COMPLEX FLOW SYSTEMS (GAS)

The equations for steady state flow are based on a single line. We can combine the concepts of driving and resisting forces shown in Chapter 10 with these equations to produce relationships that are convenient for loop lines and gathering lines.

All examples which follow are based on Weymouth's equation. However, Table 12.2 also summarizes the equations developed for the Panhandle and Clinedinst equations.

Parallel lines are used for many applications. In water crossings a group of lines might be used so that failure of any one will not shut-down the system. A common application discussed herein is the loop line, a means to increase gas flow rate for a given pressure drop by paralleling part, or all, of the original line.

Figure 12.5A illustrates a simple loop system where original line A has been partially looped with line B. The purpose of line B is to decrease the pressure drop between P_1 and P_A per unit quantity of gas flowing, so that the reduction will compensate for the increased pressure drop from P_A to P_2, when the flow rate is increased, or the pressure is lowered.

QUANTITY	WEYMOUTH	CLINEDINST	PANHANDLE
		LINES IN SERIES	
EQUIVALENT DIAMETER	$D_1 = D_2 \left(\frac{L_1}{L_2}\right)^{3/16}$	$D_1 = D_2 \left(\frac{L_1}{L_2}\right)^{1/5}$	$D_1 = D_2 \left(\frac{L_1}{L_2}\right)^{0.2060}$
EQUIVALENT LENGTH	$L_1 = L_2 \left(\frac{D_1}{D_2}\right)^{16/3}$	$L_1 = L_2 \left(\frac{D_1}{D_2}\right)^{5}$	$L_1 = L_2 \left(\frac{D_1}{D_2}\right)^{4.854}$
		LINES IN PARALLEL	
EQUIVALENT DIAMETER	$\frac{D_o^{8/3}}{L_o^{1/2}} = \frac{D_1^{8/3}}{L_1^{1/2}} + \frac{D_2^{8/3}}{L_2^{1/2}}$	$\left(\frac{D_o^5}{L_o}\right)^{1/2} = \left(\frac{D_1^5}{L_1}\right)^{1/2} + \left(\frac{D_2^5}{L_2}\right)^{1/2}$	$\frac{D_o^{2.618}}{L_o^{0.5394}} = \frac{D_1^{2.618}}{L_1^{0.5394}} + \frac{D_2^{2.618}}{L_2^{0.5394}}$
LOOPING REQUIREMENTS*	$x = \frac{1-\left(\frac{Q}{Q_1}\right)^2}{1-\left[\frac{D^{8/3}}{D^{8/3}+D_1^{8/3}}\right]^2}$	$x = \frac{1-\left(\frac{Q}{Q_1}\right)^2}{1-\left[\frac{D^{5/2}}{D^{5/2}+D_1^{5/2}}\right]^2}$	
ENTIRE LINE LOOPED*	$\frac{Q_1}{Q} = \left[1+\left(\frac{D_1}{D}\right)^{8/3}\right]$	$\frac{Q_1}{Q} = \left[1+\left(\frac{D_1}{D}\right)^{5/2}\right]$	
DIAMETER OF ORIGINAL AND PARALLEL LINES THE SAME *	$x = 4/3\left[1-\left(\frac{Q}{Q_1}\right)^2\right]$	$x = 4/3\left[1-\left(\frac{Q}{Q_1}\right)^2\right]$	

*ASSUMES THAT THE LENGTH OF ALL LINES IN THE LOOP SECTION ARE THE SAME LENGTH

Table 12.2 Comparison of Complex Flow Formulas.
(Ref. 12.1. Courtesy Oil Gas J.)

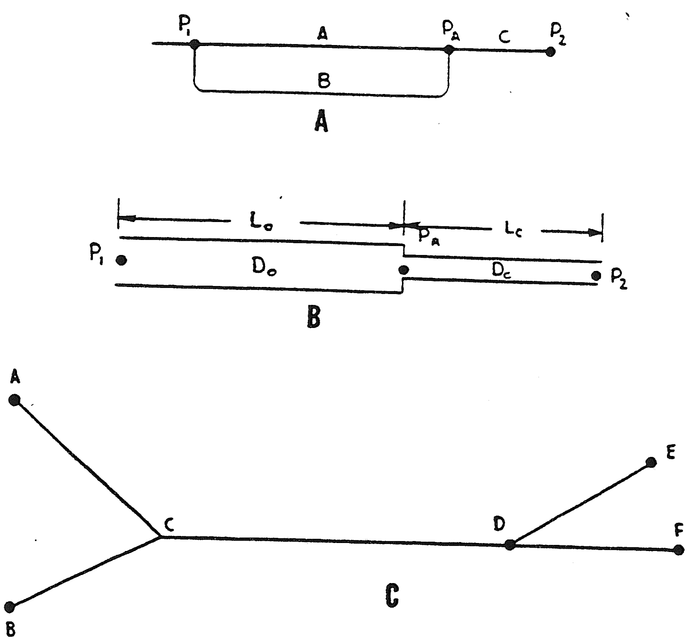


Figure 12.5 Schematic View of Pipe System For Example Problem.
(Ref. 12.1)(Courtesy Oil Gas J.)

Using the same principles as those applied to liquid flow, it is apparent that

$$Q_A + Q_B = Q_C = Q \text{ Total} \quad (12.58)$$

$$\Delta P_A = \Delta P_B \text{ (since they have two points in common)} \quad (12.59)$$

$$\Delta P_A \text{ (or } \Delta P_B) + \Delta P_C = \Delta P \text{ Total} \quad (12.60)$$

Now Weymouth's equation may be written as

$$Q = A(T_S/P_S)[(P_1^2 - P_2^2)/LGTZ_a]^{1/2} D^{8/3} \quad (12.61)$$

and may be applied for any single line between any two points between which no work is added or withdrawn.

Inasmuch as the same gas is flowing through both lines, Equation 12.61 may be written

$$Q = K(D^{16/3}/L)^{1/2} \quad (12.62)$$

where K encompasses all of the terms that are constant among the loop lines.

Equivalent of Loop. The flow characteristics of loop lines A and B may be expressed in terms of an equivalent single line of diameter D_o and L_o. This equivalent line is defined as a single line that has the same capacity as the loop system when the same pressure drop is imposed. If Equation 12.62 is written for each line and substituted into Equation 12.58, the K terms cancel and:

$$\frac{D_o^{8/3}}{L_o^{1/2}} = \frac{D_A^{8/3}}{L_A^{1/2}} + \frac{D_B^{8/3}}{L_B^{1/2}} \qquad (12.63)$$

If the lines are of the same length, the denominators cancel. The loop system in Figure 12.5A then reduces to the system shown in Figure 12.5B. With reference to the latter figure,

$$Q_o = Q_C \text{ and } (\Delta P/L)_o(L_o) + (\Delta P/L)_c(L_c) = \text{Total } \Delta P \qquad (12.64)$$

This system could be solved, in the absence of knowing the pressure at P_A, by writing an equation for each section, equating them, and solving for P_A. With this value either of the equations may then be solved for the unknown quantity.

Equivalent of Series. However, it is more convenient to express this system in terms of a single line that is equivalent to the two lines in series. This is done by finding what length of line D_o would be equivalent to L_c length of diameter D_c, or vice versa. In this case, equivalent means that both lines would have the same capacity with the same pressure drop. In general terms this may be found by writing Equation 12.62 for each line and substituting them into Equation 12.64. Then:

$$(D_1^{16/3}/L_1)^{1/2} = (D_2^{16/3}/L_2)^{1/2} \qquad (12.65)$$

and squaring both sides:

$$L_1 = L_2(D_1/D_2)^{16/3}, \quad \text{or} \quad D_1 = D_2(L_1/L_2)^{3/16} \qquad (12.66)$$

where L_1 = length of line of diameter D_1 that is equivalent to a line of diameter D_2 and length L_2.

Example: If in Figure 12.5B, D_o = 15 cm, L_o = 10 km, D_c = 20 cm and L_c = 20 km, determine the proper length and diameter of a single line that would be equivalent to the system shown.

Solution 1: $L_D = 20(15/20)^{16/3} = 4.3$ km

Total length = 10 + 4.3 = 14.3 km of 15 cm pipe

Solution 2: $L_1 = 10(20/15)^{16/3} = 46.2$ km

Total length = 20 + 46.2 = 66.2 km

This solution says 14.3 km of 15 cm pipe or 66.2 km of 20 cm pipe represents a single-line system that is equivalent to that shown in Figure 12.5B. Consequently, the substitution of either combination of values into Equation 12.61 yields a solution for the loop system.

The solution of the branch line system shown in Figure 12.5C must be basically solved by remembering that

$$Q_{BC} + Q_{AC} = Q_{CD} = Q_{DE} + Q_{DF} \qquad (12.67)$$

It is usually necessary to substitute the appropriate flow equation into this expression and solve for the unknown quantity.

Nomenclature

For lines in series:

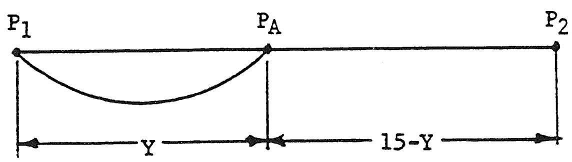
D_1 = diameter of line of length L_1 that is equivalent to a line of length L_2 and diameter D_2.
L_1 = length of line of diameter D_1 that is equivalent to a line of length L_2 and diameter D_2.

For lines in parallel:

D_o = diameter of a single line that is equivalent to a group of parallel lines
D = diameter of the original line before looping
D_1 = diameter of a single loop line (or equivalent diameter of a group of loop lines)
D_2 = diameter of a second loop line in parallel with line D_1.
L_o = length of equivalent single line corresponding to D_o
L_1 = length of loop line D_1
L_2 = length of loop line D_2
Q = original flow rate before line is looped
Q_1 = flow rate after looping line
X = fraction of length of original line that is looped

The following examples will serve to illustrate the application of the gas flow equations. For simplicity, the Weymouth equation, uncorrected for gas compressibility, will be used as an illustration of the principles involved.

Example 1:



A portion of a large gas-gathering system consists of a 15.41 cm [6.067 in.] line 15 km [9.4 miles] that is handling 206 x 10^3 std m^3 [7.6 x 10^6 std ft^3] with an average Rel. ρ of .64. The pressure at the upstream end of this section is 2.58 MPa gauge [375 psig] and the average delivery pressure is 2.07 MPa gauge [300 psig]. The average temperature is 23°C [73°F].

Due to new well completion, it is desired to increase the capacity of this line 20% by looping with additional 15 cm line. What length is required?

Let Y represent the length of the loop section

Metric Solution

New flow rate $Q_1 = 1.2(206 \times 10^3) = 247.2 \times 10^3$ std m^3

The loop may be represented by a single line D_o.

$$D_o = [(15.41)^{8/3} + (15.41)^{8/3}]^{3/8} = 19.98 \text{ cm}$$

A Weymouth equation for each section may now be written.

$$247.2 \times 10^3 = 1740(273/100)\left[\frac{2.68^2 - P_A{}^2}{Y(.64)(296)}\right]^{1/2}(19.98)^{8/3}$$

$$247.2 \times 10^3 = 1740(273/100)\left[\frac{P_A - 2.17^2}{(15-Y)(.64)(296)}\right]^{1/2}(15.41)^{8/3}$$

(Note: 0.1 MPa has been added to each gauge pressure.) Since there are two equations and two unknowns these equations may be solved algebraically.

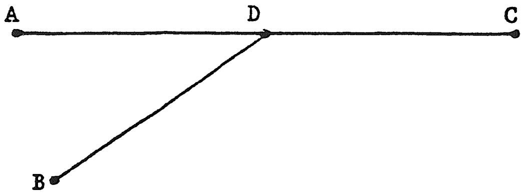
For this example Y = <u>5.96km</u>

Using the equation shown in Table 12.2 for looping requirements represents an easier solution method.

$$X = \frac{1 - (206/247.2)^2}{1 - \left[\frac{(15.41)^{8/3}}{(15.41)^{8/3} + (15.41)^{8/3}}\right]^2} = .407$$

or .407 (15 km) = <u>6.1 km</u>

Example 2:



The system at left is to be designed for the gathering of gas. Well "A" is a flowing gas well that will deliver 81.33×10^3 m^3 [3×10^6 ft^3]. Lease "B" contains high gas-oil ratio oil wells. It is necessary to determine what compressor discharge pressure is necessary in order to deliver 47.44×10^3 m^3 [1.75×10^6 ft^3] from pt. B. The pressure at the transmission line (pt. C) is 2.07 MPa gauge [300 psig]. Average flowing temp. will be 29°C [85°F]. The gravity of the flowing gas is 0.63 and that of the casing head gas is 0.71. The line diameters shown have been arbitrarily fixed because of pipe availability.

It is obvious that once the pressure at point D is found, P_B may be found; furthermore, the avg. sp. gr. in line CD is estimated:

$$\frac{81.33(.63) + 47.44(.71)}{128.77} = 0.66$$

line CD $$128.77 \times 10^3 = 1740(273/100)\left[\frac{P_D^2 - 2.17^2}{(16.1)(.66)(302)}\right]^{1/2}(15.41)^{8/3}$$

$$P_D = 2.4 \text{ MPa}$$

line BD $$47.44 \times 10^3 = 1740(273/100)\left[\frac{P_B^2 - 2.4^2}{(4.83)(.71)(302)}\right]^{1/2}(10.24)^{8/3}$$

$$P_B = \underline{2.49 \text{ MPa}}$$