Adjusted F Factor for Multiple-Outlet Pipes

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Abstract: An adjusted F factor to compute pressure head loss in pipes having multiple, equally spaced outlets is derived for any given distance from the first outlet to the beginning of the pipe. The proposed factor is dependent on the number of outlets and is expressed as a function of the Christiansen's F factor. It may be useful to irrigation engineers to estimate friction loss in sprinkle and trickle irrigation laterals and manifolds, as well as gated pipes.

Introduction

The flow of water in a pipe with a number of equally spaced outlets will certainly have less friction loss than if the total flow remained constant in a similar pipeline with the same inside diameter and length. The friction loss of a multiple outlet pipe may be expressed as a fraction of the friction loss in a similar pipeline transmitting the total flow over its length. Christiansen (1942) developed the concept of an F factor that accounts for this effect. The F factor introduced by Christiansen was derived by assuming that the first outlet is located one outlet spacing away from the lateral or manifold inlet. Reasoning that for a number of sprinkler irrigation laterals the first sprinkler is only one-half sprinkler spacing away from the lateral inlet, Jensen and Fratini (1957) derived an adjusted F factor for this condition. Chu (1978) introduced small modifications in the previous analysis and derived a modified F factor. As an improvement, he claims that the value of such factor remains approximately constant when there are five or more operating sprinklers on the lateral. In his analysis, the length of the similar pipeline transmitting the total flow exceeds in one-half sprinkler spacing the length of the lateral.

Despite being desirable, it is not always possible to set up multiple-outlet pipelines in such way that the first outlet is located either one or one-half outlet spacing away from the main line. This is commonly observed for sprinkler irrigation laterals where the sprinkler spacing results from an odd number of pipe units. The problem is increasingly important as the number of sprinklers in operation along the lateral is reduced. The purpose of this paper is to find an adjusted F factor to calculate friction loss in pipes having multiple, equally spaced outlets, where the first upstream outlet is located at any distance away from the beginning of the pipeline. Such an F factor would be useful for designing manifold, lateral, and gated pipes in irrigation works.

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ANALYSIS

The computations of the actual friction loss in multiple-outlet pipelines should start at the distal outlet on the line and work upstream, computing the friction loss between each outlet. In order to avoid this tedious process, Christiansen (1942) developed a procedure whereby the friction loss could be closely approximated just by multiplying the friction loss in a similar pipeline transmitting the total flow over its length by a factor F, developed from the following approximate equation:

$$\mathrm{F} = \frac{1}{m+1} + \frac{1}{2N} + \frac{(m-1)^{0.5}}{6N^2} \quad \text{(1)}$$

where F = Christiansen's F factor; m = velocity exponent in the formula used for friction-loss computation; and N = the number of outlets.

Christiansen's F factor was developed for multiple-outlet pipes where the first upstream outlet is one outlet spacing from the pipe inlet. In his procedure, Christiansen assumed that all outlets have equal discharges and that the total flow entering the pipe leaves through the outlets. It is also assumed that the gradual reduction of the velocity head as the flow passes the outlet causes the increase of a certain amount of pressure to nearly balance the energy losses (which are due to the coupler and the structure of the outlet itself). For these reasons, exact procedures to compute pressure loss in multiple-outlet pipelines are not justified (Pair et al. 1975). These assumptions are made valid in the approach described herein.

The total length of a multiple and equally spaced outlet pipe, as illustrated in Fig. 1, is

$$L = (N + x - 1)l \quad \text{(2)}$$

where L = total length of the multiple outlet pipe; N = number of outlets along the pipe; l = regular outlet spacing; and x = ratio of the distance of the first upstream outlet from the pipe inlet to the regular outlet spacing ($0 < x < 1$).

Alternately, Eq. 2 can be written as

$$l = \frac{L}{N + x - 1} \quad \text{(3)}$$

Let us divide the total pipe length into N sections of length l. It should be noted that the actual length of the first upstream section is less by (1 −

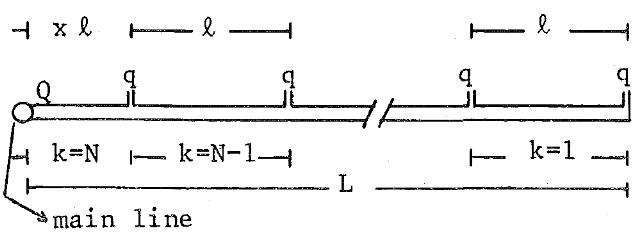

FIG. 1. Pipeline with Multiple, Equally Spaced Outlets

$x)l$. The discharge at any given section k is thus,

$$Q_k = kq \quad (4)$$

or

$$Q_k = k\frac{Q}{N} \quad (5)$$

where Q_k = discharge at the given section k of the pipe length; k = an index for the successive sections of the pipe length, starting at the distal section ($k = 1$) and increasing to N at the upstream section; q = outlet discharge; and Q = total pipe discharge.

The friction loss at a given section k of the pipe length [after Christiansen (1942)] is

$$Hf_k = \frac{CKQ_k^m l}{D^{2m+n}} \quad (6)$$

where Hf_k = friction loss; C = units coefficient; K = friction factor based on the friction loss formula used; Q_k = discharge at the given section k of the pipe length; D = inside pipe diameter; and m and n = exponents of the average velocity of flow and the inside pipe diameter, respectively, in the friction loss formula used.

The substitution of Eqs. 3 and 5 into Eq. 6 yields

$$Hf_k = \frac{CKQ^m}{D^{2m+n}} \frac{L}{N + x - 1} \frac{k^m}{N^m} \quad (7)$$

The friction loss along the pipe length can be computed as

$$\sum_{k=1}^{N} Hf_k = \frac{CKQ^m}{D^{2m+n}} \left[\frac{L}{N + x - 1} \frac{1}{N^m} \sum_{k=1}^{N} k^m - \frac{(1 - x)L}{N + x - 1} \right] \quad (8)$$

The summation of the left-hand side of Eq. 8 is the friction loss Hf along the pipe length. For convenience, Eq. 8 can be rewritten as

$$Hf = \frac{CKQ^m}{D^{2m+n}} \frac{L}{N + x - 1} \left(\frac{N}{N^{m+1}} \sum_{k=1}^{N} k^m + x - 1 \right) \quad (9)$$

The first term in parentheses in the right-hand side of Eq. 9 can be expressed as

$$\frac{N}{N^{m+1}} \sum_{k=1}^{N} k^m = N\left(\frac{1}{m + 1} + \frac{1}{2N} + \frac{m}{12N^2} \right) \quad (10)$$

It is promptly recognized that the term in parentheses in the right-hand side of Eq. 10 is the correction factor F derived by Detar (1982) for any given value for m, which is closely approximated of the Christiansen's F factor given by Eq. 1. After substituting Eq. 10 into Eq. 9 yields

$$Hf = \frac{CKQ^m L}{D^{2m+n}} \frac{NF + x - 1}{N + x - 1} \quad (11)$$

TABLE 1. Numerical Values of F_a for Multiple Outlet Pipes (m = 2)

Characteristics of x (1)	Number of Outlets, N 2 (2)	3 (3)	4 (4)	5 (5)	7 (6)	10 (7)	20 (8)	50 (9)	100 (10)
x = 2/3	0.550	0.458	0.421	0.400	0.378	0.364	0.348	0.339	0.336
x = 1	0.625	0.5185	0.469	0.440	0.408	0.385	0.359	0.343	0.338
% of x = 2/3	13.6	13.2	11.4	10.0	7.9	5.8	3.2	1.2	0.6
x = 0.5	0.500	0.422	0.393	0.378	0.363	0.353	0.342	0.337	0.335
% of x = 2/3	−9.1	−7.9	−6.6	−5.5	−4.0	−3.0	−1.7	−0.6	−0.3

The second term in the right-hand side of Eq. 11 is the adjusted factor F_a for $1 < N < \propto$ and $0 < x < 1$

$$F_a = \frac{NF + x - 1}{N + x - 1} \qquad (12)$$

From Eq. 12, it can be seen that for $x = 1$, F_a reduces to the correction F factor. It is easily proven also that for $x = 0.5$, F_a reduces to the same expression as that derived by Jensen and Fratini (1957).

Eq. 12 was used to determine the numerical values of F_a for $x = 2/3$ and $m = 2$, for different numbers of outlets along the lateral. The results were compared to those obtained by assuming $x = 1$ (correction F factor) and $x = 0.5$ (Jensen and Fratini's adjusted F factor), as given in Table 1.

The deviations in percentage showed in Table 1 reflects the magnitude of the error involved in the friction loss calculation when the factor is computed either by Christiansen's or Jensen and Fratini's procedures. Because of the given x value ($x = 2/3$) is closer to 0.5, the smaller deviations than when $x = 1$ were expected. Discrepancies as those given in Table 1 may not be negligible for a pipeline with less than about ten outlets.

Application

A numerical example will illustrate the application of the adjusted F factor proposed herein.

Example

Calculate the friction loss in a sprinkle lateral line with a discharge of 0.010 m^3/s (0.353 cfs), an actual inside diameter of 0.076 m (3 in.), and a length of 102 m (334.6 ft). The first upstream sprinkler is 12 m (39.4 ft) from the main line, and there are six operating sprinklers on the lateral spaced every 18 m (59.1 ft). The design value for the size of surface imperfections of the inside pipe wall is 0.00015 m.

Solution

The Darcy-Weisbach formula will be employed for computing the friction loss hf of a similar pipe transmitting the entire flow over its length

$$hf = f\frac{L}{D}\frac{v^2}{2g} = 0.0826 fL\frac{Q^2}{D^5} \qquad (13)$$

where hf = friction loss, m, of a similar pipe transmitting the entire flow over its length; f = friction factor; L = pipe length, m; v = average flow velocity, m; D = inside pipe diameter, m; g = gravitational constant, 9.80665 m/s^2; and Q = pipeline discharge, m^3/s.

The friction factor f is determined as a function of the Reynolds number R_e, and the relative roughness of the pipe (the ratio of the size of the surface imperfections ε to the inside diameter of the pipe (D) which are given by

$$R_e = 1.27 \times 10^6 \times \frac{Q}{D} = 1.27 \times 10^6 \times \frac{0.01}{0.076} = 1.67 \times 10^5 \quad (14a)$$

$$\frac{\varepsilon}{D} = \frac{0.00015}{0.076} = 0.00197 \quad (14b)$$

The friction factor f given in the Moody's diagram is thus 0.024. In order to calculate the friction loss in the lateral, the adjusted F factor should be determined. The first step is to compute the correction factor F (Eq. 10). The m and n values in Darcy-Weisbach formula are 2 and 1, respectively.

$$F = \frac{1}{2+1} + \frac{1}{2 \times 6} + \frac{2}{12 \times 6^2} = 0.421 \quad (15)$$

The value of x in this example is 0.667, and the pertinent adjusted F factor (Eq. 12) is thus

$$F_a = \frac{6 \times 0.421 + 0.667 - 1}{6 + 0.667 - 1} = 0.387 \quad (16)$$

Finally, the friction loss Hf in the sprinkle lateral is determined

$$Hf = 0.0826 fL \frac{Q^2}{D^5} F_a = 0.0826 \times 0.024$$

$$\times 102 \times \frac{0.01^2}{0.076^5} \times 0.387 = 3.1 \text{ m} \quad (17)$$

It should be noted that the value of the correction factor F in this numerical example is 8.8% greater than that given by the proposed F_a factor. On the other hand, Jensen and Fratini's adjusted F factor is 4.8% smaller. From these results, it is concluded that the pertinent errors in the friction-loss calculations have the same magnitudes and can not be considered negligibles.

Appendix I. References

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Appendix II. Notation

The following symbols are used in this paper:

C = units coefficient;
D = inside diameter of pipe;
F = correction factor for multiple outlet pipes where first upstream outlet is one outlet spacing away from pipe inlet;
F_a = correction factor for multiple outlet pipes where first upstream outlet is at any distance away from pipe inlet;
f = friction factor in Darcy-Weisbach formula;
g = gravitational constant, 9.80665 m/s^2 (32.174 ft/sec^2);
Hf = friction loss of multiple outlet pipe;
hf = friction loss of pipe transmitting entire flow over its length;
K = friction factor based on friction loss formula used;
L = total length of multiple outlet pipe;
l = regular outlet spacing;
m = exponent on velocity in friction loss formula used;
N = total number of outlets along pipe length;
n = exponent on inside pipe diameter in friction-loss formula used;
Q = total pipe discharge;
q = outlet discharge;
R_e = Reynolds number;
v = average velocity of pipe flow;
x = ratio of distance of the upstream outlet from pipe inlet to regular outlet spacing; and
ε = size of surface imperfections of inside wall of pipe.

Subscripts

k = index for successive outlet sections of pipe length starting at distal section (k = 1) and increasing to N at upstream section.