HYDRAULICS OF
KAU DRIP IRRIGATION SYSTEM

By

SUSAN CHERIAN, K.

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "Hydraulics of KAU Drip Irrigation System" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Vellanikkara,

Susan K Cherian
SUSAN CHERIAN, K.

CERTIFICATE

Certified that this thesis, entitled "Hydraulics of KAU Drip Irrigation System" is a record of research work done independently by Miss. Susan Cherian, K. under my guidance and supervision and that it has not previously formed the basis for award of any degree, fellowship or associateship to her.

Vellanikkara,

T.P.GEORGE,
Chairman,
Advisory Committee,
Dean-in-charge, KCAET,
Tavanur

CERTIFICATE

We, the undersigned members of the Advisory Committee of Miss. Susan Cherian, K. a candidate for the degree of Master of Science in Agricultural Engineering, agree that the thesis entitled "Hydraulics of KAU Drip Irrigation System" may be submitted by Miss.Susan Cherian, K. in partial fulfilment of the requirement for the degree.

T.P.George,
Chairman,
Dean-in-charge,
KCAET, Tavanur.

K.John Thomas,
Professor and Head (IDE),
KCAET, Tavanur.

Dr.A.N.Remadevi,
Professor & Head (Ag.Engg.),
College of Agriculture,
Vellayani.

V.K.G.Unnithan,
Associate Professor (Ag.Stat.),
College of Horticulture,
Vellanikkara.

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To

my loving parents

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ABBREVIATIONS

ASAE	American Society of Agricultural Engineers
ASCE	American Society of Civil Engineers
°C	Degree celsius
cm	Centimetre (s)
l	litre(s)
l/s	litre(s) per second
l/hr	litre(s) per hour
log	logarithm
m	Metre (s)
mm	Millimetre(s)
m/m	Metre per metre
ml	Millilitre(s)
m/s	Metre per second
m^2/s	Square metre per second
m^3/s	Cubic metre per second
s	Second(s)
%	Percentage

Introduction

INTRODUCTION

Land, water and sunshine are the basic natural resources vital to agriculture. Of these, water is increasingly becoming scarce and could be named as liquid gold. This situation has reached alarming proportions posing a threat not only to agricultural production, the backbone of the Indian economy, but also to other factors of life. In a vast country like India with a geographical area of 328 million hectares, less than 45 per cent of the area is only cultivated, the gross cultivated area being 165 million hectares. Of this, only 35 per cent gets irrigation. Water is a vital natural resource and its effective use is essential for every farmer in this world. The demand of water is increasing day by day but the allocation of water to agriculture will be reduced as more water is to be given for industries, drinking supplies for the growing population in municipal and village areas. At the same time, to feed this population, more area should be brought under irrigation. This will be possible only by introducing advanced methods of irrigation.

Modernization of Indian agriculture based on science and technology is demanding a more upto date water system, one which will permit the same to manage water to increase production and income. In the past, water was being applied to the field without any restriction. The increased demand for water has lead to the development of various improved methods of irrigation. Irrigation advancements within the last decade have been astounding. Drip irrigation is one of the latest innovations for applying water and it represents a definite advancement in irrigation technology. It was developed as a subirrigation about a century back. A significant step in the evolution of drip irrigation, occurred in Israel, in late 1950's, following the development of long path emitters. From 1960 onwards drip irrigation developed as an important new mode of irrigation. In India, the research work on drip irrigation system is done at few institutions and Universities and has remained only at a laboratory or experimental stage. Commercial adoption on large scale is now known.

Drip irrigation is a promising technology and can be defined as the precise, slow application of water in the form of discrete drops, continuous drops, tiny streams or miniature sprays through mechanical devices called emitters or applicators located at selected points along water delivery line.

Drip irrigation is the daily or frequent application of water directly to the plant's root zone to replenish water and nutrients which have been utilized by the plant. The practice is based on the concept that the best use of available water resources and optimum plant performance is realised through preventing moisture stress rather than through relieving moisture stress, by maintaining ideal soil moisture conditions in the plant's root zone. Water is applied at low pressure and at slow rates for sufficient periods of time to maintain the soil at or near field capacity. Fertilizer and other chemical amendments can be applied directly onto and into the soil. Water is carried through a pipe network viz., main, laterals and microtubes. The design of a drip irrigation system is based on the hydraulics of pipe flow. The primary objective of good drip irrigation system design and management is to provide sufficient flow capacity to adequately irrigate all the plants. Before any system is installed the hydraulic design should be adequately evaluated for assuring maximum economical and efficient operation.

Drip irrigation is usually operated under low pressure. The pressure distribution along a lateral or a submain will be greatly affected by the friction and slope of the pipe or accidental restrictions. The variation of pressure along the line will change the discharge rate through the emitters. Trickle irrigation emitters vary from elaborate variable flow rate types to simple orifices or even punched, drilled or burned holes in the pipe. In general, the flow rate through the emitter is controlled by the hydraulic pressure at the emitter and the flow path dimensions of the emitter. Since water flowing through the lateral looses energy due to friction, a pressure variation will exist along the pipe length. If the emitter geometry is fixed, then a corresponding flow rate distribution proportional to the pressure distribution will exist. Design of an efficient drip irrigation needs information concerning the relationships between the factors viz., length, diameter, discharge, pressure head and flow rate. Analytical relationship between these factors are yet to be developed for the KAU drip irrigation system. The KAU drip irrigation system is that system in which a component distributor is added. It is relatively economical than the conventional drip irrigation system. The study on the above aspects of KAU drip irrigation system will provide new information that will enable efficient design of the system.

The objectives of the study are (1) to find the variation of emitter flow rate due to frictional loss (2) to determine the effect of pressure head on flow rate (3) to determine the effect of distributor of the KAU drip irrigation system on flow rate (4) to determine the frictional loss in microtubes of various diameters (5) to develop charts and tables for determining the emitter flow under varying conditions (6) to develop a standardized design procedure for KAU drip irrigation system.

Review of Literature

REVIEW OF LITERATURE

2.1 Drip irrigation in general

Drip irrigation is an improved method of irrigation and the irrigation system is designed to deliver controlled amounts of water directly to the plant. This type of irrigation has gained in use and development in the last three decades. Current drip irrigation technology dates back to the work of Blass (1964). In recent years, drip or trickle irrigation has become quite common practice in agricultural production around the globe

International Irrigation Association (1974) reported that the advantages of this type of irrigation is numerous. Increased beneficial use of available water is possible in drip irrigation by irrigating a small portion of the soil volume which decreased surface evaporation, reduced irrigation runoff from the field and controlled deep percolation losses below the root zone (Aljibury, 1974; Davis, 1975; Shoji, 1977). According to Davis (1975) and Shoji (1977), under drip irrigation real energy conservation can also be obtained because of the reduction in the amount of water pumped.

Drip irrigation has been found useful for fruits and vegetables and a saving of 30% in water use and increase in yield by 50% have been claimed under this system (Sivanappan *et al*., 1972). Enhanced plant growth and yield can be obtained by applying water as frequently as possible (Hillel, 1972; Childs and Hanks, 1975; Rawlins and Raats, 1975). Bravan (1976) found that with the use of drip irrigation system, the crop yields increased about 120% and water consumption reduced upto 85%. Richard Griffin (1977) reported that growers using drip indicated 25 - 50% saving in water, saving in operational cost, 25% higher yield and better quality of crop as compared to sprinkler system.

Drip irrigation offers considerable flexibility in fertilization (Isobe, 1974; Lindsey and New, 1974). The amount of nitrogen applied may be reduced approximately to one half through the drip irrigation (Kenworthy and Smith, 1977).

Halevy *et al*. (1973) indicated that drip irrigation offers a challenge to producers and researchers, not only as a solution for the use of saline water but as a self-sustaining trend. Saline water could be used safely for irrigation of crops with drip irrigation (Goldberg, 1970;

Philips et al., 1974; Hiller et al., 1975). Proper design of drip system for use with poor quality water will require knowledge of water and salt distribution pattern following drip irrigation with different rate and amounts of water application.

Kaul (1979) studied the hydraulics of soil moisture front in drip irrigation. He reported that the soil moisture in the wetted zone, resulting from a point source of water application, manifested itself by a rapid increase in the soil moisture content in the soil layer close to the point of water application. This zone was identified to extent to about 15 cm depth and 20 cm diameter.

2.2 Design of the system

The design of a drip irrigation is based on the hydraulics of pipe flow. A drip irrigation system consists of main line, lateral and emitters.

The pressure distribution along a drip irrigation line is controlled by the energy drop through friction and energy loss or gain due to slope. If the pressure distribution along a lateral line can be determined, uniform irrigation can be achieved by adjusting the length and size of the microtube used (Kenworthy, 1972), by adjusting the size of the emitters (Myers and Bucks, 1972) and by slightly adjusting the spacing between the emitters (Wu and Gitlin, 1973).

Most drip irrigation laterals and submains are designed for a single pipe size. The flow condition in the lateral or submain is steady and spatially varied with decreasing discharge in the line. The energy gradient line with a single size can be determined by an exponential curve that is used as basis for designing laterals or submains of drip irrigation systems on level field or on slopes (Howell and Hiler, 1974; Wu and Gitlin, 1974).

Drip irrigation system design procedure have been developed to determine the proper size of the emitters, pipes, valves and pumps. (Wu and Gitlin, 1973, 1974; Keller and Karmeli, 1974; Howell and Hiler, 1974a, 1974b). The pressure losses across emitter connection, should also be considered in the lateral line design procedure (Howell and Hiler, 1974; Keller and Karmeli, 1975).

Irrigation pipe laterals with multiple outlets are subjected to gradually diminishing flow. Wu and Gitlin (1974) found that by changing the outlet dimensions, or spacings, so that the specific outflow remains constant and a linearly diminishing flow will be obtained.

The basic hydraulic concepts of drip irrigation is developed by Wu and Gitlin (1974). The design charts for lateral lines were introduced by them. The pressure profiles along a lateral line on uniform slope was introduced by Wu and Fangmeier (1974) and Gillespie *et al*. (1979). Wu and Gitlin (1980) classified the pressure profiles into five types based on the dimensionless ratio between the minimum and maximum pressure at the end of the lateral line.

2.2.1 Lateral Hydraulics

Since friction coefficient is related to both the relative roughness and velocity distribution, any change in these will affect the head loss.

The friction loss in an irrigation lateral can be computed by the following method (Christiansen, 1942).

$$H_f = 0.617\ FLD^{-4.865} \quad \frac{100\ Q_t}{C}^{1.852}$$

Where

H_f = friction loss, m
F = coefficient for divergent pipe flow
Q_t = total discharge, l/hr
L = length of the pipe, m
D = diameter of the pipe, m

Christiansen (1942) presented an equation to estimate F as follows:

$$F = \frac{1}{M + 1} + \frac{1}{2 N} + \frac{M-1}{6 N^2}$$

Where

M = flow rate exponent

N = numbers of emitters

For smooth straight Polyvinyl Chloride pipe (PVC), C is assumed to be 150 in general practice. However, Hansen (1973) found that for laboratory trickle lining, depending upon the specific emitter type, C can vary from 98 to 136.

One of the characteristics of drip irrigation is low application rate, therefore the flow in the lateral or submain is low. This low flow in the small pipes, such as lateral of ½ inch, cannot be found in hydraulic handbook or tables (Williams and Hazen, 1960). So the drip irrigation pipes are hydraulically smooth, an empirical equation suggested by them is

$$H = 15.27 \quad \frac{Q^{1.852}}{D^{4.871}} \quad x \quad L$$

Where

H = energy drop by friction, m

Q = total discharge in pipe, l/s

D = inside diameter of the pipe, cm

L = length of a pipe, m

The value of friction factor f for turbulent flow in smooth pipes can be determined by Blasius equation (Giles, 1962).

$$f = \frac{0.316}{Re^{\frac{1}{4}}}$$

where

Re = Reynolds number

The following relationship is valid for laminar region (Giles, 1962)

$$f = \frac{64}{Re}$$

Most design for drip system ignore the laminar flow range in calculating the head loss (Watters and Keller, 1978). Darcy-Weisbach equation can be used in calculating the head loss in drip irrigation system (Watters and Keller, 1978).

$$H_f = \frac{f'lv^2}{2\ gd}$$

Where

H_f = Headloss, m
f = friction factor
l = length of pipe, m
v = fluid flow velocity, m/s
g = acceleration due to gravity, m/s^2
d = the diameter of pipe, m

In addition, localized losses are caused by the emitter barb projecting in the lateral line. A method presented by Watters and Keller (1978) considered barb friction losses, equivalent length of pipe that produces a friction loss of the same magnitude of the localized loss produced by the barb. They presented graphic data of emitter barb losses for various pipe diameters and barb diameters. The following equation, with a correlation coefficient of R = 0.99 was based on the result of Watters and Keller (1978).

$$L_e = 0.25\ B_w\ (19\ D^{-1.9})$$

Where

L_e = equivalent length of pipe, m
D = diameter of lateral, mm
B_w = emitter barb diameter, mm

To compute head loss by using Darcy-Weisbach equation, the length of lateral should be replaced by L^1,

$$L^1 = \frac{l\ (S_e + L_e)}{Se}$$

where

Se = emitter spacing, m

2.2.2 Emitter Hydraulics

Microtubes can be considered as a small plastic tubes with an inside diameter less than 6 mm. Microtubes discharge certain small amounts of water for irrigation. The tube length and size can be selected for different emitter flow rate.

The emitter design can greatly influence the pipe roughness. An in-line emitter which is directly inserted into a cut end of the pipe can cause significant pressure loss due to the flow restriction caused by the emitter. The pressure loss can be as large as 0.035 psi per emitter with a through flow of 0.5 gpm (Kenworthy, 1972).

Early research using microtube emitter was reported by Kenworthy (1972). Analysis and design of microtube emitter in drip irrigation was studied and reported by Bucks and Myers (1973), Wu and Gitlin (1973) and Karmeli (1977).

Many type of drip emitters and systems are available and generally the hydraulic operating characteristics of each individual emitter type are different. Bucks and Myers (1973) estimated that greater than 50 different emitters were on the market.

The general equation for drip irrigation emitter flow has been determined by Howell and Hiler (1974a, b) Wu and Gitlin (1974) and Karmeli (1977) to be

$$q = kh^{x}$$

where

q = emitter discharge, l/hr

k = constant of proportionality

h = pressure head at the emitter, m

x = emitter discharge component

Laboratory calibration and statistical regression analysis showed that the logarithm of microtube length is a log function of flow rate, pressure and inside diameter (Kenworthy and Kesner, 1974).

The essential item in the microtube emitter design is the calculation of energy drop caused by a certain flow discharge from the microtube emitter. The total energy drop in a microtube emitter can be expressed as a summation of friction drop, minor loss due to entrance and fittings and the velocity head at the exit end of the microtube.

A basic equation for energy drop by friction is a simple exponential formula.

$$H_f = C \frac{Q^x}{D^y} L$$

where

H_f = energy drop by friction, m

Q = flow rate, l/hr

D = inside diameter, mm

L = length of microtube, m

x and y are two exponential constants

C = a coefficient

Khatri et al. (1979) observed a correlation between the friction coefficient f and Reynolds number R_e when minor loss was separated from the total energy loss. It showed that the microtube is smoother than the hydraulically smooth tube as specified in the Moodydiagram. The relationship was found true by Paraquiema (1977) for ½" plastic, copper and PVC tubes and Watters and Keller (1978) for smaller sizes ranging from ½" - 1/8". Watters and Keller (1978) reported that the friction drop for smaller size pipe (4 - 12 mm) can be calculated by Darcy-Weisbach equation for smooth pipe. Since both the Williams and Hazen equation and Blasius equation were determined relatively for larger size pipe with turbulent flow, an empirical verification was needed for microtubes with a size less than 4 mm and with flow conditions in all regions.

Khatri <u>et</u> <u>al</u>. (1979) observed that as the microtube emitter diameter was small and the length was short the minor loss was significant. A computer simulation was applied to find out the relationships for total pressure head, minor loss and friction loss. The minor loss for laminar flow condition is small and can be neglected.

The emitter flow variation along a lateral line caused by hydraulics can be determined by emitter and flow profiles. For uniform slope situations, five smooth pressure profiles are developed (Gillespie <u>et</u> <u>al</u>., 1979).

If the hydraulic pressure at each emitter can be determined, it is possible to determine, emitter by emitter, the flow variatioh due to pressure vafiation within the system. The variance of a population can be found from the following equation

$$S_Q^2 = \frac{1}{n} \text{ sum } (Q_i - Q_m)^2$$

where

s_Q^2 = variance of emitter flow due to hydraulics

Q_i = discharge from emitter i, l/h

Q_m = mean emitter discharge, l/h

n = number of emitters

The coefficient of hydraulic variation, V_Q is found from the following equation (Bralts et al., 1981).

$$V_Q = \frac{s_Q}{\bar{Q}_m}$$

where

s_Q = standard deviation of emitter flow rates due to hydraulics, l/h

2.3 Distributor

George (1977) developed a drip irrigation technique by introducing the distributor. Distributor was made from a polyethylene pipe used for laterals, plugged at both ends with plastic caps. It was connected to the lateral through a microtube and four microtubes were taken out from distributor and were acted as drippers.

He observed that, with one meter head, with a microtube of diameter 1.5 to 2 mm, water flows into the distributor at the rate of 6-10 l/hr and it was reduced to 1-2 l/hr through the dripper.

2.4 Clogging

A serious problem associated with drip irrigation is emitter clogging caused by physical, chemical and biological build up in the minute water passage ways. By modifying microbial activity with chlorine treatment clogging can be controlled (Sharp, 1956).

Because water pathways of trickle emitters are small, filtration to remove suspended particles has been extensively used to avoid clogging as reported by Wilson (1972, 1975). The chemical treatments perform two major functions, viz., the hypochlorite inhibits microbial growth and slime development and the acid dissolves or maintains carbonates in solution which enhances the bactericidal activities of the Chlorine (White, 1972).

Trickle irrigation researchers and equipment manufacturers have chosen two approaches to solve the clogging problems. The first is to develop emitter devices which may require less or minimum maintenance (Wilson, 1972; Solomon, 1977). A second approach is to focus attention on improving the quality of water before it reaches the emitter (Ford and Tucker, 1974; McElhoc and Hilton, 1974; Bucks *et al.*, 1977;

Nakayama et al., 1978). Chlorination by bacterial control is not recommended when water has 0.4 mg/l or more dissolved iron, because chemical reaction will form iron oxide which can precipitate and cause blockages of emitters (Ford and Tucker, 1974).

Shearer (1975) found that high flushing velocity are needed to clean the laterals. Morris and Black (1975) reported that a minimum velocity of 2.5 m/s is required at the downstream end of the lateral and that the optimum range is 2.5 to 5 m/s. Wallis (1976) reported that the Hawaiian Sugar Planters Association recommends a minimum flushing velocity of 0.3 m/s.

Removal of suspended particles larger than 75 microns with sand media filters, wire mesh screens, centrifugal separators and settling basins has been used to reduce emitter clogging (Wallis, 1976; Schnedl, 1976; Nakayama et al., 1978). According to Bucks et al. (1977) and Shearer (1977) clogging causes a reduction in discharge.

Materials and Methods

MATERIALS AND METHODS

The variation of discharge from emitter and lateral is a function of length, diameter, pressure head and velocity. Experiments were conducted to study the basic hydraulics of microtubes and laterals. Experiments were conducted to find out the following.

i. Hydraulics of microtube emitters.
ii. Effect of distributor on flow rate.
iii. Effect of clogging on flow rate in the microtube emitters.
iv. Determination of friction loss in the laterals.

3.1 Location

The experimental site was the quadrangle, near Agricultural Engineering Research Workshop of Kerala Agricultural University, Mannuthy. The plot size was 25 x 20 m.

3.2 Levelling of the plot

The floor of the experimental site was not level. Hence to get a uniformly levelled surface, small pillars were made with bricks and cement. A water tube was used to check the level of pillars, while making them. Long wooden planks of uniform thickness were placed over the pillars.

Plate 1 & 2 Experimental site

3.3 Source of water

Tap water was used for the present study.

3.4 Tank

Two oil drums each having two hundred litres capacity were used as tank for the present study. The tank was fabricated by welding these two drums together. The height of the tank was 170 cm. Another drum of two hundred litres capacity was used as a storage drum. It was placed over a stand at a height of 200 cm. The tank and the drum were connected by a polyethylene pipe of one inch diameter. The outlets of the drum and the tank were controlled by wheel valves which were connected to a 20 cm long threaded 25 mm GI pipe, with 5 cm length of the pipe extending inside. It was fixed to the tank and to the drum, 4 cm above the bottom. So the suspended impurities were not entered into the outlet. The mouth of the outlet of the overhead drum was covered with a plastic wire mesh in order to prevent the suspended impurities entering into the tank.

As this drip system worked at low pressure, any small airlock in the system would stop the flow of water. An air outlet was provided in the outlet pipe of the tank. When the valve from the tank was opened, air in the system

Plate 3 Arrangement of the airvent, transparent tube and extra outlets made to the tank

Plate 4 Connection of the storage drum with the tank


1.5M
1.0M
0.5M

escaped through the air vent. When air escaped, water could be seen spurting out of the air vent. This process takes about two to three minutes.

The study was conducted at different pressure heads viz., 50 cm, 100 cm and 150 cm. In order to keep these hydralic pressure heads constant, extra outlets with wheel valves were provided at these levels. While doing the experiment, the valve in connection with the desired head was opened so that, the excess water in the tank was drained off through that outlet. In order to see the water level of the tank, a small transparent tube of length 175 cm and diameter 8 mm was attached to the tank.

3.5 Main and laterals

Black low density polyethylene pipes of sizes 25 mm and 12.5 mm were used as main and laterals respectively. Both these pipes were attached to the wooden planks with clamps. The laterals were connected to the main pipe by using 25 x 12 mm G.I.T's through 12 mm hose collar.

3.6 Microtubes

In this system, microtubes were used as the emitters. Microtube is a simple type of emitter with an inside diameter less than 6 mm which is easy to install and relatively low in cost compared to other type of emitters.

In the present study, microtubes of 1 mm, 2 mm and 3 mm diameters were used. These were connected to the laterals by drilling holes having slightly lesser diameter than the external diameter of the microtube and the microtubes were pushed slightly into these holes for a tight fit. As the system worked on low pressure the joints were leak proof. One end of the microtube was connected to the lateral and the other end to a distributor.

3.7 Distributor

The 'heart' of the KAU drip irrigation system is the distributor developed in the Agronomic Research Station, Kerala Agricultural University, Chalakudy in 1977. The drip system developed at this centre works on low pressure. The total head required for this system is only one metre. The conventional system works on high pressure. The initial cost of the conventional drip irrigation system is high and this limits its large scale adoption. KAU drip irrigation system is relatively economical.

Distributor was a polyethylene pipe having 15 cm length and 1.25 cm diameter, plugged at both ends with plastic caps. Distributor was connected to the lateral through a microtube known as inlet tube. Four microtubes having the same diameter and length were taken out from

Plate 5 Distributor with different sizes of emitters

Plate 6 Experiment laid up for the evaluation of friction loss in laterals

the distributor and these were acted as drippers. Both entry and exit tubes connected to the distributor were of the same diameter. The discharge through each dripper can be controlled by varying the length of the microtube.

Microtubes of 1 mm, 2 mm and 3 mm sizes were used as inlet tube and drippers. The rate of discharge through the inlet tube was about 5-30 l/hr. The function of the distributor was to reduce the high discharge of 5-30 l/hr to about 1.5 to 5 l/hr. The disadvantage of the high discharge rate was that a large area would be wetted and this would increase the evaporation loss and reduce the efficiency of the system. A dripper can wet one square metres of land. This means that an area of four square metres can be irrigated with the distributor. The drip irrigation unit with the distributor is named as KAU Drip irrigation system.

3.8 Stop watch

The time required for collecting a certain volume of water was noted by a stop watch.

3.9 Measuring jars

Measuring jars of different sizes viz., 50 ml, 200 ml, 500 ml and 1000 ml were used for collecting the discharge from the microtubes and laterals.

3.10 Basic hydraulics

A drip irrigation system is made by combining different sizes of plastic pipes which are usually considered as smooth.

For laterals, the head loss due to friction can be computed by using the formula

$$H = 15.27 \frac{Q^{1.852}}{D^{4.871}} L$$

Where

H = total energy drop by friction, m

Q = total discharge, l/hr

D = inside diameter of lateral, cm

L = length of lateral, m

Microtube is a small tube. When such a small tube is used, the tube itself will dissipate energy and discharge certain small amounts of flow for irrigation. The essential item in the microtube emitter design is the calculation of energy drop caused by a certain flow discharge from the microtube emitter. This energy drop is a combination of minor loss and friction drop. This energy drop represents also the inlet pressure or operating pressure of the microtube since the outlet pressure is zero. The entrance loss and energy drop from fitting in regular pipe flow design are considered as minor losses and expressed as a function of velocity head.

The basic hydraulics of microtube is also a part of the hydraulics of pipe flow. A basic equation for energy drop by friction is a simple exponential formula

$$H_f = C \frac{Q^x}{D^y} L$$

Where

H_f = the energy drop by friction, m

Q = flow rate, l/hr

D = inside diameter, mm

L = length of microtube, m

The total energy drop in a microtube emitter can be expressed as a summation of friction drop (H_f), minor loss (H_m) due to entrance, fittings and the velocity head at the exit end of the microtube. If the velocity head is also considered as a minor loss, the total pressure head can be expressed as

$$H = H_f + H_m$$

H = operating pressure, m

H_f = friction drop, m

H_m = minor losses, m

Since both the entrance and fitting losses can be expressed as a function of velocity head, the minor loss H_m can be expressed as

$$H_m = K . \frac{V^2}{2g}$$

Where

H_m = minor loss, m

K = minor loss coefficient

V = mean velocity, m/s

g = acceleration due to gravity, m/s^2

Both entrance and fitting losses for laminar flow condition may be very small and in many practical problems, it can be neglected.

Design information about minor loss has been determined for larger diameter pipes but information was needed for small microtubes covering the flow regions viz., laminar, transition zone and turbulent. There was no empirical equations available for calculating friction drop from a microtube with a diameter ranging from 1 mm - 4 mm. Since both the Williams and Hazen equation and the Blasius equation (in the Moody diagram) were determined empirically for relatively larger size pipes with the turbulent flow, empirical equations were needed for microtubes with a size less than 4 mm and with flow conditions in all regions viz. laminar, transition and turbulent.

3.11 Experimental set up

The experiments were conducted at 28-30°C. A black polyethylene pipe of length 18 m and diameter 25 mm was used as the main line. In the main line, at 6 m apart, 3 laterals of length 20 m and diameter 12.5 mm were connected by T' joints. In each lateral, at 5 m apart, holes were drilled to insert 1 mm, 2 mm and 3 mm microtube emitters. A T' joint with an end plug was used to close the main line and small plastic caps were used to close the laterals. The first three experiments were conducted in the quadrangle with the above set up.

The first experiment was conducted to establish a relationship among the pressure head H, discharge rate Q, length of the microtube emitter L and microtube diameter D. The diameters of the microtubes were measured. The microtubes were given a straight cut at both ends. Three lengths of 50 cm, 100 cm and 150 cm of each size of diameter were used. Each microtube was tested under three pressure heads of 50 cm, 100 cm and 150 cm, each test was repeated six times by collecting a certain volume of water and the time taken for the same was noted.

Polyethylene pipes of 12.5 mm were used as laterals. One end of these pipes were connected to the main pipe with T's and were closed at the other end with insert caps. Measuring jars were used for collecting water from the microtubes and time taken for collecting a certain volume of water was noted with a stop watch. The pressure head was maintained at constant levels.

The effect of distributor on flow rate was determined by a second experiment. Three different microtube sizes viz., 1 mm, 2 mm and 3 mm were connected to the laterals. For each diameter of inlet tubes and drippers, three different lengths viz., 50 cm, 100 cm and 150 cm were tested. Various combinations of microtube sizes and lengths were tested in the study. For each diameter of the microtube the following combination of lengths for inlet tube and drippers were used respectively 50 + 50 cm, 50 + 100 cm, 50 + 150 cm, 100 + 50 cm, 100 + 100 cm, 100 + 150 cm, 150 + 50 cm, 150 + 100 cm, 150 + 150 cm (Fig. 1, 2, 3). The time taken for collecting a certain volume of water from the drippers were noted. Experiments were done at different pressure heads.

An experiment was conducted to assess the degree of clogging. For this, microtubes of 1 mm, 2 mm and 3 mm were connected to the laterals. The discharge rate of these microtubes at the beginning of the experiment were measured. Water was allowed to flow through these tubes, for three months continuously during the day time. Then the discharge rate was noted. The degree of clogging was calculated from the following equation.

$$q = 100 \times \frac{(1 - q_i)}{\bar{q}_i}$$

Where

q = degree of clogging (%)

q_i = average discharge (l/hr)

$\bar{q}_i$ = nominal average discharge (l/hr)

A fourth experiment was conducted for determining the head loss due to friction in lateral pipe. The plot selected for this study was the Instructional Farm, Agricultural Research Station, Mannuthy. For this experiment, a lateral of 100 m length was connected to the main pipe and the main pipe was connected to the tank. Pressure head was maintained at different levels viz., 50 cm, 100 cm and 150 cm. The time taken for collecting a certain volume of water from the lateral at 100 m length was noted. 25 m length of the lateral was then cut off and the time taken for collecting a certain volume of water at 75 m length was noted. The same procedure was continued for 50 m and 25 m length of the lateral.

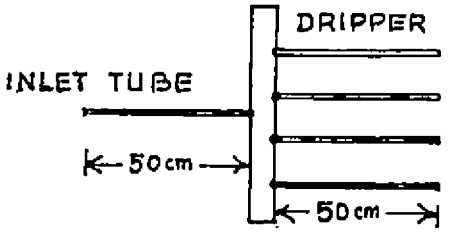


FIG. 1a. 50+50 cm

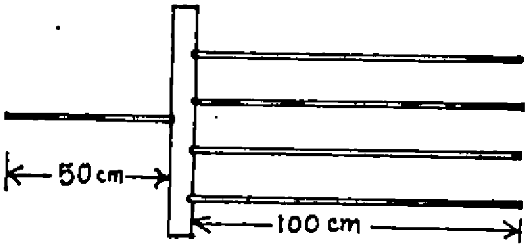


FIG. 1b. 50+100 cm

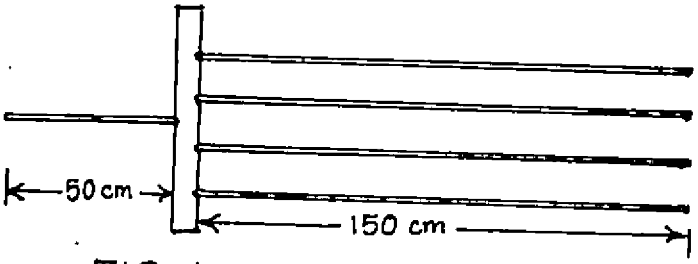


FIG. 1c. 50+150 cm

FIG. 1. DIFFERENT LENGTH COMBINATIONS OF DISTRIBUTOR (INLET TUBE 50 cm.)

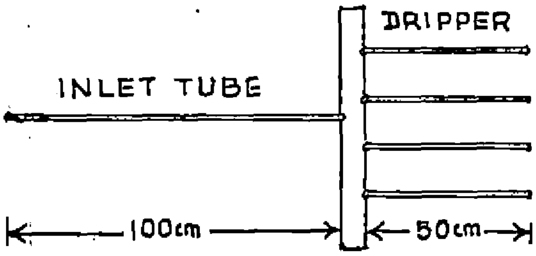


FIG. 2 a. 100+50 cm

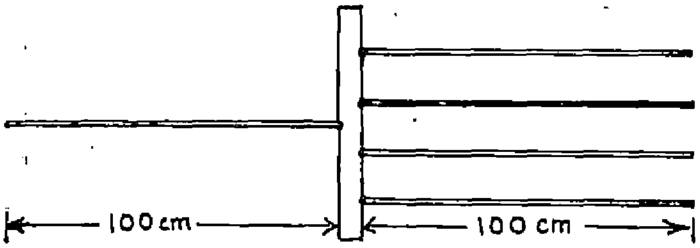


FIG. 2 b. 100+100 cm

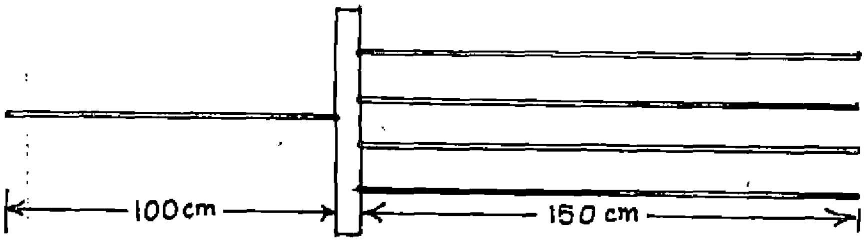


FIG. 2c. 100+150 cm

FIG. 2. DIFFERENT LENGTH COMBINATIONS OF DISTRIBUTOR (INLET TUBE 100cm.)

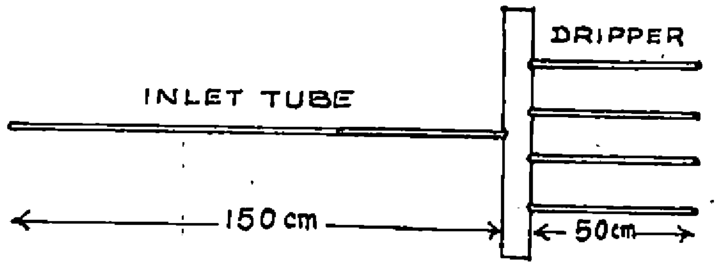


FIG. 3 a. 150 + 50 cm.

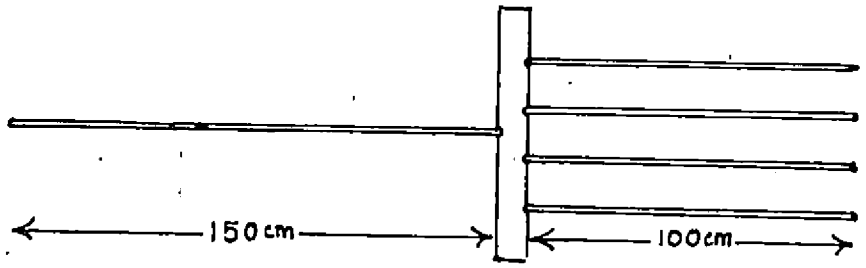


FIG. 3 b. 150 + 100 cm.

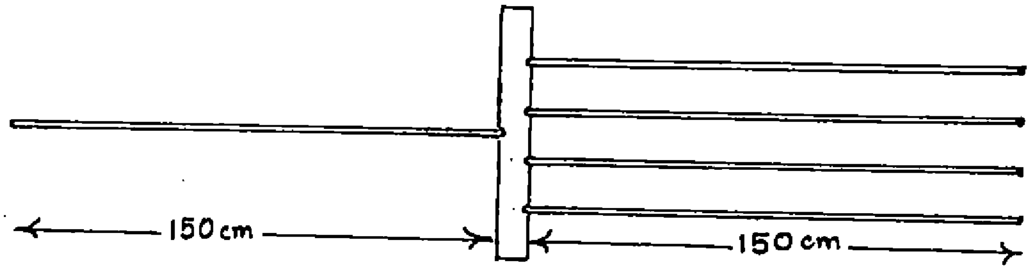


FIG. 3 c. 150 + 150 cm.

FIG. 3. DIFFERENT LENGTH COMBINATIONS OF DISTRIBUTOR (INLET TUBE 150 cm.)

Results and Discussion

RESULTS AND DISCUSSION

The results of the following four experiments conducted are presented and discussed in this chapter.

i. Hydraulics of microtube emitters
ii. Effect of distributor on flow rate
iii. Effect of clogging on flow rate of microtube emitters
iv. Determination of friction loss in the laterals

4.a. Velocity

Average values of measured discharges of the tubes were taken. Velocity was found out from the continuity equation.

$$Q = AV \qquad (1)$$

$$V = \frac{Q}{A} \qquad (1a)$$

Where

Q = average discharge, m^3/s

A = area of cross section of the tube, m^2

4.b. Identification of flow regime

In order to identify the flow regime in which the flow occurs, Reynolds number was calculated. The concept of

Reynolds number which distinguishes the regimes of laminar and turbulent flow is indeed quite useful in the study of water flow phenomenon. If the Reynolds number is below 2000, the flow is in laminar region. If it is in between 2000 and 4000, the flow is in transition region and when the Reynolds number is above 4000, the flow is in turbulent region. Reynolds number was calculated by

$$Re = \frac{V\,D}{\nu} \qquad (2)$$

Where

Re = Reynolds number
V = velocity of the flow, m/s
D = diameter of the pipe, m
ν = kinematic viscosity of water at 30°C
= $0.804 \times 10^{-6}\ m^2/s$

Based on the data obtained from different sizes of microtubes at different lengths and pressure heads, it was found that all the three types of flows (laminar, turbulent and flow in transition region) were occurred in the present study. In 1 mm tube, the discharge was small as compared to those in 2 mm and 3 mm tubes. In all the three different heads at different lengths, perfect laminar flow was occurred in 1 mm tube. But in 2 mm tube, the three types of flows were occurred at different heads and lengths. In the case of 3 mm tube, eventhough the three types of flows occurred, the turbulent flow was prominent.

4.c. Effect of pressure head and length on flow rate

It was observed that the pressure head was having a great influence on flow rate. When pressure head was increased, velocity was increased and thereby discharge was also increased. Length of tube also had an effect on flow rate. Discharge was decreased with an increase in the length of the tube (Table 1 and Fig.4, 5 and 6).

4.i. Hydraulics of microtube emitters

From the first experiment it was observed that the total energy drop in a microtube can be expressed as a summation of friction drop (H_f), minor loss (H_m) due to entrance, fittings and the velocity head at the exit end of the microtube. Considering the velocity head also as the minor loss, the total pressure head can be expressed as

$$H = H_f + H_m \qquad (3)$$

There was no empirical equation available for calculating the friction drop from a microtube with an inside diameter ranging from 1 - 4 mm. Since both Williams and Hazen equation and Blasius equation were determined empirically for relatively larger size pipe with turbulent flow, an empirical verification was needed for microtubes with a size less than 4 mm and with flow conditions in all regions viz., laminar, transition and turbulent.

The basic hydraulics of microtubes were studied. Experiments were conducted to establish the relationships between pressure head H, length L, diameter D and discharge Q. Average values of measured discharges of the microtubes in the three laterals were taken. Discharge measurements were taken at three different pressure heads viz., 50 cm, 100 cm and 150 cm. Microtubes of diameters 1 mm, 2 mm and 3 mm and lengths 50 cm, 100 cm and 150 cm were tested. The data is presented in Table 1.

4.i.1 Empirical equations for pressure head

The relationships between the parameters, viz., pressure head, length, diameter and discharge were estimated for different flow conditions by fitting log linear multiple regression equations. With the help of a computer, the above analysis was made for combined flow condition and for each individual flow condition viz., laminar, transition and turbulent (Appendix I). The empirical equations obtained are as follows:

1. Combined flow condition

$$H = 0.01402 \quad \frac{Q^{1.23938}}{D^{3.54926}} \quad L^{0.86030} \qquad (4)$$

2. Turbulent flow condition

$$H = 0.00764 \quad \frac{Q^{1.82655}}{D^{4.61537}} \quad L^{0.77823} \qquad (5)$$

3. Flow in transition region

$$H = 0.00817 \quad \frac{Q^{1.56882}}{D^{3.83531}} \quad L^{0.83541} \qquad (6)$$

4. Laminar flow condition

$$H = 0.00796 \quad \frac{Q^{1.23461}}{D^{3.59105}} \quad L^{0.98712} \qquad (7)$$

where

H = pressure head, which is the summation of minor loss and the friction drop from the microtube, m

D = diameter of the microtube emitter, mm

Q = discharge, l/hr

L = length of the microtube emitter, cm

For the above equations, the coefficients of determination, R^2 were 0.96599, 0.9996, 0.99692, 0.99994 respectively. Since the coefficients of determination were very near to one, the errors in estimation for total head loss in the above four conditions were negligible.

The powers of L were not unity in the empirical equations for total pressure head. This may be caused by the fact that the total pressure was used in the regression analysis where the minor loss was included in the calculation. The minor loss was significant because of the smaller size of tube and short length of the microtube.

4.i.2 Separation of minor loss

The separation of minor loss was done by a computer calculation using the relationship for friction drop and the minor loss function.

The basic equation for friction drop has the form of

$$H_f = C \frac{Q^x}{D^y} L \qquad (8)$$

The minor losses include entry and exit losses, losses due to fittings and sudden contraction. The minor losses of energy have been found to vary as the square of the mean velocity of flow. Hence all the above losses can be expressed as a function of velocity head and can be expressed as

$$H_m = K \frac{V^2}{2g} \qquad (9)$$

where

H_m = minor loss, m

K = minor loss coefficient

V = mean velocity of the flow, m/s

g = acceleration due to gravity, m/s^2

The numerical solution for minor loss coefficient K was obtained by using different K values in order to make the power of 'L' unity in the estimating equation for head loss due to friction from the total discharge Q, microtube length L and diameter D (Appendix II).

$$H - H_m = H_f = C \frac{Q^x}{D^y} L \qquad (10)$$

The predicted minor loss equations were estimated for combined flow which included all the data regardless of the flow condition, laminar flow, flow in the transition zone and turbulent flow. The equations obtained are given below.

1. Combined flow

$$H_m = 2.34 \frac{V^2}{2g} \qquad (11)$$

2. Turbulent flow

$$H_m = 2.14 \frac{V^2}{2g} \qquad (12)$$

3. Flow in transition region

$$H_m = 3.18 \frac{V^2}{2g} \qquad (13)$$

4. Laminar flow

$$H_m = 0.84 \frac{V^2}{2g} \qquad (14)$$

where

H_m = minor loss, m

V = mean velocity of flow, m/s

g = acceleration due to gravity, m/s^2

In this study, a K value of 0.84 was obtained for laminar flow. According to Khatri et al. (1979), in the laminar region the value of friction loss and total losses were same, which indicated that there was no minor loss.

In the present study, for transition region the minor loss coefficient K was high but the total minor loss 'H_m' was less because of the low velocity. In turbulent zone, the value of K obtained was less than that in transition region. But here, the total minor loss was higher than the other two regions due to high velocity.

4.i.3 Empirical equations for friction drop

When the minor loss is separated from the total pressure head, the remaining part is the loss due to friction

(H_f). The empirical equations for friction drop for microtubes were developed for different flow conditions by fitting multiple log linear regression equations. The equations obtained are:

1. Combined flow

$$H_f = 0.00737 \frac{Q^{1.18905}}{D^{3.58352}} L \qquad (15)$$

2. Turbulent flow

$$H_f = 0.00359 \frac{Q^{1.74866}}{D^{4.80544}} L \qquad (16)$$

3. Flow in transition region

$$H_f = 0.00397 \frac{Q^{1.46302}}{D^{3.74436}} L \qquad (17)$$

4. Laminar flow

$$H_f = 0.00743 \frac{Q^{1.22546}}{D^{3.58420}} L \qquad (18)$$

where

H_f = friction head, m

D = diameter of microtube emitter, mm

Q = discharge, l/hr

L = length of microtube emitter, cm

For the above equations the coefficients of determination R^2 were 0.97577, 0.99848, 0.99600, 0,99992, respectively. Since the coefficients of determination were

Table 1. Hydraulics of microtube emitters

Flow region	Pressure head (m) H	Length (cm) L	Diameter (mm) D	Dis-charge (l/hr) Q	Velocity (m/s) V	Reynolds number Re	Friction loss (m) H_f	Minor loss (m) H_m	Computed pressure head (m) H_c
1	2	3	4	5	6	7	8	9	10
Turbulent flow	1.5	50	3	54.50	2.140	7985	1.00	0.50	1.50
	1.0	50	3	44.00	1.729	6451	0.69	0.33	1.02
	1.5	100	3	40.39	1.587	5922	1.18	0.27	1.45
	1.5	150	3	34.20	1.344	5015	1.33	0.20	1.53
	1.0	100	3	32.73	1.290	4813	0.82	0.18	1.00
	0.5	50	3	29.80	1.171	4369	0.35	0.15	0.50
	1.5	50	2	19.58	1.731	4306	1.17	0.33	1.50

Table 1. (Contd.)

1	2	3	4	5	6	7	8	9	10
Flow in transition region	1.0	150	3	22.30	0.876	3269	0.91	0.12	1.03
	1.0	50	2	14.40	1.273	3167	0.73	0.26	0.99
	1.5	100	2	12.88	1.140	2836	1.25	0.21	1.46
	0.5	100	3	17.01	0.668	2493	0.41	0.07	0.48
	1.5	150	2	10.40	0.919	2286	1.37	0.14	1.51
	1.0	100	2	10.11	0.894	2225	0.87	0.13	1.00
	0.5	50	2	9.47	0.837	2082	0.40	0.11	0.51

Table 1. (Contd.)

1	2	3	4	5	6	7	8	9	10
Laminar flow	0.5	150	3	12.74	0.501	1869	0.49	0.010	0.50
	1.0	150	2	6.82	0.603	1500	0.98	0.020	1.00
	1.5	50	1	3.05	1.078	1340	1.46	0.003	1.46
	0.5	100	2	5.40	0.477	1188	0.49	0.009	0.50
	1.0	50	1	2.20	0.778	968	0.98	0.026	1.01
	0.5	150	2	3.92	0.347	863	0.50	0.005	0.51
	1.5	100	1	1.75	0.619	770	1.48	0.016	1.50
	1.5	150	1	1.27	0.449	558	1.49	0.009	1.50
	1.0	100	1	1.27	0.449	558	1.00	0.009	1.01
	0.5	50	1	1.25	0.442	550	0.49	0.008	1.50
	1.0	150	1	0.91	0.318	396	0.99	0.004	0.99
	0.5	100	1	0.72	0.255	317	0.50	0.003	0.50
	0.5	150	1	0.52	0.184	229	0.50	0.001	0.50

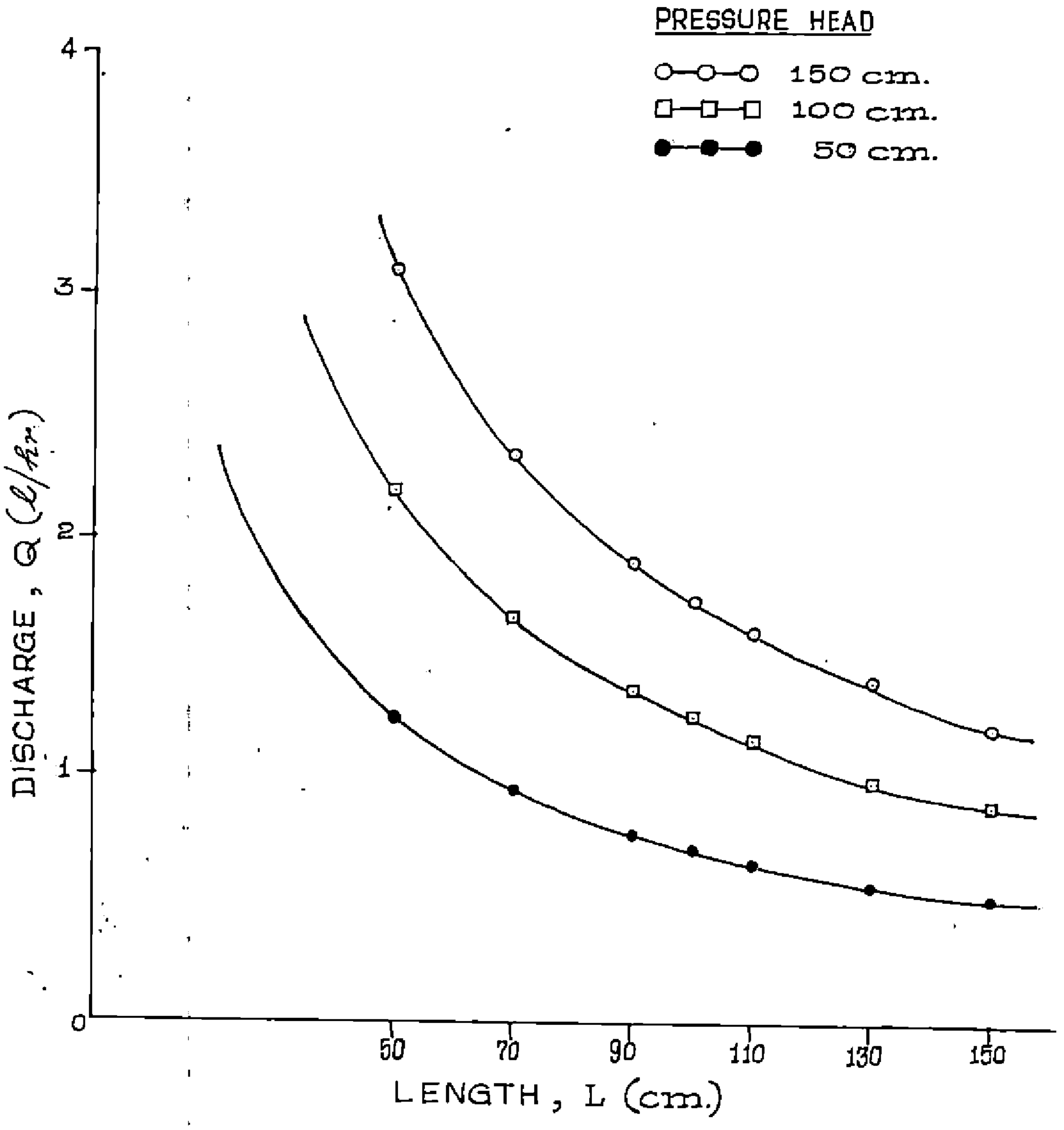


FIG.4. LENGTH-DISCHARGE RELATIONSHIP OF 1 mm MICROTUBE AT DIFFERENT PRESSURE HEADS

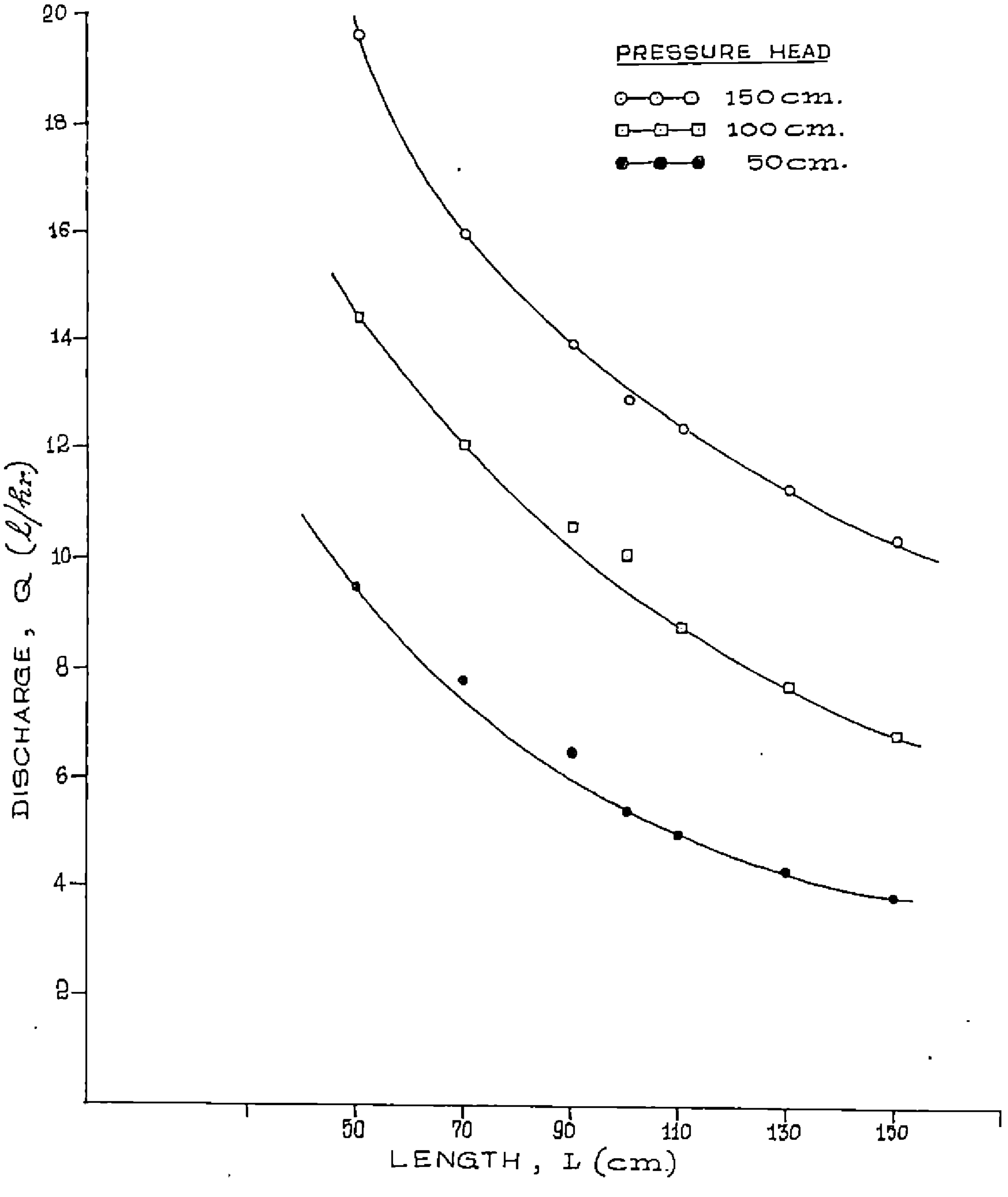


FIG.5. LENGTH - DISCHARGE RELATIONSHIP OF 2 mm MICROTUBE AT DIFFERENT PRESSURE HEADS

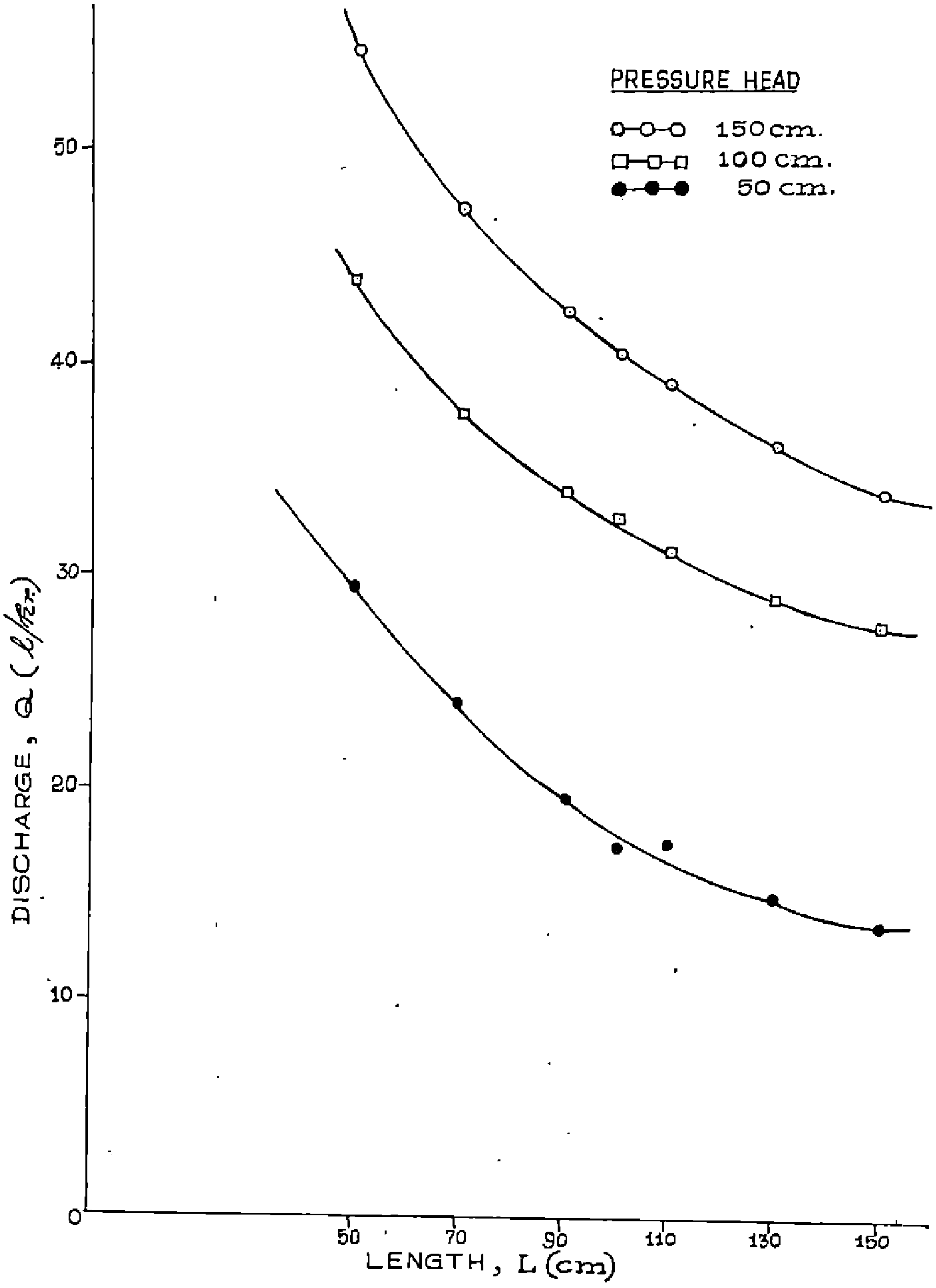


FIG. 6. LENGTH - DISCHARGE RELATIONSHIP OF 3mm MICROTUBE AT DIFFERENT PRESSURE HEADS

very near to unity, the errors in estimation for friction loss in the above four equations were negligible.

4.i.4 Friction factor, f.

For larger pipe flow, the value of friction factor f can be determined from the Moody diagram if the numerical value of Reynolds number is known. However, for microtubes, values obtained from the Moody diagram do not hold good. An attempt was made to find out the relationship between Reynolds number Re and friction factor f in the case of microtubes.

The values of H_f were computed from equations 16, 17 and 18 for different regions. The friction factor f was calculated by using the computed values of H_f in the Darcy-Weisbach equation,

$$H_f = \frac{flV^2}{2gd} \qquad (19)$$

where,

H_f = head loss due to friction, m

f = friction factor

l = length of pipe, m

v = velocity of flow, m/s

g = acceleration due to gravity, m/s^2

d = diameter of the pipe, m

By equating the different known values of H_f, the values of friction factor f were calculated for the three different regions (Table 2).

The Blasius equation and the general equation are used for calculating friction factor for larger diameter pipe in turbulent and laminar region respectively. The equations for friction factor f of microtube emitters for turbulent and laminar flow were determined by computer analysis. Similar to Blasius equation, an equation was developed for turbulent flow. The Blasius equation for turbulent flow is

$$f = \frac{0.316}{Re^{\frac{1}{4}}} \qquad (20)$$

where

f = friction factor

Re = Reynolds number

The equation developed in the present study is

$$f = \frac{0.248}{Re^{\frac{1}{4}}} \qquad (21)$$

In this case, the coefficient of determination r^2 was 0.8949.

Table 2. Friction factor

Flow region	Diameter of microtube (mm) D	Length of microtube (cm) L	Velocity (m/s) V	Reynolds number Re	Friction loss (m) H_f	Friction factor f
1	2	3	4	5	6	7
Turbulent flow	3	50	2.140	7985	1.00	0.026
	3	50	1.729	6451	0.69	0.027
	3	100	1.587	5922	1.18	0.027
	3	150	1.344	5015	1.33	0.029
	3	100	1.290	4813	0.82	0.029
	3	50	1.171	4369	0.35	0.030
	2	50	1.731	4306	1.17	0.031

Table 2. (Contd.)

1	2	3	4	5	6	7
Flow in transition region	3	150	0.876	3269	0.91	0.047
	2	50	1.273	3167	0.73	0.035
	2	100	1.140	2836	1.25	0.038
	3	100	0.668	2493	0.41	0.054
	2	150	0.919	2286	1.37	0.042
	2	100	0.894	2225	0.87	0.043
	2	50	0.837	2082	0.40	0.045

Table 2. (Contd.)

1	2	3	4	5	6	7
Laminar flow	3	150	0.501	1869	0.49	0.077
	2	150	0.603	1500	0.98	0.071
	1	50	1.078	1340	1.46	0.049
	2	100	0.477	1188	0.49	0.085
	1	50	0.778	968	0.98	0.064
	2	150	0.347	863	0.50	0.109
	1	100	0.619	770	1.48	0.076
	1	150	0.449	558	1.49	0.097
	1	100	0.449	558	1.00	0.097
	1	50	0.442	550	0.49	0.098
	1	150	0.318	396	0.99	0.128
	1	100	0.255	317	0.50	0.151
	1	150	0.184	229	0.50	0.193

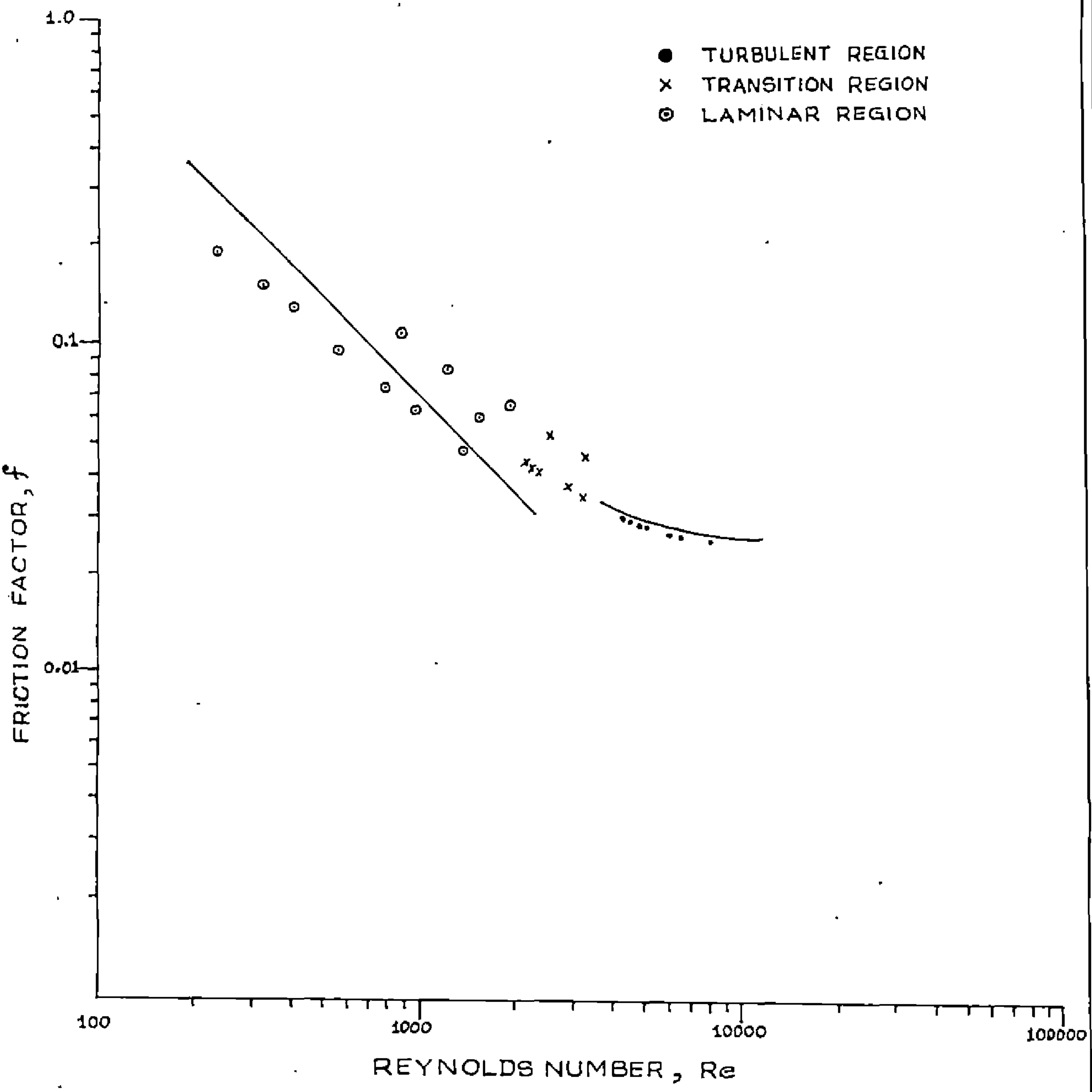


FIG. 7. REYNOLDS NUMBER - FRICTION FACTOR RELATIONSHIP BASED ON FRICTION LOSS OF MICROTUBE EMITTERS

The general equation for laminar flow is

$$f = \frac{64}{Re} \qquad (22)$$

The coefficient of determination, r^2 of 0.7408 was obtained for the developed equation,

$$f = \frac{67.2}{Re} \qquad (23)$$

In transition region, generally no relationship exist between friction factor f and Reynolds number Re. However, an attempt was made to find a relationship between f and Re as in the other two cases. An error of prediction of 90% was obtained in this case. Hence, no formula was recommended for this region (Appendix III).

A graphical representation of the friction factor f Vs Reynolds number Re is shown in Fig.7. It shows a consistent fall below the Moody diagram indicating lower values of friction factor for microtubes compared to smooth pipes.

4.1.5 Design chart for microtube emitters

The empirical equations 15, 16, 17 and 18 can be used for microtube emitter design. From equations 4, 5, 6 and 7 discharges were found out for different lengths. When the friction drop is expressed as friction drop per unit length, design charts can be made. Two design charts were plotted to show the relationship between friction drop (expressed as per unit length) H_f/L and flow rates Q for different microtube sizes D viz., 1 mm, 2 mm and 3 mm and are presented in Fig.8 and 9. Fig.8 is plotted from equations 16, 17 and 18 for all the three flow conditions. Fig.9 is plotted from equation 15, for the combined flow condition. Since Fig.8 gives design information for different flow regimes, it is more accurate than Fig.6 in the microtube emitter design.

The design procedure is as follows.

1. List the design information
   a. Required emitter flow (discharge), l/hr
   b. Operating pressure expressed as pressure head, m
   c. Microtube size, mm
2. Use design chart (Fig.8)
   a. Determine the flow condition (laminar, transition zone or turbulent); and
   b. Determine the friction drop in meters per unit length
3. Determine the velocity

$$V = \frac{Q}{A}$$

where

V = mean velocity, m/s

Q = discharge, l/hr

A = area of cross section of the tube, mm

4. Determine the minor loss

Equations 12, 13 and 14 can be used to calculate minor loss for the three regions, viz., turbulent, transition and laminar respectively.

5. Determine the friction drop H_f

The friction drop can be determined from equation 3.

6. Design the length of microtube emitter

The microtube length can be calculated from the total friction drop H_f and the friction drop per unit length.

Two design examples are shown below:

Design example 1.

The laterals for a vegetable plot will operate on a pressure head of 2 m. It is desired to use microtube emitter with 3 l/hr output. If the microtube size is 1 mm, determine the length of the microtube emitter.

Basic information - microtube emitter flow = 3 l/hr

Operating pressure H = 2 m

Inside diameter D = 1 mm

From the design chart, Fig.8, the flow condition is laminar and the friction drop is 2.8 m/m.

Since the flow condition is laminar, minor loss is neglected and it is not necessary to calculate the velocity.

The friction drop $H_f \doteq H = 2 \text{ m}$

Microtube length L $= \frac{2}{2.8} = 0.71 \text{ m} = \underline{\underline{71 \text{ cm}}}$

Design example 2

The laterals for an orchard will operate on a pressure head of 1.5 m. It is desired to use a microtube emitter with 22 l/hr output. If the microtube size is 2 mm, determine the length of the microtube emitter.

Basic information -

microtube emitter flow Q = 22 l/hr

operating pressure H = 1.5 m

microtube size D = 2 mm

From design chart, Fig.8 the flow condition is turbulent and the friction drop is 2.9 m/m.

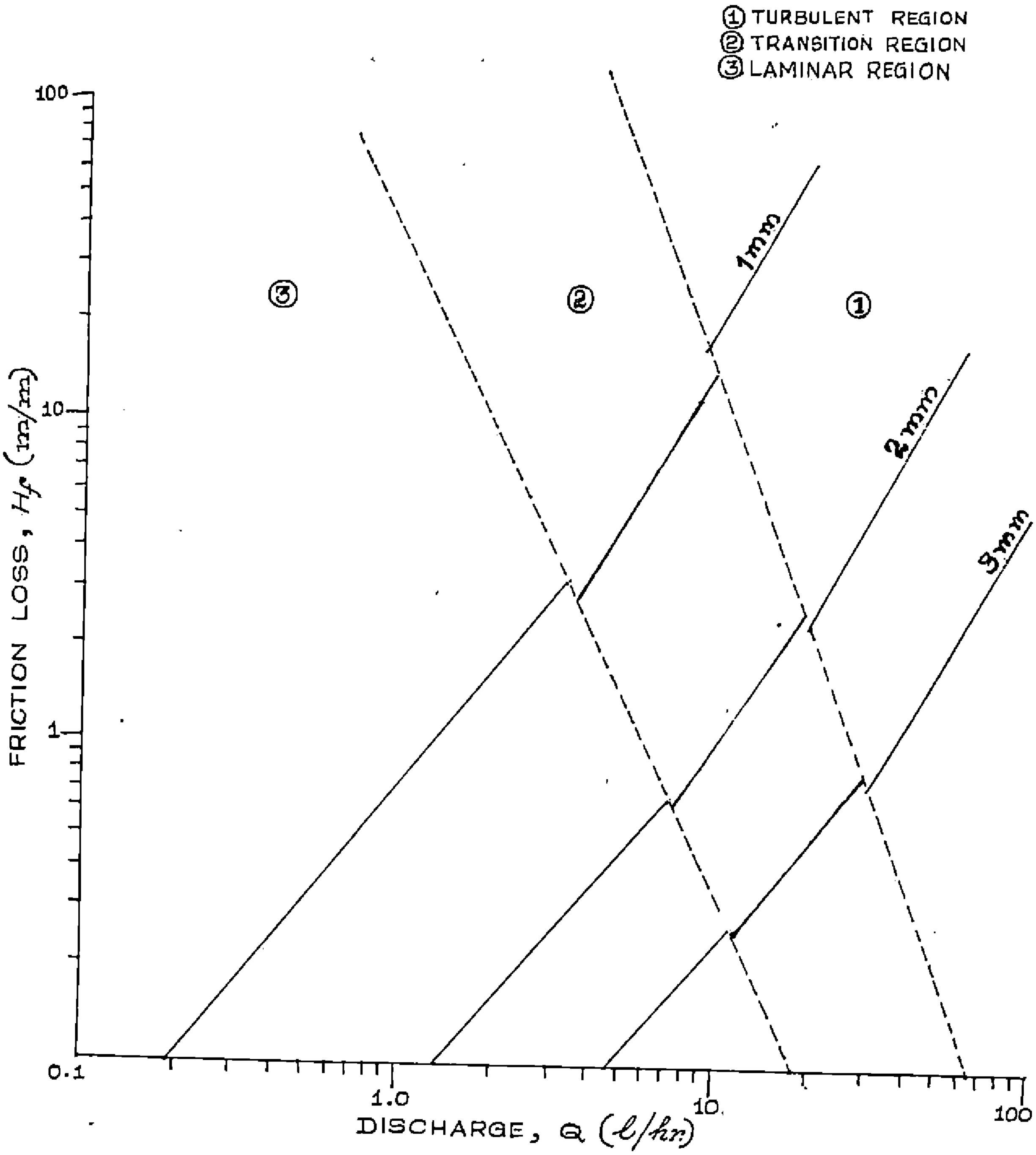


FIG. 8. DISCHARGE - FRICTION LOSS RELATIONSHIP OF MICROTUBE EMITTERS BASED ON VARIOUS FLOW CONDITIONS

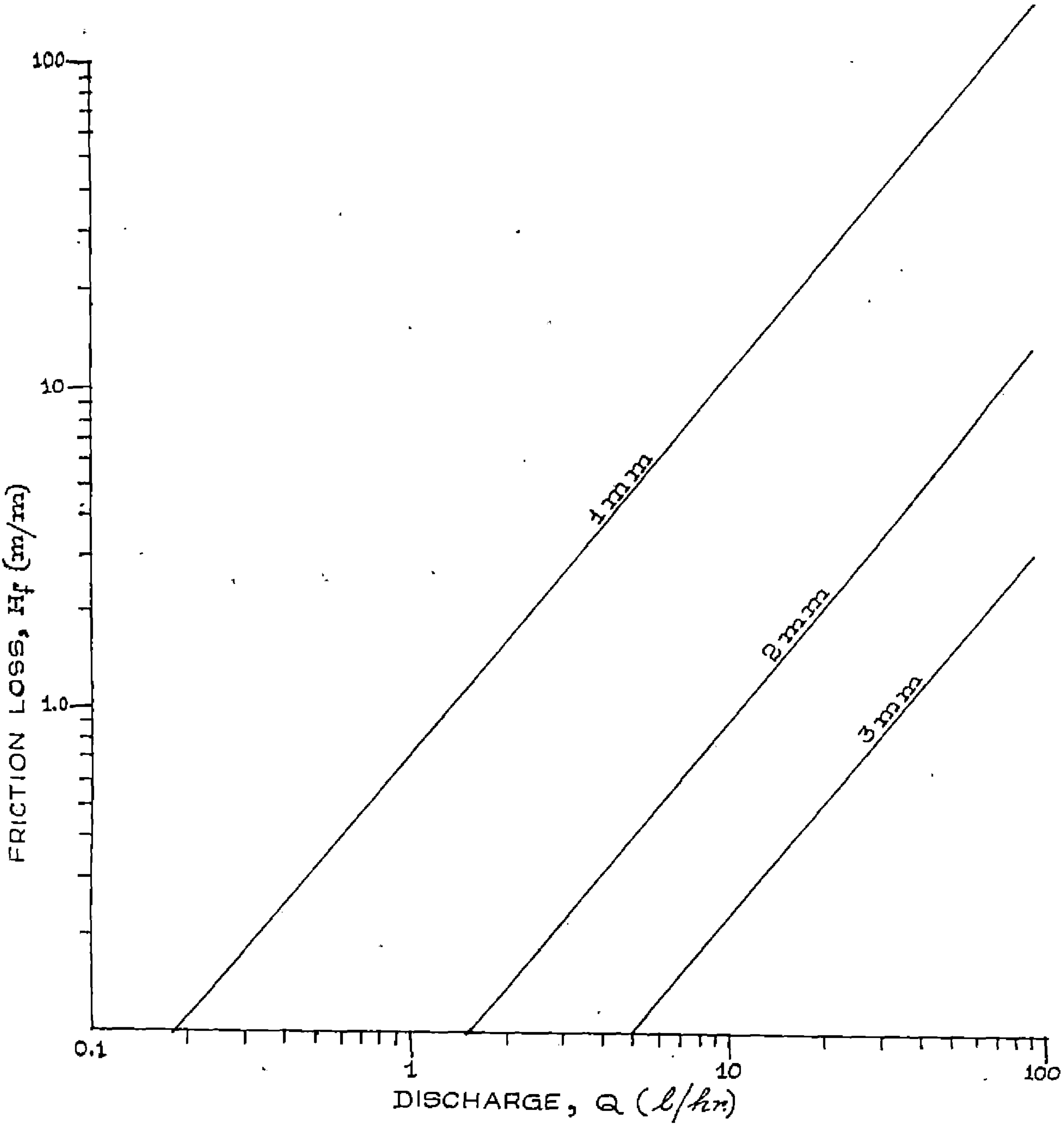


FIG.9. DISCHARGE – FRICTION LOSS RELATIONSHIP OF MICROTUBE EMITTERS FOR COMBINED FLOW CONDITION

Velocity is calculated by

$$V = \frac{Q}{A}$$

$$Q = \frac{32}{3.6} = 6.11 \times 10^{-6} \ m^3/s$$

$$A = \frac{77}{4} d^2 = 3.142 \times 10^{-6} \ m^2$$

$$V = \frac{6.11}{7.069} = 1.945 \ m/s$$

The minor loss is determined from equation 12

$$H_m = 2.14 \times \frac{V^2}{2g} = 2.14 \times \frac{1.945^2}{2 \times 9.81} = 0.413 \ m$$

The friction drop $H_f = H - H_m = 1.5 - 0.413 = 1.087$ m

Microtube length $= \frac{1.087}{2.9} = 0.37 \ m = \underline{\underline{37 \ cm}}$

4.ii Effect of distributor on flow rate

The KAU drip system has an additional component 'distributor'. As explained in earlier chapters, distributor is connected to the lateral by a microtube. From the distributor, four microtubes are taken out. The former and latter tubes will be referred to as inlet tubes and drippers in this chapter. The discharge rate from each dripper is same if they are of same diameter and length.

In the present study, in all cases, the drippers were of same length and diameter. Moreover, the inlet tube and the drippers were of same diameter.

It was observed that the discharge rate from the system with distributor was higher than that of microtube having same length and size. For eg. a 50 + 50 cm distributor combination gave more discharge than a microtube of 100 cm length for the same head. The reason for this is obvious. The discharge rate of each dripper was only one-fourth of that the inlet tube and hence the total friction drop would be reduced considerably when distributor was introduced and this in turn would increase discharge.

The following combinations of lengths of inlet tubes and drippers were used respectively for different diameters 50 + 50 cm, 50 + 100 cm, 50 + 150 cm, 100 + 50 cm, 100 + 100 cm, 100 + 150 cm, 150 + 50 cm, 150 + 100 cm, 150 + 150 cm.

Experiments were conducted from 0.5 m to 1.5 m pressure heads. The highest and lowest discharges obtained were 11 l/hr and 0.068 l/hr respectively.

The KAU drip system works on low pressure. The maximum pressure head recommended is 2 m. A high pressure head may cause leaks in the system. In this system, no accessories are used for connecting the microtubes, all are push fit types and this limit the use of high pressure. Due to some practical difficulties in the site, the experiments were conducted only upto a pressure head of 1.5 m.

In general, both the major and minor losses are occurred in a pipe flow. The major loss is the friction loss. The minor loss includes, entrance, exit and losses due to fittings and bends. When the distributor was introduced in the system, there were some distributor losses.

An attempt was made to separate all these three losses, i.e. the friction loss, the minor loss and the distributor loss. However, it was found that more elaborate study was necessary to separate the minor losses and the distributor losses. The friction losses and the combined losses of minor and distributor for different regions are given in Table 3, 4 and 5.

The major loss, i.e., the total friction loss was the summation of the friction losses in the inlet tube and in the drippers. In parallel connections, the friction loss of one of the drippers need be considered.

$$H_f = H_{f_1} + H_{f_2} \qquad (24)$$

where

H_f = total friction loss, m

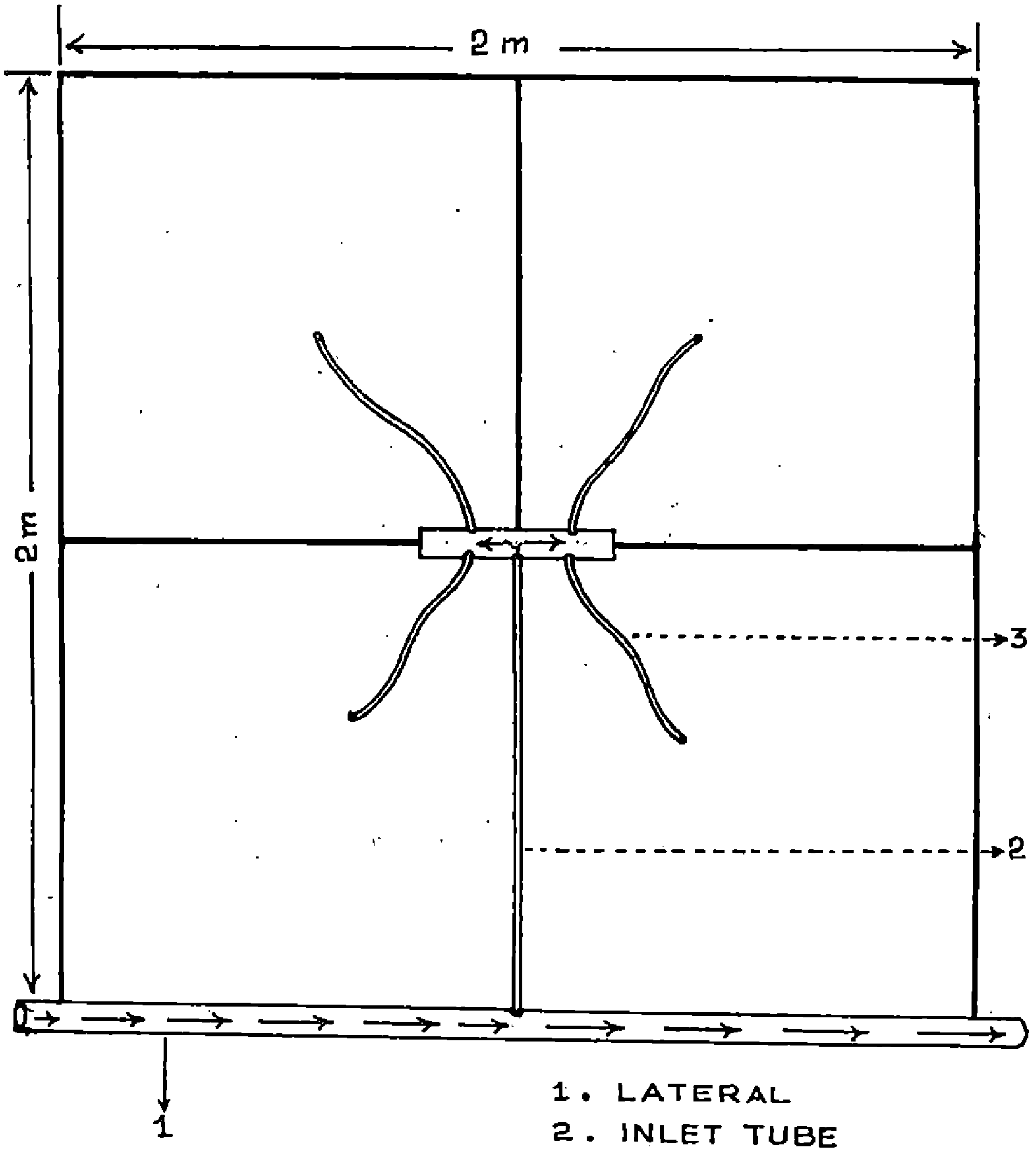
H_{f_1} = friction loss in inlet tube, m

H_{f_2} = friction loss in drippers, m

H_{f_1} was calculated from the equations 16, 17 and 18 according to the flow regime. The rate of flow of the drippers were in laminar region in all the cases and hence H_{f_2} was calculated from the equation 18.

Generally, the accepted average discharge rate per dripper is 1.5 - 10 l/hr. In the present study, it was observed that 3 mm and 2 mm tubes gave discharge rates in the above range for all the pressure heads. Very low discharge rates were obtained from the 1 mm tubes and hence they were not recommended.

Generally, in the case of close growing crops, the minimum area commanded or irrigated by a dripper is one square metre. This means that an area of four square meters can be irrigated with the distributor. In such cases, the distributor has to be positioned in the centre of the four square meter area it commands (Fig.10). For this, it was seen that the minimum length of inlet tube and dripper should be 1 m.



1. LATERAL
2. INLET TUBE
3. DRIPPER

FIG.10. DISTRIBUTOR PLACEMENT FOR IRRIGATING FOUR SQUARE METRES

Table 3. Effect of distributor on flow rate - 3 mm tube

Pressure head (m)	Diameter of micro tube (mm)	Length of inlet tube (cm)	Discharge from inlet tube (l/hr)	Velocity (m/s)	Reynolds number	Friction loss in inlet tube (m)	Length of dripper (cm)	Discharge from dripper (l/hr)	Velocity (m/s)	Reynolds number	Friction loss in dripper (m)	Total friction loss (m)	Minor loss + distributor loss (m)
H	D	L_1	Q_1	V_1	Re_1	H_{f_1}	L_2	Q_2	V_2	Re_2	H_{f_2}	H_f	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.5	3	50	44.3	1.740	6493	0.69	50	11.08	0.435	1623	0.14	0.83	0.67
		50	42.0	1.650	6156	0.63	100	10.50	0.413	1541	0.26	0.89	0.61
		50	38.6	1.516	5657	0.54	150	9.65	0.379	1414	0.35	0.89	0.61
		100	36.8	1.446	5396	1.00	50	9.20	0.362	1351	0.11	1.11	0.39
		100	35.1	1.379	5146	0.92	100	8.78	0.345	1287	0.21	1.13	0.37
		100	33.5	1.317	4914	0.85	150	8.38	0.329	1228	0.29	1.14	0.36
		150	32.9	1.293	4825	1.23	50	8.23	0.323	1205	0.10	1.33	0.17
		150	31.2	1.226	4575	1.13	100	7.80	0.307	1146	0.18	1.31	0.19
		150	29.9	1.176	4388	1.04	150	7.48	0.294	1097	0.26	1.30	0.20

Table 3. (Contd.)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.0	3	50	41.1	1.616	6030	0.61	50	10.28	0.404	1507	0.13	0.74	0.26
		50	38.9	1.529	5705	0.55	100	9.73	0.382	1425	0.24	0.79	0.21
		50	37.2	1.461	5451	0.51	150	9.30	0.365	1362	0.33	0.84	0.16
		100	30.6	1.202	4485	0.73	50	7.65	0.301	1123	0.09	0.82	0.18
		100	29.4	1.156	4313	0.68	100	7.35	0.289	1078	0.17	0.85	0.15
		100	28.5	1.120	4179	0.64	150	7.13	0.280	1045	0.24	0.88	0.12
		150	20.8	0.818	3052	0.83	50	5.20	0.205	765	0.05	0.88	0.12
		150	19.8	0.778	2903	0.77	100	4.95	0.195	728	0.10	0.87	0.13
		150	19.0	0.747	2787	0.72	150	4.75	0.187	698	0.15	0.87	0.13

Table 3. (Contd.)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
0.5	3	50	27.2	1.069	3989	0.41	50	6.80	0.267	996	0.08	0.49	0.01
		50	21.3	0.837	3123	0.28	100	5.33	0.209	780	0.11	0.39	0.11
		50	20.1	0.789	2944	0.26	150	5.03	0.197	735	0.16	0.42	0.08
		100	15.3	0.601	2243	0.35	50	3.83	0.150	560	0.04	0.39	0.11
		100	14.1	0.555	2071	0.31	100	3.53	0.139	519	0.07	0.38	0.12
		100	13.4	0.526	1963	0.35	150	3.35	0.132	493	0.10	0.45	0.05
		150	11.5	0.451	1683	0.43	50	2.88	0.113	422	0.03	0.46	0.04
		150	10.6	0.416	1552	0.39	100	2.65	0.104	388	0.05	0.44	0.06
		150	9.9	0.389	1451	0.36	150	2.48	0.097	362	0.07	0.43	0.07

Table 4. Effect of distributor on flow rate - 2 mm tube

Pressure head (m)	Diameter of microtube (mm)	Length of inlet tube (cm)	Discharge from inlet tube (l/hr)	Velocity (m/s)	Reynolds number	Friction loss in inlet tube (m)	Length of dripper (cm)	Discharge from dripper (l/hr)	Velocity (m/s)	Reynolds number	Friction loss in dripper (m)	Total friction loss (m)	Minor loss + distributor loss (m)
H	D	L_1	Q_1	V_1	Re_1	H_{f_1}	L_2	Q_2	V_2	Re_2	H_{f_2}	H_f	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.5	2	50	17.8	1.572	3910	1.00	50	4.45	0.393	978	0.19	1.19	0.31
		50	16.5	1.458	3627	0.89	100	4.13	0.365	908	0.35	1.24	0.26
		50	15.7	1.388	3453	0.83	150	3.93	0.347	863	0.50	1.33	0.17
		100	11.4	1.009	2510	1.04	50	2.85	0.252	627	0.11	1.15	0.35
		100	10.3	0.910	2264	0.90	100	2.58	0.228	567	0.20	1.10	0.40
		100	9.6	0.850	2114	0.81	150	2.40	0.213	530	0.27	1.08	0.42
		150	9.3	0.821	2042	1.16	50	2.33	0.205	510	0.09	1.25	0.25
		150	8.5	0.751	1868	1.28	100	2.13	0.188	468	0.16	1.44	0.06
		150	7.9	0.697	1734	1.17	150	1.98	0.174	433	0.21	1.38	0.12

Table 4. (Contd.)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.0	2	50	12.9	1.139	2833	0.62	50	3.23	0.285	709	0.13	0.75	0.25
		50	11.8	1.044	2597	0.55	100	2.95	0.261	649	0.23	0.78	0.22
		50	11.1	0.980	2438	0.50	150	2.78	0.245	610	0.33	0.83	0.17
		100	8.9	0.786	1955	0.90	50	2.23	0.197	490	0.08	0.98	0.02
		100	8.0	0.707	1759	0.79	100	2.00	0.177	440	0.14	0.93	0.07
		100	7.4	0.656	1632	0.72	150	1.85	0.164	408	0.20	0.92	0.08
		150	5.8	0.516	1284	0.81	50	1.46	0.129	321	0.05	0.86	0.14
		150	5.1	0.455	1132	0.69	100	1.29	0.114	284	0.08	0.77	0.23
		150	4.6	0.404	1005	0.60	150	1.14	0.101	251	0.11	0.71	0.29

Table 4 (Contd.)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
0.5	2	50	8.63	0.764	1900	0.43	50	2.16	0.191	475	0.06	0.49	0.01
		50	6.85	0.605	1505	0.33	100	1.71	0.151	376	0.12	0.45	0.05
		50	6.66	0.589	1465	0.32	150	1.67	0.147	366	0.17	0.49	0.01
		100	4.64	0.411	1022	0.41	50	1.16	0.103	256	0.04	0.45	0.05
		100	3.88	0.344	856	0.33	100	0.97	0.086	214	0.06	0.39	0.11
		100	3.27	0.289	719	0.26	150	0.82	0.072	179	0.07	0.33	0.17
		150	3.27	0.289	719	0.40	50	0.82	0.072	179	0.02	0.42	0.08
		150	2.66	0.235	584	0.31	100	0.67	0.059	147	0.04	0.35	0.15
		150	2.23	0.197	490	0.25	150	0.56	0.049	122	0.05	0.30	0.20

Table 5. Effect of distributor on flow rate - 1 mm tube

Pressure head (m) H 1	Diameter of micro-tube (mm) D 2	Length of inlet tube (cm) L_1 3	Discharge from inlet tube (l/hr) Q_1 4	Velocity (m/s) V_1 5	Reynolds number Re_1 6	Friction loss in inlet tube (m) H_{f_1} 7	Length of dripper (cm) L_2 8	Discharge from dripper (l/hr) Q_2 9	Velocity (m/s) V_2 10	Reynolds number Re_2 11	Friction loss in dripper (m) H_{f_2} 12	Total friction loss (m) H_f 13	Minor loss + distributor loss (m) 14
1.5	1	50	2.06	0.728	905	0.90	50	0.52	0.182	226	0.17	1.07	0.43
		50	1.36	0.481	598	0.54	100	0.34	0.120	149	0.20	0.74	0.76
		50	1.30	0.460	572	0.51	150	0.33	0.115	143	0.29	0.80	0.70
		100	1.31	0.463	576	1.03	50	0.33	0.116	144	0.10	1.13	0.37
		100	0.53	0.187	233	0.34	100	0.13	0.047	58	0.06	0.40	1.10
		100	0.27	0.095	118	0.15	150	0.07	0.024	30	0.04	0.19	1.31
		150	0.75	0.265	330	0.78	50	0.19	0.066	82	0.05	0.83	0.67
		150	0.36	0.127	158	0.32	100	0.09	0.032	40	0.04	0.36	1.14
		150	0.12	0.042	52	0.08	150	0.03	0.011	14	0.02	0.10	1.40

Table 5. (Contd.)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.0	1	50	1.40	0.495	616	0.56	50	0.35	0.124	154	0.10	0.66	0.34
		50	1.10	0.390	484	0.42	100	0.28	0.099	122	0.16	0.58	0.42
		50	0.48	0.169	210	0.15	150	0.12	0.042	52	0.08	0.23	0.77
		100	0.86	0.304	378	0.62	50	0.22	0.076	95	0.06	0.68	0.32
		100	0.43	0.152	189	0.26	100	0.11	0.038	47	0.05	0.31	0.69
		100	0.18	0.064	80	0.09	150	0.05	0.016	20	0.03	0.12	0.88
		150	0.66	0.233	290	0.67	50	0.17	0.058	72	0.04	0.71	0.29
		150	0.48	0.169	210	0.45	100	0.12	0.042	52	0.06	0.51	0.49
		150	0.21	0.074	92	0.16	150	0.05	0.019	24	0.03	0.19	0.81

Table 5. (Contd.)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
0.5	1	50	0.84	0.297	369	0.30	50	0.21	0.074	94	0.06	0.36	0.14
		50	0.65	0.229	285	0.22	100	0.16	0.057	72	0.08	0.30	0.20
		50	0.18	0.064	80	0.05	150	0.05	0.016	20	0.03	0.08	0.42
		100	0.61	0.215	267	0.41	50	0.15	0.054	68	0.04	0.45	0.05
		100	0.28	0.099	123	0.16	100	0.07	0.025	32	0.03	0.19	0.31
		100	0.11	0.038	47	0.05	150	0.03	0.009	13	0.02	0.07	0.43
		150	0.26	0.092	114	0.21	50	0.07	0.023	29	0.01	0.22	0.28
		150	0.09	0.033	41	0.06	100	0.02	0.008	10	0.01	0.07	0.43
		150	0.07	0.024	30	0.04	150	0.02	0.006	8	0.01	0.05	0.45

Table 6. Design table for KAU drip irrigation system

Pressure head (m) H	Diameter of microtube (mm) D	Length of inlet tube (cm) L_1	Length of dripper (cm) L_2	Discharge from dripper (l/hr) Q
1	2	3	4	5
1.5	3	100	100	8.78
		100	150	8.38
		150	100	7.80
		150	150	7.48
1.0	3	100	100	7.35
		100	150	7.13
		150	100	4.95
		150	150	4.75

Table 6. (Contd.)

1	2	3	4	5
0.5	3	100	100	3.53
		100	150	3.35
		150	100	2.65
		150	150	2.48
1.5	2	100	100	2.58
		100	150	2.40
		150	100	2.13
		150	150	1.98
1.0	2	100	100	2.00
		100	150	1.85

Eventhough many combinations of length, heads and diameters were tried, only few combinations that satisfy the minimum requirements listed below, were selected. That are

1. Discharge rate 1.5 - 10 l/hr
2. Minimum length of drippers - 1 m
3. Minimum length of inlet tube - 1 m

The discharge obtained for different combinations of length, pressure head and diameter are given in Table 3, 4 and 5. The selected combinations are given in Table 6. This table gives discharge rates from 1.85 l/hr to 8.78 l/hr per dripper. This table can be used as a guideline for the design of KAU drip irrigation system.

4.iii Effect of clogging on flow rate of microtube emitters

Effect of clogging on discharge rate was studied. For this, water was allowed to flow every day for a period of three months. Then the discharge from each tube was measured at the beginning and at the end of three months. The degree of clogging was calculated by using the formula.

$$q = 100 \frac{(1 - q_i)}{\bar{q}_i} \qquad (25)$$

where,

q = degree of clogging, %

q_i = average discharge, l/hr

$\bar{q}_i$ = nominal average discharge, l/hr

Table 8. Friction loss in laterals

Pressure head (cm) H	Diameter (cm) D	Length (m) L	Discharge (l/s) Q	Velocity (m/s) V	Reynolds number Re	Friction factor f	Friction loss (cm) H_f
150	1.25	25	0.087	0.707	10992	0.031	137.62
150		50	0.060	0.490	7618	0.034	139.46
150		75	0.048	0.391	6079	0.036	140.87
150		100	0.042	0.342	5317	0.037	143.13
100		25	0.068	0.554	8613	0.033	87.94
100		50	0.047	0.383	5955	0.036	89.68
100		75	0.039	0.318	4944	0.038	93.13
50		25	0.043	0.350	5442	0.037	38.61

Table 7. Degree of clogging in microtube emitters

Pressure head (cm) H	Diameter of microtube (mm) D	Length of inlet tube (cm) L_1	Length of dripper (cm) L_2	Nominal average discharge (l/hr) $\bar{q}_i$	Average discharge (l/hr) q_i	Degree of clogging (%) q
1	2	3	4	5	6	7
150	3	100	100	35.10	30.30	13.7
100	3	100	100	29.41	23.75	19.2
50	3	100	100	14.10	11.05	21.6
150	2	100	100	10.30	8.62	16.3
100	2	100	100	8.00	6.09	23.9
50	2	100	100	3.88	2.80	27.8
150	1	100	100	0.53	0.39	25.4
100	1	100	100	0.43	0.29	32.6
50	1	100	100	0.28	0.18	37.1

The percentage of decrease in conveyance were obtained from the observations. Table 7 gives the details of the observations and computed values. The clogging in 3 mm tube was less and the degree of clogging was in between 14% and 22%. The degree of clogging in the 2 mm tube was in between 16 - 28% and the same in 1 mm tube was in between 25 - 37%. The clogging in 1 mm was highest.

4.iv Hydraulics of laterals

Discharge measurements were done for laterals at different lengths (Table 8). It was observed that the discharge in the line decreased with length. The energy drop by friction was calculated by using the formula,

$$H_f = 15.27 \frac{(Q^{1.852})}{(D^{4.871})} L \qquad (26)$$

where,

H_f = head loss due to friction, m

Q = discharge, 1/s

D = diameter of the tube, cm

L = length of the tube, m

This equation was found suitable for turbulent region and not for laminar and transition regions.

4.v. The following are some of the suggestions for further investigations.

1. Determine the losses that occur in the distributor and separate it out from the minor losses.
2. Find preventive measures for clogging, caused by physical chemical and biological build up.
3. Develop equations for friction loss in laminar and transition region for laterals.

Summary

SUMMARY

Drip irrigation is one of the latest innovations for applying water to the field and it represents a definite advancement in irrigation technology. A drip system with an additional component 'distributor' developed in the Agronomic Research Station, Chalakudy, Kerala Agricultural University is named as KAU drip system. This system works on low pressure and is relatively economical than the conventional drip system.

The site selected for the experiments was the quadrangle, near Agricultural Engineering Research Workshop of Kerala Agricultural University, Mannuthy. For the study, a polyethylene pipe of length 18 m was used as main line. In the main line, at 6 m apart, laterals were connected and in laterals, at 5 m apart, microtubes were inserted. Discharge measurements were taken at different pressure heads viz., 1.5 m, 1 m and 0.5 m. Microtubes of sizes 1 mm, 2 mm and 3 mm were used.

There were no empirical equations available for calculating the friction drop from a microtube with a diameter less than 4 mm. So empirical equations were needed

for the same. Hence an investigation was conducted in this regard.

Hydraulics of microtube emitters were studied by using different lengths and diameters of microtubes. The total energy drop (H) in a microtube emitter is the summation of friction drop (H_f) and minor loss (H_m). The relationships between pressure head H, length L, diameter D and discharge Q were estimated by a computer analysis by fitting multiple log linear equations. The equations obtained for different flow conditions were

1. Combined flow condition

$$H = 0.01402 \; \frac{Q^{1.23938}}{D^{3.54926}} \; L^{0.86030}$$

2. Turbulent flow condition

$$H = 0.00764 \; \frac{Q^{1.82655}}{D^{4.61537}} \; L^{0.77823}$$

3. Flow in transition region

$$H = 0.00817 \; \frac{Q^{1.56882}}{D^{3.83531}} \; L^{0.83541}$$

4. Laminar flow condition

$$H = 0.00796 \; \frac{Q^{1.23461}}{D^{3.59105}} \; L^{0.98712}$$

where

H = total pressure head, m

D = diameter of microtube emitter, mm

Q = discharge, l/hr

L = length of microtube, cm

The separation of minor loss was done by a computer calculation using the relationship for friction drop and the minor loss function. In this study, velocity head loss was also considered as minor loss. The numerical solution for minor loss coefficient K was obtained by using different K values in order to make the power of 'L' unity in the estimating equation for head loss due to friction. Minor loss equations obtained are,

1. Combined flow

$$H_m = 2.34 \quad (V^2/2g)$$

2. Turbulent flow

$$H_m = 2.14 \quad (V^2/2g)$$

3. Flow in transition region

$$H_m = 3.18 \quad (V^2/2g)$$

4. Laminar flow

$$H_m = 0.84 \quad (V^2/2g)$$

where,

H_m = minor loss, m

V = mean velocity of flow, m/s

g = acceleration due to gravity, m/s^2

When the minor loss was separated, the remaining was the loss due to friction (H_f). By fitting multiple log linear equations, the equations obtained for friction loss (H_f) are,

1. Combined flow

$$H_f = 0.00737 \frac{Q^{1.18905}}{D^{3.58352}} L$$

2. Turbulent flow

$$H_f = 0.00359 \frac{Q^{1.74866}}{D^{4.80544}} L$$

3. Flow in transition region

$$H_f = 0.00397 \frac{Q^{1.46302}}{D^{3.74436}} L$$

4. Laminar flow

$$H_f = 0.00743 \frac{Q^{1.22546}}{D^{3.58420}} L$$

Relationships between friction factor f and Reynolds number Re for laminar and turbulent region were estimated by a computer analysis by using the computed values of H_f on the Darcy-Weisbach equation. The equation obtained for turbulent region is

$$f = \frac{0.248}{Re^{\frac{1}{4}}}$$

and for laminar region is

$$f = \frac{67.2}{Re}$$

Experiments were conducted to study the effect of distributor on flow rate. For each diameter of microtube, different length combinations of inlet tubes and drippers were tried. It was found that the discharge rate from the system with distributor was higher than that of microtube having the same length and size. The frictional losses and the combined losses of minor and distributor for different flow condition were estimated. From the observed data, few combinations which satisfy the requirements viz., length, discharge and pressure head were selected to use as a guideline for design of KAU drip irrigation system.

The effect of clogging on flow rate of microtube emitters was studied and it was observed that clogging was higher in 1 mm tube than the 2 mm and 3 mm tubes. After a prolonged use, discharge rate was reduced due to clogging.

Experiments were conducted to study the basic hydraulics of laterals. Discharge measurements were taken at different lengths viz., 100 m, 75 m, 50 m and 25 m.

The friction loss for turbulent region was found out. The Hazen-William equation was found suitable for turbulent region and not for laminar and transition regions.

With the help of the equations and the guidelines developed in the present study, it is now possible to design the KAU drip irrigation system for different flow conditions.

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Appendices

Appendix I. Multiple log linear equation of pressure head on other parameters

a) Combined flow condition

Variables X	Mean	Standard deviation	Correlation X vs Y*	Regression coefficient	Standard errors of regression coefficient	Computed t value
Length	1.95835	0.20075	-0.00000	0.86030	0.06326	13.59916
Diameter	0.25938	0.20075	0.00000	-3.54926	0.13727	-25.85604
Discharge	0.84518	0.61259	0.25542	1.23938	0.07038	17.60984
Intercept				-1.85330		

Coefficient of determination 0.96599

Standard error of estimate 0.02530

*Y is the pressure head

Appendix I. (Contd.)

Table of residuals

Sl.No.	$\log_e H_o$	H_o^*	$\log_e H_e$	H_e^{**}	Residual
1	2	3	4	5	6
1	0.17609	1.50	0.06696	1.17	0.10910
2	0.00000	1.00	-0.04824	0.89	0.04824
3	0.17609	1.50	0.16480	1.46	0.01129
4	0.17609	1.50	0.22662	1.69	-0.05053
5	0.00000	1.00	0.05148	1.13	-0.05148
6	-0.30103	0.50	-0.25798	0.55	-0.04305
7	0.17609	1.50	0.14150	1.39	0.03459
8	0.00000	1.00	-0.00356	0.99	0.00356
9	0.00000	1.00	-0.02446	0.95	0.02446
10	0.17609	1.50	0.17532	1.50	0.00077
11	-0.30103	0.50	-0.30112	0.50	0.00009
12	0.17609	1.50	0.21085	1.62	-0.03476

Appendix I. (Contd.)

1	2	3	4	5	6
13	0.00000	1.00	0.04361	1.11	-0.04361
14	-0.30103	0.50	-0.24834	0.56	-0.05269
15	-0.30103	0.50	-0.30490	0.50	0.00387
16	0.00000	1.00	-0.01627	0.96	0.01627
17	0.17609	1.50	0.20856	1.62	-0.03247
18	-0.30103	0.50	-0.29342	0.51	-0.00761
19	0.00000	1.00	0.03272	1.08	-0.03272
20	-0.30103	0.50	-0.31432	0.48	0.01329
21	0.17609	1.50	0.16853	1.47	0.00756
22	0.17609	1.50	0.14745	1.40	0.02864
23	0.00000	1.00	-0.00404	0.99	0.00404
24	-0.30103	0.50	-0.27156	0.54	-0.02947
25	0.00000	1.00	-0.03197	0.93	0.03197
26	-0.30103	0.50	-0.30951	0.49	0.00848
27	-0.30103	0.50	-0.33318	0.46	0.03215

*H_o is the observed values of pressure head

**H_e is the estimated values of pressure head

Appendix I. (Contd.)

b) Turbulent flow condition

Variables X	Mean	Standard deviation	Correlation X Vs Y*	Regression coefficient	Standard errors of regression coefficient	Computed t value
Length	1.85314	0.20104	0.34738	0.77823	0.00637	122.12904
Diameter	0.45196	0.06656	-0.29249	-4.61537	0.01074	-429.62314
Discharge	1.54310	0.14141	0.13296	1.82655	0.00730	250.06516
Intercept				-2.11711		

Coefficient of determination	0.9996
Standard error of estimate	0.00244

*Y is the pressure head

Appendix I. (Contd.)

Table of residuals

Sl.No.	$\log_e H_o$	H_o^*	$\log_e H_e$	H_e^{**}	Residual
1	0.17609	1.50	0.17461	1.49	0.00148
2	0.00000	1.00	0.00483	1.01	-0.00483
3	0.17609	1.50	0.17139	1.48	0.00470
4	0.17609	1.50	0.17628	1.50	-0.00019
5	0.00000	1.00	0.00439	1.01	-0.00439
6	-0.30103	0.50	-0.30427	0.50	0.00324
7	0.17609	1.50	0.17609	1.50	0.00000

$^*H_o$ is the observed values of pressure head

$^{**}H_e$ is the estimated values of pressure head

Appendix I. (Contd.)

c) Flow in transition region

Variables X	Mean	Standard deviation	Correlation X vs Y*	Regression coefficient	Standard errors of regression coefficient	Computed t value
Length	1.96430	0.19762	0.48097	0.83541	0.03556	23.49390
Diameter	0.35134	0.08592	-0.39689	-3.83531	0.11114	-34.50834
Discharge	1.12097	0.13547	-0.06204	1.56882	0.06534	24.00997
Intercept				-2.08779		

Coefficient of determination	0.99692
Standard error of estimate	±0.01666

*Y is the pressure head

Appendix I. (Contd.)

Table of residuals

Sl.No.	$\log_e H_o$	H_o^*	$\log_e H_e$	H_e^{**}	Residual
1	0.00000	1.00	0.01549	1.04	-0.01549
2	0.00000	1.00	-0.00574	0.99	0.00574
3	0.17609	1.50	0.17080	1.48	0.00529
4	-0.30103	0.50	-0.31652	0.48	0.01549
5	0.17609	1.50	0.17113	1.48	0.00496
6	0.00000	1.00	0.00408	1.01	-0.00408
7	-0.30103	0.50	-0.28913	0.51	-0.01190

*H_o is the observed values of pressure head

**H_e is the estimated values of pressure head

Appendix I. (Contd.)

d) Laminar flow condition

Variables X	Mean	Standard deviation	Correlation X vs Y*	Regression coefficient	Standard errors of regression coefficient	Computed t value
Length	2.01180	0.19496	-0.15600	0.98712	0.00410	240.70644
Diameter	0.10617	0.17150	-0.44542	-3.59105	0.00649	-553.29187
Discharge	0.32087	0.40937	-0.07506	1.23461	0.00294	419.38229
Intercept				-2.09907		

Coefficient of determination 0.99994
Standard error of estimate 0.00111

*Y is the pressure head

Appendix I.(Contd.)

Table of residuals

Sl.No.	$\log_e H_o$	H_o^*	$\log_e H_e$	H_e^{**}	Residual
1	-0.30103	0.50	-0.29992	0.50	-0.00111
2	0.00000	1.00	-0.00264	0.99	0.00264
3	0.17609	1.50	0.17593	1.50	0.00016
4	0.30103	0.50	-0.30163	0.50	0.00060
5	0.00000	1.00	0.00077	1.00	-0.00077
6	-0.30103	0.50	-2.29955	0.50	-0.00148
7	0.17609	1.50	0.17522	1.50	0.00087
8	0.17609	1.50	0.17714	1.50	-0.00105
9	0.00000	1.00	0.00332	1.01	-0.00332
10	-0.30103	0.50	-0.30234	0.50	0.00131
11	0.00000	1.00	-0.00159	1.00	0.00159
12	-0.30103	0.50	-0.30098	0.50	-0.00005
13	-0.30103	0.50	-0.30165	0.50	0.00062

*H_o is the observed values of pressure head

**H_e is the estimated values of pressure head

Appendix II. Numerical solution for separation of minor loss from total head loss

a) Combined flow condition K = 2.34

Variables X	Mean	Standard deviation	Correlation X vs Y*	Regression coefficient	Standard errors of regression coefficient	Computed t value
Length	1.95835	0.20075	0.17666	0.99981	0.44340	22.55076
Diameter	0.25938	0.20075	-0.18065	-3.58352	0.09620	-37.24917
Discharge	0.84518	0.61259	0.03845	1.18905	0.04932	24.10659
Intercept				-2.13242		

Coefficient of determination	0.97577
Standard error of estimate	0.01773

*Y is the pressure head

Appendix II. (Contd.)

Table of residuals

Sl.No.	$\log_e H_o$	H_o^*	$\log_e H_e$	H_e^{**}	Residual
1	-0.02054	0.95	-0.07887	0.83	0.05833
2	-0.19148	0.64	-0.18939	0.65	-0.00209
3	0.07904	1.20	0.06751	1.17	0.01153
4	0.10876	1.28	0.15754	1.44	-0.04878
5	-0.09608	0.80	-0.04121	0.91	-0.05487
6	-0.47307	0.34	-0.39061	0.41	-0.08246
7	0.05791	1.14	0.02405	1.06	0.03386
8	-0.04169	0.91	-0.06329	0.86	0.02160
9	-0.09327	0.81	-0.13516	0.73	0.04189
10	0.12872	1.34	0.10901	1.29	0.01971
11	-0.34991	0.45	-0.37949	0.42	0.02958
12	0.14590	1.40	0.17382	1.49	-0.02792
13	-0.04351	0.90	-0.01735	0.96	-0.02616

$^*H_o$ is the observed values of pressure head

$^{**}H_e$ is the estimated values of pressure head

Appendix II. (Contd.)

Sl.No.	$\log_e H_o$	H_o*	$\log_e H_e$	H_e**	Residual
14	0.38044	0.42	-0.34995	0.45	-0.03049
15	-0.32784	0.47	-0.35240	0.44	0.02456
16	-0.01925	0.96	-0.04408	0.90	0.02483
17	0.13399	1.36	0.14209	1.39	-0.00810
18	-0.32526	0.47	-0.34069	0.46	0.01543
19	-0.03254	0.93	-0.02661	0.94	-0.00593
20	-0.31368	0.49	-0.33003	0.47	0.01635
21	0.16265	1.45	0.15619	1.43	0.00646
22	0.16907	1.48	0.16668	1.47	0.00239
23	-0.01057	0.98	-0.00937	0.98	-0.00120
24	-0.32175	0.48	-0.31854	0.48	-0.00321
25	-0.00527	0.99	-0.00544	0.99	0.00017
26	-0.30782	0.49	-0.30244	0.50	-0.00538
27	-0.30455	0.50	-0.29443	0.51	-0.01012

*H_o is the observed values of pressure head

**H_e is the estimated values of pressure head

Appendix II. (Contd.)

b) Turbulent flow condition Km = 2.14

Variables X	Mean	Standard deviation	Correlation X vs Y*	Regression coefficient	Standard errors of regression coefficient	Computed t value
Length	1.85314	0.20104	0.50823	1.00095	0.01460	68.57312
Diameter	0.45196	0.06656	-0.29041	-4.80544	0.02461	-195.27422
Discharge	1.54310	0.14141	0.02229	1.74866	0.01673	104.51014
Intercept				-2.44436		

Coefficient of determination	0.99848
Standard error of estimate	0.00558

*Y is the pressure head

Appendix II.(Contd.)

Table of residuals

Sl.No.	$\log_e H_o$	H_o^*	$\log_e H_e$	H_e^{**}	Residual
1	0.00021	1.00	-0.00018	1.00	0.00039
2	-0.17138	0.67	-0.16272	0.69	-0.00866
3	0.08824	1.23	0.07377	1.19	-0.01447
4	0.11494	1.30	0.12352	1.33	-0.00858
5	-0.08698	0.82	-0.08611	0.82	-0.00087
6	-0.45539	0.35	-0.45865	0.35	0.00326
7	0.06936	1.17	0.06936	1.17	0.00000

*H_o is the observed values of pressure head

*H_e is the estimated values of pressure head

Appendix II. (Contd.)

c) Flow in transition region K = 3.18

Variables X	Mean	Standard deviation	Correlation X vs Y*	Regression coefficient	Standard errors of regression coefficient	Computed t value
Length	1.96430	0.19762	0.59155	0.99998	0.04276	23.38557
Diameter	0.35134	0.08592	-0.32304	-3.74436	0.13365	-28.01572
Discharge	1.12097	0.13547	-0.04270	1.46302	0.07857	18.61957
Intercept				-2.40117		

Coefficient of determination	0.99600
Standard error of estimate	0.02004

*Y is the pressure head

Appendix II. (Contd.)

Table of residuals

Sl.No.	$\log_e H_o$	H_o^*	$\log_e H_e$	H_e^{**}	Residual
1	-0.05768	0.88	-0.03902	0.91	-0.01866
2	-0.13233	0.74	-0.13469	0.73	0.00236
3	0.11037	1.29	0.09645	1.25	0.01392
4	-0.36888	0.43	-0.38754	0.41	0.01866
5	0.13453	1.36	0.13565	1.37	-0.00112
6	-0.06025	0.87	-0.05903	0.87	-0.00122
7	-0.41290	0.39	-0.39897	0.40	-0.01393

$^*H_o$ is the observed values of pressure head

$^{**}H_e$ is the estimated values of pressure head

Appendix II. (Contd.)

d) Laminar flow condition K = 0.84

Variables X	Mean	Standard deviation	Correlation X vs Y*	Regression coefficient	Standard errors of regression coefficient	Computed t value
Length	2.01180	0.19496	-0.14330	0.99999	0.00486	205.75432
Diameter	0.10617	0.17150	-0.45159	-3.58420	0.00769	-465.97003
Discharge	0.32087	0.40937	-0.08748	1.22546	0.00349	351.24677
Intercept				-2.12886		

Coefficient of determination	0.99992
Standard error of estimate	0.00132

*Y is the pressure head

Appendix-III Analysis for friction factor

a) Turbulent region

The general equation is

$$f = \frac{K}{Re^x}$$

Using the method of least squares, the straight line trend for this region is

$$\log_e f = \log_e K + x \log_e Re$$

$$\log_e f = -1.394 + 0.25 \log_e Re$$

$$K = e^{-1.394} = \underline{\underline{0.248}}$$

b) Transition region

For the transition region, the straight line trend is

$$\log_e f = -1.185 + 0.25 \log_e Re$$

$$K = \underline{\underline{0.306}}$$

c) Laminar region

For this region, the relationship between f and Re was taken as

$$f = \frac{K}{Re}$$

By fitting a straight line trend,

$$\log_e f = \log_e K + \log_e Re$$

$$\log_e f = 4.208 + \log_e Re$$

$$K = e^{4.208} = \underline{\underline{67.2}}$$

Appendix II. (Contd.)

Table of residuals

Sl.No.	$\log_e H_o$	H_o^*	$\log_e H_e$	H_e^{**}	Residual
1	-0.31047	0.49	-0.30854	0.49	-0.00193
2	-0.00681	0.98	-0.00997	0.98	0.00316
3	0.16144	1.45	0.16359	1.46	-0.00215
4	-0.30957	0.49	-0.31031	0.49	0.00074
5	-0.01140	0.97	-0.01028	0.98	-0.00112
6	-0.30553	0.49	-0.30469	0.50	-0.00084
7	0.17132	1.48	0.16896	1.48	0.00236
8	0.17359	1.49	0.17441	1.49	-0.00082
9	-0.00376	0.99	-0.00167	1.00	-0.00209
10	-0.30835	0.49	-0.31114	0.49	0.00279
11	-0.00188	1.00	-0.00298	0.99	0.00110
12	-0.30345	0.50	-0.30371	0.50	0.00026
13	-0.30229	0.50	-0.30082	0.50	-0.00147

$^*H_o$ is the observed values of pressure head

$^{**}H_e$ is the estimated values of pressure head

HYDRAULICS OF
KAU DRIP IRRIGATION SYSTEM

By

SUSAN CHERIAN, K.

ABSTRACT OF THE THESIS

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Master of Science in Agricultural Engineering

Faculty of Agricultural Engineering
Kerala Agricultural University

Department of Land and Water Resources and Conservation Engineering
Kelappaji College of Agricultural Engineering and Technology
Tavanur - 679 573
Malappuram
1988

ABSTRACT

Irrigation advancements within the last decade have been astounding. Drip irrigation is one of the latest innovations for applying water to the field and it represents a definite advancement in irrigation technology.

An attempt was made to study the hydraulics of microtube emitters of 1-3 mm size, Black polyethylene tube of 1" was used as main line. In the main line, three laterals of ½" diameter were connected. Discharge measurements were taken at different pressure heads. The total energy drop (H) in a microtube emitter is the summation of friction loss (H_f) and minor loss (H_m). There was no empirical equation available for calculating the friction drop from a microtube of size less than 4 mm. With the help of a computer, analysis was made to establish the relationships between pressure head H, length L, diameter D and discharge Q. The empirical equations obtained are

1. Combined flow condition

$$H = 0.01402 \frac{Q^{1.23938}}{D^{3.54926}} L^{0.86030}$$

2. Turbulent flow condition

$$H = 0.00764 \quad \frac{Q^{1.82655}}{D^{4.61537}} \quad L^{0.77823}$$

3. Flow in transition region

$$H = 0.00817 \quad \frac{Q^{1.56882}}{D^{3.83531}} \quad L^{0.83541}$$

4. Laminar flow condition

$$H = 0.00796 \quad \frac{Q^{1.23461}}{D^{3.59105}} \quad L^{0.98712}$$

Where

Q = discharge, l/hr

L = length of tube, cm

D = diameter of tube, mm

The minor losses, viz. exit, entry, losses due to fittings and sudden contraction can be expressed as a function of velocity head. The minor loss was significant because of the smaller size and short length of the microtube. The numerical solution for minor loss coefficient K was obtained in order to make the power of L unity in the estimating equations for head loss due to friction. The equations obtained are

1. Combined flow

$$H_m = 2.34 \quad \frac{V^2}{2g}$$

2. Turbulent flow

$$H_m = 2.14 \quad \frac{V^2}{2g}$$

3. Flow in transition region

$$H_m = 3.18 \frac{V^2}{2g}$$

4. Laminar flow

$$H_m = 0.84 \frac{V^2}{2g}$$

Where

V = velocity, m/s

g = acceleration due to gravity, m/s^2

The empirical equations for friction drop were developed for different flow condition by fitting multiple log linear regression equations. The equations obtained are

1. Combined flow

$$H_f = 0.00737 \frac{Q^{1.18905}}{D^{3.58352}} L$$

2. Turbulent flow

$$H_f = 0.00359 \frac{Q^{1.74866}}{D^{4.80544}} L$$

3. Flow in transition region

$$H_f = 0.00397 \frac{Q^{1.46302}}{D^{3.74436}} L$$

4. Laminar flow

$$H_f = 0.00743 \frac{Q^{1.22546}}{D^{3.58420}}$$

Similar to Blasius and general equations, the following equations were developed for friction factor in turbulent and laminar regions.

$$f = \frac{0.248}{Re^{0.25}}$$

and

$$f = \frac{67.2}{Re}$$

where

f = friction factor

Re = Reynolds number

The KAU drip system has an additional component 'Distributor'. Experiments were conducted to study the effect of distributor on flow rate. It was observed that the discharge rate was higher from the system with distributor than that of microtube having the same length. The frictional losses and the combined loss of minor and distributor for different flow conditions were estimated. Few combinations which satisfy the requirements of discharge, length and pressure head were selected for the design purpose of KAU drip irrigation system.

The effect of clogging on discharge rate was studied and it was found that clogging was higher in 1 mm tube than the 2 mm and 3 mm tubes.

Experiments were conducted to estimate friction loss in laterals. Hazen-Williams equation was found suitable for turbulent region and not for laminar and transition region.

By adopting drip system we can bring more area under cultivation by maximum utilisation of available water. By combining improved agronomic practices along with an efficient drip irrigation system, it is possible to bring about a substantial progress in the farm front.