Prediction of Optimum Economic Pipe Diameter by Nomograph

Dr G K Roy, *Fellow*

Appropriate sizing of process piping systems based on economic consideration is an essential requirement in almost every type of the fluid processing unit. In addition to the fluid transport properties the two cost factors viz, the cost of piping (fixed cost) and the cost of pumping (running cost) are to be taken into account for the prediction of optimum economic pipe diameter. Available correlations and nomographs in this context have used a constant cost factor, which restricts their use for years to come. An attempt has, therefore, been made in this communication to predict the optimum economic pipe diameter for the viscous and the turbulent flow regimes with the help of nomograph prepared on the basis of modified equations, incorporating the cost factor. Values of economic pipe diameter obtained from the nomograph have been found to compare fairly well with the respective values calculated by the developed equations.

The investment for piping and pipe fittings amounts to 10 to 15% of the total investment in case of most of the chemical plants. It is, therefore, imperative to make a judicious choice as regards pipe sizes which gives close to a minimum total cost for pumping and fixed charges. Flow conditions being set, an increase in pipe diameter results in an increase of the fixed charges for the piping system and a decrease in the pumping or blowing charges, which implies that an optimum economic pipe diameter must exist.

Based on the principles of fluid dynamics and the economic data for the cost of power and pipe material the following equations have been developed for the prediction of optimum economic pipe diameter for flow in steel pipes[1]. In case of viscous flow,

For $D < 1''$

$$(D_i)_{opt} = 3.6 \, q_f^{0.36} \, \mu_f^{0.18} \tag{1}$$

For $D \geqslant 1''$

$$(D_i)_{opt} = 3.0 \, q_f^{0.36} \, \mu_f^{0.18} \tag{2}$$

In case of turbulent flow,

For $D < 1''$

$$(D_i)_{opt} = 4.7 \, q_f^{0.45} \, \rho_f^{0.13} \tag{3}$$

For $D \geqslant 1''$

$$(D_i)_{opt} = 3.9 \, q_f^{0.45} \, \rho_f^{0.13} \tag{4}$$

where,

$(D_i)_{opt}$ = optimum inside diameter of pipe, inch

q_f = fluid flow rate, ft³/sec

ρ_f = fluid density, lb/ft³

μ_f = fluid viscosity, centipoise

Keeping in view the usage pattern of steel pipes in industry (in most cases $D \geqslant 1$ inch is used) and the closeness of the numerical values of the equations, (2) and (4) have been used for the preparation of a nomograph for a quick estimation of optimum economic pipe diameter[2].

In the derivation of the above equations, the cost factor (*ie*, the ratio of the power cost to the cost of pipe material) has been taken to be constant. In view of its universal acceptability for years to come the cost factor has been introduced and the above equations have been rewritten in a more conventional form and acceptable units as under. For viscous flow condition,

$$(D_i)_{opt} = 0.0257 \, q_f^{0.36} \, \mu_f^{0.18} \left(\frac{K}{X} \right)^{0.18} \tag{5}$$

Dr G K Roy is with Department of Chemical Engineering, Regional Engineering College, Rourkela.

For turbulent flow condition

$$(D_i)_{opt} = 0.0144 \; q_f^{0.45} \; \rho_f^{0.13} \left(\frac{K}{X}\right)^{0.16} \qquad (6)$$

where,

$(D_i)_{opt}$ = optimum inside pipe diameter, m

q_f = fluid flow rate, m³/h

μ_f = fluid viscosity, centipoise

ρ_f = fluid density, kg/m³

K = cost of electricity per kWh

X = purchase cost of new pipe per metre of pipe length if pipe diameter is 0.0254 m(= 1″)

[K and X values are to be in the same unit, eg, Rs, $, £, etc]

Figs 1 and 2 are the nomographs prepared on the basis of equations (5) and (6), respectively for a rapid estimation of economic pipe diameter for the complete flow regime of fluids.

RANGE OF APPLICABILITY OF THE NOMOGRAPH

The range of applicability of the nomographs is presented in Table 1.

The ranges of variables cover the normal operating ranges for industrial piping systems.

ACCURACY OF NOMOGRAPHS

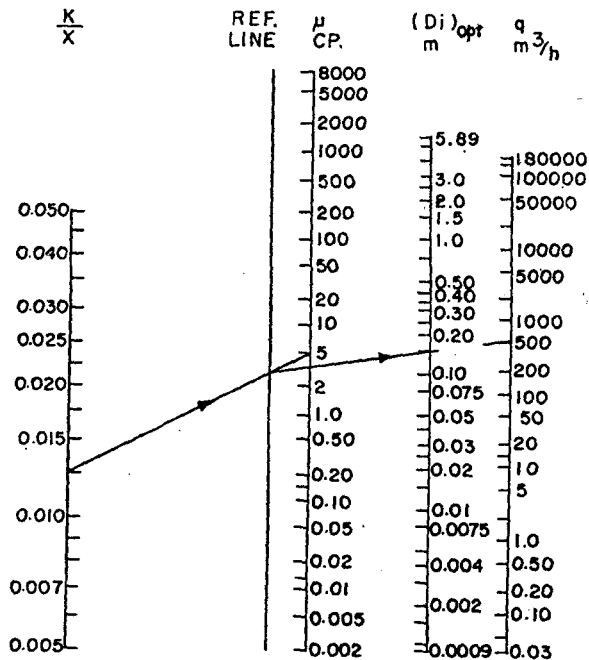The values of optimum economic pipe diameter obtained from the nomographs have been found to agree
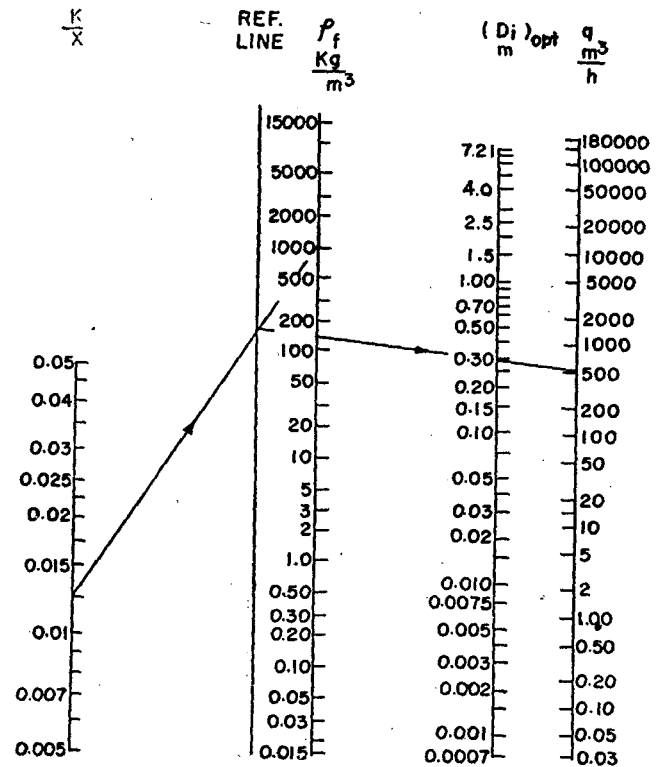
Fig 2 Prediction of optimum pipe diameter (Turbulent Flow)

TABLE 1 RANGE OF APPLICABILITY OF NOMOGRAPHS

FIGURE/ NOMOGRAPH	VARIABLES	UNIT	RANGE OF APPLICABILITY
	q_f	m³/h	0.03-180 000
	μ_f	centipoise	0.002-8 000
	K/X	m/kWh	0.005-0.05
2	q_f	m³/h	0.03-180 000
	ρ_f	kg/m³	0.015-15 000
	μ_f	centipoise	0.02-20
	K/X	m/kWh	0.005-0.05

well with their respective values obtained from the equations (5) and (6).

Example :

q_f = 500 m³/h

ρ_f = 1000 kg/m³

μ_f = 5 centipoise

K = Rs 0.25/kWh (≈ 0.02/kWh)

X = Rs 20/metre (≈ 1.6/metre)

($ 1.0 ≈ Rs 12.5)

The optimum economic pipe diameter for the above case for both the viscous and the turbulent flow conditions can be calculated and compared in the following manner.

Fig 1 Prediction of optimum pipe diameter (Viscous Flow)

Solution :

(a) Viscous flow condition:

From equation (5)

$$(D_i)_{opt} = 0.0257 \ (500)^{0.36} \ (5)^{0.18} \left(\frac{0.25}{20}\right)^{0.18}$$

$$= 0.146 \text{ m}$$

From nomograph (Fig 1),

$$(D_i)_{opt} = 0.150 \text{ m}$$

Percentage deviation of nomograph value from the calculated ones,

$$= \frac{0.150 - 0.146}{0.146} \times 100 = 2.74$$

(b) Turbulent flow condition:

From equation (6),

$$(D_i)_{opt} = 0.0144 \ (500)^{0.45} \ (1000)^{0.13} \left(\frac{0.25}{20}\right)^{0.16}$$

$$= 0.287 \text{ m}$$

From nomograph (Fig 2),

$$(D_i)_{opt} = 0.300 \text{ m}$$

Percentage deviation of nomograph value from the calculated one,

$$= \frac{0.300 - 0.287}{0.287} \times 100 = 4.53$$

REFERENCES

1. M S Peters and K D Timmerhaus. 'Plant Design and Economics for Chemical Engineers', McGraw Hill Book Co, 1968, 302.

2. Ibid, Fig 13-2, p 435.