DESIGN PROCEDURES FOR CHEMETRON HALON 1301 FIRE SUPPRESSION SYSTEMS

APPENDIX A
TWO-PHASE HYDRAULICS

A-1.1 HISTORICAL. The two-phase flow equation, which is used for calculating pressure drop in Halon-1301 and Carbon Dioxide fire extinguishing systems, is a statement of the basic laws of energy conservation. The equation is in a form particularly suited to calculating flow in systems where the density of the flowing media is constantly changing. Dr. James Hesson is credited with developing the two-phase flow equation. H.V. Williamson pioneered use of the equation for calculating pressure drop in Halon-1301 systems.

A-1.2 TWO-PHASE FLOW EQUATION. The two-phase flow equation can be derived from the fundamental equation of hydrodynamics known as Bernoulli's equation. The following is a qualitative statement of the flow equation:

$$\Delta \text{ pressure head} + \Delta \text{ velocity head} + \Delta \text{friction head} + \Delta \text{elevation head} = 0 \qquad (1)$$

Normally, the change in elevation head is zero and thus, it can be dropped from the above equation. When a change in elevation is present in a system the resultant loss or gain in pressure can be calculated separately from the basic two-phase low equation. The basic flow equation is as follows:

$$K_1 \frac{Q^2 f}{D^5} dL + \frac{\rho \, dP}{144} - K_2 \frac{Q^2 d\rho}{D^4 \rho} = 0 \qquad (2)$$

where:
$K_1 = 96/\pi^2 g$
$K_2 = 17.6/\pi^2 g$
Q = flow rate in lbs./sec.
D = internal diameter of pipe in inches
L = equivalent length in feet
ρ = agent density in lbs./cu.ft.
P = pressure in PSIA
f = the friction factor for the pipe

A-1.3 Y and Z FACTORS. Equation (2) is stated in differential form. If we integrate, rearrange terms and explicitly state the constants, the following equation is the result:

$$Q^2 = \frac{YD^5}{7.97DZ + 43.5fL} \qquad (3)$$

where the factors Y and Z are defined as follows:

$$Y = -\int_{P_O}^{P_f} \rho \, dP \qquad (4)$$

$$Z = -\int_{\rho_O}^{\rho_f} \frac{d\rho}{\rho} \qquad (5)$$

where:
P_O is the pressure at the start of pipe section L
P_f is the pressure at the end of pipe section L
ρ_O is the density at the start of pipe section L
ρ_f is the density at the end of pipe section L.

A-2 FRICTION FACTORS. The two-phase flow equation contained in the NFPA Standards 12 and 12A is equation (3) with the friction factor for commercial grade black steel pipe implicitly contained. Figure A-1 is a plot of friction factor versus pipe I.D. for galvanized pipe, black steel pipe and drawn tubing. It should be noted that the friction factors given are based on the assumption that completely turbulent flow is present in the pipeline. Thus, for accurate pressure drop calculation, it is necessary that the flow densities be great enough to produce a completely turbulent state. The following three equations give a reasonably good fit to the friction factor data for galvanized, black and drawn pipe:

Galvanized Steel Pipe	$f = .032/D^{.35}$	(6)
Black Steel Pipe	$f = .0227/D^{.25}$	(7)
Drawn Tubing	$f = .011/D^{.177}$	(8)

A-3 PRESSURE-DENSITY. It should be apparent that a proper relationship between the pipeline pressure and density need be established in order to use the two-phase flow equation. If one can assume that the heat pick-up from the pipeline is negligible during the agent discharge, a pressure-density relationship can be established rather easily from the basic thermodynamic properties of the agent. In the case of Carbon Dioxide, the calculation is very straight forward. The calculation of the pipeline pressure-density relationship for nitrogen super-pressurized Halon-1301 is a bit more complicated due to the fact that the nitrogen does dissolve in the Halon. Given the pressure-density relationship, however, tables of Y and Z factors can be constructed. The tables of Y and Z factors contained in NFPA 12A can be used with the two-phase flow equation to calculate pipeline pressure drop. It should be noted, however, that in some cases pressure drops calculated manually will disagree with those calculated by means of the CHEMETRON FIRE SYSTEMS computer program. This is due to the fact that the computer program does take into account density changes at tee junctions which alter the pipeline pressure-density relationship.

A-4 VELOCITY HEAD. Although the flow equation contains a term which accounts for changes in velocity head due to changing density, it will not compensate for velocity head changes which are encountered when the flow density (lbs./sec./sq.in. of pipe area) changes. Such velocity head changes are encountered when there is a change in pipe size or a change in flow rate due to a junction in the pipeline. The following expression gives the velocity head energy in PSI:

$$\text{Velocity head (PSI)} = 3.63\,Q^2/\rho D^4 \qquad (9)$$

A-5.1 MAXIMUM FLOW RATES. In paragraph A-1.2 we saw that the flow equation is a statement of balance between pressure, velocity and friction head. At the end of a pipeline no more equivalent length need be overcome and ideally the friction head term in equations (1) and (2) should become equal to zero. Therefore, the condition at the end of

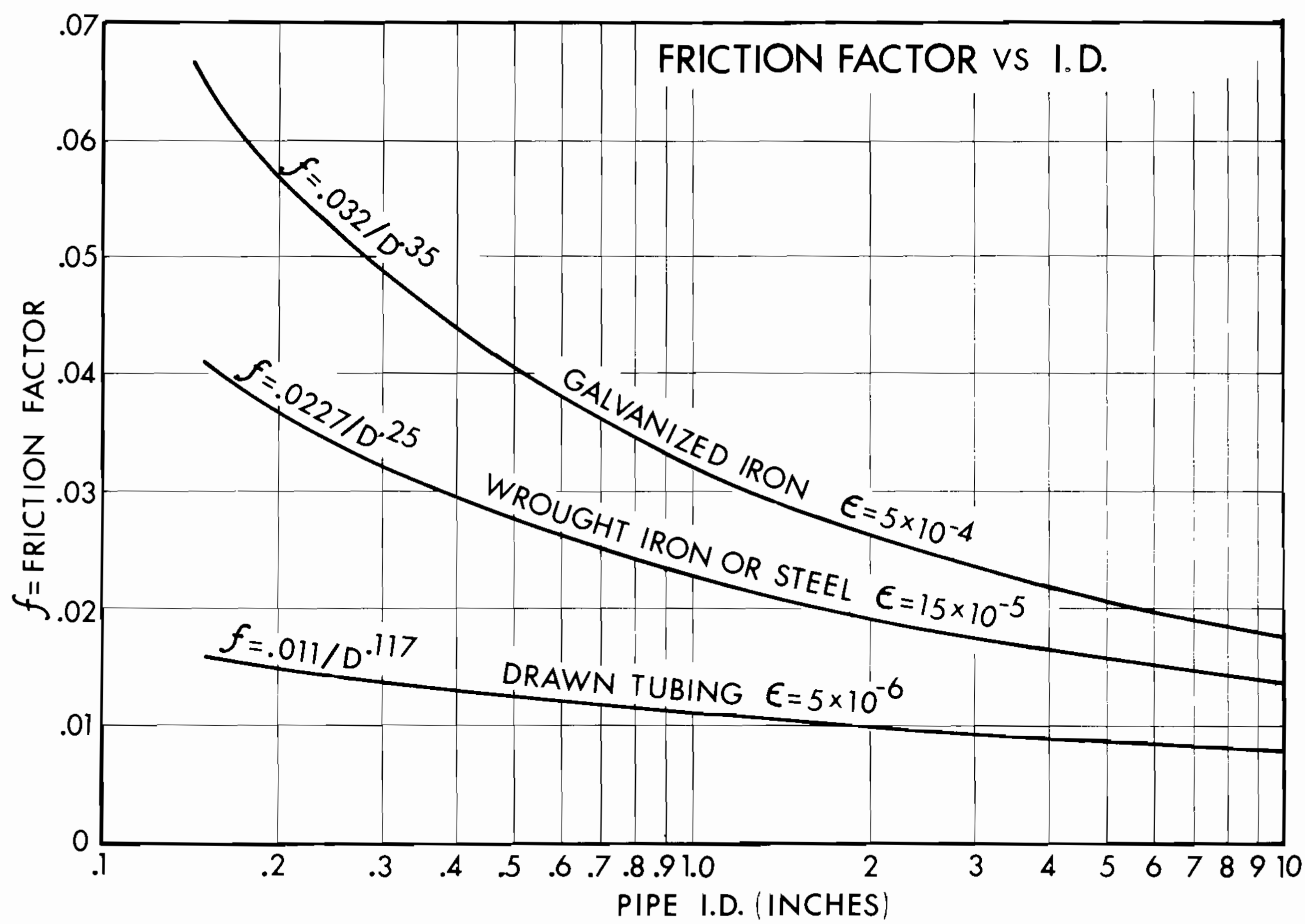

Figure A-1. Plot of friction factor versus pipe I.D. for galvanized pipe, black steel pipe and drawn tubing.

the pipeline is one in which any change in pressure head is converted to velocity head. The maximum flow rate at the end of a pipeline under a given set of pressure-density conditions can be calculated by setting the velocity head term equal to the pressure head term in equation (1) or (2) and solving for the flow rate. The calculated maximum pipeline specific flow rates plotted in Figure 2-8 of this manual are based on such consideration. The densities used for this calculation correspond to the average pipeline densities with a factor added to compensate for velocity affects.

A-5.2 ORIFICE FLOW RATE. The subject of orifice flow has been the topic of many books, papers and dissertations. Although the orifice is an extremely important part of many systems, it is one of the least understood system components. Until recently orifices used in two-phase systems were rated by means of testing with water for equivalent area. As the science of predicting the flow of two-phase media in pipelines became more advanced, the rating of orifices with water for Halon-1301 systems was found to have major shortcomings. The method of coding orifices of Halon-1301 systems described in Chapter II is intended to replace the traditional water rating of nozzles. Simply stated, the basis for this method is the postulate that any orifice or nozzle which is placed at the end of a pipe will necessarily restrict the flow rate to a rate less than that which would issue from the pipe if the orifice or nozzle were not present. Nozzles are coded in terms of the fraction, in percent, of the theoretical maximum open-end pipeline flow rate which they permit. Thus, the flow rate from a nozzle can be predicted from the following equation:

$$Q_{Nozzle} = \frac{Code}{100} \times Area_{Pipe} \times R_{PSI} \qquad (10)$$

where:

Q_{Nozzle} = flow rate with the nozzle in place in lbs/sec.

Code = nozzle code in percent

A_{Pipe} = the area of the feedpipe in sq.in.

R_{PSI} = the theoretical maximum pipeline specific flow rate in lbs./sec./sq.in. for the calculated pressure-density condition at the total terminal pressure (PSI). The total terminal pressure (PSI) is the sum of the static pressure from equation (2) and the velocity head pressure calculated from equation (9).

The total terminal pressure must be used since it is the measure of energy available to drive the flowing media from the orifice(s).