DRIP IRRIGATION SYSTEM FOR ORCHARD TREES IN MALAYSIA

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ABSTRACT

The high annual rainfall of Malaysia is unevenly distributed throughout the year. Supplemental irrigation will be beneficial for good yields and quality of crops. The water saving feature of drip irrigation system warrants adoption of the system on some soils and crops in Malaysia. Marginal land such as bris soils and tin-tailings may be developed for productive agriculture by installing a drip irrigation system to supply moisture, especially during the critical growth stage of the crops. This paper presents drip irrigation system design using drilled holes as emitters. Discharge calibration on 1 mm diameter drilled hole is given. The use of drilled holes instead of commercial emitters reduces system cost, and a less expensive system would make drip irrigation more attractive to potential users.

INTRODUCTION

The average rainfall of Malaysia exceeds 2500 mm annually. With this much water orchard trees are grown without irrigation. However, there are periods of inadequate moisture when supplemental irrigation will be needed to meet the crop water requirement, especially during the critical growth stage, in order to ensure good yields and quality of the crops. The irrigation method to use will depend on the slope of the land, texture and depth of the soil, type of crops, availability, quantity and quality of water, salinity and drainage problems, and the overall irrigation system cost.

Drip or Trickle irrigation technology as the most recent of all commercial irrigation methods is growing rapidly in arid areas of the world. Most of the scientific knowledge and practical experience to date are derived from arid areas. Drip irrigation is widely recognised for its high water use efficiency and low labour requirement. In our climate, the water use efficiency and labour cost are not the most important factors to consider in the selection of a type of irrigation system; nevertheless, the water saving feature, the potential of an improved crop production on existing land and the possibility of cultivating marginal land warrant adoption of the system on some soil types and crops in Malaysia.

Much of Malaysia's arable land is already cultivated. To increase food production to cope with population growth, marginal land such as bris soils and tin-tailings may be developed. Bris soils are found along the coastal stretches of Kelantan, Trengganu, Pahang and Johore, and tin-tailings areas are found in tin producing states of Perak and Selangor. These soils are predominantly sandy with poor moisture retension capacity due to high percolation and high evaporation. They also have intense reflected heat and poor nutrient status. Drip irrigation technology may be adopted here to develop these areas for productive agriculture.

Drip irrigation uses an extensive network of small diameter tubes with water emission points or emitters at necessary spacing to deliver water and soluble fertilizer to the crop root zone. The sizing of tubes for a drip system is based on several factors such as hydraulic principles, emitter flow characteristics, row length, elevation, equipment and energy costs, and water application uniformity desired. The relationship among the above mentioned factors is complex. However, recent research on small tube hydraulics gives us new information that can improve the energy, water and material used efficiency, Watters and Keller (1978), Howell and Hiler (1974), Solomon and Keller (1974) Wu and Gitlin (1974)

This paper presents analytical expressions to relate the physical variables in lateral line hydraulics. Design equations are presented in implicit form that relates lateral length, diameter, operating pressure, emitter flow characteristics, tube friction, discharge uniformity coefficient, emitter discharge exponent, emitter spacing requirement and land slope. The equations are in a formthat can be inserted into many programmable digital calculators and are very convenient for direct application to field use. The equations eliminate the need for design charts and tables. Discharge calibration for drilled hole emitters is given in the second part of this paper.

DRIP IRRIGATION SYSTEM

In a drip irrigation system, water and nutrients are carried in small polyethylene pipes from the supply and applied directly to the soil around the plant roots. Water is applied frequently but at low flow rates, usually between 2 and 10 lph under operating pressure head of a least 10m, to keep the root reservoir near field capacity. Water application efficiency may be as high as 95% which is much higher than other irrigation methods, surface or sprinkler.

The principle parts of a drip irrigation system are the emitters, laterals, submain and main lines. The lateral is a small diameter plastic tube combined with emitters or simply with drilled holes to distribute water to the field. The submain acts as a control system which can adjust water pressure in order to deliver the required amount of flow into each lateral; it is also used to control irrigation time for individual fields. The main line serves as a conveyance system for delivering the total amount of water for the system. Supporting parts such as filters, flushing units, pressure regulator, pressure gauge, valves and fertilizer injector serve different functions in a drip irrigation system.

Lateral Pressure Relations

As the pressure along a lateral line changes due to pipe friction and elevation so does the discharge from the emitters. This causes a non-uniform application of water. Emitter sensitivity to pressure changes can impose serious limitations on lateral line length for a specified uniformity of irrigation, especially on sloping land.

The emitter discharge rate is a function of operating pressure

$$q = kH^x \quad \text{.......................................} \quad (1)$$

The magnitude of x characterizes the discharge-versus-pressure relationship. It is the measure of how sensitive the emitter discharge is to pressure, Fig. 1. The value of x will typically fall between 0.1 and 1.0 depending on the design of the emission device. The magnitude of the coefficient k is a size or capacity parameter for an emitter since its magnitude is equal to the emitter discharge when H equals unity.

The emitter is an important part of a drip irrigation system. Solomon (1976), Karmeli and Keller (1975), and Karmeli (1972) list the desired qualities of a drip emitter. Although the ideal emitter has not yet been invented, Pitchford (1979) is optimistic that an emitter with a high degree of pressure compensation ($x \to 0$) is technically possible to achieve. Many emitters are sensitive to pressure variations. In laminar flow x = 1.0. Long-flow-path emitters have x = 0.7 to 0.8. Non-compensating orifice and nozzle emitters are always fully turbulent with x near 0.5. Compensating emitters have x ranging from 0.1 to 0.4.

Emitters may have a designated operating pressure range for predictable discharge, flushing action and safety from rupture. The designated range should be recognized and not be exceeded in the field (Figs. 1 & 2). A wide range of operating pressure (HMAX-HMIN) is a desirable quality in an emitter. The pressure limits should be stated by the manufacturer. Emitter operating pressure limits imply that HN<HMAX and HO>HMIN in the lateral.

Refering to Fig.2, friction loss HF and/or elevation differences HE cause the difference in supply end pressure HN and far end pressure HO. All quantities are defined in Table 1. To get a relation among the variables let us begin with these pressure head terms. As diagrammed in Fig. 2, pressure head components in a lateral are :

TABLE 1. VARIABLES IN LATERAL DESIGN

Variable	Symbol	Units	Description
Roughness coefficient	C	-	Hazen-Williams roughness coefficient for pipe wall
Emitter friction	CE	-	Friction in lateral due to barb or other obstruction to flow
Diameter	D	mm	Inside diameter of lateral tube
Reduction factor	F	-	Reduction coefficient for friction loss in multiple outlet conduit. F = 0.36 for $N \geq 30$
Pressure	H	m	Operating pressure in the lateral
Elevation	HE	m	Elevation difference in inlet and far end of lateral line
Friction	HF	m	Head loss due to lateral friction
Pressure	HMAX	m	Maximum operating pressure for an emitter
Pressure	HMIN	m	Minimum operating pressure for an emitter
Pressure	HN	m	Pressure head at supply end of lateral
Pressure	HO	m	Pressure head at far end of lateral
Constant	k	-	A numerical constant for an emitter
Length	L	m	Lateral length
No. of emitters	N	-	N = L/S
Emitter flow variation	P	-	Emitter flow variation due to pressure variation for example ± 10% from q equals a P of 10
Emitter discharge	q	lph	Emitter discharge, average design value
Reynolds number	RE	-	Based on total lateral flow at supply end
Emitter spacing	S	m	Emitter spacing on lateral
Discharge exponent	x	-	Emitter discharge exponent, $q = kH^x$

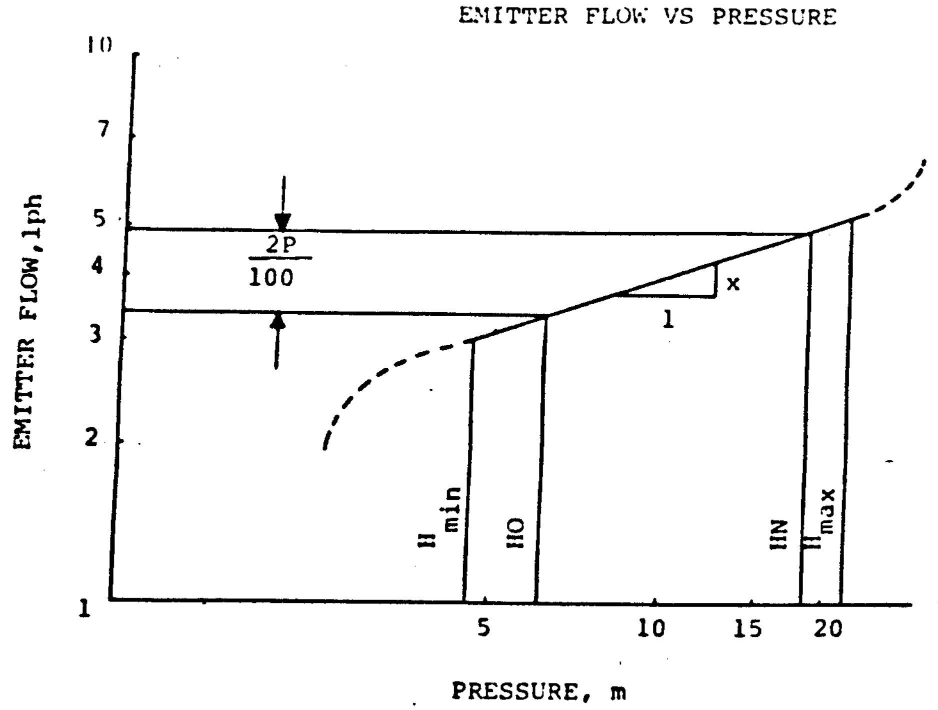

FIG. 1 Discharge versus pressure head for an emitter. The region of validity of $q = kH^x$ is defined by HMAX and HMIN.

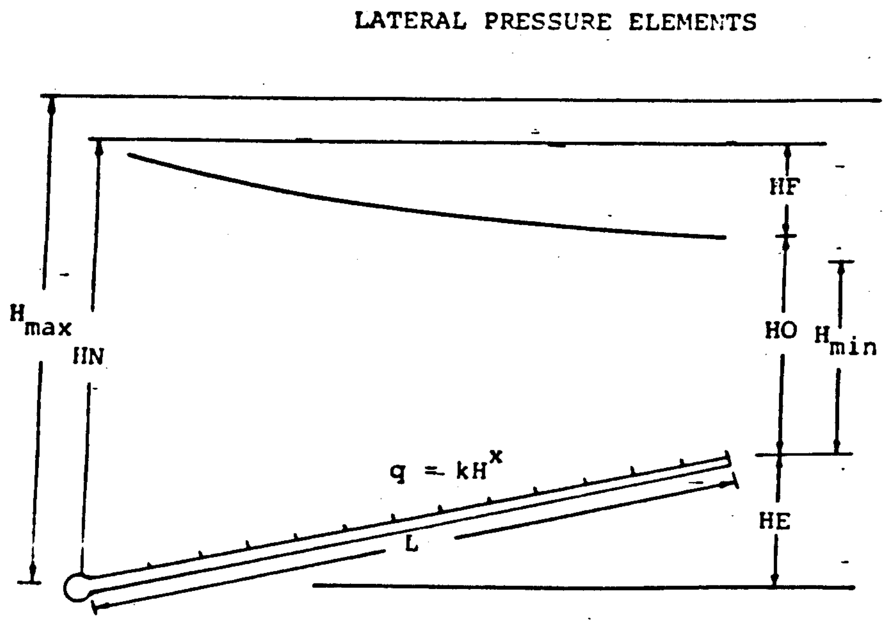

FIG. 2 Pressure head terms in a lateral shown with uphill slope.

$$HN = HF + HO + HE \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

in which HE is the pressure loss or gain due to elevation differences, positive when the lateral runs upslope and negative when the lateral runs downslope. The operating pressure ratio HO/HN is then

$$\frac{HO}{HN} = 1-\left(\frac{HF}{HN} + \frac{HE}{HN}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

The formation of dimensionless ratios reduces the number of parameters by one and eases unit problems.

For irrigation tube economy it is desirable to have wide range of operating pressure range (low HO/HN) so long laterals in a given size can be used on steep slopes (high HE/HN). Fig. 3 shows that the allowable friction loss and elevation can be great when emitters having low x values are used. A preselected value of uniformity P can be maintained.

The irrigation application uniformity is influenced by the emitter discharge characteristics and the pressure differences in the lateral. The design engineer usually establishes a goal in application uniformity and attempts to meet it in the system design.

Howell and Hiler (1974) express emitter discharge variation in a lateral with a parameter P which expresses the difference in supply end emitter flow and far end flow as a percentage. P is the flow variation in a lateral line. For example, ± 10 percent variation equals a P of 10. The selection of a design uniformity P value places limits on the pressure difference HO and HN in the lateral and the discharge variation of the emitter. Using the procedure of Howell and Hiler we can express the inlet pressure, HN

$$HN = \frac{q}{k}\,(1+P/100)^{\frac{1}{x}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

and the far end pressure, HO

$$HO = \frac{q}{k} (1-P/100)^{\frac{1}{x}} \qquad \text{.............................. (5)}$$

The ratio HO/HN

$$\frac{HO}{HN} = \left(\frac{1-P/100}{1+P/100}\right)^{\frac{1}{x}} \qquad \text{.............................. (6)}$$

relates beginning and end pressure, emission uniformity coefficient P, and the emitter discharge exponent x. A graphic solution to equation [6] is shown in Fig. 3. The selection of a uniformity coefficient P defines the emitter discharge exponent x and pressure ratio HO/HN allowable in the lateral.

If we combine equations [3] and [6] we get a dimensionless ratio of frictional pressure loss HF to the inlet pressure HN

$$\frac{HF}{HN} = 1- \frac{HO}{HN} - \frac{HE}{HN} = 1- \left(\left(\frac{1-P/100}{1+P/100}\right)^{\frac{1}{x}} - \frac{HE}{HN}\right) \qquad \text{................ (7)}$$

or,

$$HF = HN \left(1 - \left(\frac{1-P/100}{1+P/100}\right)^{\frac{1}{x}} - \frac{HE}{HN}\right) \qquad \text{................ (8)}$$

in which HE is zero for level land. The lateral pressure head characterized by the beginning pressure HN on the lateral, the lateral line flow variation P, the emitter discharge exponent x, and the elevation head HE, all of which impose a limit on the allowable lateral friction loss HF.

The value of P and x relate to HO/HN in equation [6] and Fig.3. Values of (HF/HN $\pm$ HE/HN) are plotted as a function of HO/HN in Fig. 4.

By simultaneous use of Figs. 3 and 4 the irrigation uniformity P and emitter exponent x are related to HF/HN and HE/HN. The algebraic sum of HF/HN $\pm$ HE/HN is a single parameter that fixes pressure limits in the lateral. At this point the engineer could

FLOW VARIATION, FLOW EXPONENT, AND PRESSURE RATIO

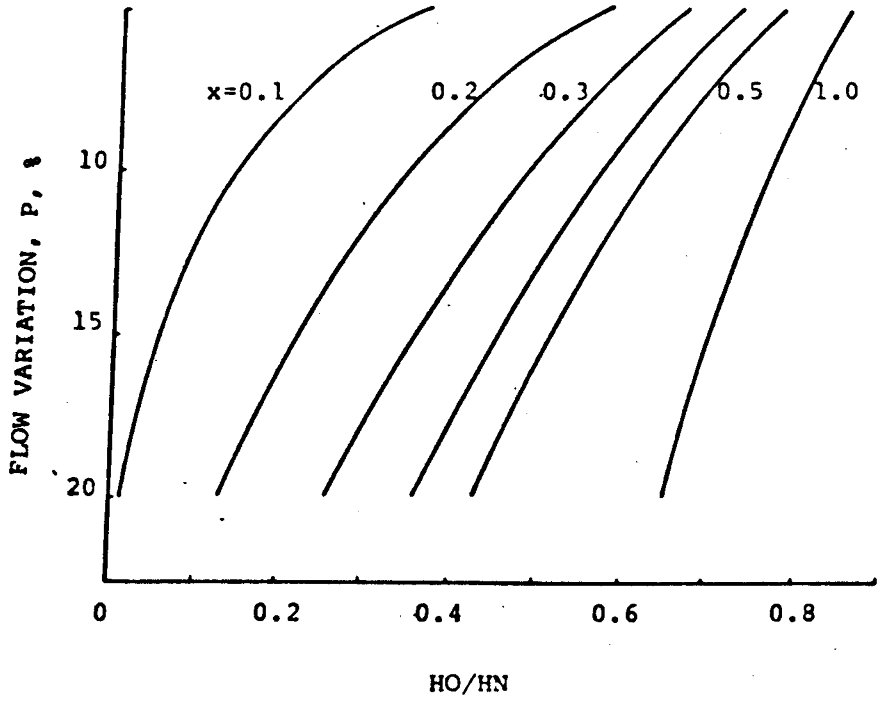

FIG. 3 Graphic solution to equation { 6 }

LATERAL PRESSURE NOMOGRAPH

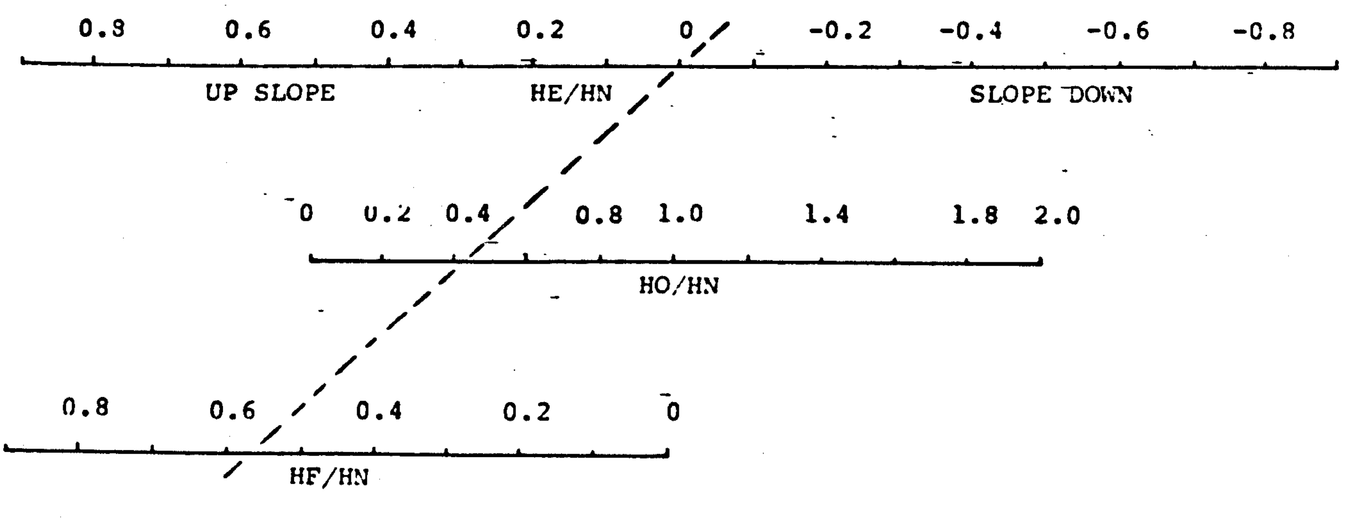

FIG. 4 Nomograph solution to equation(7). Can be used with Fig. 3 to find friction and elevation limits and emitter exponent for desired irrigation uniformity P.

Because pumping costs are proportional to operating pressure, one should remember this fact when choosing a pressure for drip irrigation. Depending on the number of hours per year of operating time, the economic balance of small lateral size with higher friction must be decided. Uys (1977) suggests that the most economic lateral size has 50 to 100 kPa (5 to 10m) friction loss per 100 meters of length.

Application Uniformity, P

Drip irrigation system application uniformity is influenced by the emitter design and pressure differences in the pipe distribution network. A general rule for arid area uniformity is to limit the discharge variation in a lateral line to ten percent of the average discharge. With emitters having discharge exponent of 0.5, this is the result of twenty percent variation in pressure.

In drip irrigation, unlike other irrigation methods, water is applied to a restricted area or volume of soil. In arid areas, the design criteria require that the system be able to supply on a daily basis all water used by the crop. Uniformity of irrigation should be high because the growth and productivity of the crop is directly related to the amount of water it gets. In Malaysia, rainfall is expected to supply most of the moisture needed by the crop. Rainfall is uniformly distributed over the field surface. The rooting system is not restricted to the volume of soil that is wetted by the emitter. Since drought is seldom severe enough to produce no moisture at all, the drip system application uniformity is not so critical as in an arid area. I believe that a 20 percent value for P is not too large for supplemental irrigation in Malaysia.

Drilled Holes as Emitters

Drip irrigation system using commercial emitters wet a small portion of the root zone A larger coverage is possible only with additional cost for the emitters or an extra lateral line for each row of trees. Emitters may cost as high as 30 percent of the total system cost. To reduce cost, the use of drilled holes as emitters is suggested. A drilled hole gives a jet discharge. The trajectory of the jet discharge can be varied by drilling the holes at different locations around the circumference of the lateral tube. Hence a wider moisture spread is possible. The jet discharge can also be used as an indicator of emitter clogging. The use of drilled holes instead of commercial emitters for water release reduces system cost. A less expensive system would make drip irrigation more attractive to potential users.

Discharge Calibration on Drilled Holes

The performance of drilled holes as emitters was studied at the Agricultural Engineering Faculty, Universiti Pertanian Malaysia. Tests were carried out on two performance criteria: the pressure-discharge relationship and the flow rate sensitivity to water temperature. The experimental drip system consisted of a centrifugal pump driven by a 3 Hp petrol engine, 25mm ID PVC main line, and 300m long lateral line. The lateral was a 13mm black polyethylene tube. Other components include a gate valve, a pressure regulator and a pressure gauge. An in-line filter was placed at the supply end of the lateral. Holes were drilled using 1mm diameter drill bit, and spaced 6m apart. Pressure head at the supply end of the lateral was varied from 10m to 2m.

Results

The discharge from a drilled hole emitter is sensitive to pressure. As pressure decreases along the lateral line, so does the discharge. Fig. 5 shows that the first emitter, 6 m away from the supply end, has discharge which ranged from 25 lph at 10 m head to 12 lph at 2 m head. At the 20th emitter, 120 m away from the supply end of the lateral, the flow rates ranged from 13 lph at 10 m head to 6 lph at 2 m head. At the far end of the lateral, 300 m away, the flow rates ranged from 4 lph at 10 m head to about 1 lph at 2 m head. No discharge was observed from the emitters at the far end of the lateral at pressure heads less than 2 m.

Discharge calibration results showed that the flow rates from the first emitter was about twice as much as those from the 20th emitter, 120 m away. The flow rates from the last emitter, 300 m away, were only 17% of those from the first emitter. The pressure discharge relationship as graphed in Fig. 5 showed that the discharge exponent of this emitter is very near 0.5. Equation 1 for drilled hole emitter of 1 mm diameter is then, $q = kH^{0.5}$.

Under the hot sun, water heats up as it travels along the black lateral line. With a water source temperature of 30°C, the water temperature at 120 m away from the source was about 34°C and the water temperature was as high as 42°C at the far end of the 300 m lateral line. The temperature discharge relationship showed that there was an increase in flow rates of about 4.6% per degree rise in temperature. The flow rates at 34°C and 42°C were respectively about 20% and 50% greater than the flow rates at 30°C.

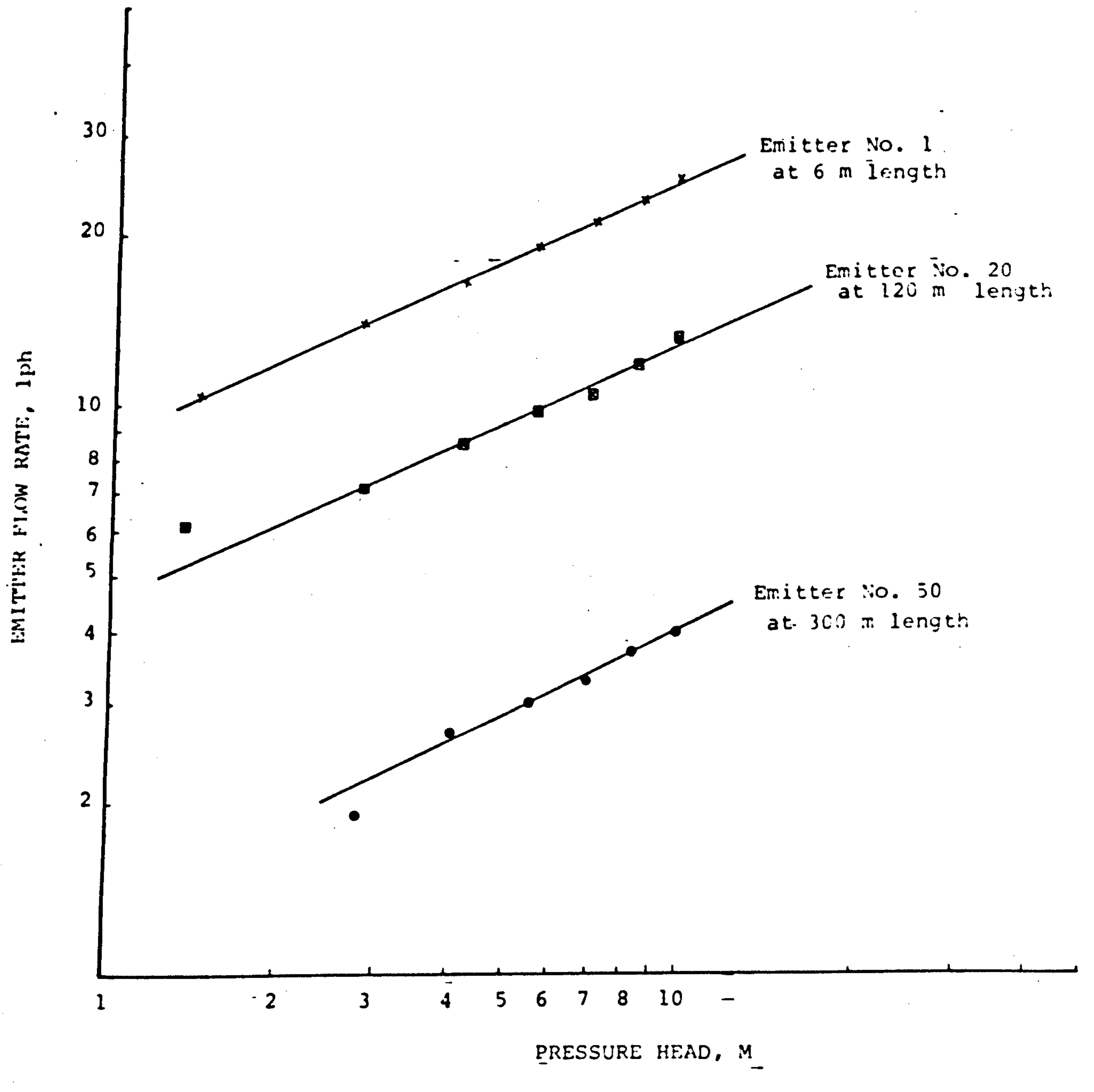

FIG. 5 Discharge versus Pressure head for 1 mm diameter drilled hole. $q = kH^{.45}$

Example

Determine the maximum length of a lateral line on a flat land when drilled holes are used as emitters. Emitter spacing is 6 m and supply end pressure is 50 kPa (5 m head). Application uniformity criteria call for an emitter discharge variation in the lateral not to exceed 20 percent. Three tube sizes are available: 10 mm, 13 mm and 16 mm.

Solution

The limiting length for three tube diameters will be found using equation (12). The actual friction loss HF and the far end head value HO can be calculated using equation (10).
Numerical values for the variables are:

D = 10 mm, 13 mm, 16 mm; x = 0.5 (Fig. 5); F = 0.36 (Karmeli and Keller, 1974); S = 6 m; q = 15 lph; HN = 5 m; P = 20%; HE = 0.

D, mm	HN, m	L, m	HF, m	HO, m	HF/HN	HO/HN
10	5	83	2.84	2.16	.57	.43
13	5	130	2.81	2.19	.56	.44
16	5	187	2.85	2.15	.57	.43

SUMMARY

The paper presents new analytical expressions for the variables in a drip irrigation lateral line hydraulics. Design equations are given in implicit form to relate lateral length, diameter, operating pressure, emitter flow characteristics, tube friction, discharge uniformity coefficient, emitter discharge exponent, emitter spacing and land slope. The equations are very convenient for direct application to field problems. A system employing drilled holes as water release is suggested for use in Malaysia. Drilled hole emitters reduces system cost and makes drip irrigation more attractive to potential users.

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