed suddenly. Concrete pillars or pipe supports such as that shown in Figure 2 are designed to prevent pipe movement and to maintain pipe grade if the pipe is removed and than later replaced. The pillars are used at each drop, in the center of a section, and as needed so that the distance between supports does not exceed 60 feet.

Soil erosion is a problem associated with the pipe gates being located near the top of the pipe. An energy dissipating means is needed to prevent erosion where streams of emitted water strike the soil surface. Socks such as those shown in Figure 2 are often used. However, because of the upturned angle at which they are mounted, they kink, and water sometimes cannot flow through them. An alternative practice is to place 5- to 6-foot wide plastic sheets on the furrow side of the gated pipe. A more effective method is to use energy dissipating screens[2] located over the gate opening such as that shown in Figure 3.

Valves

A butterfly valve is used at each drop to release water to the next downstream set. The valve is preferably located just below the drop, or it may be installed within the drop. Some of the first butterfly valves were operated with tension springs. However, the improved torsion spring operated valves developed later (4) and shown in Figure 2 are now being used. A 24-hour mechnical timer is used to trip the valve. Valves in 6-, 8-, and 10-inc sizes are now available commercially.[3]

An automated valve is usually used at the inlet end of the flo-thru system to divert water from the supply source into the pipeline. Pneumatically-operated butterfly valves or water-operated valves (3) may be used for this purpose as well as the spring-operated valves.

Modified Flo-Thru System

A technique similar in principle to the flo-thru gated pipe system is sometimes used in the Magic Valley of southern Idaho. Gated pipe is placed

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[2]"Softflow" screens are available from Gary McClellan, Rt. 2, Box 303, Vale, Oregon.

[3]Irrigation Systems Co., Fruita, Colorado 81521.

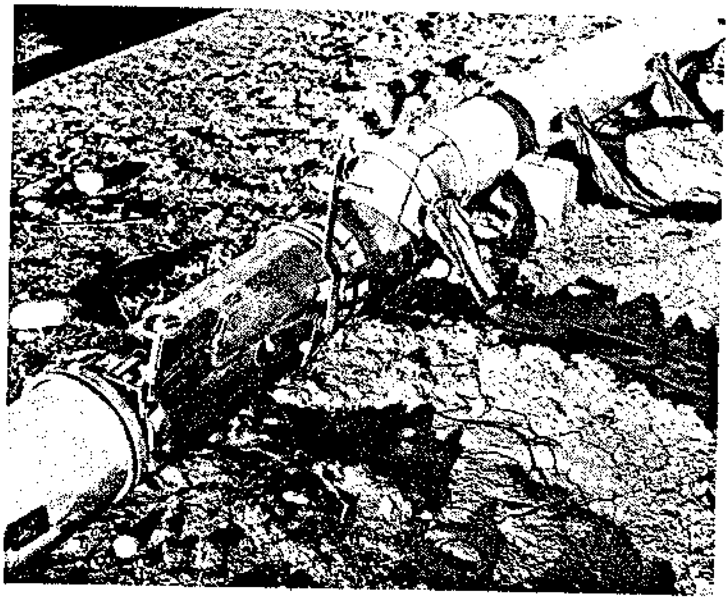

Figure 2. Semiautomatic torsion-spring operated butterfly valve used in a flo-thru gated pipe system in the Grand Valley of Colorado.

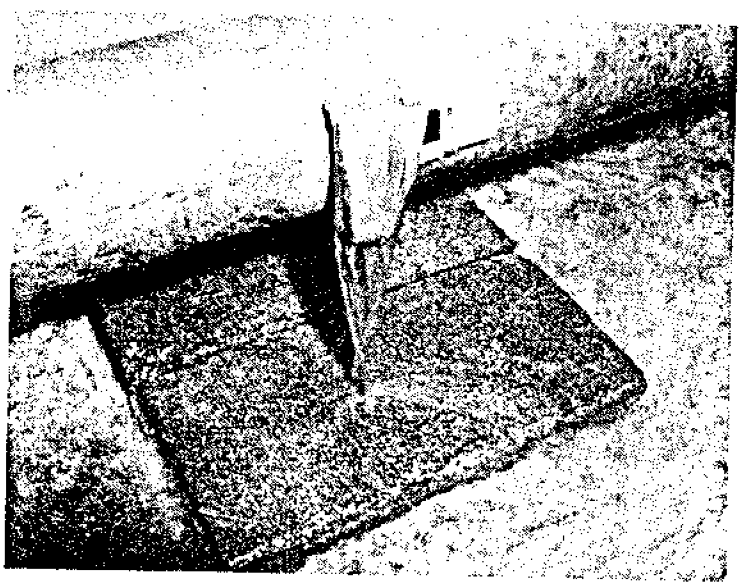

Figure 3. Soft-flo energy dissipating screens used with gated pipe.

in the field with the gates located at the top of the pipe. A homemade pipe-turning tool is used to rotate or roll all of the lengths of pipe that comprise one irrigation set to turn the gates downward. The pipes are rolled or turned slightly different from each other as needed to adjust the amount of flow from the gates. The next set is made by turning the gates downward in the same manner while the gates of the previous set are turned upward to allow water to pass beneath them to the next downstream set. This procedure is continued to the last set where the gates in the end pipe length are sometimes turned to the bottom of the pipe so that an end plug is not used. This technique requires less labor to make an irrigation set than to adjust individual pipe gates. It also prevents sediment buildup in the pipes at the end of the line.

Single Pipe with Pneumatically Controlled Outlets

System Description

An experimental 900-foot single-pipe system with pneumatically controlled outlets was installed in a field near Kimberly, Idaho in 1980. This system, shown in Figure 4, uses 6-, 8-, and 10-inch PVC and fiberglass pipe having one outlet for each two furrows. The outlets are installed in the PVC pipe by first drilling an undersized hole and then using the forming tool shown in Figure 5 to enlarge the hole. The area surrounding the hole is heated with a heat gun to soften the pipe material before inserting the forming tool. The pipe material surrounding the hole forms an inward protruding lip as the hole is enlarged. This lip supports the outlet pipe and provides a surface contact area for cementing the outlet into the hole. The outlet, a 6-inch long, 1½ inch nominal diameter PVC pipe, is inserted into the hole and cemented with an epoxy.

The complete outlet, shown in Figure 6, consists of the outlet pipe with an attached tee, a rubber air pillow or bladder inside the tee, a small butterfly flow adjusting valve and corrugated PVC tubing for erosion control. The rectangular miniature air pillows, made special from 1½-inch diameter tubing are 5 inches long, with the ends vulcanized closed and a tire inner tube type valve stem attached. The bladders are installed in the tee opposite the side inlet leg of the tee so that when the bladder is inflated, it closes the inlet opening to the tee. For wide furrow spacings, only one side of the tee may be needed while the other side is capped as shown in Figure 6. All of the outlets comprising one irrigation set are connected in parallel with ¼-inch O.D. polyethylene air tubing. This size tubing is also used as a manifold line from the compressed air source to the groups of outlets comprising the individual irrigation sets. Irrigation proceeds from one set to another in sequence as the air pillows of one set are exhausted to begin irrigation while those of the preceding set are inflated to terminate irrigation.

Controls

During 1980, the first year that the system was used, an eight horsepower self-start gasoline engine was used to drive the air compressor and to

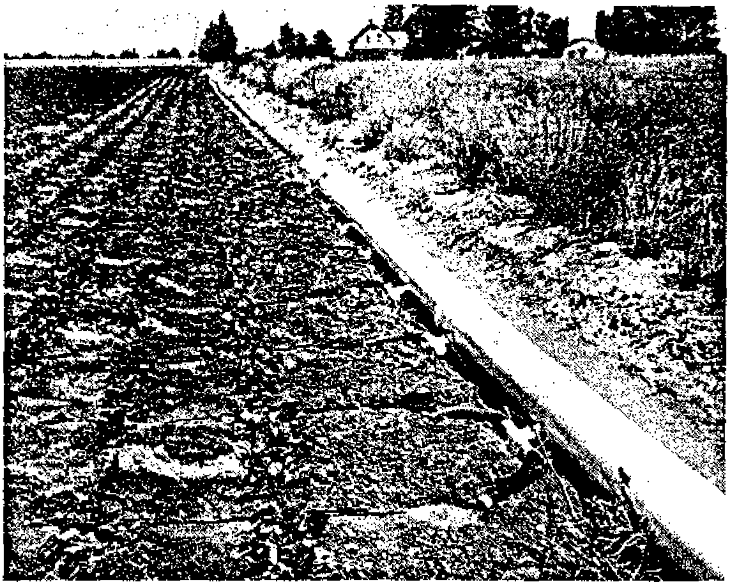

Figure 4. Single-pipe irrigation system using pneumatically controlled pipe outlets.

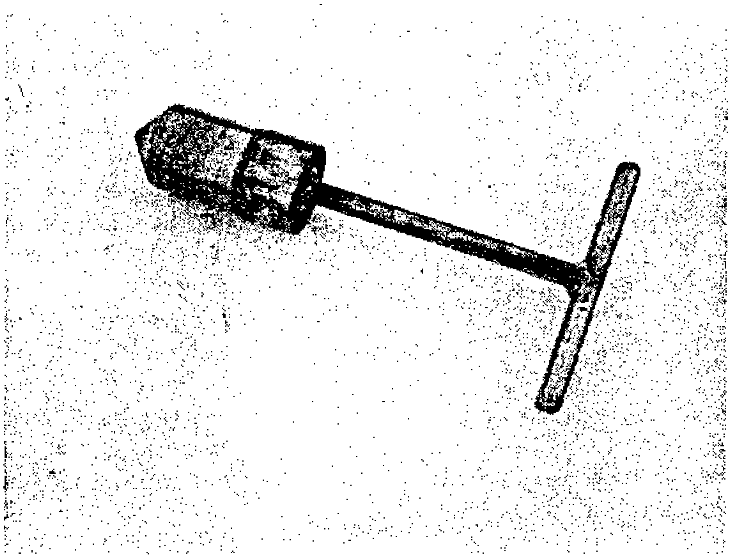

Figure 5. Forming tool used to make holes in PVC distribution pipe for discharge outlets.

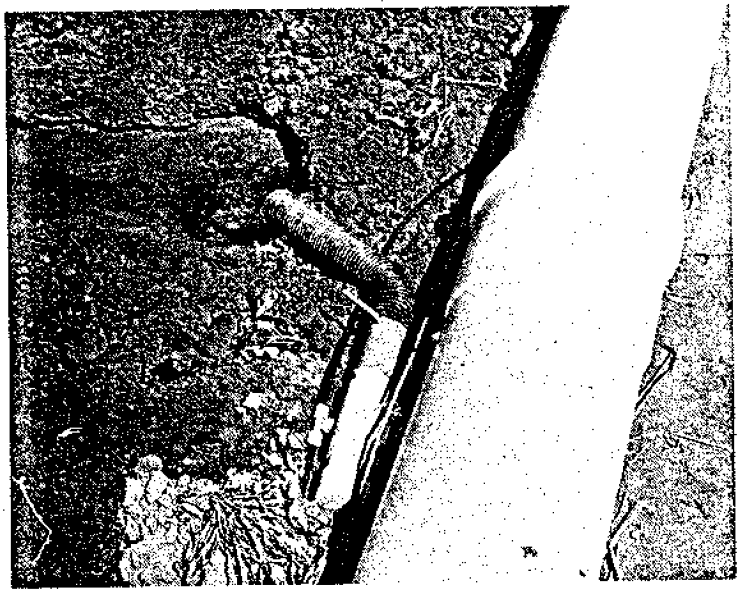

Figure 6. Discharge outlet for single-pipe irrigation system showing a butterfly flow-regulating valve, PVC corrugated tubing used for energy dissipation and tubing which supplies air to an air pillow inside the outlet tee.

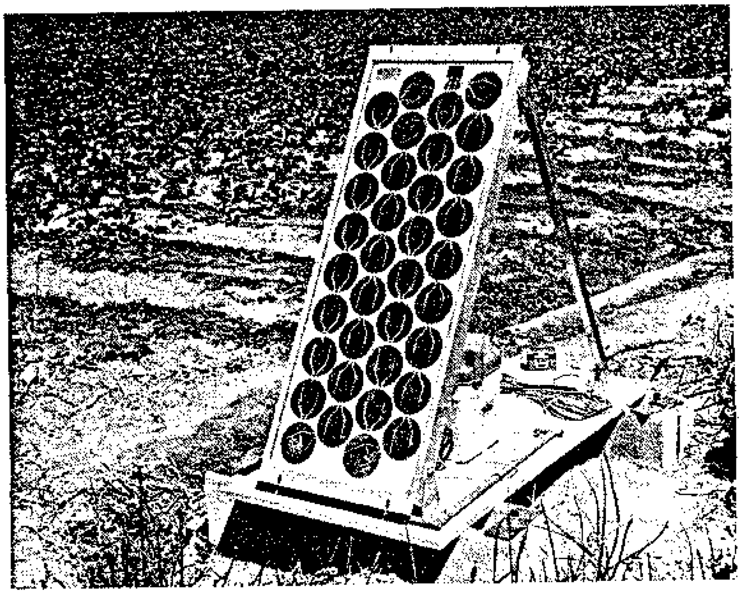

Figure 7. Photovoltaic solar cell battery charger used to provide power for an irrigation controller.

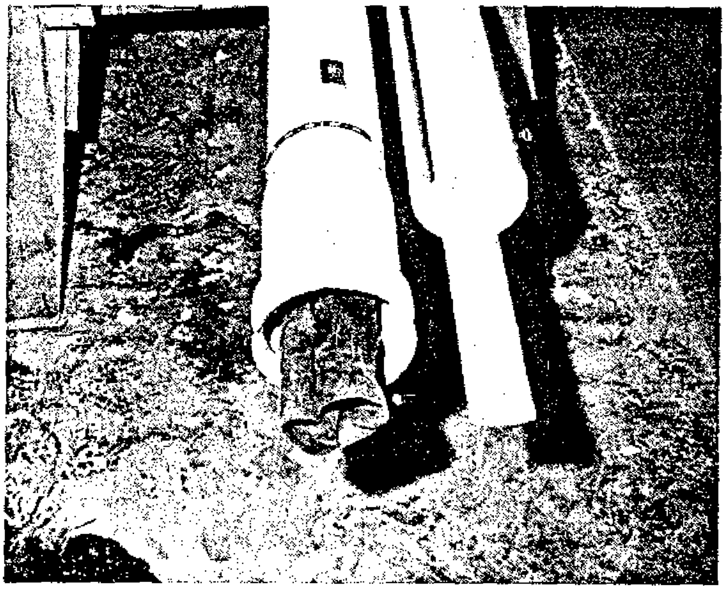

Figure 8. Flexible, nylon-reinforced rubber tubing inside the distribution pipe of a modified miniwai irrigation system. A PVC retainer strip similar to that installed inside of the flexible tube is also shown.

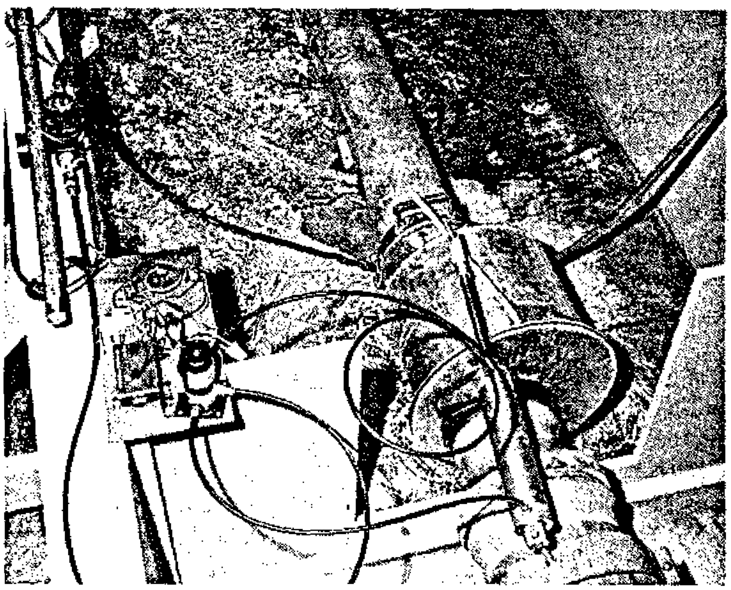

Figure 9. Endurance tests with a modified miniwai irrigation system being conducted in the irrigation laboratory using a diverter valve operated by an air cylinder.

charge 12-volt storage batteries used to power the irrigation controller. This was not satisfactory because the self-start engine was unreliable. During 1981, the compressor was located where electrical power is available and is now driven by an electric motor. The photovoltaic solar cell battery charger shown in Figure 7 was installed to provide power for the solid state controller located in the field. Air for inflating the air pillows is regulated from 8 to 9 psi.

An experimental, solid state irrigation controller is being developed for use with this system; however, it is not yet fully operational. Therefore, irrigation set changes were made manually by using a 22½ volt dry cell battery to operate the latching solenoid valves which control the air supply to the pillows of each irrigation set.

Operation

The experimental system has been used for two years with no major problems. None of the air pillows failed during this period. Some difficulty was experienced the first year with the latching solenoid valves unlatching unexpectedly. This was corrected by installing different springs supplied by the manufacturer.

Because the farmer uses small furrow stream sizes, the butterfly flow regulating valves sometimes became clogged with snails and trash during the first year of operation. Since the valves are used for flow regulation and are not required to completely shut off the flow, a vee notch was cut in one side of the butterfly disc prior to the 1981 season. The notch was large enough to discharge most of the required flow while valve adjustment provided the balance of the flow needed. The notch provided a wall-to-wall distance large enough to pass debris that was in the water and solved the clogging problem.

The flexible corrugated tubing attached to each outlet directed the flow into each furrow and was effective in breaking up the water jet as it emerged from the flow regulating valve so that erosion was effectively controlled.

Modified Miniwai System

System Description

An experimental single-pipe system using the miniwai concept is being developed at the Snake River Research Center. Both laboratory and preliminary field tests were conducted with prototype systems. Instead of splitting a pipe lengthwise as in the original miniwai concept, a nylon reinforced flexible rubber tube is inserted into a conventional gated pipe as shown in Figure 8. Flow is diverted either into, or on the outside of, the flexible tube by a diverter valve. In the irrigation mode, flow is diverted to the outside of the flexible tube and flows from the gated pipe openings. When the pipe is used for conveyance, the flow is diverted into the tube through which it is conveyed to another set or section of pipe.

Flow from gated openings is automatically shut off when water is diverted into the tube. A diverter valve is installed in the section of pipe at the upstream end of each set.

The downstream end of the tube is clamped into the pipe so that flow can pass through the tube but not around it at that point. The flexible tube passes through all of the pipe sections of one irrigation set. A retainer strip cut lengthwise from a thin-wall PVC pipe is inserted into the tube to hold it to the side of the pipe opposite the flow openings. Otherwise, the tube migrates to the openings and closes them when water is flowing on the outside of the tube. The retainer strip is fastened to the pipe opposite the flow openings with pop rivets and "clamps" a portion of the tube between it and the wall of the pipe.

Except for endurance tests conducted in the laboratory, the diverter valves were operated manually during the system's development stage. Either pneumatic or spring operators will be used to operate the valves during the 1982 field tests.

Laboratory and Field Tests

A number of different diverter valve models were built and tested in the laboratory during the process of developing a satisfactory and functional diverter valve. The final prototype valve shown in Figure 9 is relatively simple and performed well in both laboratory and preliminary field tests. The primary element of the valve is a standard female pipe coupling. The tube is fastened to the downstream end of the coupling and is connected to the upstream inlet pipe when the coupling is positioned so that it fits over the male end of the inlet pipe.

Two different prototype models were tested in the laboratory after the diverter valve design was finalized. The tests were conducted with both PVC and aluminum 6-inch gate pipe. An endurance test was conducted with the aluminum pipe to evaluate the durability of the tube liner with repeated cycling. We wanted to determine where the wear points are, if any, and whether the tube would develop leaks near the heads of the pop rivets. The system was automatically cycled approximately once every minute using an air cylinder to operate the diverter valve, Figure 9. The system was cycled 2140 times before failure occurred at the downstream end where the tube liner was clamped into the pipe. There was no evidence of wear at any other point on the tube. Failure would have occurred much later except that at about 2050 cycles the test was accelerated to hasten failure by increasing the flow to 1.4 cfs. This is a large flow to distribute through the 17 openings in one 30-foot length of pipe and a small pressure surge was created at each cycle when the pipe suddenly filled. This would not occur in a full length pipeline.

Preliminary field tests were made with a two-section system totaling 210 feet on an experimental plot in 1980 and 1981 to evaluate the concept, to test different diverter valve designs and to evaluate field assembly procedures. The tests using the final diverter valves were very encouraging. The system performed well during three irrigations in 1981 with insignificant leakage from the diverter valves.

The tests conducted to date are encouraging. One of the disadvantages of the system is the amount of labor required for initial assembly. This, however, is a one-time cost, since, once assembled, the system can usually be used repeatedly at one location without being moved or disassembled. The potential for this type system is great because of the large acreage in the U.S. that is presently irrigated with gated pipe. These existing systems can be automated by using the equipment and techniques now being developed.

Summary

Methods used by previous investigators to automate single-pipe systems include: (1) using air or hydraulic cylinders to actuate cables or rods connected to a series of gates comprising one irrigation set, (2) using a flexible liner to cover gated openings in distribution pipe or channels, and (3) using different types of pneumatically controlled valves on individual pipe discharge outlets.

Other more recent developments include the flo-thru gated pipe system where gated pipe is installed in a stair-step manner so that water flows as pipe flow in the irrigating or distribution section of the pipe and as free surface flow in upstream sections of the pipe. The free water surface in open channel flow is below the distribution outlets which are located near the top of the pipe. Semiautomatic valves are located at each stair-step drop.

Another system uses small, lay flat, rectangular air pillows to control the flow from individual distribution pipe outlets. Small, butterfly, flow-regulating valves are used on the outlets to control flow discharge into individual furrows. A centrally located solid state controller powered by solar cells is being developed to control opening and closing of the pneumatic valves in groups that comprise different irrigation sets.

A modified miniwai system is being developed using a flexible rubber tube inside of a length of gated pipe to control flow from all of the discharge outlets in one irrigation set. A diverter valve has been developed to divert water either into or on the outside of the flexible tube for either conveyance or irrigation from gates or outlets in the pipe.

These systems have a great potential for automating both new and existing pipe systems to conserve both water and energy and to reduce labor.

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