DEVELOPMENT AND PERFORMANCE EVALUATION OF A CABLEGATION SYSTEM FOR SURFACE IRRIGATION

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PROJECT REPORT

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MALAPPURAM

1996

DECLARATION

We hereby declare that this project report entitled **"DEVELOPMENT AND PERFORMANCE EVALUATION OF A CABLEGATION SYSTEM FOR SURFACE IRRIGATION"** is a bonafide record of project work done by us during the course of project and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship, or other similar title of any other University or Society.

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CERTIFICATE

Certified that this project report, entitled **"DEVELOPMENT AND PERFORMANCE EVALUATION OF A CABLEGATION SYSTEM FOR SURFACE IRRIGATION"** is a record of project work done jointly by GEETHA, S., PRASAD, V.P. and VINODKUMAR, P.R. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to them.

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29th May, 1996

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SYMBOLS AND ABBREVIATIONS

ARS	-	Agricultural Research Service
ASAE	-	American Society of Agricultural Engineers
cm	-	centimetre
Dept.	-	Department
et al.	-	and others
etc.	-	and all others
Fig.	-	figure
Inc.	-	Incorporation
Irrign.	-	Irrigation
J.	-	Journal
KCAET	-	Kelappaji College of Agricultural Engineering and Technology
lit/sec	-	litres per second
lps	-	litres per second
LWRCE	-	Land and Water Resources and Conservation Engineering
m	-	metre
m/m	-	metre(s) per metre
mm	-	millimetre(s)
MS	-	mild steel
No.	-	number
pp.	-	pages
PVC	-	Polyvinyl chloride

Trans.	-	Transactions
TNAU	-	Tamil Nadu Agricultural University
USDA	-	United States Department of Agriculture
viz.	-	namely
:	-	is to
/	-	per
%	-	per cent
°	-	degrees
θ	-	Orientation of outlet from the vertical centre line

INTRODUCTION

Agriculture, the first and foremost vocation, mankind has ever founded, has formed an inseparable part of man's life style. In a simple way, it can be defined as the production of food, fodder and fibre. In Indian context, agriculture is the back bone of the economy since more than 70 per cent of population of the country depend on it. Out of the total geographical area of 328 million bectares of land, about 164 million hectare is under crop cultivation. Agriculture contributes more than 50 per cent of the gross national product (GNP). But the agricultural scenario has not succeeded in satisfying the basic human needs. Uncertainty in the yields of food grains produced has been the primary determinant. Our development and life patterns have also led to a gnaw of our natural life-support systems. Moreover the rapid growth of population has appraised the increased demand of food.

In Indian agriculture, especially in arid and semi-arid areas, rain is the primary source of water to the soil plant system. In conformity with Indian conditions 73 per cent of total rainfall occur during monsoon months i.e., June to September, 2 to 6 per cent rainfall occur as winter rain, 13 per cent as post monsoon rain and 10 per cent as premonsoon rain. There is a high degree of uncertainty in spatial distribution and in the time of commencement and recedence of rainfall during monsoon months. The remaining eight months tend to be dry. The erratic occurrence of monsoon and their varying degrees of distribution aggravate the problems of water availability for crop production. This prompted man to supplement the naturally available moisture by artificial supply. Thus the human efforts to fight against nature's niggardiness in the supply of water to plants, takes the form of irrigation in the first attempt, the main function of which is to negate the adverse effect of irregular, uneven and inadequate rainfall. Irrigation is the nucleus of all the technical developments and a key variable in economic development. Irrigated water accounts for nearly 30 per cent of the cost of inputs on any crop yield. The optimization of water under irrigated agriculture should aim at controlled supply but conservation should be given priority under rainfed conditions.

Irrigation is carried out in many ways, the most prevalent one being the traditional surface irrigation methods such as uncontrolled flooding from a ditch - "wild flooding" check basin, ring, border, strip and furrow irrigation methods. The 'wild flooding' is the oldest method of irrigation practice known, in which water from a ditch or canal is allowed to flow over a flat land without any levees to guide its flow. Eventhough its cost is less, the efficiency is as low as about 20 per cent but the adaptability is limited to conditions when water is available in plenty and cost of labour is high.

The check basin method involves running comparatively large streams into relatively level plots surrounded by levees. This method is well suited to very permeable soils which must be quickly covered with water in order to prevent excessive losses near the supply ditches through deep percolation. In heavy soil where it becomes necessary to hold the water on the surface to assure adequate penetration, this method is adopted. Sometimes the check is provided for each tree or a group of trees which is known as ring or basin flooding.

The border strip method of irrigation is adapted to most soils where depth and topography permit the required land levelling at a reasonable cost and without permanent reduction in soil productivity. The supply of moisture is uniformly fulfilled by maintaining the same opportunity time throughout the areas of small strips. In furrow method of irrigation water is applied to the field in furrows between the two ridges and it is adaptable to great variation in slope. On steep slopes and in heavy soils, by reducing the flow into a furrow when the advance phase reaches the tail end of furrow, tail water losses can be avoided and application efficiency can be increased. This process of scuttling the initial stream of flow is known as cutback flow. Later it was found that less water was required to complete an advance if the inflow were cycled during advance phase. Thus the innovation of surge irrigation entered into the scene of surface irrigation practices. Surge irrigation systems involve application of design rates of flow through irrigation furrows in specified ON-OFF cycle periods.

The surface irrigation methods have an overall efficiency of 25-60 per cent and causes problems like erosion, salinization, waterlogging and deep percolation losses. Over the years, minor changes have been made to improve the efficiency of surface irrigation. The efficiency of surface irrigation can be improved by using siphon tubes, gated pipes and similar devices like irrigation modules which help to control the flow quantities and rate of flow. A significant portion of the total cost involved in surface irrigation farming goes to labour charges. The sprinkler and drip systems are found to decrease labour requirements and increase the uniformity of water application. But the high initial cost of the system is a chief constraint for adoption. On steep slopes and heavy soils the accumulation of tail water occurs during furrow irrigation and even spills over its boundaries thus viciating the storage of irrigation water and its uniform distribution. The surge irrigation can speed up water advance and helps to reduce runoff and deep percolation along the irrigation run.

The cablegation system was developed for the semi-automation of surface irrigation. Although the system was initially developed for furrow irrigation, it can be effectively adapted to other surface irrigation methods such as border and basin irrigation. Consequently, a system which automatically changes flow from one border to the next will provide substantial labour savings. The automated system can more easily be operated on a schedule based on crop water needs or soil characteristics rather than farmer convenience. Other automated surface irrigation systems do have to use automated gates or valves at each border which will respond to a time-based control. So these types of systems have spatially distributed control points and tend to be expensive.

The cablegation system costs less and are more reliable than other automated systems because they do not require gates and the system operation can be controlled from one location. The limited supply of fossil fuels and their rate of depletion signify eventual shortage and continuing increase in energy cost. So it becomes apparent that irrigation methods requiring less energy input must be developed if irrigated farms are to remain economically viable. The cablegation irrigation helps farmers to achieve desired application efficiencies and avoid one of the major energy costs involved in the farming operations, because this system just need adequate elevation drop to overcome the frictional force inside the pipe.

The cablegation system is an advanced technique in which the design rates of flow are delivered into the irrigation furrows through gates or outlets positioned along a conveyance pipe laid on a certain gradient and a plug moves slowly through the pipe, causing water to flow through the outlets into the furrows. The essential components of the cablegation system are a main conveyance pipe line, which may be fully or partially buried, a cablegation plug, cable, a plug speed controller and riser outlets. Outlets are placed near the top of the pipes circumference (offset at an angle towards the field from the pipe's vertical centre line) and spaced corresponding to the spacing of the furrows. The plug blocks water flow in the main pipe line and forces it out through the outlets. The flow rates are controlled by manipulating the speed of movement of the plug. The pipe is sized large enough to carry the water flow on the available slope without completely filling its cross-section. Water flows in the pipe below the level of the outlets until it approaches the plug. This construction causes the water to fill the pipe and flow from outlets near the plug.

To automate the system, the plug is allowed to move downslope through the pipe at a controlled rate. A cable on a reel at the inlet structure is attached to the upstream end of the plug. The rate at which the cable is reeled out determines the rate at which the plug moves and at which irrigation progresses across the field. The water pressure provides the force to move the plug. As the plug moves past a specific outlet, water flows out of that outlet at a relatively high rate. As the plug moves further down the pipe, the flow rate from the specific outlet decreases and eventually drops to zero. Thus a cutback flow is provided.

The efficiency of an advanced cablegation technique is established by proper laboratory studies. To evaluate the performance of the system, a semi-automated cablegation irrigation system was developed and tested under laboratory conditions at KCAET, Tavanur. The specific objectives of the present study are:

1. Development of a cablegation system.

2. Evaluation of the cablegation system by varying

   a. the slope or gradient of the main pipeline.

   b. the orientation of the outlets from the vertical centre line.

REVIEW OF LITERATURE

Indian agriculture revolves around efficient and economic utilization of the limited water resources that are basically rainfed. Irrigation becomes an unavoidable part of agriculture if the rainfall in an area is not sufficient to meet the requirements of crops throughout their growth period. Agricultural production need to be accelerated to the ever-increasing demand of the growing population. This has led to rapid expansion in the field of irrigation.

Cablegation is an automated system for applying surface irrigation water. A review of the work done by researchers in the field of cablegation irrigation is presented in this chapter.

2.1 Origin and development of cablegation irrigation system

The primary objective of any irrigation method is to supply moisture which will be readily available for crop growth, at all times, without indiscriminatly adding to the water table and avoiding influence of soil salinity. The surface irrigation systems though they are in vogue at present, have their own disadvantages of more deep percolation losses, poor application and distribution efficiencies.

In 1979 funds were appropriated to the Agricultural Research Service of the United States Department of Agriculture to develop systems and management practices which would reduce the vulnerability of irrigation farmers to increasing energy costs. Cablegation is a product of that research.

Stringham and Keller (1978) attempted to develop a furrow cut-back system, was resorted to minimize irrigation losses. A more effective method to obtain cut-back flow streams was developed by Stringham and Keller (1979). They used the term 'surge flow' to describe the regime of cycling furrow inflows. Surge flow irrigation system involves application of design rates of flow through irrigation furrows in specified ON-OFF cycle times so as to speed up water and to reduce runoff and deep percolation losses. They have also proposed that it would be more practical to achieve cut-back for furrow irrigation with gated pipe by cycling the inflow rather by partially closing the gates supplying each furrow. Preliminary research works on surge irrigation were carried out by the USDA Agricultural Research Service and they have developed a cablegation system of irrigation, a new concept in surface irrigation, in 1979.

2.2 Furrow cablegation systems

Cablegation was introduced as an automated method of applying water for furrow irrigation, through a gated pipe system laid on a precise grade. In this, the discharge is caused to flow through the outlets, in sequence, through furrows in the field by moving slowly a cable attached plug through the pipe (Kemper *et al.*, 1981). The surge flow or surging effect was accomplished with the cable system by moving a plug rapidly across the field several times over a number of cycles. Orifices near the plug had the highest flows, orifices further upstream had diminishing flows inversely with the distance of the outlets from the plug, their size, spacing and slope of the pipe line (Kemper *et al.*, 1981).

Goel *et al.* (1982) assessed the field performance of cablegation systems described by Kemper *et al.* (1981). Flow rates into and out of furrows were used to calculate furrow intake rates as a function of time. The initial supply rates to the furrows were within ± 13 per cent of the designed flow rates. Seventy eight per cent of the variation was associated with deviations of the pipe elevation from the design grade. It was also found that nearly 73 per cent of the water applied to the field infiltrated. Runoff rate was relatively constant and total runoff was only about half of that which would have occurred under fixed set surface irrigation. In general, the cablegation system was found to provide more uniform water application than is normally achieved with other surface irrigation systems. The cutback in supply reduces runoff and the runoff is very easily reused because of its continuous nature. Consequently this runoff water causes less erosion, requires a smaller drainage way and is easier to use on lower fields for irrigation.

Kincaid and Kemper (1984) proposed a bypass method and a cut-off outlet method to improve water distribution in cablegation system. The bypass method involves starting the plug at the first outlet and initially bypassing most of the flow to the downstream end of the pipeline which is plugged. As the plug moves down the pipe the bypass flow gradually decreases to zero. This method nearly equalizes the inflow distribution to all furrows and allows the use of a constant outlet opening size. Thus the problem of end effects is eliminated.

The cut-off outlet method deals with the low outlet flows during the final stages of a set which are insufficient to reach the end of the furrows such that excess water is applied to the upper end of the furrows. The cut-off outlets are recommended for soils with high intake rates.

Kincaid (1984) developed a simplified design method using dimensionless relationships for cablegation automated surface irrigation system. The method consists of two parts: the pipe flow distribution and the infiltration runoff distribution. The maximum outlet head, maximum stream size and number of flowing outlets are calculated using a set of dimensionless equations, given the pipe size, pipe slope, outlet size and spacing and total inflow rate. These equation enable a direct determination of the design variables without calculating the entire distribution of outlet flows. If the desired maximum stream size is known, the required outlet size can be calculated directly.

The infiltration, runoff analysis is presented as a series of dimensionless relationships in graphical form. These curves are used mainly for determining the required maximum stream size given a time-based furrow intake curve, furrow length and spacing gross water application and per cent runoff.

Kincaid (1985) developed water brake as a low cost means of controlling the plug speed in the cablegation automated surface irrigation system. The water brake is a simple hydraulic device requiring no external power source and can be built with locally available materials.

Kemper *et al.* (1987) has dealt with the cablegation automated supply for surface irrigation in detail, the background for development, description of the cablegation system, basic components of the system, models and design, arrangements to improve application uniformity, installation, operation, maintenance (USDA-ARS Kimberly Staff, 1985, 1986 and 1987) evaluations and its application.

2.3 Plugs, cables and speed control mechanisms

Cablegation plugs, cables and various types of speed controllers are described in detail by Kemper *et al.* (1985), Kemper *et al.* (1987) and USDA-ARS, 1987.

The plug must fit snugly inside the pipe to minimize leakage past the plug, but it must also slide down the pipeline as tension on the cable is released. Many of the original plugs were constructed using commonly available plastic bowls or buckets. Two bowls were used to maintain alignment of the plug in the pipe and to improve sealing. Each bowl was clamped between metal plates spaced about one pipe diameter from each other. The circumferences of the bowls were trimmed so that they would just slip inside the pipe. Most PVC pipe has uniform inside circumference. When pipe sections are deformed to oval shapes, the bowls also deform and maintain reasonably good seals. The non-compressible plastic bowls have been replaced by compressible flexible PVC gaskets in commercially manufactured plugs. The inside of the pipeline should be kept as smooth and uniform as possible. Leakage past the plugs range from nearly 0 upto 20 litre/min and is generally negligible in systems carrying 1800 to 6000 litres/min.

The cable must hold the force of the pressure head against the plug, the drag of water on the cable and any surge forces resulting from sudden changes in rate of plug travel. Cables used have ranged from 40 kg test braided Dacron fishing line to steel and polypropylene cables with over 300 kg test strength.

The reel is designed to store the cable between irrigations and the drum width must be sufficient to store the required cable length. Reel design calculations for various cable sizes and field layouts are outlined in Appendix B of the Cablegation Manual (Kemper *et al.*, 1985).

Water pressure pushes the plug down the pipe. The rate of the plug's advance can be controlled by several types of mechanisms depending on the power available to the site. The simplest and most commonly used type of controller is the 'water brake' designed by Kincaid (1985). Other controllers using ac electric power, wet cell batteries or paddle wheels imposed in the flowing water are also being used to control the rate of cable and plug movement in the pipe (Kemper *et al.*, 1985).

2.4 Border cablegation systems

Studies were made by Booher (1974) on irrigating border strips using cablegation systems especially for close growing crops such as alfalfa, pasture and small grains. it was found to be an effective method of achieving reasonably uniform irrigation on higher intake rate soils.

Several systems to automate border irrigation have been developed by Humpherys (1986) and Thomas *et al.* (1989). These systems generally use automated gates or valves at each border which open and/or close in response to a time based controller. The outlets operate hydraulically like weirs at heads below 80 mm. Belled ends on the outlets increases their capacity to 75 per cent at low heads. Cablegation reduces the labour input to border and basin irrigation by automatically transferring the water to consecutive borders. The system uses sliding plug with a plug speed controller and a buried conveyance pipe line with open riser outlets on each border. Border cablegation requires adequate field cross-slope or elevation drop between consecutive borders to overcome pipe or elevation drop between consecutive borders to overcome pipe friction loss and riser entrance loss, and to discharge water from the risers. Cross slopes generally must exceed 0.003 m/m for economical border cablegation systems. Part of this slope can be generated by elevated risers.

Kincaid and Trout (1989) have described the components and operation of border cablegation systems, the discharge calibrations of larger riser outlets and a procedure for designing the application systems. Border cablegations are less costly and more reliable than other automated systems because they do not require gates and the system operation is controlled from one location. Adequate elevation drop between borders is essential. In this the controller speed is set to advance the plug from one riser to the next in the irrigation time required to apply the desired amount of water. Water routing is accomplished by hydraulic design of the main pipe and riser outlets to insure all water discharges onto the border directly upstream of the plug. The elevation difference between riser outlets on consecutive borders must exceed the head (pressure) required to overcome friction loss in the main pipe between outlets and discharge the design flow from a riser or a set of risers. The riser outlet size must be large enough to discharge the design flow without backing water up such that it spills from upstream risers. Outlet capacity can be increased by using larger risers, by installing multiple risers on each border and by expanding or belling the ends of the outlets. Riser outlets as used on border cablegation systems were calibrated in the USDA-ARS Hydraulics laboratory at Kimberly, Idaho.

2.5 Buried pipelines

Rasmussen *et al.* (1973) attained surface irrigation application efficiencies exceeding 80 per cent with a multiset design using surface gated pipe.

Varlev (1973) and Milligan (1974) have reported briefly on buried lateral systems used in Bulgaria and Texas, respectively. Their systems required pressurized lines equipped with emitters that were more intricate than the orifices used in this system. Preliminary tests in 1973 with a buried lateral system indicates that a system with simple orifices can be automated and operated at an application efficiency exceeding 80 per cent.

Worstell (1976) studied the criteria for the design, construction and operation of an experimental buried lateral, gravity multiset irrigation system. He has found that the system operating without automatic controls has a potential water application efficiency of 80 per cent with very little runoff or erosion. With automatic controls and with water available on demand, light, frequent irrigations can be applied with 90 to 95 per cent efficiencies. The energy required to operate the system is minimal and only periodic inspection and maintenance services are required of the operator. Estimated cost and benefits indicate that this system may be economically feasible, practical and attractive with increasing energy costs and labour shortages.

Cablegation pipes can be buried a few centrimeters below the ground surface so as to provide some substantial reduction in the damage due to sunlight, weathering and being hit by the cultivation equipment (Kemper *et al.*, 1981) but will not provide complete protection from wheels bearing heavy loads.

Studies have shown that the improved surface irrigation systems such as cablegation systems involving orifices or siphon tubes to keep the furrow supply rates uniform, often gets blocked or partially blocked by trash such as weeds, grass, crop residues etc. Monitoring and cleaning outlets and restarting siphon tubes often consumes large amounts of labour and the interruptions prevent some crop rows from getting adequate water. Screening systems to remove trash from water supplies have been suggested as a good method even when the water supply is carrying only a few pieces of trash per hour (Kemper *et al.*, 1986).

2.6 Pipe size and grade

Pipe size needed is determined by water-supply rate, slope on which the pipe will lie, roughness of the pipe walls and temperature (viscosity) of the water. For practical purposes, irrigation water is assumed to have a temperature of about 20°C. At this viscosity, the Hazen-Williams formula relating the remaining factors can be used to find to the pipe size.

$$Sf = 6.17 \times 10^{6} (Qc/c)^{1.85} D^{-4.87}$$

or

$$Qc = 2.15 \times 10^{-4} C\ Sf^{0.54} D^{2.63}$$

where

Sf is the head gradient along the pipe in meters/meter due to friction

Qc is the flow rate in litres/minute

D is the inside diameter of the pipe in millimeters and

C is the roughness coefficient of the pipe

The roughness coefficient of the pipe is larger when pipes are smoother. The value of c is about 150 for polyvinyl chloride pipe and for rougher aluminium pipe a value for c of 130 is commonly assumed. The pipe size should be large enough so that the head loss will be less than 75% of the grade on which the pipe will be laid or Q should not be more than 85 per cent of Qc.

The pipe must be placed and maintained on a precise grade to achieve desired uniformity of water delivery. When the grade is low (<0.4%), pipe (or outlet) elevation must be maintained within 1 cm of the designed grade. Pipelines placed on steep slopes can generally tolerate more variation from the designed grade than those on flat slopes and still maintain reasonably uniform delivery. The minimum slope at which cablegation pipes have worked properly with practically feasible maintenance is 0.002 m/m. Polyvinyl chloride pipe and aluminium gated pipe have commonly been used. Plastic pipe exposed to sunlight should have ultraviolet inhibitors to prevent rapid deterioration.

2.7 Models

A mathematical cablegation model was developed and verified experimentally by Goel *et al.* (1982) to provide predictions of outlet flow rates as a function of total water supply rate, pipe size, type and slope, outlet size and spacing, plug speed and time. Inputs of specifications such as pipeline slope(s), total water supply rate(s), outlet spacing, furrow supply rates etc. into the model enable potential installers of cablegation systems to predict how the system would work before making major investments. The model and expansions thereof have played a major role in the development of cablegation system improvements. For instance, the bypass concept for minimizing end effects was evaluated by and eventually incorporated into the design model.

2.8 Equipment and controls for automation of surface irrigation

Farm irrigation systems must be automated to fully utilize the surge flow technique. Automated equipment and control facilities include gating and valving devices, timers, controllers and distribution systems. Split-set gated pipe systems use conventional gated pipe in a split-set design to distribute water to individual furrows. A single furrow valve control system uses individually automated outlets, one for each furrow, operated simultaneously in groups or blocks.

Researchers developed equipment and techniques to achieve surge flow from open channels. An automatic check gate is located between two consecutive bays and alternately releases water to the downstream bay and checks the water in the upstream bay for surge irrigation.

Surge irrigation research at the USDA-ARS Snake River Conservation Research Centre of Idaho largely concerned the development of valves and other control devices for automating and semi-automating surface irrigation systems. Air and water operated irrigation valves were developed for gated pipe systems that can be cycled repeatedly when controlled by appropriate timers. Battery powered pilot valves and mechanical, electromechanical or electronic timers are used. The water operated valves which are activated with water from the pipeline, may be too slow for short cycle times. However air operated valves are well suited for this application and may use either a portable or permanent air supply.

Garton (1966) made the first attempt to automate open ditch irrigation systems. His automatic furrow cut back system consisted of level bays fitted with tubes which extended through the ditch to allow for the discharge of water. An automatic check dam was placed at the end of each bay. Irrigation began in the bay which had the tubes at the highest elevation. When the furrows for that bay had been irrigated, the check dam was removed. The checks were automated by using mechanical timers which released a lever mechanism, this in turn caused the check dam to collapse, sending the water down the ditch to the next bay.

Flschabach and Godding (1971) attempted to automate surface irrigation by using irrigation valves on buried pipe lines. The automated surface irrigation valve was connected to riser on the buried pipe line. The valve consisted of a casing and a nylon reinforced butyl rubber diaphragm. Air pressure was used to inflate the diaphragm, thus stopping the flow of water. The movement of the diaphragm was controlled by a three-way valve.

Malano (1982) suggested that some of the existing timer controlled systems fitted with multiple cycle controllers have the potential to be adopted for use in surge irrigation. Automated surge flow irrigation requires both timer controlled outlet structures and water sensors to cut off irrigation supply. The only automatic system that is commercially available for surge flow in border irrigation consists of a typical butterfly valve which allows the flow to be cycled between two adjacent borders. This device is used in pipeline systems and does not have automatic flow shut-off control.

Humpherys (1983) used butterfly valves in gravity pipeline irrigation distribution systems. These valves could be operated using springs or pneumatic methods. Air cylinders or rotary actuators were used to operate the butterfly valves. A four-way pilot valve was used to apply air-pressure to either one side or the other of the butterfly valve. He suggested using solenoid pilot valves in conjunction with the double acting air cylinders. The battery powered solenoid valves, used to operate the pilot valve, normally require an electrical impulse rather than a continuous supply of electricity. This electrical impulse can be obtained through the discharging of a capacitor. Humpherys used 12 volt AC solenoids which operated on the dc voltage for the pulsing application. Mechanical and electronic timers were used to control the automated valves.

MATERIALS AND METHODS

Irrigation methods vary in different parts of the world and on different farms within a community because of differences in soil, topography, water supply, crops and customs. The most widely adapted irrigation method in our country is the surface irrigation, eventhough the sprinkler and drip systems are gaining popularity. Of the many new innovations in the field of surface irrigation, the cablegation is one of the recent outcomes and is yet to gain popularity. The efficacy of such a system need to be established by proper laboratory studies. With this view a manually controlled cablegation irrigation system was developed and its performance was evaluated under laboratory conditions. The test was conoducted in the Hydraulics Laboratory of KCAET, Tavanur. This chapter describes the materials used and methods employed for achieving the objectives.

3.1 Development of cablegation system

The cablegation arrangement (Fig.1) essentially consisted of a main conveyance pipe line with outlets at regular intervals for discharging water into individual furrows, a cablegation plug, water storage unit and cable.

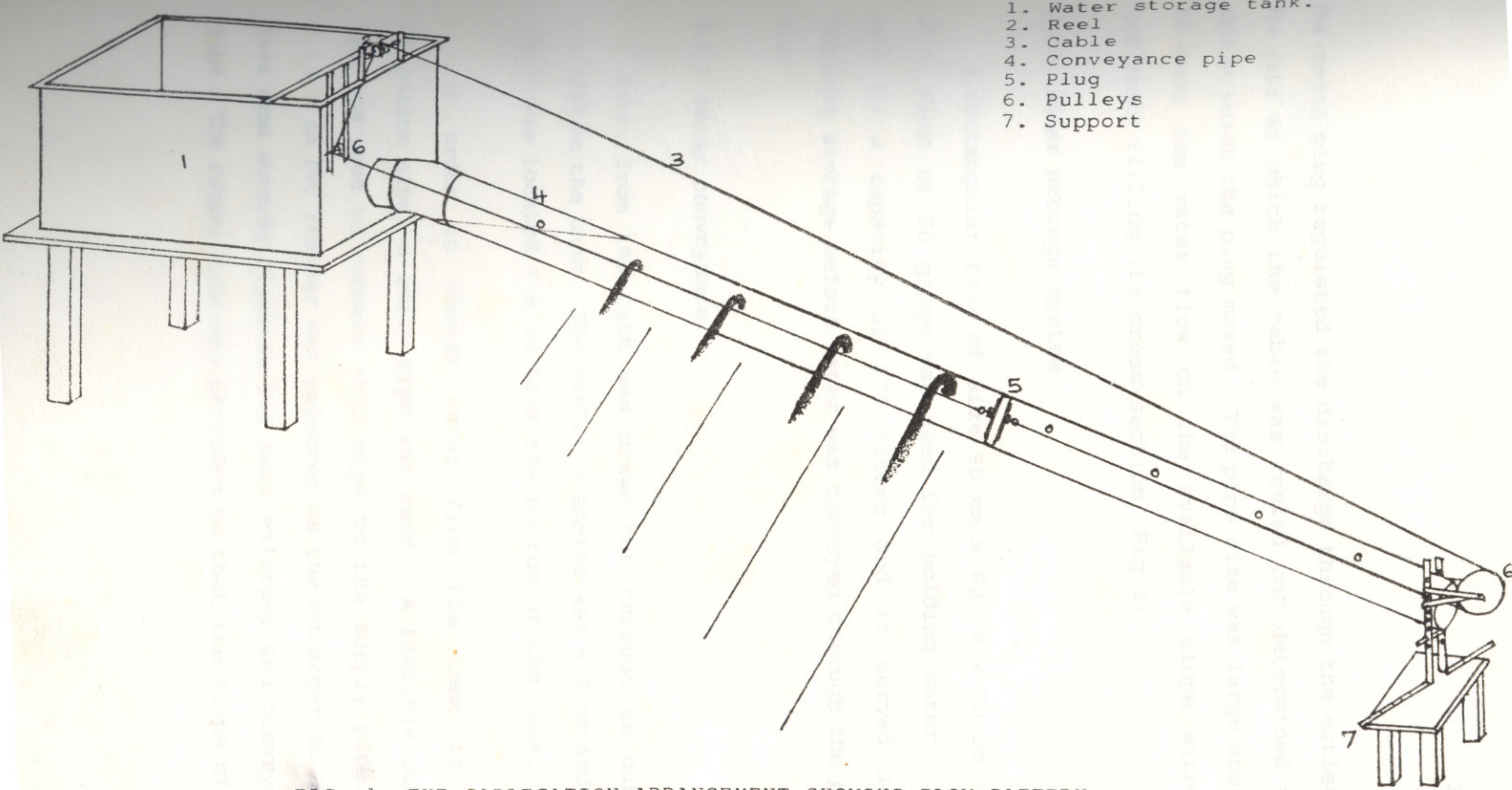


FIG. 1. THE CABLEGATION ARRANGEMENT SHOWING FLOW PATTERN.

The moving plug regulated the discharge through the outlets. The rate at which the cable was reeled out determined the rate at which the plug moved. The pipe size was large enough to carry the water flow on the available slope without completely filling its cross-section (Fig.2).

3.1.1 **Water storage system**

A rectangular tank of size 90 cm x 60 cm x 50 cm made of MS sheet of 20 gauge was used for holding water. The tank had a capacity of 270 litres and it served as a temporary storage before water was conveyed through the pipe line.

3.1.2 **Water conveyance**

Water from the tank was drawn out through an outlet provided on the tank. The outlet diameter was 6.3 cm and its centre was located 7.5 cm from the bottom of the tank.

In order to convey water from the tank to the irrigation pipe, a small pipe was used. A flexible rubber tube was used to connect this pipe to the supply pipe. A 6.3 x 5 cm PVC reducer was selected as the enlarger so as to have same outside diameter for both enlarger and conveyance pipe. The rubber tube was provided so that the slope of the

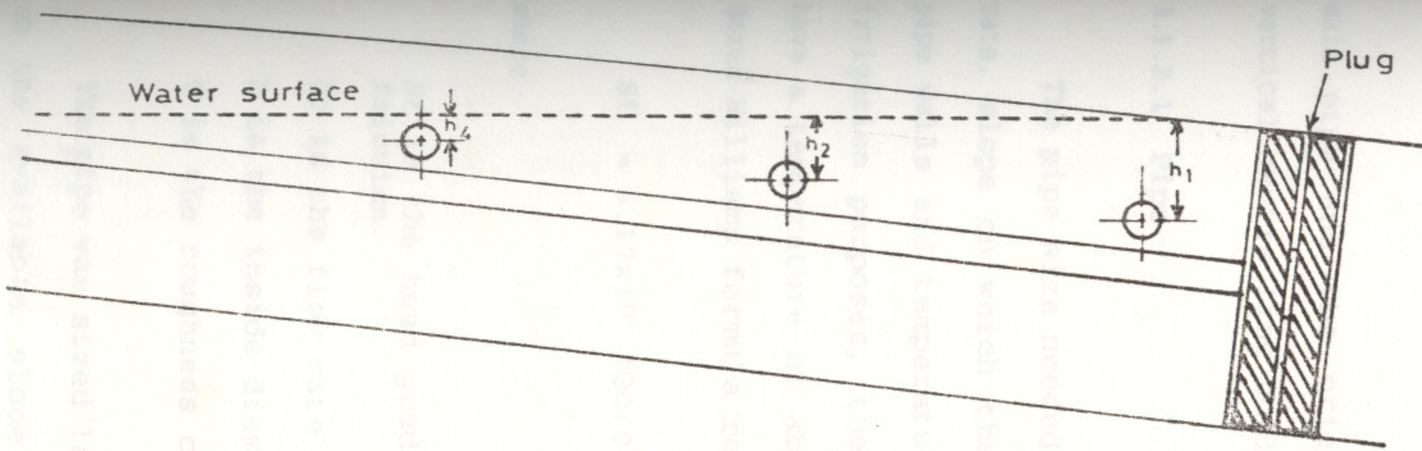


FIG. 2. CABLEGATION IRRIGATION - FLOW HEAD AT THE OUTLETS.

main pipe and the orientation of the outlets from the vertical centre line could be varied (Fig.3).

3.1.2.1 Pipe

The pipe size needed was determined by the water supply rate, slope on which the pipe will lie, roughness of the pipe walls and temperature (viscosity) of the water. For irrigation purposes, the irrigation water was assumed to have a temperature of about 20°C. At this viscosity, the Hazen-Williams formula relating the remaining factors is

$$Sf = 6.17x10^{6} \ (Qc/c)^{1.85} D^{-4.87}$$

where,

Sf is the head gradient along the pipe in m/m due to friction

Qc is the flow rate in lit/min.

D is the inside diameter of the pipe in mm and

C is the roughness coefficient of the pipe

The pipe was sized large enough to carry the water flow on the available slope without completely filling its cross-section. Considering the above factors, the current price and the resistance to degradation, a PVC pipe of length 500 cm and inside diameter 87.5 mm was selected.

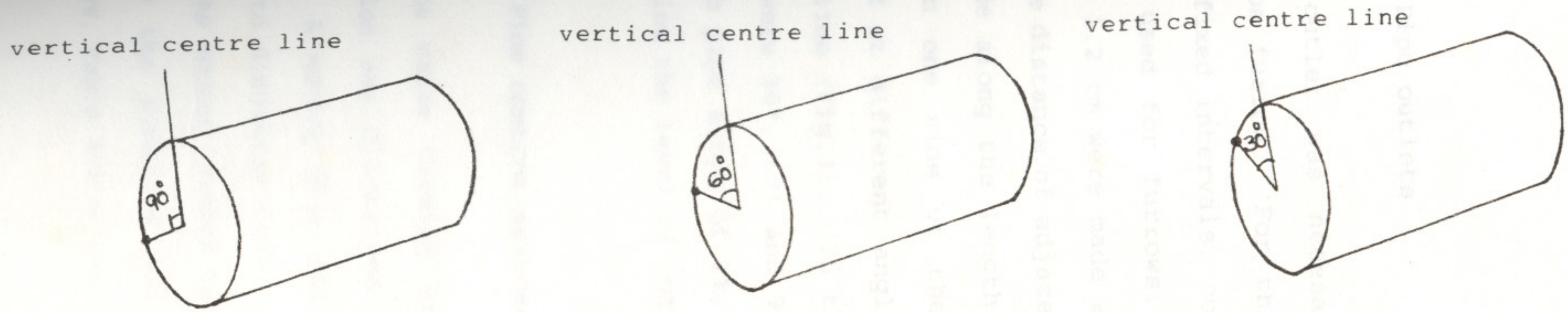


FIG. 3. PIPE CROSS SECTIONS SHOWING DIFFERENT ORIENTATION OF OUTLETS FROM THE VERTICAL CENTRE LINE.

3.1.2.2 Pipe outlets

An outlet was necesary to supply water for each irrigation furrow. For this holes of definite size were made at fixed intervals, corresponding to the spacing that will be used for furrows. Outlets of uniform size and diameter 1.2 cm were made at regular intervals with centre to centre distance of adjacent holes being 50 cm. Nine holes were made along the length of the pipe so as to discharge water on one side of the pipe. The outlets could be oriented at different angles with respect to the vertical centre line (Fig.3). In this study the orientation angles chosen were 30°, 60° and 90° from the vertical centre line for each pipe slope of 1%, 2% and 3%. Water flowed in the pipe below the level of outlets until it approached the plug (Fig.2).

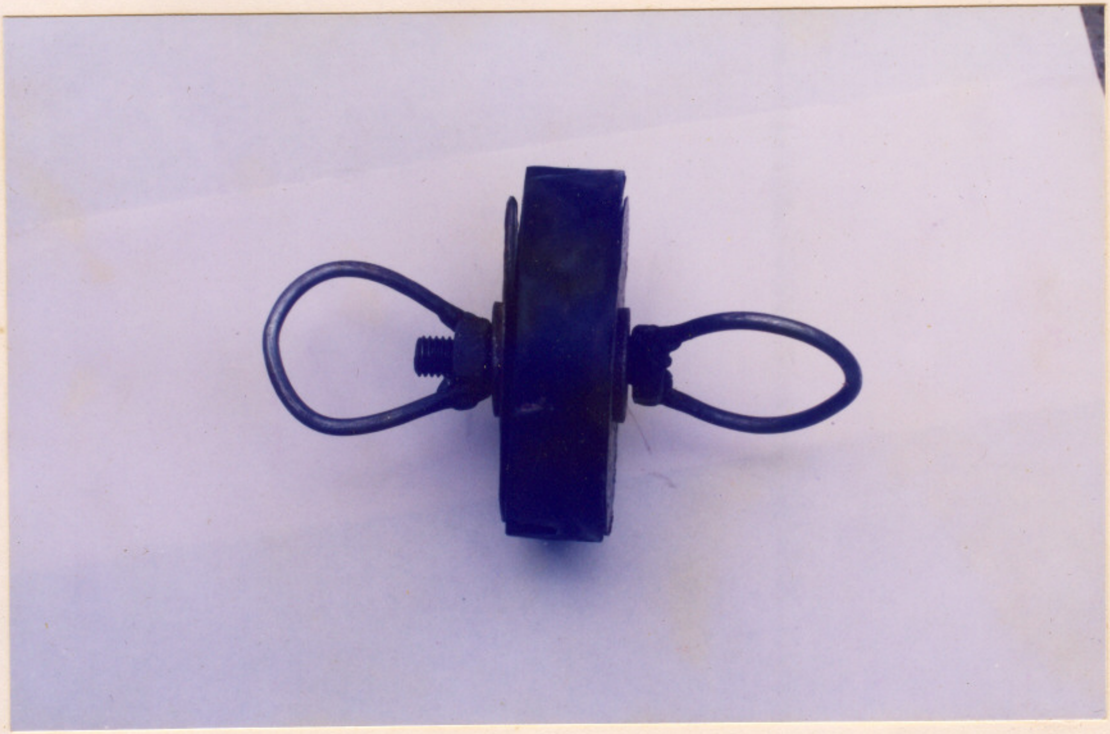
3.1.3 Flow control devices

The water flowing through the pipe in the downward direction was discharged through the outlets made on the pipe. A moving plug was incorporated in the pipeline in order to discharge water through the outlets in accordance with the amount needed to be applied. The movement of plug inside the pipeline was accomplished with the help of pulleys, cable and a reel (Plate 1).

3.1.3.1 Plug

The plug had to be moved along the pipe from one end to the other such that the flow inside the pipe could be checked adequately (Plate 2). As the movement of the plug was in the downward direction the water flow tend to confine in the portion upward of the plug. As a result the water was discharged through the outlets prior to the plug position. The plug was to move smoothly inside the pipe without any interruption. So it was to be of accurate size. It should fit snugly inside the pipe to minimize leakage past the plug. Reductions in pipe circumference were formed on the male ends by manufacturers to strengthen the ends and facilitate easy coupling of the pipe. So the plug was so constructed that it could overcome these limitations.

Contemplating the above factors, the plug material was selected as rubber. A circular rubber disc of thickness 1.5 cm was made with diametr sufficient to meet the various requirements of the plug. The diameter of the plug was the same as the inside diameter of the pipe through which the plug was to be moved. An aluminium metal plate was provided on either ends of the rubber disc. These were fitted on a bolt of 10 mm size and was fastened with a nut. Two iron rings were fixed on the bolt head and the nut to tie the cable.



3.1.3.2 Cables

The cable was to hold the force of the pressure head against the plug, the drag of the water on the cable and any surge forces resulting from sudden changes in the rate of plug travel or water supply rate. It also possessed good tensile strength to resist the force of friction between the plug and the inner surface of the pipe, especially in portions of constrictions. The cable chosen should be such that it would not lose its strength by the action of water. Considering the above mentioned factors a plastic rope of thickness 0.5 cm and length sufficient to make a closed system was chosen as the cable.

3.1.3.3 Reel and pulleys

A reel and two pulleys were used to achieve the efficient and smooth operation of the plug-cable assembly. One of the pulleys was situated inside the tank to guide the cable straight through the pipe. This pulley was made of mild steel and it was allowed to rotate on a static iron bar supported by a frame which was fixed on the tank. The second pulley was allowed to rotate freely on a stationary bar at the bottom end of the pipe. The pulley along with the iron bar was assembled on a frame which was meant to serve as a support to the pipe at the bottom end. The cable which was coming from the inside of the pipe was allowed to pass over the pulley which was fixed such that its bottom end touches the centre line of the pipe. This arrangement was made to make the cable as straight as possible inside the pipe.

A reel was attached rigidly to a rod which was rotated so as the make the plug move. The rotation of the rod was accomplished with the help of a handle attached to the end of the rod. So the plug speed could be adjusted with the help of the handle and made uniform. The rate at which the cable is reeled out determines the speed of the plug. When the plug was forced to move in one direction by the rotation of the handle, the portion of the cable in front of the plug upto the reel was in tension and the rest of the cable was loosened to facilitate easy sliding of the plug.

3.1.4 Supports

The water tank was held at a height of 82.5 cm from the ground surface. The downstream end of the pipeline was supported on an iron frame fixed on a wooden block. The iron frame provided adequate means to change the height of the pipe end above the ground surface, so as to attain different pipe grades used in the experiment viz. 1%, 2% and 3%. Another support of iron frame was provided for the main pipe at a mid-section to prevent sagging of the pipe due to the weight of water.

3.2 Experimental study

The study was aimed to evaluate the performance of the cablegation system subjected to different pipe gradients and orientation of the outlets, under laboratory conditions.

The cablegation arrangement involved the use of a 9 cm PVC pipe with 1.2 cm diameter outlets at a spacing of 50 cm to serve as outlets for discharging water into individual furrows (Plate 3). The first outlet was at a distance of 60 cm from the upstream end. The outlet discharge was regulated with the help of a moving plug. The plug was attached to a cable which was wound on a reel and the cable was inserted in the cablegation line.

The head was maintained in the tank to such a level that the pipe would not flow full. The flow inside the pipe was open channel flow. The outlets were oriented at angles of 30°, 60° and 90° from the vertical centre line and for each of these orientations, the pipe was laid on slopes of 1%, 2% and 3%. The plug movement was achieved by reeling out the cable.

The water discharged through each outlet was monitored for a period of 30 seconds. Flow through the outlets was affected by the water surface backing up behind the plug which in turn depended on the outlet orientation and pipe gradient. When the plug moved down the pipe, the discharge upstream gradually decreased. At a particular plug position, a certain number of upstream outlets on the downstream side of the plug and those faraway on the upstream side did not discharge. This was because the outlets near the plug were under the highest head and delivered water at a maximum rate whereas those farther upstream from the plug flowed at a lower rate (Fig.2).

Two experiments were conducted, one with decreasing head inside the tank and the other with a constant low discharge applied to the pipe. In the first case, the water surface level inside the tank was maintained at a level just above the tank outlet, for each plug position. The discharge through all the outlets were monitored for a period of 30 seconds. Initially the plug was positioned between the first and second outlets. It was then moved downward to the next position keeping the water surface level the same as explained earlier and the process was repeated. The experiment was done for outlet orientations of 30°, 60° and 90° from the vertical centre line and pipe slopes of 1%, 2% and 3% were maintained for each orientation.

In the second case a low constant discharge of 0.064 l.p.s. was supplied to the pipe and the discharge was monitored for a period of 30 seconds, for each plug position. The experiment was conducted for pipe slopes of 2% and 3% and outlet orientations of 30°, 60° and 90° from the vertical centre line.

RESULTS AND DISCUSSION

Cablegation is a relatively new system that uses an oversized single pipe line laid on a precise grade, so that automation of the various farm irrigation methods can be achieved. This advanced technique delivers the design rates of flow into the field through orifice outlets positioned along a conveyance pipe with a moving plug inside for flow control. A manually controlled cablegation irrigation system was developed and evaluated with a view to establish the efficiency of such a technique.

The results obtained from the laboratory evaluation are discussed in this chapter.

4.1 Pipe selection

In the cablegation system water was allowed to flow inside the pipe below the level of outlets until it approached the plug and delivered water through outlets nearer to the plug.

According to the methodology explained in 3.1.2.1 the diameter of the pipe was calculated as per Hazen-Williams formula (Appendix 1). Since the pipe size should be large enough to carry the flow without completely filling its cross-section, a diameter greater than the calculated value was selected. The diameter chosen was 9 cm conforming to the standard sizes available in the market.

4.2 Evaluation of the system

Water was supplied to the pipe so that flow occurred below the level of outlets until it approached the plug. The obstruction caused the water to fill the pipe and flow from outlets near the plug. When the plug was near the first outlet the entire discharge was routed through the single outlet itself. When the plug was held near the other outlets, the different outlets shared the inflow discharge. The outlets near the plug delivered water at a maximum rate, whereas those farther upstream from the plug flowed at a lower rate. This could be attributed to the increased hydraulic head in the pipe until the inflow equalled the outflow due to obstruction caused by the plug.

The plug was allowed to be held in a position between two outlets for 30 seconds which could be equalized to an effective plug speed of 1.66 cm/sec. The experiment was conducted by applying water to the pipe under varying head in the first case and a constant low discharge in the second case. The outlets were numbered from upstream to downstream chronologically i.e., number 1 indicated the outlet nearest to the tank and number 9 indicated the outlet farthest from the tank at the downstream end.

4.2.1 Analysis of discharge under decreasing head

The discharge obtained from the outlets at each plug position when the pipe slope(s) was 1% and the orientation of the outlets with respect to the vertical(O) was 30° are represented in Table 1. When the plug was held in between outlets 1 and 2 for a period of 30 seconds the discharge occurred only through the first outlet. As the plug moved further down, to a position in between outlets 2 and 3, discharge occurred through outlets 1 and 2. More discharge occurred at the outlet nearest to the plug because the hydraulic head available at this outlet was the maximum. When the plug moved further downstream discharge occurred through more number of outlets. In all cases the discharge was maximum through the outlet nearest the plug.

When the plug reached a position in between outlets 7 and 8 the discharge through the first outlet ceased. This was because the water surface level in the pipe was lowered below the outlets at this position. Thereafter, for any downstream position of the plug no discharge occurred through the first outlet. For all the outlets nearest to the plug the discharge increased as the plug slided

EXPERIMENT I. DISCHARGE UNDER DECREASING HEAD

Table 1. Outlet discharge distribution

S = 1.0% and Φ = 30 degree

Plug position	Distance of outlet from the upstream end (m)	Discharge through each outlet (litres/second)								
		1	2	3	4	5	6	7	8	9
1.	0.6	0.0413								
2.	1.1	0.053	0.0706							
3.	1.6	0.058	0.090	0.097						
4.	2.1	0.046	0.080	0.090	0.106					
5.	2.6	0.033	0.073	0.083	0.100	0.113				
6.	3.1	0.013	0.060	0.076	0.093	0.103	0.108			
7.	3.6	-	0.0206	0.056	0.0746	0.0867	0.093	0.101		
8.	4.1	-	0.020	0.043	0.062	0.0753	0.083	0.095	0.0967	
9.	4.6	-	-	0.010	0.030	0.060	0.073	0.080	0.0947	0.0947
Total discharge through each outlet (l.p.s)		0.2443	0.4142	0.4556	0.4639	0.438	0.357	0.276	0.1914	0.0947

downsard. The discharge through the outlets nearest the plug increased till the plug position was between outlets 6 and 7 and then it decreased as the plug moved further downstream. This was because the water level in the tank had gone below the bottom level of the tank outlet, thereby causing a reduction in the pipe supply. So the hydraulic head available also decreased.

Table 2 shows the discharge through outlets at a pipe slope of 2% and outlets oriented at 30° with the vertical. The discharge through the first outlet became zero when the plug was between outlets 7 and 8. The discharge in the second outlet also ceased when the plug was held beyond the nineth outlet. The discharge through the outlet nearest to the plug increased upto the plug position between outlets 7 and 8 and decreased afterwards. The total discharge from all the outlets in this case was more than that in the case of 1% pipe slope. The increase in discharge was caused due to the increase in head available at the outlets with increase in slope of the pipe.

The same effect was observed when the slope of the pipe was increased to 3% with 30° orientation of outlets from the vertical (Table 3). It was observed that the discharge in the first outlet became zero for the plug position between outlets 7 and 8. The discharge through the second outlet

Table 2. Outlet discharge distribution

S = 2.0% and θ = 30 degree

Plug position	Distance of outlet from the upstream end (m)	Discharge through each outlet (litres/second)								
		1	2	3	4	5	6	7	8	9
1.	0.6	0.0447								
2.	1.1	0.0426	0.0813							
3.	1.6	0.0393	0.0793	0.0089						
4.	2.1	0.0200	0.0540	0.0780	0.103					
5.	2.6	0.033	0.0513	0.076	0.0946	0.113				
6.	3.1	0.0067	0.0367	0.070	0.083	0.110	0.117			
7.	3.6	-	0.0133	0.043	0.073	0.106	0.112	0.1326		
8.	4.1	-	0.0087	0.0206	0.046	0.088	0.10	0.120	0.123	
9.	4.6	-	0.0067	0.0206	0.040	0.073	0.087	0.120	0.123	0.1267
Total discharge through each outlet (l.p.s)		0.1667	0.3246	0.3971	0.4396	0.490	0.4154	0.3726	0.246	0.1267

Table 3. Outlet discharge distribution

S = 3.0% and ϕ = 30 degree

Plug position	Distance of outlet from the upstream end (m)	Discharge through each outlet (litres/second)								
		1	2	3	4	5	6	7	8	9
1.	0.6	0.067								
2.	1.1	0.067	0.0933							
3.	1.6	0.050	0.0967	0.1067						
4.	2.1	0.040	0.0913	0.1073	0.1340					
5.	2.6	0.040	0.0667	0.0867	0.1193	0.1347				
6.	3.1	0.0046	0.050	0.0880	0.1180	0.133	0.140			
7.	3.6	-	0.0313	0.0667	0.1027	0.1233	0.128	0.1480		
8.	4.1	-	-	0.313	0.0687	0.10	0.10	0.133	0.1367	
9.	4.6	-	-	0.0173	0.0433	0.0793	0.1033	0.1247	0.1307	0.133
Total discharge through each outlet (l.p.s)		0.2681	0.4293	0.504	0.586	0.5703	0.4713	0.4057	0.2674	0.133

also ceased when the plug reached between outlets 8 and 9. It could be seen that the total discharge from all the outlets were highest for a pipe slope of 3% with 30° oriented outlets. The discharge through the outlet nearest to the plug was maximum when the plug was between outlets 7 and 8.

The discharge through the outlets oriented at 60° with the vertical for pipe slopes of 1%, 2% and 3% are shown in Tables 4, 5 and 6 respectively. The discharge through the outlet nearest to the plug was increased upto the outlet 5, when the pipe slope was 1%. Thereafter it reduced because the supply to the pipe decreased thus decreasing the hydraulic head. The discharge through the outlet nearest to the plug for pipe slope of 2% increased upto outlet 8 and for 3% pipe slope it increased upto outlet 7 and thereafter decreased. The discharge in the first outlet diminished when the plug was positioned between outlets 8 and 9 for all pipe slopes of 1%, 2% and 3%. The discharge in the second outlet never reached zero value for pipe slopes of 1% and 2%. But for 3% pipe slope the discharge in the second outlet ceased when the last plug position was reached.

Tables 7, 8 and 9 gives the rate of discharge through the outlet orifices along the length of pipe, for outlet orientations of 90° with vertical at pipe slopes of 1%, 2%

Table 4. Outlet discharge distribution

S = 1.0% and ϕ = 60 degree

Plug position	Distance of outlet from the upstream end (m)	Discharge through each outlet (litres/second)								
		1	2	3	4	5	6	7	8	9
1.	0.6	0.0873								
2.	1.1	0.0858	0.1058							
3.	1.6	0.0853	0.1058	0.1083						
4.	2.1	0.0635	0.0912	0.0983	0.1105					
5.	2.6	0.0485	0.0829	0.0932	0.1075	0.1194				
6.	3.1	0.0526	0.0758	0.0812	0.0975	0.1064	0.1067			
7.	3.6	0.034	0.0726	0.0783	0.0945	0.1064	0.1047	0.109		
8.	4.1	-	0.0092	0.033	0.0505	0.0787	0.085	0.090	0.0882	
9.	4.6	-	0.008	0.0283	0.0505	0.065	0.073	0.083	0.0835	0.067
Total discharge through each outlet (l.p.s)		0.457	0.5513	0.5206	0.511	0.4759	0.3696	0.282	0.1717	0.067

Table 5. Outlet discharge distribution

S = 2.0% and Φ = 60 degree

Plug position	Distance of outlet from the upstream end (m)	Discharge through each outlet (litres/second)								
		1	2	3	4	5	6	7	8	9
1.	0.6	0.0840								
2.	1.1	0.080	0.1033							
3.	1.6	0.0733	0.0933	0.1033						
4.	2.1	0.0533	0.0833	0.10	0.120					
5.	2.6	0.04	0.0793	0.0933	0.1133	0.1267				
6.	3.1	0.0247	0.0533	0.0767	0.0967	0.100	0.120			
7.	3.6	0.0133	0.050	0.0733	0.0933	0.108	0.1087	0.1267		
8.	4.1	-	0.0167	0.0433	0.0667	0.0867	0.1113	0.1267	0.130	
9.	4.6	-	0.0133	0.0333	0.0567	0.08	0.1047	0.1233	0.1247	0.130
Total discharge through each outlet (l.p.s)		0.3686	0.3892	0.5232	0.5467	0.5114	0.4427	0.3767	0.2547	0.13

Table 6. Outlet discharge distribution

S = 3.0% and Q = 60 degree

Plug position	Distance of outlet from the upstream end (m)	Discharge through each outlet (litres/second)								
		1	2	3	4	5	6	7	8	9
1.	0.6	0.0767								
2.	1.1	0.0667	0.0967							
3.	1.6	0.0633	0.1020	0.1146						
4.	2.1	0.04	0.0967	0.110	0.14					
5.	2.6	0.01467	0.09	0.110	0.13	0.1433				
6.	3.1	0.0067	0.0667	0.088	0.1167	0.1333	0.1380			
7.	3.6	0.0065	0.04	0.110	0.1067	0.1233	0.1333	0.1583		
8.	4.1	-	0.0213	0.0533	0.09	0.1147	0.1273	0.1467	0.1480	
9.	4.6	-	-	0.01467	0.0467	0.0813	0.1107	0.1293	0.1367	0.150
Total discharge through each outlet (l.p.s)		0.2687	0.5134	0.6005	0.6301	0.5959	0.5093	0.4293	0.2847	0.150

Table 7. Outlet discharge distribution

S = 1.0% and ϕ = 90 degree

Plug position	Distance of outlet from the upstream end (m)	Discharge through each outlet (litres/second)								
		1	2	3	4	5	6	7	8	9
1.	0.6	0.084								
2.	1.1	0.0867	0.103							
3.	1.6	0.0806	0.106	0.106						
4.	2.1	0.074	0.0967	0.106	0.120					
5.	2.6	0.06	0.09	0.10	0.116	0.126				
6.	3.1	0.023	0.073	0.0867	0.106	0.106	0.113			
7.	3.6	-	0.0367	0.067	0.082	0.098	0.108	0.113		
8.	4.1	-	0.0267	0.05	0.078	0.0853	0.0983	0.144	0.120	
9.	4.6	-	-	0.0067	0.036	0.0706	0.0853	0.106	0.106	0.110
Total discharge through each outlet (l.p.s)		0.4023	0.5321	0.5224	0.538	0.4859	0.4046	0.363	0.226	0.110

Table 8. Outlet discharge distribution

S = 2.0% and θ = 90 degree

Plug position	Distance of outlet from the upstream end (m)	Discharge through each outlet (litres/second)								
		1	2	3	4	5	6	7	8	9
1.	0.6	0.092								
2.	1.1	0.0906	0.110							
3.	1.6	0.09	0.110	0.113						
4.	2.1	0.0683	0.0953	0.103	0.116					
5.	2.6	0.0533	0.087	0.098	0.113	0.126				
6.	3.1	0.0573	0.08	0.086	0.103	0.113	0.115			
7.	3.6	0.0387	0.0767	0.083	0.10	0.113	0.133	0.12		
8.	4.1	-	0.0133	0.038	0.056	0.0853	0.0933	0.101	0.1067	
9.	4.6	-	0.012	0.033	0.056	0.0716	0.0813	0.094	0.10	0.1
Total discharge through each outlet (l.p.s)		0.4902	0.5843	0.554	0.544	0.5089	0.4026	0.315	0.2067	0.1

Table 9. Outlet discharge distribution

S = 3.0% and Φ = 90 degree

Plug position	Distance of outlet from the upstream end (m)	Discharge through each outlet (litres/second)								
		1	2	3	4	5	6	7	8	9
1.	0.6	0.1067	-	-	-	-	-	-	-	-
2.	1.1	0.1040	0.130	-	-	-	-	-	-	-
3.	1.6	0.1033	0.130	0.1333	-	-	-	-	-	-
4.	2.1	0.0933	0.1267	0.1320	0.1367	-	-	-	-	-
5.	2.6	0.0833	0.1067	0.1167	0.1253	0.1413	-	-	-	-
6.	3.1	0.0567	0.0833	0.0927	0.1007	0.132	0.1433	-	-	-
7.	3.6	0.0267	0.034	0.0513	0.0987	0.1147	0.1313	0.1467	-	-
8.	4.1	-	0.0173	0.0467	0.0933	0.1127	0.1293	0.1433	0.1453	-
9.	4.6	-	0.0053	0.0267	0.05	0.08	0.10	0.12	0.1247	0.1280
Total discharge through each outlet (l.p.s)		0.5734	0.6333	0.5993	0.6147	0.5807	0.5039	0.41	0.27	0.128

and 3% respectively. The discharge through the outlets nearest to the plug increased as the plug was slided downward through the pipe, till the plug was positioned between outlets 5 and 6. The discharge through the outlet 5 which was nearest to the plug was the highest. After that the discharge through the outlets nearest to the plug decreased as the plug was slided downstream. This was observed for pipe slopes of 1% and 2%. For the slope of the pipe as 3%, the discharge through the outlet nearest to the plug was maximum when the plug was positioned between outlets 7 and 8 and this discharge occurred through the outlet 7. In all the cases for different pipe slopes of 1%, 2% and 3%, the discharge through the first hole ceased when the plug was between outlets 7 and 8.

4.2.1.1 Effect of slope

Figure 4 represents the discharge through the outlets oriented at 30° with the vertical for pipe slopes of 1%, 2% and 3%. Although the discharge through the first four outlets were greater for 1% slope, the total discharge through all the outlets was more for 2%. When the slope increased to 3%, cumulative discharge through each outlet and the total discharge from all the outlets were greater than the other two pipe slope (Appendix II). The increase in hydraulic head caused the increase in discharge when the pipe slope was increased.

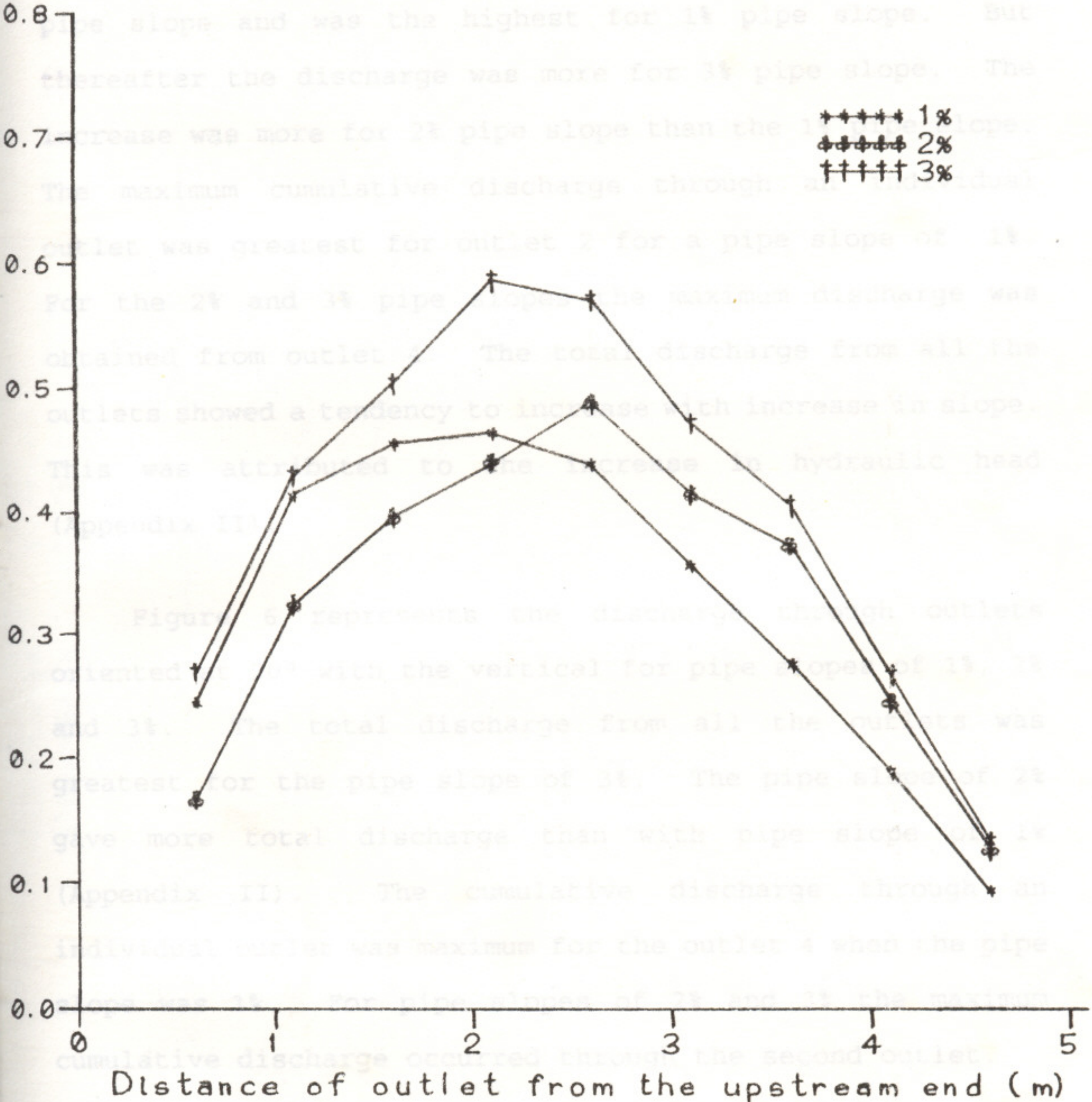


FIG.4. VARIATION OF TOTAL DISCHARGE FROM AN OUTLET WITH SLOPE, FOR OUTLET ORIENTATION (Ø) = 30°

The cumulative discharge through the outlets when the orientation angle was 60° and for pipe slopes of 1%, 2% and 3% are represented graphically in Fig.5. The discharge through the first few outlets were lesser for 3% than 2% pipe slope and was the highest for 1% pipe slope. But thereafter the discharge was more for 3% pipe slope. The increase was more for 2% pipe slope than the 1% pipe slope. The maximum cumulative discharge through an individual outlet was greatest for outlet 2 for a pipe slope of 1%. For the 2% and 3% pipe slopes the maximum discharge was obtained from outlet 4. The total discharge from all the outlets showed a tendency to increase with increase in slope. This was attributed to the increase in hydraulic head (Appendix II).

Figure 6 represents the discharge through outlets oriented at 90° with the vertical for pipe slopes of 1%, 2% and 3%. The total discharge from all the outlets was greatest for the pipe slope of 3%. The pipe slope of 2% gave more total discharge than with pipe slope of 1% (Appendix II). The cumulative discharge through an individual outlet was maximum for the outlet 4 when the pipe slope was 1%. For pipe slopes of 2% and 3% the maximum cumulative discharge occurred through the second outlet.

The cumulative discharge through each outlet in all the cases showed that upto a certain position of the plug the

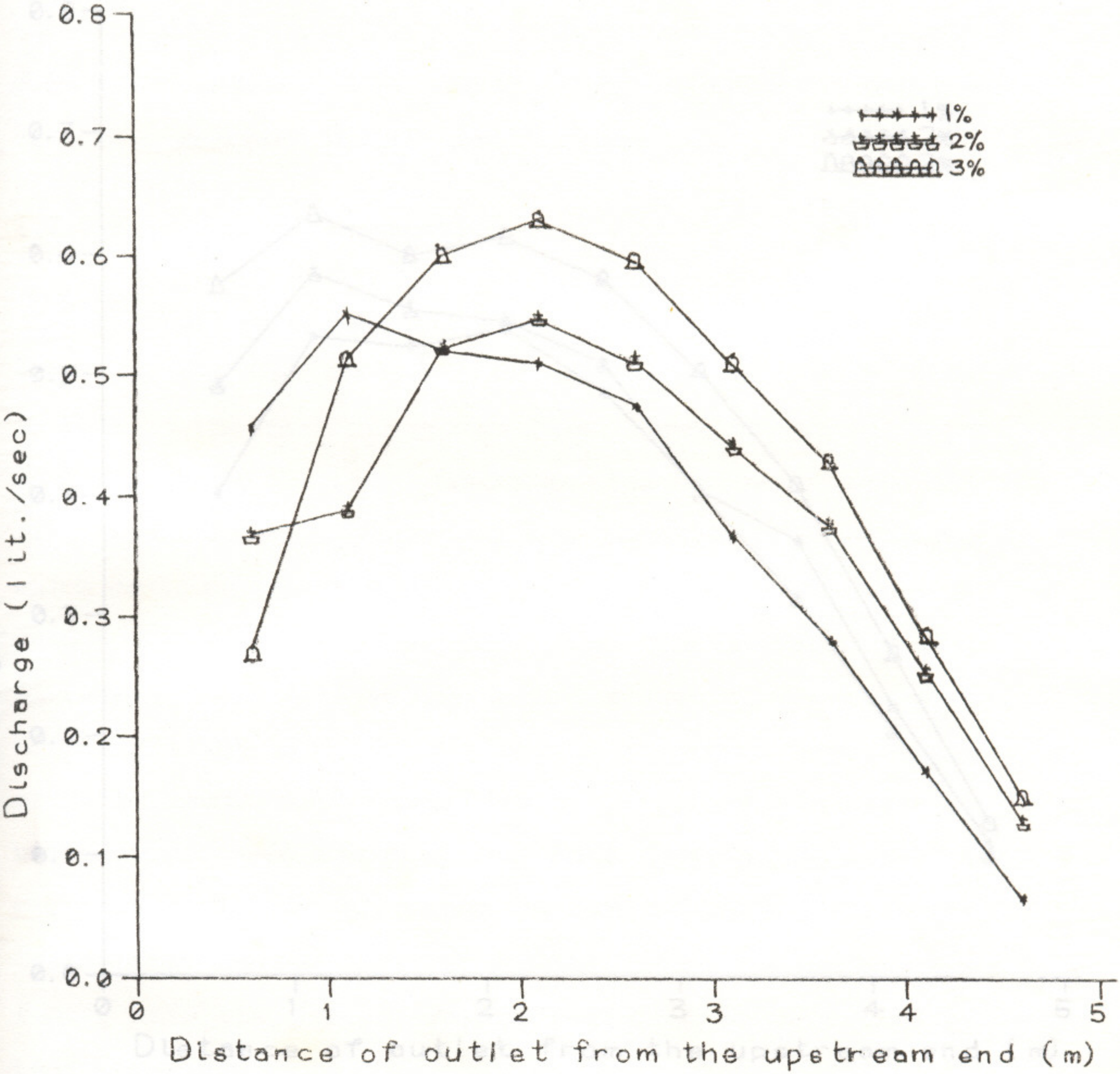


FIG.5. VARIATION OF TOTAL DISCHARGE FROM AN OUTLET WITH SLOPE, FOR OUTLET ORIENTATION (Ø) = 60°

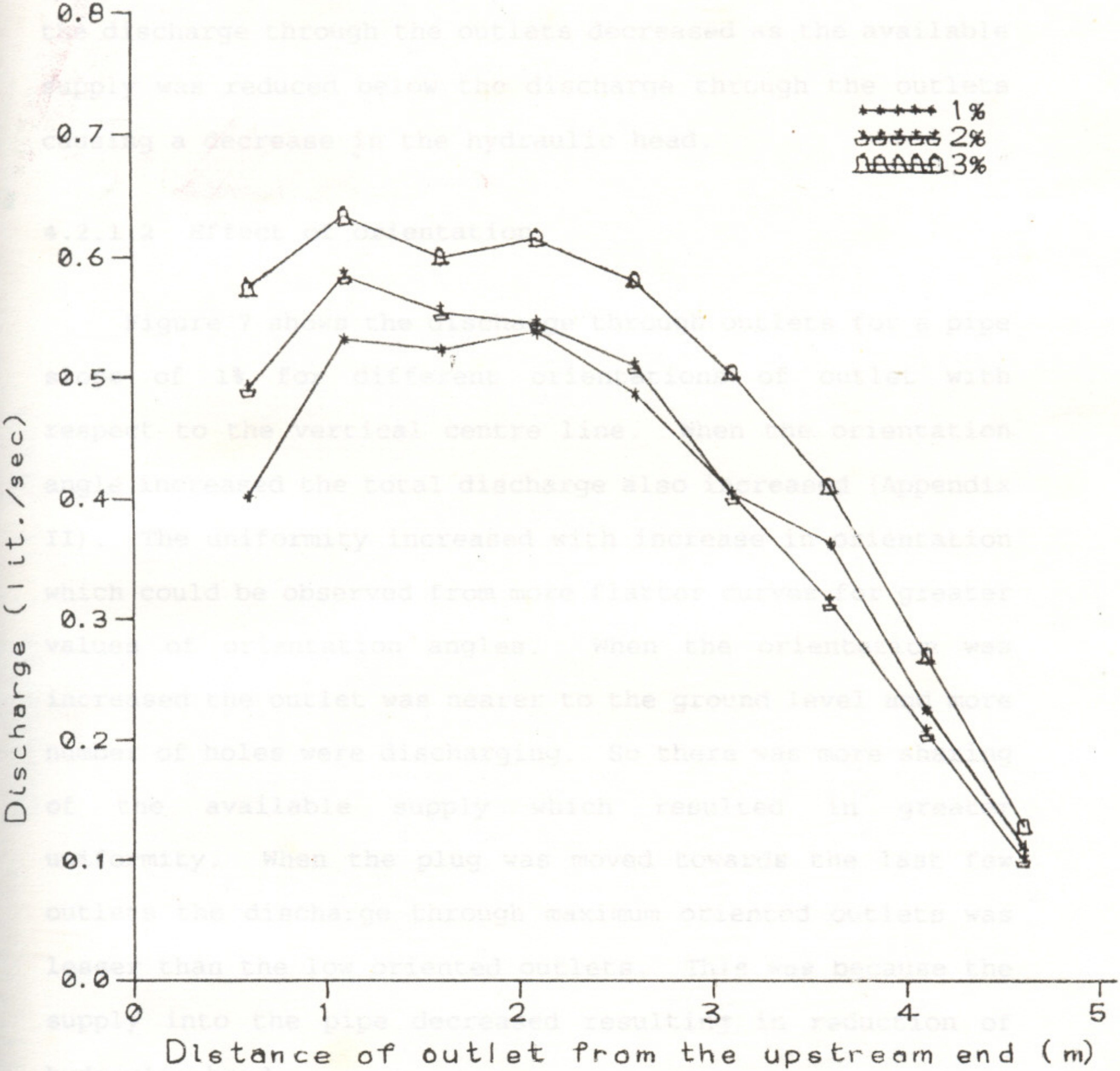


FIG.6. VARIATION OF TOTAL DISCHARGE FROM AN OUTLET WITH SLOPE, FOR OUTLET ORIENTATION (Ø) = 90°

discharge increased as the plug was moved downward. This was caused due to the increase in hydraulic head as far as the available supply was greater than the discharge through the outlets. But after the plug reached a certain position the discharge through the outlets decreased as the available supply was reduced below the discharge through the outlets causing a decrease in the hydraulic head.

4.2.1.2 Effect of orientation

Figure 7 shows the discharge through outlets for a pipe slope of 1% for different orientations of outlet with respect to the vertical centre line. When the orientation angle increased the total discharge also increased (Appendix II). The uniformity increased with increase in orientation which could be observed from more flatter curves for greater values of orientation angles. When the orientation was increased the outlet was nearer to the ground level and more number of holes were discharging. So there was more sharing of the available supply which resulted in greater uniformity. When the plug was moved towards the last few outlets the discharge through maximum oriented outlets was lesser than the low oriented outlets. This was because the supply into the pipe decreased resulting in reduction of hydraulic head.

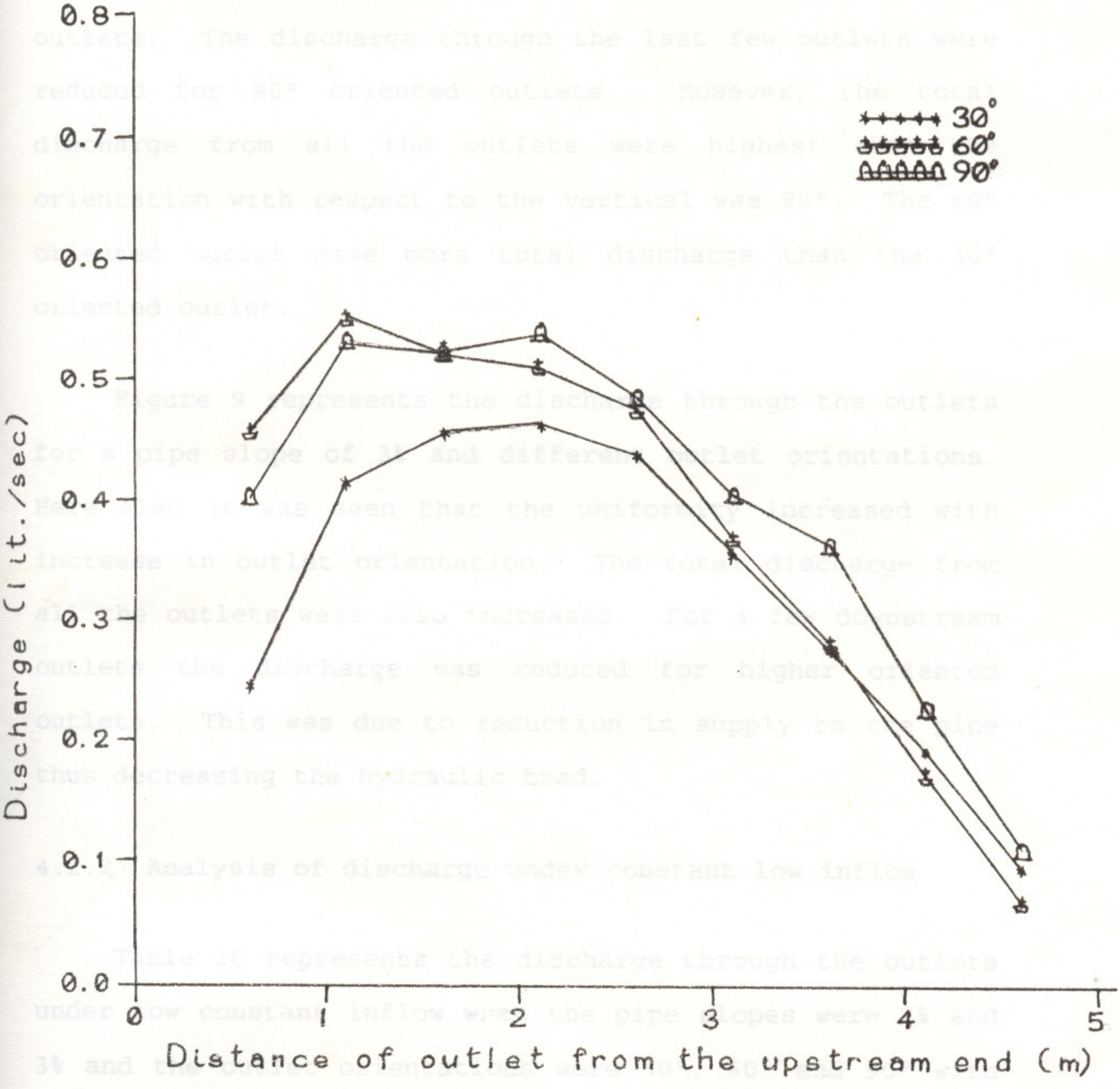


FIG.7. VARIATION OF TOTAL DISCHARGE FROM AN OUTLET AT DIFFERENT OUTLET ORIENTATIONS, FOR S = 1 %

The effect of orientation of the outlets on the discharge for a pipe slope of 2% is shown in Fig.8. The uniformity increased in this case. This was because of greater sharing of the available supply by more number of outlets. The discharge through the last few outlets were reduced for 90° oriented outlets. However, the total discharge from all the outlets were highest when the orientation with respect to the vertical was 90°. The 60° oriented outlet gave more total discharge than the 30° oriented outlet.

Figure 9 represents the discharge through the outlets for a pipe slope of 3% and different outlet orientations. Here also it was seen that the uniformity increased with increase in outlet orientation. The total discharge from all the outlets were also increased. For a few downstream outlets the discharge was reduced for higher oriented outlets. This was due to reduction in supply to the pipe thus decreasing the hydraulic head.

4.2.2 Analysis of discharge under constant low inflow

Table 10 represents the discharge through the outlets under low constant inflow when the pipe slopes were 2% and 3% and the outlet orientations were 30°, 60° and 90° with the vertical. The discharge increased with increase in slope for all the three orientations. This was due to increase in hydraulic head available at the outlet. The discharge through the first few outlets were less for all the experiments. This was because the supply which was directly applied to the pipe returned to the tank to cause a reduction in the hydraulic head. This discharge through all the other outlets were almost equal. There were discharges through two outlets nearest to the plug when 90° orientation was used for a pipe slope of 2%. At this orientation angle the outlets were lowered nearer to the ground level, thus water behind the plug reached more number of outlets.

Figure 10 is a graphical representation of outlet discharge which occurred for pipe slope of 2% under different outlet orientation angles of 30°, 60° and 90° from the vertical. The 90° orientation with vertical gave maximum discharge eventhough there were few cases of sharing the supply. The orientations of 30° and 60° outlets gave lesser discharge than for 90° oriented outlet. At a pipe slope of 2% and outlet orientation of 30°, flow did not occur in the first three outlets. At the same slope and with 60° and 90° oriented outlets the first outlet did not discharge. In all the cases the flow through the outlets after a first few became constant as constant head was maintained. The discharge through first outlets were lesser due to lower hydraulic head. After the flow became almost constant there was minor fluctuations in the discharge which could be attributed to the non-uniformity in the area of the outlets.

Figure 11 shows the graphical representation of discharge for a pipe slope of 3% under outlet orientations of 30°, 60° and 90° from the vertical. The variation in discharge with orientation was same as that for the 2% slope. At a pipe slope of 3% and outlet orientation of 30° flow did not occur in the outlets 1 and 2. For 60° and 90° oriented outlets, all the outlets discharged. In this case also the discharge became almost constant after first few outlets due to constant head maintained in the tank.

Suggestions

In the present study the plug consisted of a rubber disc. To reduce friction and to enable a smoother movement of the plug inside the pipe, plugs made of more flexible materials like buckets, rubber ball etc. may be used. The cable may also be substituted with Dacron fishing line, steel or polypropylene cables which have greater strength.

Table 10. Outlet discharge distribution

S = 2% at Φ = 30°, 60° and 90° and S = 3% at Φ = 30°, 60° and 90°

Outlet discharging water	Distance of outlet from the upstream end (m)	Discharge in l.p.s. for S=2%			Discharge in l.p.s. for S=3%		
		30°	60°	90°	30°	60°	90°
1	0.6	-	-	-	-	0.033	0.041
2	1.1	-	0.0296	0.0403	-	0.048	0.0573
3	1.6	-	0.04	0.044	0.0356	0.051	0.0583
4	2.1	0.0416	0.0473	0.056	0.047	0.0506	0.058
5	2.6	0.0426	0.0483	0.0566 (0.0036)*	0.0476	0.051	0.0576
6	3.1	0.0446	0.0476	0.0583 (0.0067)	0.050	0.0526	0.0606
7	3.6	0.0433	0.047	0.0556 (0.008)	0.0463	0.0503	0.0563
8	4.1	0.0423	0.0466	0.0546 (0.007)	0.0466	0.052	0.057
9	4.6	0.044	0.047	0.0553	0.046	0.0506	0.0553

* Figures in parenthesis represent shared discharge through outlets adjacent to the one nearest to the plug

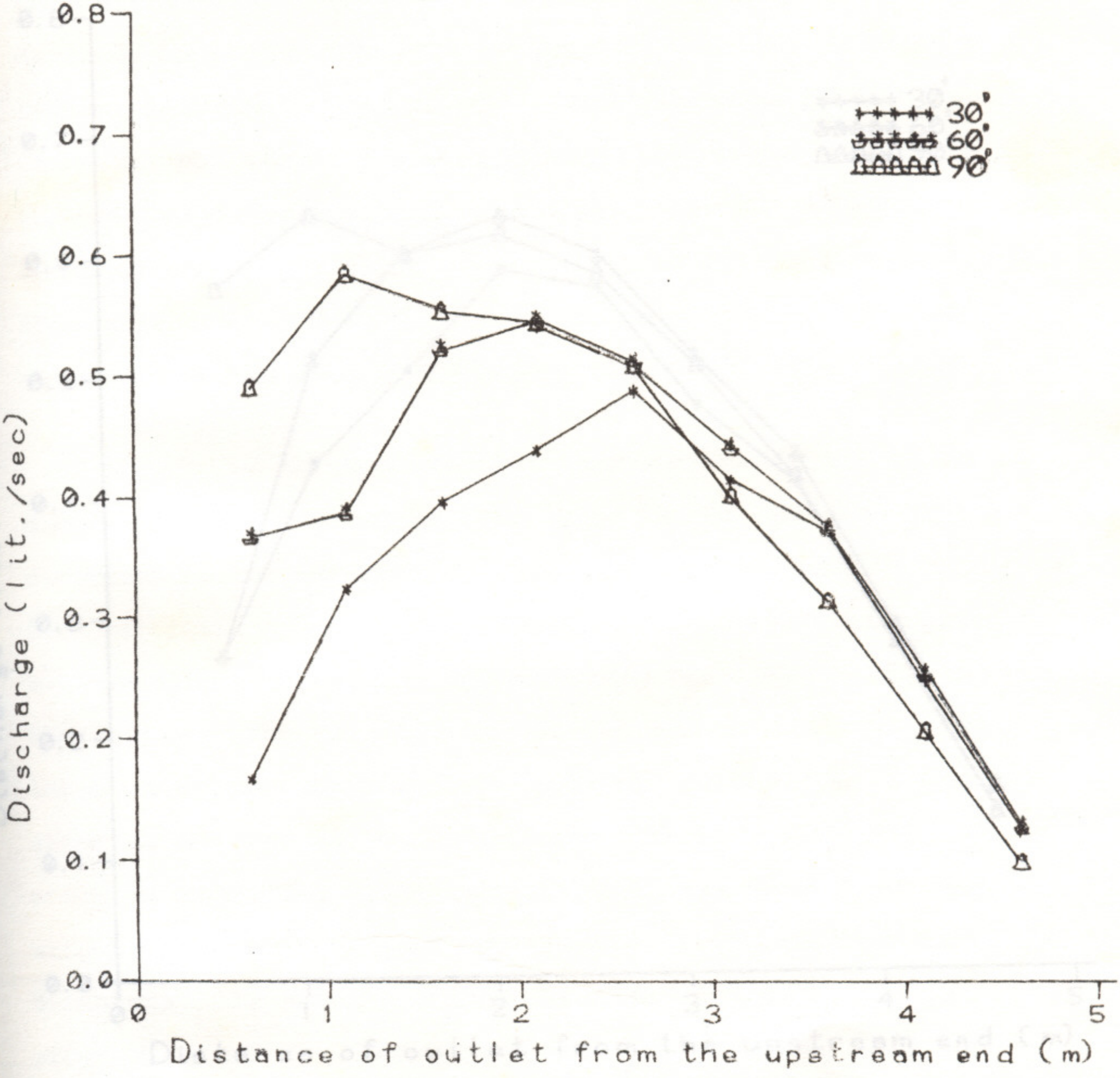


FIG.8. VARIATION OF TOTAL DISCHARGE FROM AN OUTLET AT DIFFERENT OUTLET ORIENTATIONS, FOR S = 2 %

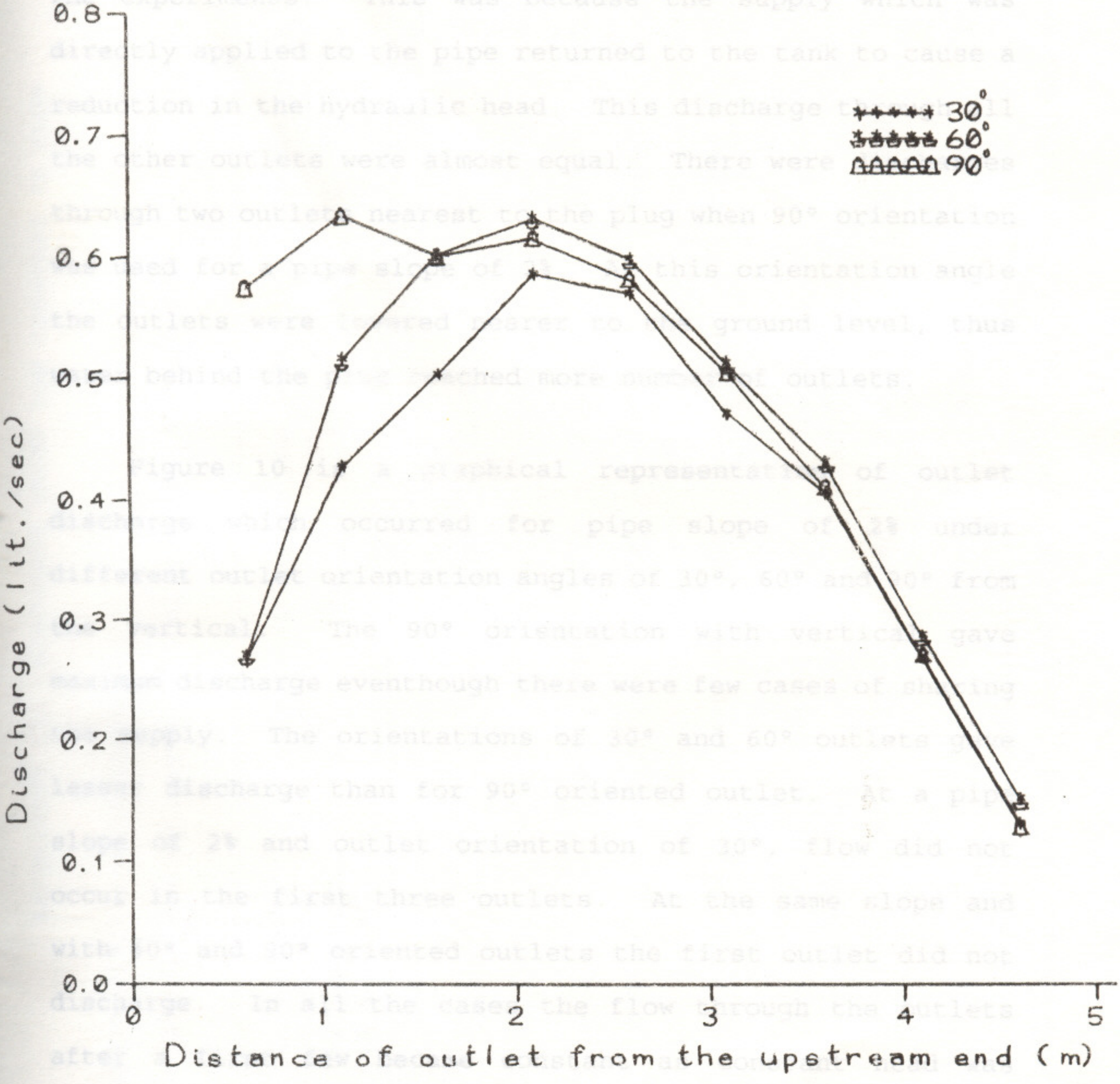


FIG.9. VARIATION OF TOTAL DISCHARGE FROM AN OUTLET AT DIFFERENT OUTLET ORIENTATIONS, FOR S = 3 %

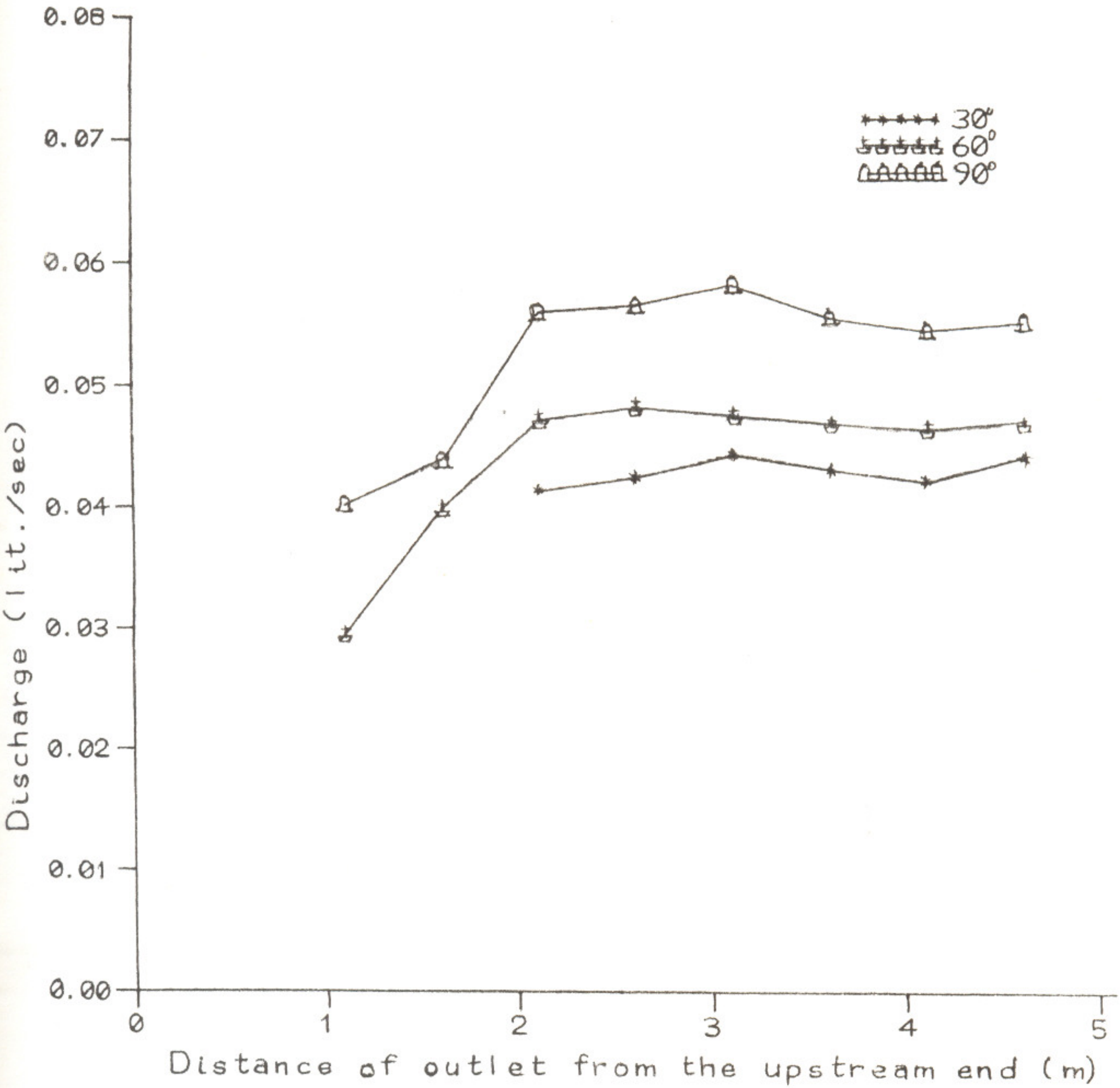


FIG.10. VARIATION OF DISCHARGE WITH OUTLET ORIENTATION UNDER CONSTANT LOW INFLOW, FOR S = 2 %

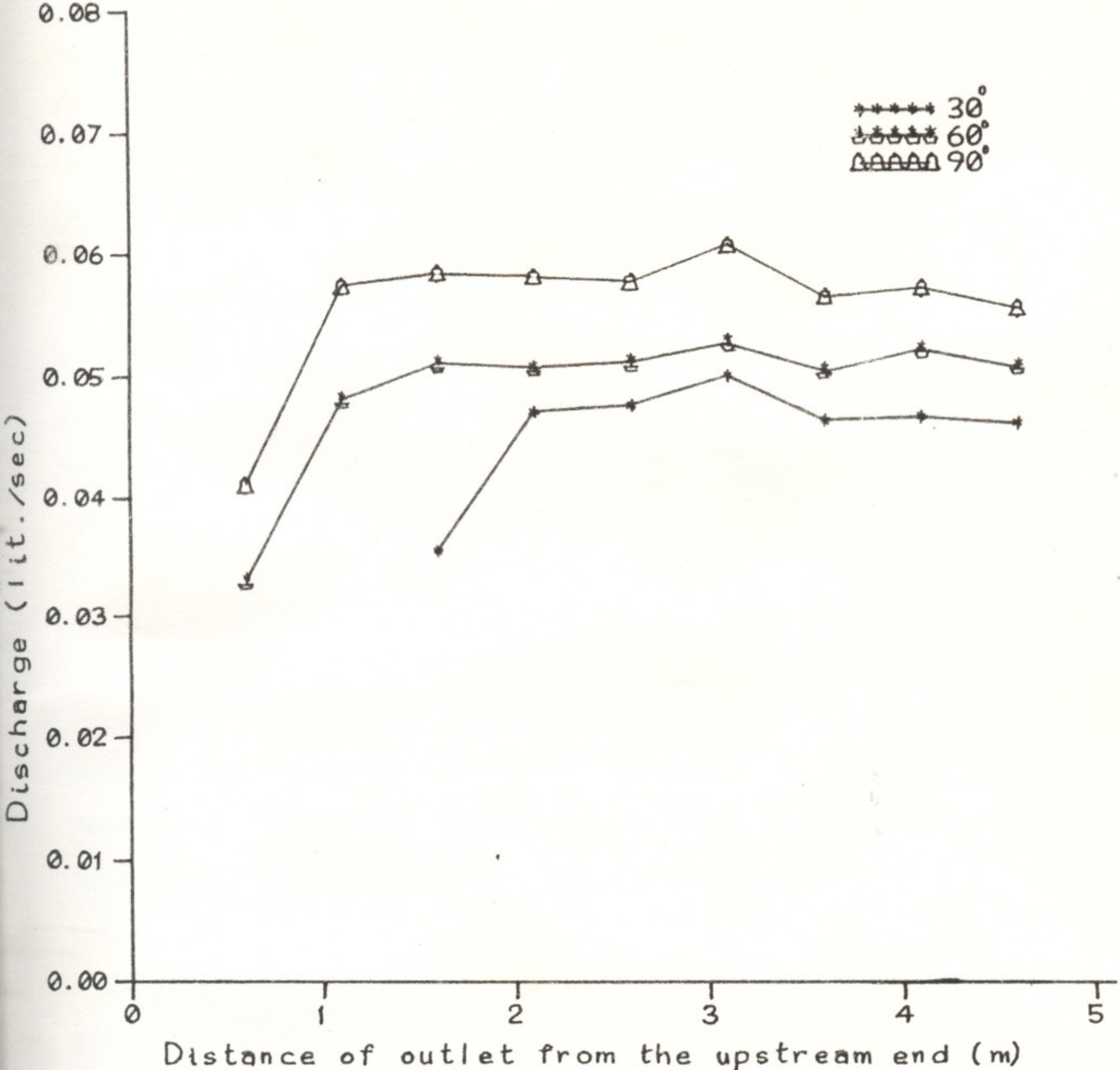


FIG.11. VARIATION OF DISCHARGE WITH OUTLET ORIENTATION UNDER CONSTANT INFLOW, FOR S = 3 %.

SUMMARY AND CONCLUSIONS

Water, being a limited resource, every effort must be made to make the best use of available water so as to achieve sustainable crop production. Over the years, many research works were carried out to improve the efficiency of surface irrigation.

Besides poor irrigation efficiency of 50 to 60 per cent, a considerable portion of the total cost involved in surface irrigation farming goes to labour charges. Though water saving methods like sprinkler system provides more application uniformity and less labour requirements, they have their inbuilt disadvantages of higher initial cost and increased energy requirements.

The Agricultural Research Service of USDA took up these points into consideration in 1979 and concentrated on research works to develop systems that would provide more application uniformity with less labour and energy inputs. Cablegation was a product of that research. The system was initially developed for furrow irrigation, but can be effectively adapted to border and basin irrigation.

The system used an over-sized pipe laid to a precise grade in which a plug obstructed the flow through the pipe.

Water accumulated behind the plug, thus increasing the hydraulic head and the supply was delivered through outlets provided along the pipe. The parameters which would influence the performance and efficiency of such an innovative system need be analysed.

A semi-automated cablegation system was developed and its performance assessed under laboratory conditions. Tests were carried out with the cablegation arrangement at different pipe slopes and orientation angles of the outlets under decreasing head and under a constant low inflow.

In the first case i.e., for discharge under decreasing head, the initial water surface elevation for each plug position was maintained at the same level. The plug was positioned between every two outlet orifices and the discharge was monitored for a period of 30 seconds. The experiment was conducted for different pipe slopes of 1 per cent, 2 per cent and 3 per cent and outlet orientations of 30°, 60° and 90° for each slope.

In the second case i.e., for a constant low inflow of 0.064 lit/sec, pipe slopes of 2 per cent and 3 per cent were used for outlet orientations of 30°, 60° and 90° with the vertical centre line.

The two experiments helped to get knowledge about the performance of the cablegation system under different pipe slopes and outlet orientations from the vertical centre line. Results of the experiments can be summarized as follows.

1. The discharge through the outlets was greatest for pipe slope of 3 per cent and least for pipe slope of 1 per cent in the case of decreasing head experiment. So it can be concluded that the increase in pipe gradient resulted in increased discharge due to greater hydraulic head available at the outlet.

2. When the outlet orientation was 90° with vertical, greater discharge was obtained than for the 30° and 60° oriented outlets. Least discharge was observed for 30° oriented outlet. This was due to increase in hydraulic head for 90° oriented outlets, due to lowering of outlets towards the ground level. Greater uniformity was observed for 90° oriented outlets due to more sharing of water by the outlets.

3. When constant low inflow was supplied, flow occurred only through the outlet nearest to the plug. The discharge through outlets tend to increase with increase in slope for all the three orientations. This could be

attributed to the increase in hydraulic head due to increase in pipe slope.

4. Analysis of the effect of orientation under constant discharge showed that increase in outlet orientation procured more discharge for all slope. For an outlet orientation of 90° at 2 per cent pipe slope there was sharing of the supply by more than one outlet due to higher hydraulic head.

When the system is operated at a specified pipe slope and outlet orientation, the discharge rate can be adjusted by varying the plug speed. At lower plug speeds, higher discharge will be obtained and as the speed increased the discharge rate decreased. So in order to get the desired discharge the plug speed need be carefully calibrated.

At a definite pipe slope, the orientation can be selected according to the inlet supply and the desired outlet discharge. With a constant inlet supply, more discharge can be obtained for outlet oriented more from the vertical and vice versa.

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CALCULATION OF PIPE SIZE

Pipe size can be calculated by Hazen-Williams formula

$$Qc = 2.15x10^{-4}\ C\ Sf^{0.54}D^{2.63} \qquad \text{--------}\ (1)$$

where,

Sf is the head gradient along the pipe in m/m due to friction

Qc is the flow rate in litres/minute

D is the inside diameter of the pipe in mm

C is the roughness coefficient of the pipe

For PVC, C=150

$$\text{Flow rate } Qc = \frac{0.9 \times 0.6 \times 0.032 \times 60}{1000x30} = 34.56 \text{ lit/min}$$

$$Sf = \frac{0.02}{100} \text{ m/m}$$

Substituting in (1)

$$34.56 = 2.15x10^{-4}x150xx(0.0002)^{0.54}D^{2.63}$$

$$\therefore D = 81.58 \text{ mm}$$

========

$\therefore$ An inside diameter of 87.5 mm was chosen as the pipe size

APPENDIX-II

Pipe slope S	Orientation of outlets from vertical centre line (Q)	Total discharge through each outlet (litres/second) 1	2	3	4	5	6	7	8	9	Discharge through all the outlets for a given S and Q (lit/sec)
	30°	0.2443	0.4142	0.4556	0.4639	0.439	0.357	0.276	0.1914	0.0947	2.9351
1%	60°	0.457	0.5513	0.5206	0.511	0.4759	0.369	0.282	0.1717	0.067	3.4061
	90°	0.4023	0.5321	0.5224	0.538	0.4859	0.4046	0.363	0.226	0.110	3.5843
	30°	0.1667	0.3246	0.3971	0.4396	0.490	0.4154	0.3726	0.246	0.127	2.9785
2%	60°	0.3686	0.3892	0.5232	0.5467	0.5114	0.4427	0.3767	0.2547	0.130	3.6719
	90°	0.4902	0.5843	0.554	0.544	0.5089	0.4026	0.315	0.2067	0.10	3.7057
	30°	0.2681	0.4293	0.504	0.586	0.5703	0.4713	0.4057	0.2674	0.133	3.635
3%	60°	0.2687	0.5134	0.6005	0.6301	0.5959	0.5093	0.4293	0.2847	0.150	3.9813
	90°	0.5734	0.6333	0.5993	0.6147	0.5807	0.5039	0.41	0.270	0.128	4.313

APPENDIX-III

Friction alhead loss in metres per 100 metres length of PVC pipe line

Flow litre/ second	Friction loss in metres per hundred metres Diametr of pipe (cm)			
	5.08	6.25	7.61	8.9
0.126				
0.252	0.03	0.01		
0.378	0.06	0.02		
0.503	0.11	0.04	0.01	
0.631	0.16	0.06	0.02	0.01
0.946	0.35	0.14	0.05	0.02
1.26	0.60	0.23	0.09	0.04
1.58	0.91	0.36	0.12	0.07
1.89	1.27	0.50	0.19	0.10
2.21	1.70	0.67	0.25	0.13
2.52	2.18	0.86	0.32	0.18
2.84	2.71	1.07	0.40	0.21
3.15	3.30	1.30	0.49	0.25
3.47	3.94	1.54	0.59	0.30
3.79	4.62	1.81	0.69	0.36
4.10	5.36	2.10	0.80	0.40
4.42	6.14	2.42	0.92	0.47
4.73	6.99	2.75	1.06	0.55
5.05	7.86	3.10	1.19	0.62

DEVELOPMENT AND PERFORMANCE EVALUATION OF A CABLEGATION SYSTEM FOR SURFACE IRRIGATION

By

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PRASAD, V. P.
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ABSTRACT OF THE PROJECT REPORT

Submitted in partial fulfilment of the
requirement for the degree

**Bachelor of Technology in
Agricultural Engineering**

Faculty of Agricultural Engineering
KERALA AGRICULTURAL UNIVERSITY

Department of Land and Water
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ABSTRACT

Cablegation is an automated method of supplying water for surface irrigation. This technique has been derived after a series of researches conducted towards lessening the labour input and energy costs of irrigation. The system has great application owing to its low initial cost and energy requirements and high water application efficiency. The cablegation system delivers the design rates of flow into irrigation furrows through outlets positioned along a conveyance pipe laid on a certain gradient with a moving plug inside for flow control. The flow rates are controlled by manipulating the speed of movement of the plug, the gradient of the main pipe and the size and orientation of the orifice holes. The movement of the plug past a hole induces water delivery through the upstream outlets due to the backup of water.

Laboratory tests were conducted to evaluate the performance of a manually controlled cablegation system, by applying water under varying head and by applying a constant low discharge to the pipe, for various pipe slopes and different outlet orientations from the vertical centre line. The pipe slopes chosen were 1 per cent, 2 per cent and 3 per cent and outlet orientations of 30°, 60° and 90° with the

vertical. The study revealed that the discharge increased with increase in pipe slope and outlet orientation. Greater uniformity was obtained for the 90° oriented outlet. The discharge through the outlets can be controlled by adjusting the plug speed.

Thus the system can reduce labour input, increase the water application efficiency and costsless. So it is more reliable than other automated systems.