

Design of Drip Irrigation Lines

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SUMMARY

The friction drop in a drip irrigation line can be determined by considering turbulent flow in a smooth pipe. The pattern of friction drop along the length of a drip line is determined and expressed as a dimensionless curve. This curve combined with the slope effect will show the pressure distribution along the line. Design charts are introduced for determining pressure and length of drip irrigation lines.

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INTRODUCTION

A drip irrigation system consists of a main line, submains, laterals, and emitters. The main line delivers water to the submains, and the submains deliver water into laterals. The emitters, which are attached to the laterals, distribute water for irrigation. The flow condition in the submains and laterals can be considered as steady and spatially varied with lateral outflows (Figure 1). The flow from submains into laterals or the outflow of each emitter from a lateral is controlled by the pressure distribution along the submain and lateral lines. The pressure distribution along a drip irrigation line—submain or lateral—is controlled by the energy drop through friction and the energy gain or loss due to slopes either down or up.

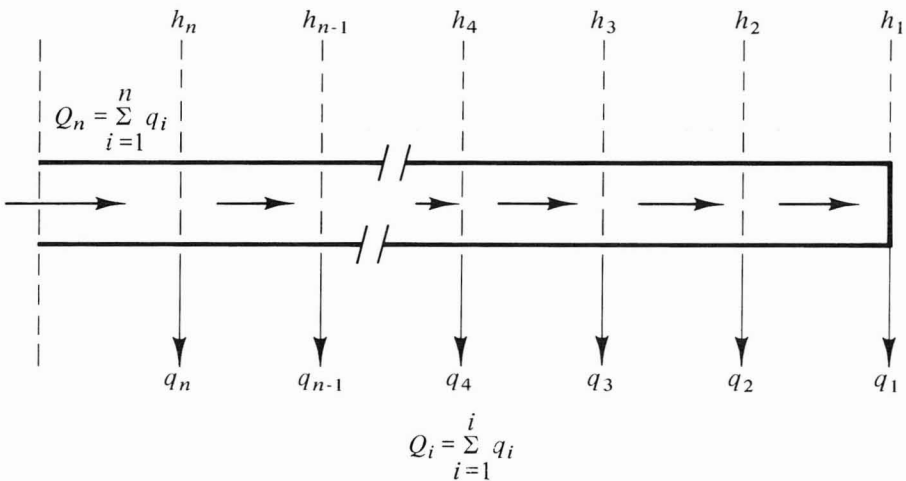


Fig. 1. Water distribution and pressure along a drip irrigation line.

If the pressure distribution along a lateral line can be determined, uniform irrigation can be achieved by adjusting the size of emitters, as suggested by Myers and Bucks (4), adjusting the length and size of the microtube—a special type of emitter used by Kenworthy (3), or slightly adjusting the spacing between emitters (7). If the design allows a certain variation of emitter outflow along the lateral line, a single type of emitter can be used, eliminating the troubles of adjustments. The degree of variation of emitter outflow can be shown by using the uniformity coefficient equation by Christiansen (2) (see p. 14).

The variation of discharge from emitters along a lateral line is a function of the total length and inlet pressure, emitter spacing, and total flow rate. This creates a design problem to select the right combination of length and pressure in order to achieve an acceptable, non-uniform pattern of irrigation.

This report presents a simple way of estimating friction drop along the lateral line, pressure distribution along the drip line, and variation of emitter discharge along the lateral. Design charts are presented for determining pressure and length of the lateral lines and submains of a drip irrigation system.

FRICION DROP

Low Flow in a Small Tubing

One of the characteristics of drip irrigation is low application rate; therefore, the flow in the lateral or submain is small. This low flow in the small pipe, such as a lateral of ½ inch, cannot be found in hydraulic handbooks or tables (6). By considering that drip irrigation pipes are hydraulically smooth, two empirical equations can be used to determine friction drop.

One is the Williams and Hazen formula (5):

$$\Delta H = \frac{3.023}{C^{1.852}} \frac{V^{1.852}}{D^{1.167}} L \quad \dots (1)$$

When C equals 150 for smooth plastic pipe, the formula is

$$\Delta H = 2.77 \times 10^{-4} \frac{V^{1.852}}{D^{1.167}} L \quad \dots (2)$$

where ΔH is the total friction drop, in feet; V is the mean velocity, in feet per second; D is the diameter, in feet; and L is the pipe length, in feet.

The other is Blasius' formula (5):

$$f = \frac{0.3164}{(N_R)^{0.25}} \quad \dots (3)$$

where f is the friction coefficient and N_R is the Reynolds number. The friction drop equation of pipe flow is

$$\Delta H = f \frac{L}{D} \frac{V^2}{2g} \quad \dots (4)$$

By combining equations 3 and 4, and simplifying, the formula becomes

$$\Delta H = 2.79 \times 10^{-4} \frac{V^{1.75}}{D^{1.25}} L \quad \dots (5)$$

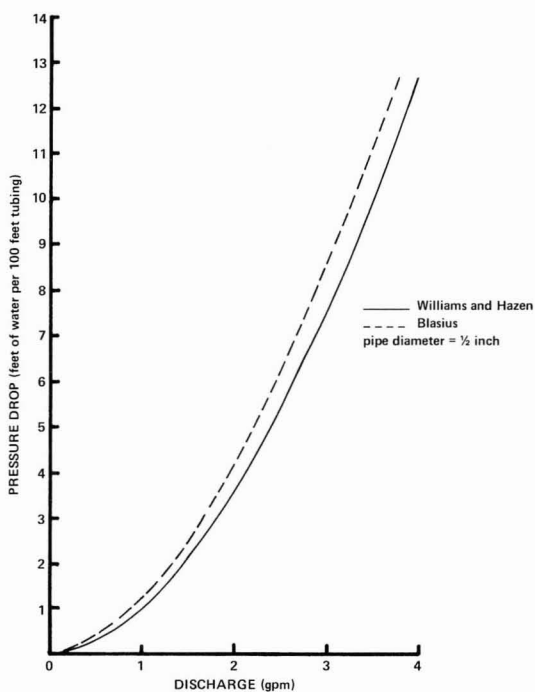


Fig. 2. Pressure drop by friction in a 1/2-inch plastic lateral line.

It is interesting to note that equations 2 and 5 are similar—but with a slight difference. Since the lateral line is usually $\frac{1}{2}$ inch, a plot of friction drop against discharge for a $\frac{1}{2}$ -inch pipe, using both equations 2 and 5, is shown in Figure 2. Figure 2, which shows the two curves are close to each other, can be used to determine friction drop in the $\frac{1}{2}$ -inch lateral line. For other sizes, use equations 2 and 5 to calculate ΔH or use the tables, which were calculated by using equation 2, for PVC pipe.

Along a Lateral Line

The flow condition in the lateral line is steady and spatially varied with decreasing discharge (Figure 1). Assume the outflows for n sections are $q_1, q_2, q_3, \dots, q_n$ —counting from the end—and the corresponding pressures are $h_1, h_2, h_3, \dots, h_n$. Since the end is plugged, the flow in section 1, which is between the outlets 1 and 2, is q_1 and the flow in section 2 is $q_1 + q_2$. The flow in each section can be expressed as

$$Q_i = \sum_1^i q_i \quad \dots (6)$$

$$i = 1, 2, 3, \dots, n$$

The total discharge supplied from the head end is

$$Q_n = \sum_1^n q_i \quad \dots (7)$$

or

$$Q_n = q_1 + q_2 + q_3 \dots + q_n \quad \dots (8)$$

The friction drop of pipe flow given by equation 4 shows that the friction drop from each section is

$$\Delta h = f \frac{\Delta L}{D} \frac{V^2}{2g} \quad \dots (9)$$

where Δh is the friction drop at a given section and ΔL is the length of the section. Assume the drip line is smooth and Blasius' empirical formula is used. By substituting equation 3 into equation 9 and simplifying, the formula becomes

$$\Delta h = KQ^{1.75} \Delta L \quad \dots (10)$$

where

$$K = \frac{2.53 (\nu)^{0.25} (A)^{0.25}}{g\pi^2 D^{5.25}} = \text{Constant}$$

where ν is the kinematic viscosity. If uniform discharge is distributed from each outlet, the energy drop along the line can be calculated as

$$\begin{aligned} \Delta h_n &= K [nq]^{1.75} \Delta L \\ \Delta h_{n-1} &= K [(n-1)q]^{1.75} \Delta L \\ &\cdot \\ &\cdot \\ &\cdot \\ \Delta h_2 &= K [2q]^{1.75} \Delta L \\ \Delta h_1 &= K [q]^{1.75} \Delta L \end{aligned} \quad \dots (11)$$

The total energy drop will be

$$\Delta H = Kq^{1.75} [n^{1.75} + (n-1)^{1.75} + \dots + 2^{1.75} + 1^{1.75}] \frac{L}{n} \quad \dots (12)$$

The total energy drop at the first quarter of the total length will be

$$\Delta H_{0.25} = Kq^{1.75} [n^{1.75} + (n-1)^{1.75} \dots + (0.75n)^{1.75}] \quad \dots (13)$$

The total energy drop at half the total length will be

$$\Delta H_{0.5} = Kq^{1.75} [n^{1.75} + (n-1)^{1.75} \dots + (0.5n)^{1.75}] \quad \dots (14)$$

A general equation expressing the total friction at any section will be

$$\Delta H_i = Kq^{1.75} \{n^{1.75} + [n-1]^{1.75} \dots [(1-i)n]^{1.75}\} \quad \dots (15)$$

$$i = 0.1, 0.2, 0.3, \dots, 1.0$$

where i represents the percentage of the length.

By comparing equation 15 with equation 12 the shape of the energy gradient line can be determined. A computer program was made to determine the friction drop ratio, $\Delta H_i/\Delta H$ ($i = 0.1, 0.2, \dots, 0.9$); it was found that for different n values (50, 100, 200, \dots , 1000) the ratios are about the same. Therefore, the shape of the friction drop pattern can be obtained. A dimensionless curve showing the friction drop ratio $\Delta H_i/\Delta H$ and length ratio ℓ/L can be plotted as shown in Figure 3.

If the flow in each section of the drip line is small enough and the laminar flow condition exists, then the friction coefficient is

$$f = \frac{64}{N_R} \quad \dots (16)$$

By substituting equation 16 into equation 9 and simplifying, the formula becomes

$$\Delta h = K_1 Q \Delta L \quad \dots (17)$$

where

$$K_1 = \frac{512Av}{g\pi D^6} = \text{Constant}$$

And, if the flow in each section is large enough so that full turbulence develops where the friction coefficient is a constant, the friction drop can be expressed from equation 9 as

$$\Delta h = K_2 Q^2 \Delta L \quad \dots (18)$$

where

$$K_2 = \frac{f}{DA^2 2g} = \text{Constant}$$

Equations 17 and 18 can be used to determine the friction drop for a laminar flow and a fully turbulent flow, respectively. The difference between these two equations and equation 10 is only the power of discharge. A general equation expressing friction drop can be shown as

$$\Delta h = a Q^m \quad \dots (19)$$

where

$a = \text{constant}$

$m = 1$ for laminar flow

$m = 1.75$ for turbulent flow in smooth pipe

$m = 1.85$ for turbulent flow (using Williams and Hazen formula)

$m = 2$ for fully turbulent flow ($f = \text{constant}$)

By using the same technique and computer program to determine the shape of the friction drop pattern as for the turbulent flow in smooth pipe ($m = 1.75$), the shape of the friction drop pattern can be determined for a laminar flow and a fully turbulent flow ($m = 1$ and $m = 2$, respectively). The dimensionless curves showing the relationship between friction drop ratio and length ratio for laminar and fully turbulent flow in pipes were also plotted and are shown in Figure 3.

Figure 3 shows that the dimensionless curves for turbulent flow in smooth pipe ($m = 1.75$) and for fully turbulent flow ($m = 2$) are of similar shape and close to each other. If the Williams and Hazen formula is used ($m = 1.85$), it will be located between the two curves.

Results of laboratory experiments using different pressure and emitter spacings (I) showed the friction drop pattern is close to the

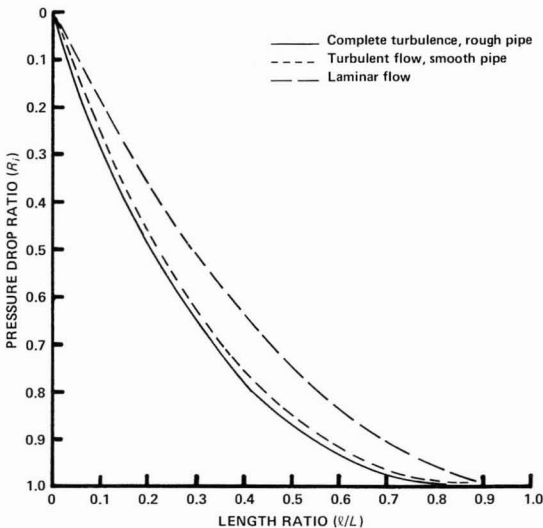


Fig. 3. Dimensionless curves showing the friction drop pattern caused by laminar flow, turbulent flow in a smooth pipe, and complete turbulent flow in a lateral line.

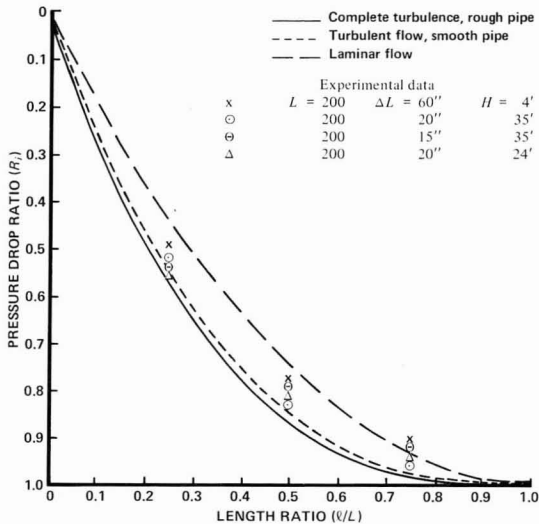


Fig. 4. Laboratory experiments of pressure distribution along a lateral line compared with theoretical dimensionless curves.

pattern given by turbulent flow in smooth pipe, which is plotted as shown in Figure 4. It is interesting to note that in the lower sections, where the flow rate is small, the pattern is approaching laminar flow. Assuming there is only a small portion of laminar flow, the friction drop pattern of turbulent flow in smooth pipe can be used to represent the friction drop along a drip irrigation line.

The dimensionless curves were obtained assuming a constant outflow from each emitter, but the friction drop pattern was actually caused by an uneven distribution along the line. These two energy drop patterns cannot be compared unless the emitters can be adjusted to give a constant discharge according to the corresponding pressure at any given section. However, if the variation of outflow from each section (emitter) is kept (designed) to a reasonable minimum, the determined friction drop pattern shown in Figure 3 can be used to predict the friction loss along a drip line.

PRESSURE DISTRIBUTION

Pressure Affected by Slopes

A drip line laid up or down slopes will affect the hydrostatic pressure along the line. When the line is laid up slope it will lose pressure, and

when the line is laid down slope it will gain pressure. The loss or gain in pressure is linearly proportional to the slope and length of the line.

Along a Drip Line

The total energy at any section of a drip line can be expressed by the formula

$$H = Z + h + \frac{V^2}{2g} \quad \dots (20)$$

where H is the total energy expressed in feet, Z is the potential head, or elevation, in feet, h is the pressure head, in feet, and $V^2/2g$ is the velocity head, in feet. The change of energy with respect to the length of line can be expressed as

$$\frac{dH}{dL} = \frac{dZ}{dL} + \frac{dh}{dL} + \frac{d\left(\frac{V^2}{2g}\right)}{dL} \quad \dots (21)$$

Considering the outflow from emitters is low, the change of velocity head with respect to the length (dL) is small and neglected. Therefore, the energy equation can be reduced to

$$\frac{dH}{dL} = \frac{dZ}{dL} + \frac{dh}{dL} \quad \dots (22)$$

where dH/dL is the slope of energy line or energy slope, then

$$\frac{dH}{dL} = -S_f \quad \dots (23)$$

The minus sign means friction loss with respect to the length. The dZ/dL represents the slope of the line, as in

$$\frac{dZ}{dL} = -S_o \text{ (down slope)} \quad \dots (24)$$

and

$$\frac{dZ}{dL} = S_o \text{ (up slope)} \quad \dots (25)$$

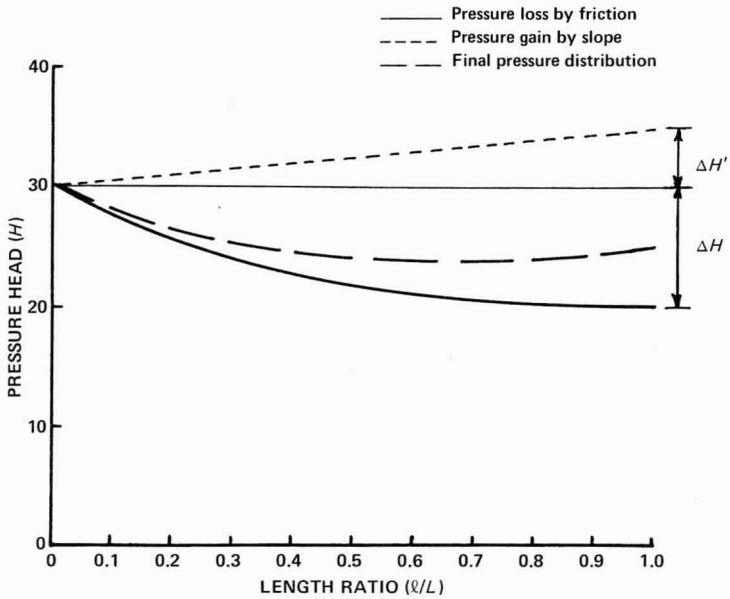


Fig. 5a. Pressure distribution along a drip irrigation line (down slope).

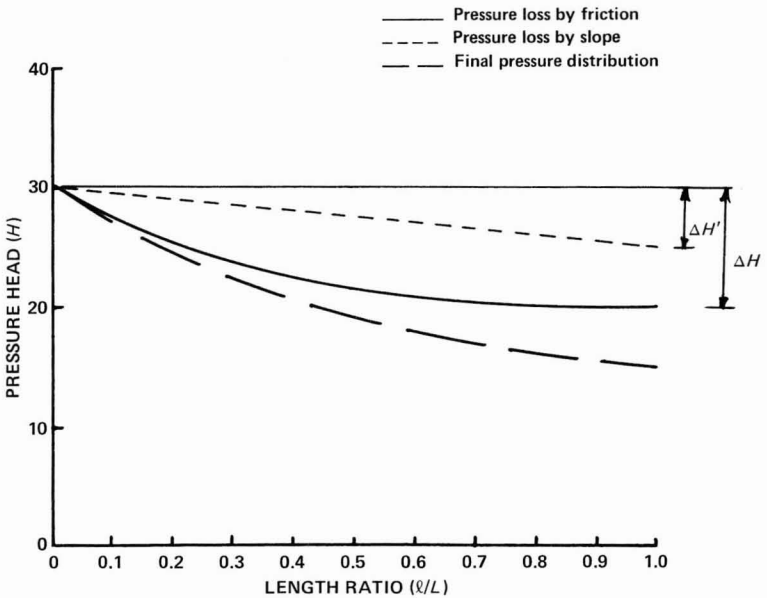


Fig. 5b. Pressure distribution along a drip irrigation line (up slope).

The pressure distribution for a drip line if it is laid down slope is

$$\frac{dh}{dL} = S_o - S_f \quad \dots (26)$$

The pressure distribution for a drip line if it is laid up slope is

$$\frac{dh}{dL} = -S_o - S_f \quad \dots (27)$$

If the dimensionless curve (turbulent flow in smooth pipe) shown in Figure 3 can be used, the friction drop at any given length of the line can be predicted when a total energy loss (ΔH) is known. If the length of line and slope are known, the pressure head gain or drop ($\Delta H'$) at any section of the line can be calculated. The pressure distribution along a drip line, if an initial pressure is given, can be determined from equations 26 and 27, as shown in Figures 5a and 5b.

EMITTER DISCHARGE

Along a Lateral Line

The discharge (emitter outflow) at any section of a drip line is controlled by the pressure at that section. Hydraulically the emitter outflow is a function of the square root of the pressure, as in

$$q_i = C_1 \sqrt{H_i} \quad \dots (28)$$

where C_1 is a coefficient and a constant, q_i is the emitter discharge at the i th section, and h_i is the pressure at the i th section.

If the total pressure (inlet pressure) is H , the friction drop at any given length is ΔH_i , the maximum friction drop at the end of the line is ΔH , the pressure gain or drop is $\Delta H'_i$, and the maximum pressure gain or drop is $\Delta H'$, as shown in Figure 5, the discharge (for a down slope) can be expressed as

$$q_i = C_1 \sqrt{H - \Delta H_i + \Delta H'_i} \quad \dots (29)$$

$$i = 1, 2, 3, \dots, n$$

The ratio of discharge at any given section and the maximum discharge can be expressed as

$$\begin{aligned} \frac{q_i}{q} &= \sqrt{\frac{H - \Delta H_i + \Delta H'_i}{H}} \\ &= \sqrt{1 - \frac{\Delta H_i}{H} + \frac{\Delta H'_i}{H}} \end{aligned} \quad \dots (30)$$

If the ratio of ΔH_i and ΔH , which can be predicted by considering turbulent flow in smooth pipe as shown in Figure 3, is expressed by

$$R_i = \frac{\Delta H_i}{\Delta H} \quad \dots (31)$$

then the gain or loss of pressure affected by slopes can be expressed as

$$R'_i = \frac{\Delta H'_i}{\Delta H'} \quad \dots (32)$$

Equation 30 can be expressed by

$$\frac{q_i}{q} = \sqrt{1 - R_i \frac{\Delta H}{H} + R'_i \frac{\Delta H'}{H}} \quad \dots (33)$$

The friction drop ratio R_i for the different length ratio ℓ/L of the drip line can be read from Figure 3, and the pressure gain ratio R'_i is the same as the length ratio ℓ/L . The discharge distribution can be easily determined if H , ΔH and $\Delta H'$ are known.

Uniformity Coefficient

When the discharge distribution is determined, the degree of uniformity can be expressed by the uniformity coefficient equation by Christiansen (2).

$$C_u = 1 - \frac{\Delta \bar{q}_i}{\bar{q}} \quad \dots (34)$$

where \bar{q} is the mean discharge and $\Delta \bar{q}_i$ is the mean deviation from the mean.

DESIGN CHARTS

For Laterals

A computer program was made for equation 33 using different combinations of $\Delta H/H$ and $\Delta H'/H$ to calculate discharge ratio q_i/q . Assuming that the total length of the drip line was arbitrarily assigned into ten sections, the calculation was made by setting the ℓ/L ratios at 0.1, 0.2, 0.3, . . . , 0.9, and 1.0. From Figure 3 the friction drop ratio R_i , using the curve for turbulent flow in smooth pipe, was found to be 0.25, 0.46, 0.63, 0.75, 0.85, 0.92, 0.97, 0.99, 1.00, and 1.00 for each length ratio, respectively. The pressure gain (or loss) affected by slopes is linearly related to the length; therefore, the pressure gain (or loss) ratio R'_i is 0.1, 0.2, 0.3, 0.4, 0.5, . . . , 0.9, and 1.0. For each set of $\Delta H/H$ and $\Delta H'/H$, ten q_i/q ratios can be calculated. By using equation 34 the uniformity coefficient of the discharge distributions (based on the outflow from 10 sections) can be determined. A total of 10 $\Delta H/H$ from 0.1 to 1.0 and 15 $\Delta H'/H$ from 0.1 to 1.5 was programmed, and a total of 150 uniformity coefficients was calculated. The uniformity coefficient for different sets of $\Delta H/H$ and $\Delta H'/H$ was plotted in Quadrant I of Figure 6. The equal-uniformity lines were plotted as shown in Figure 6.

Quadrant II is designed to show the relationship between L (length) and ΔH (total energy drop) with respect to the total discharge (maximum discharge) in a given size pipe. If a turbulent flow in smooth pipe and uniform outflow are assumed, the total friction drop can be determined by equation 12:

$$\Delta H = Kq^{1.75} [n^{1.75} + (n-1)^{1.75} + \dots + 2^{1.75} + 1^{1.75}] \frac{L}{n}$$

while, if the mean discharge is used to calculate the friction drop, the total friction drop, ΔH_m , will be

$$\Delta H_m = Kq^{1.75} \left[\frac{n+1}{2} \right]^{1.75} L \quad \dots (35)$$

The difference of $\Delta H - \Delta H_m$ divided by H will show a percentage of error if equation 35 is used to calculate the total friction drop. The percentage of error will be

$$\frac{\Delta H - \Delta H_m}{\Delta H} = 1 - \frac{\Delta H_m}{\Delta H}$$

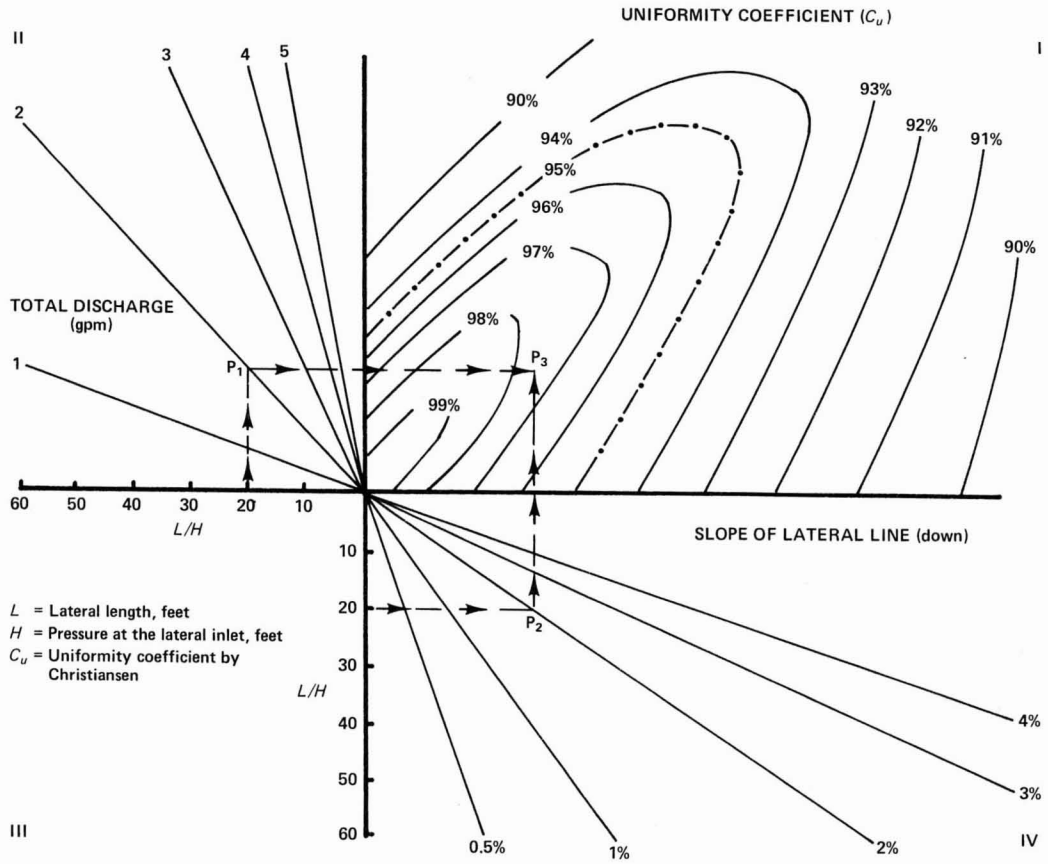


Fig. 6. Design chart of a 1/2-inch lateral line (down slope).

$$= 1 - \frac{n \left[\frac{n+1}{2} \right]^{1.75}}{[n^{1.75} + (n-1)^{1.75} + \dots + 2^{1.75} + 1^{1.75}]} \dots (36)$$

The percentage of error was determined by using different n values in equation 36. The calculations were made for n values from 1 to 1000. It was found that the percentage of error is increased with respect to n value; however, the percentage of error levels off after $n = 100$ and finally is around 18%. If the 18% error is used, then

$$1 - \frac{\Delta H_m}{\Delta H} = 18\%$$

or

$$\frac{\Delta H_m}{\Delta H} = 82\% \dots (37)$$

Equation 37 shows that the ΔH can be calculated by using the value of ΔH_m , which is calculated by using mean discharge in the pipe. The value of ΔH_m per 100 feet drip line can be found from Figure 2 using the dash-line curve, and ΔH can be determined from equation 37. For a given mean discharge, the friction drop ΔH_m (and also ΔH) is linearly proportional to the length of the drip line. Therefore, different straight lines presenting different discharge rates were plotted in Quadrant II of Figure 6. In Quadrant II, the total discharge was used.

Quadrant IV shows the relationship between slope gain $\Delta H'$ and length L , since

$$\frac{\Delta H'}{L} = S_o$$

or

$$\Delta H' = S_o L \dots (38)$$

By plotting equation 38 in Quadrant IV, a family of straight lines representing different slopes was obtained. Quadrant III is used only to

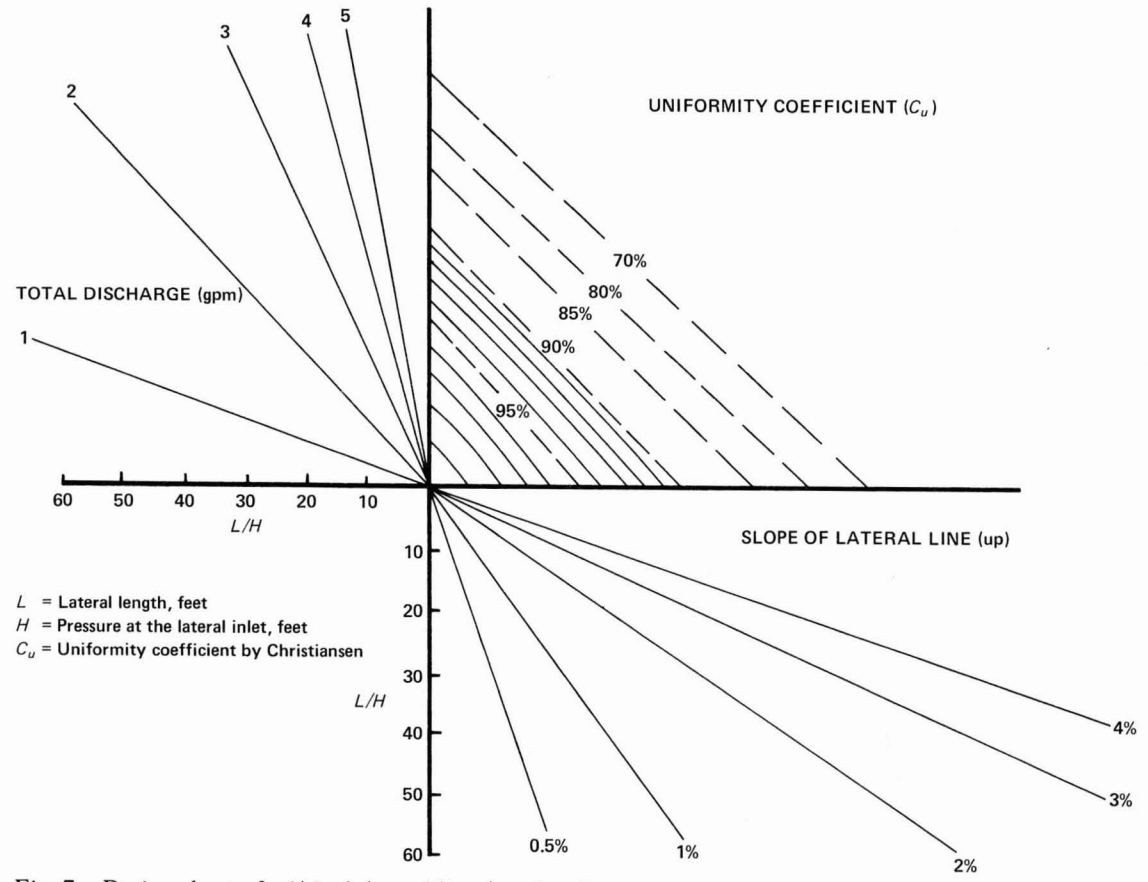


Fig. 7. Design chart of a 1/2-inch lateral line (up slope).

show the scales of L/H , and it can be considered a design parameter. Figure 6 is a design chart; a designer can try different L s and H s and check the uniformity coefficient of the design.

The same design chart can be constructed for the drip line having an up slope merely by changing equation 33 to

$$\frac{q_i}{q} = \sqrt{1 - R_i \frac{\Delta H}{H} - R'_i \frac{\Delta H'}{H}} \quad \dots (39)$$

and following the same procedure for designing Figure 6. The design chart for having a drip line laid up slope can be obtained and is shown in Figure 7.

Figures 6 and 7 show different uniformity patterns; Figure 6 shows a higher uniformity pattern than Figure 5. It is reasonable to expect the high uniformity pattern for Figure 6 when the energy drop is combined with energy gain from the down slope, whereas, in Figure 7, energy drop is combined with energy loss from the up slope.

A design criterion should be set regarding the uniformity coefficient that will be used. The concept here of uniformity coefficient should be considered differently from the uniformity coefficient used in sprinkler irrigation design, even though the definition and equation of uniformity coefficient is the same. A uniformity coefficient of 80 to 90%, which is considered good enough, may not be acceptable in a drip irrigation design. A sprinkler irrigation system irrigates a whole area where water can be redistributed easily after irrigation, whereas a drip irrigation system irrigates discrete points where a point of low application may well affect the growth of crops.

A study was made of the relation between uneven distribution and the uniformity coefficient. It was found that a discharge ratio q_{\max}/q_{\min} can be correlated with the uniformity coefficient; this was plotted as shown in Figure 8. Figure 8 shows that the q_{\max} is 40% more than the q_{\min} when the uniformity coefficient is 90%; and the q_{\max} is 85% more than the q_{\min} when the uniformity coefficient is 80%. Considering the discharge variations, design criteria were set so that a uniformity of 98% or more is considered to be desirable where the q_{\max} and q_{\min} variation is less than 10%; a uniformity coefficient from 95 to 98 is considered to be acceptable where the q_{\max} and q_{\min} variation is less than 20%; a uniformity coefficient of less than 95% is not recommended.

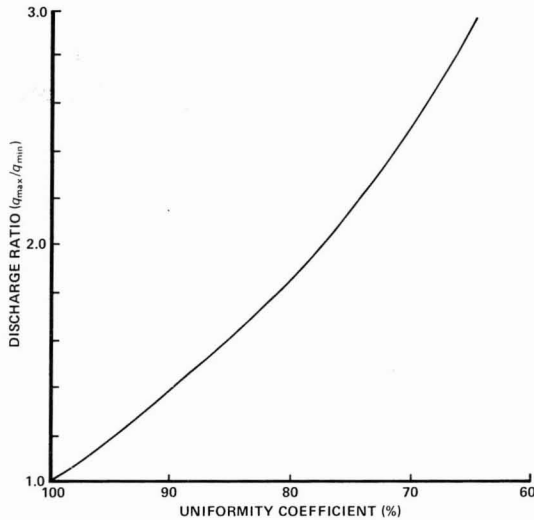


Fig. 8. Relationship between discharge ratio q_{\max}/q_{\min} and the uniformity coefficient.

Engineering Application

The design chart shown in Figures 6 and 7 can be used to design a drip irrigation lateral line. The chart consists of inlet pressure (H), length (L), total discharge (Q), slopes of the drip line (S_o), and the uniformity coefficient (C_u) that are used as the bases on which to judge the design. Assuming the emitter's discharge and spacing are given, one can use a trial-and-error technique, on the chart, to pick a set of H (pressure) and L (length) to fit the field condition and give the degree of uniformity desired.

An example is as follows:

If the pressure at the inlet (H) is 6.5 and the psi is 15 feet of water, then

Natural line length, $L = 300$ feet

Total discharge, $Q = 2$ gpm

Slope of lateral line (down), $S_o = 2\%$

Lateral line size = $\frac{1}{2}$ inch

The uniformity coefficient of the above design can be read from Figure 6 by the following procedures:

- a. Calculating $L/H = 20$.

- b. Drawing a vertical dash line in Quadrant II of Figure 6 from $L/H = 20$ up to meet 2 gpm discharge line at a point P_1 .
- c. Drawing a horizontal dash line from $L/H = 20$ in Quadrant IV to the right to meet the 2% slope line at a point P_2 .
- d. Drawing a horizontal dash line from P_1 and a vertical line from P_2 , so that the two lines will meet at a point, P_3 , which will show the uniformity coefficient, $C_u = 97\%$.

This procedure shows the design is acceptable.

Suppose the same drip irrigation system is used except the line is laid up slope. Using the same procedure and Figure 7, the uniformity coefficient is found to be 85%, which is not acceptable.

For Submains

Similar types of charts can be developed for the submain design. This can be done simply by using different sizes of pipes in Quadrant II of the design chart. The design charts for submains for sizes ranging from 3/4 inch to 1 1/2 inches were developed and are shown in Figures 9 and 16.

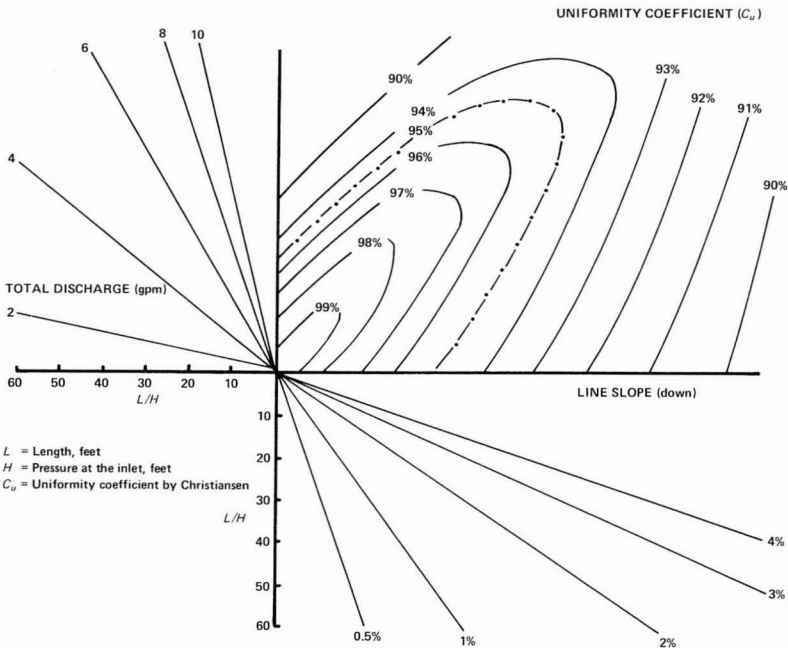


Fig. 9. Design chart of a 3/4-inch submain (down slope).

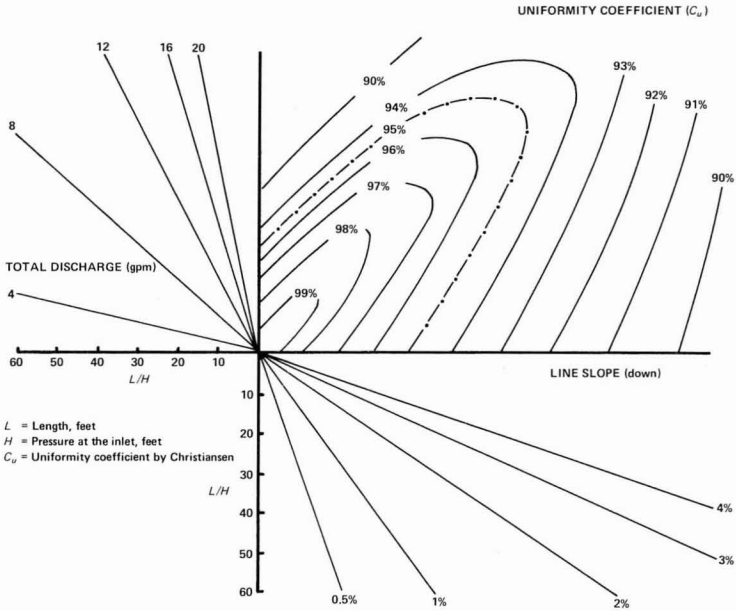


Fig. 10. Design chart of a 1-inch submain (down slope).

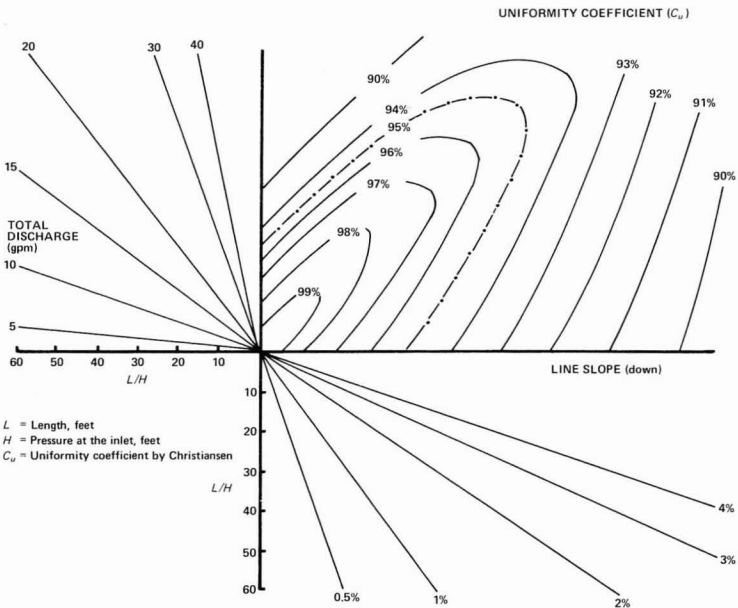


Fig. 11. Design chart of a 1 1/4-inch submain (down slope).

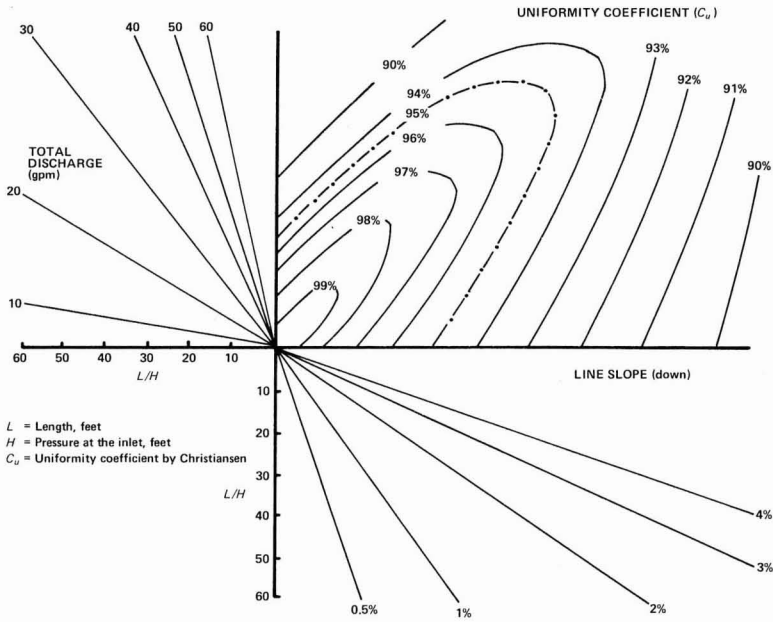


Fig. 12. Design chart of a 1½-inch submain (down slope).

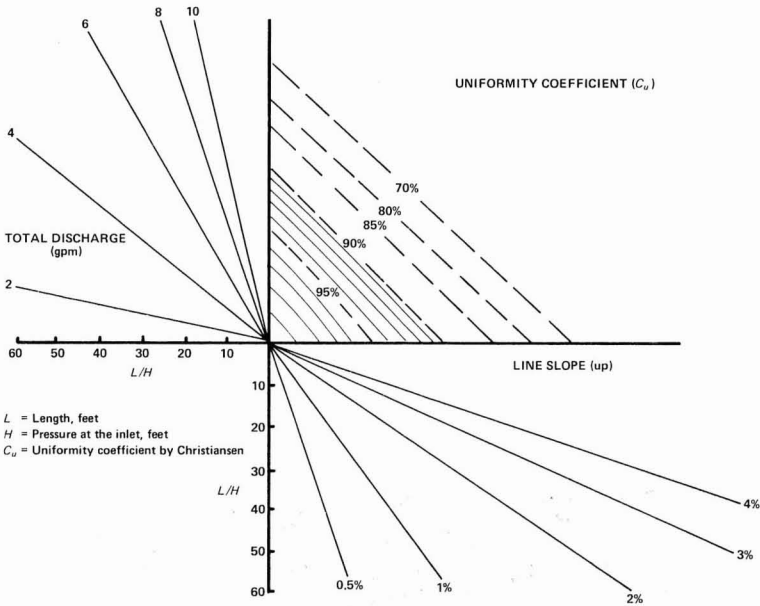


Fig. 13. Design chart of a ¾-inch submain (up slope).

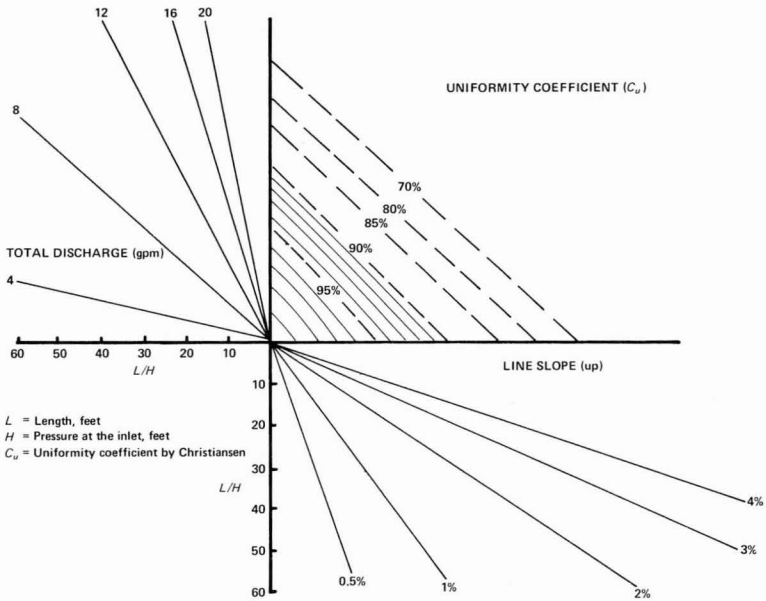


Fig. 14. Design chart of a 1-inch submain (up slope).

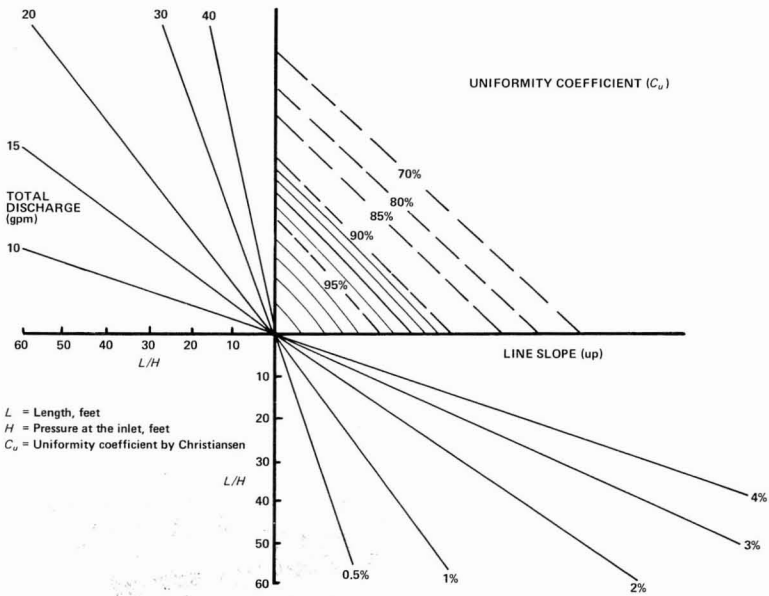


Fig. 15. Design chart of a 1/4-inch submain (up slope).

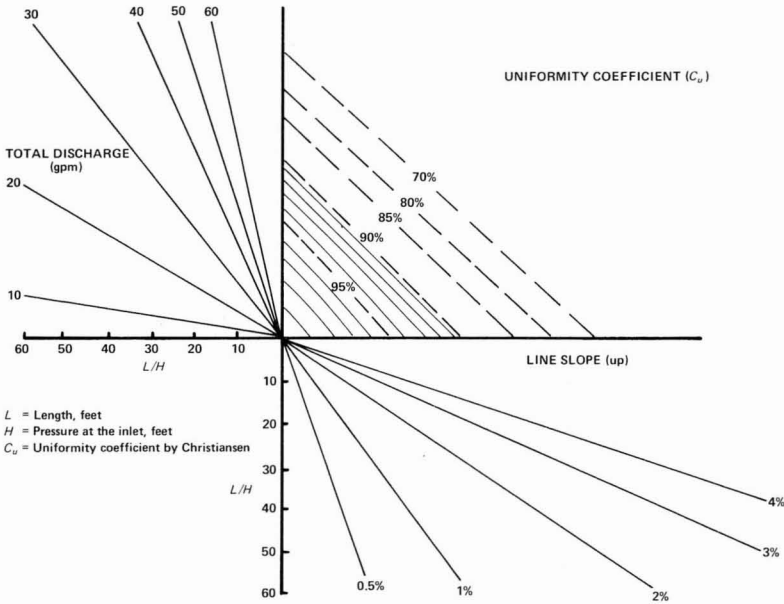


Fig. 16. Design chart of a 1½-inch submain (up slope).

SUMMARY AND DISCUSSION

The friction drop in a drip line irrigation system can be determined by considering turbulent flow in a smooth pipe; either the Blasius equation or the Williams and Hazen equation can be used. Due to the characteristics of drip irrigation, where the discharge in the pipe decreases according to length, the friction drop is not linearly proportional to the length but is an exponential function of the length of the pipe.

The friction drop pattern, however, has a fixed shape depending on the flow conditions. Laboratory results showed the curve (Figure 3) for turbulent flow in smooth pipe can be used to represent the friction drop pattern along a drip line. If the total friction drop ΔH and length L are known, the friction drop at any point along the drip line can be estimated.

The curve of friction drop combined with the pressure gain or loss due to down slopes or up slopes (where the drip line is laid) determines the pressure distribution along the line. Since the outflow (orifice or

emitter outflow) is controlled by the pressure, if the pressure distribution is known, the emitter discharge distribution can be determined. A uniformity coefficient can be calculated from the discharge distribution.

A design chart has been introduced, consisting of design pressure and length of the drip line, total discharge, slope of the line, and uniformity coefficient. The chart will help to design a drip irrigation line based on a desirable or acceptable uniformity. The designer can try different combinations of pressure (H) and length (L) in order to obtain one that is acceptable and fits the field condition.

The same design chart can be made for up slope conditions, which lose pressure with respect to the length, and for the different sizes of pipes that may be used for submain line design.

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APPENDIX: NOTATIONS

The following symbols are used in this bulletin:

a	= A constant in equation 19
A	= Area of the cross section of the emitter, ft ²
C	= A constant in equation 1
C_1	= A constant in equation 28
C_u	= Christiansen uniformity coefficient
D	= Diameter of the pipe, ft ²
f	= Friction coefficient
g	= Gravitational acceleration, ft/sec ²
h	= Pressure head in the pipe, ft
h_i	= Pressure head at the i th section, ft
Δh	= Friction drop, ft
H	= Total inlet pressure head, ft
ΔH	= Total friction drop, ft
$\Delta H'$	= Total pressure gain or loss by line slope, ft
ΔH_i	= Total friction drop at the i th section, ft
$\Delta H'_i$	= Total pressure gain or loss by slopes at the i th section, ft
ΔH_m	= Total friction drop determined from the mean discharge, inch
i	= Percentage of the length, expressed as numeric value
K	= A constant in equation 10
K_1	= A constant in equation 17
K_2	= A constant in equation 18
ℓ	= A given pipe length, ft
L	= Total length of the pipe, ft
ΔL	= Length of a section or length between two emitters, ft
m	= A constant of power function in equation 19
n	= Number of emitters or sections
N_R	= Reynolds number
q	= Emitter discharge or outflow from each section, cfs
q_i	= Emitter discharge or outflow from the i th emitter, cfs
\bar{q}	= Mean discharge
$\Delta \bar{q}_i$	= Mean deviation from the mean
Q	= Total discharge in the pipe, cfs
Q_i	= Total discharge in the i th section, cfs

R_i	= Friction drop ratio, $\Delta H_i/\Delta H$
R'_i	= Pressure loss or gain ratio from the slope, $\Delta H'_i/\Delta H'$
S_f	= Friction slope
S_o	= Slope of a drip line
V	= Mean velocity, ft/sec
ν	= Kinematic viscosity, ft^2/sec
Z	= Potential head, ft

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