The two-K method used in the program is accurate for either low or high Reynolds number. This method is more favorable than the conventional one-K method.

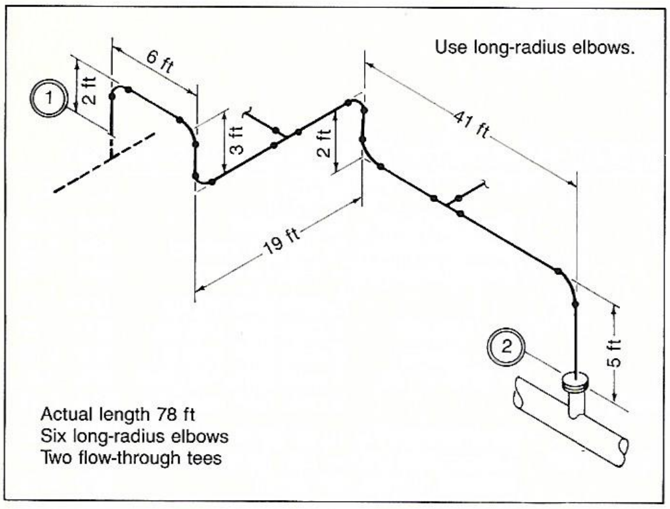

Fig. 1—Example piping isometric.

one-K technique. Most published K values apply to fully developed turbulent flow as K is found to be independent of N_{Re} where N_{Re} is sufficiently high. However, the two-K method has a correction factor for different fittings. Hooper[7] has given a detailed analysis of his method compared to others[5,9,10] and has shown that his method is suitable for any size of pipe.

The two-K method is in general independent of the roughness of the fitting, but it is a function of Reynolds number and of the exact geometry of the fitting. The method can be expressed as:

$$K = K_1/N_{Re} + K_\infty\ (1 + 1/ID) \quad (3)$$

where K_1 = K for the fitting at $N_{Re} = 1$

K_∞ = K for a larger fitting at $N_{Re} = \infty$

ID = Internal diameter of attached pipe, inch.

Table 1 lists values of K_1 and K_∞ for the two-K method.

Friction factor. The estimation of friction factor for calculating pressure losses for single phase fluids through a pipe has been mainly through the Moody[11] chart, which is made up of the following equations:

For laminar flow with $N_{Re} < 2{,}100$, the Hagen-Poiseuille equation gives:

$$f_D = 64/N_{Re} \quad (4)$$

TABLE 2—Values of absolute pipe roughness

	ϵ, ft
Riveted steel	0.003 to 0.03
Concrete	0.001 to 0.01
Wood stave	0.0006 to 0.00
Cast iron	0.00085
Galvanized iron	0.0005
Asphalted cast iron	0.0004
Commercial steel or wrought iron	0.00015
Drawn tubing	0.000005

where f_D is the Darcy friction factor which is four times the Fanning friction factor, f_F, i.e. $f_D = 4\,f_F$

N_{Re} is the Reynolds number = $Dv\rho/\mu$

For fully developed turbulent flow regions in smooth and rough pipes, the Colebrook (6) equation is universally adopted and can be expressed as:

$$1/f_D^{1/2} = -\ 0.8686\ \ln\ (\epsilon/3.7D + 2.51/N_{Re}f_D^{1/2}) \quad (5)$$

However, this equation is implicit in f_D, as it can not be rearranged to derive f directly and thus requires an iterative solution. Several explicit equations[12,13] have been developed as alternatives to the Colebrook's which yield results of sufficient accuracy for most engineering problems. A detailed review of these explicit equations is given by Gregory and Fogarsi[14]. Different piping materials are often used in the chemical process industries, and at a high Reynolds number, the friction factor is affected by the roughness of the surface. This is measured as the ratio ϵ/D of projections on the surface to the diameter of the pipe. Glass and plastic pipe essentially have $\epsilon = 0$. In this program commercial steel (wrought iron) with $\epsilon = 0.00015$ ft is used. Values of ϵ are shown in Table 2.

Numerical technique. The Colebrook equation for friction factor, f_D, involves a trial and error procedure and thus requires the use of a numerical method.

The Newton-Raphson method is applied in the program with convergence to ± 0.0001. This requires differentiating the objective function. The Newton-Raphson method is of the form:

$$X_{j+1} = X_j - F\,(X_j)/F'\,(X_j) \quad (6)$$

where $j = 1,2,3 \ldots jmax$.

X_j is the guessed root of the equation given by $F\,(X) = 0$. $F\,(X_j)$ is the objective function. $F'\,(X_j)$ is the value of the differential of the objective function. The j is the iterative counter and $j$max is the maximum iteration.

The derivative of the objective function given by equation 5 is given as equation 7.

$$F\,(f) = -\ 0.5/f^{1.5} - 4.033/(N_{Re}\,f^{1.5}\ \epsilon/D + 9.287f) \quad (7)$$

The first guess, i.e. the first iteration in Newton-Raphson's method must be carefully selected as sometimes the root does not converge even after many iterations. The Newton-Raphson method has been found to converge quadratically. In the present program, a default value of 0.01 for the first iteration of f_D is chosen. The value has been found to converge to yield an actual value (root of the equation) of the friction factor after few iterations in various problems.

Equivalent length. The equivalent pipe length concept is the most convenient method for calculating the overall pressure loss in a pipe. The method adds some hypothetical length of pipe to the actual length of the fitting, giving an equivalent length of pipe that has the same total loss as the fitting. However, the drawback to this approach is that the equivalent length for a given fitting is not constant, but de-