E. Special Considerations for Sewage and Sludge

Sewage and sludge are mechanical mixtures of water and solids. As such, particles in the mixture tend to settle out while the mixture is in motion. The critical velocity of a water-solid mixture is the velocity below which particles start to settle out. As they settle out, the particles form a sliding bed on the pipe bottom which eventually clogs the pipe.

The critical velocity is difficult to predict. For small particles under 50 microns in size, 3 to 7 ft/sec is the minimum range. A rough guide for larger particles (above 150 microns) is the Durand formula:

$$v_{critical} = 14\sqrt{D} \qquad 3.50$$

The actual velocity in digested sludge mains is typically in the 3 to 5 ft/sec range. Sewer mains are generally self-cleaning if a minimum velocity of 2 ft/sec is maintained. 1.5 ft/sec may even be used in sewer mains if the pipe is occasionally flushed out by peak flow.

8. Discharge from Tanks

A. General Discussion

Flow from a tank discharging liquid to the atmosphere through an opening in the tank wall (figure 3.8) is affected by both the area and shape of the opening. Correction factors for both velocity and flow rate are given in Table 3.4.

At the orifice, the total head of the fluid is converted into kinetic energy according to equation 3.51.

$$v_o = C_v\sqrt{2gh} \qquad 3.51$$

C_v is the coefficient of velocity which can be calculated from the coefficients of discharge and contraction.

$$C_v = C_d/C_c \qquad 3.52$$

The discharge is

$$Q_o = (C_cA_o)v_o = C_cA_oC_v\sqrt{2gh} = C_dA_o\sqrt{2gh} \qquad 3.53$$

The head loss due to turbulence at the orifice is

$$h_f = \left(\frac{1}{C_v^2} - 1\right)\frac{v_o^2}{2g} \qquad 3.54$$

Figure 3.8

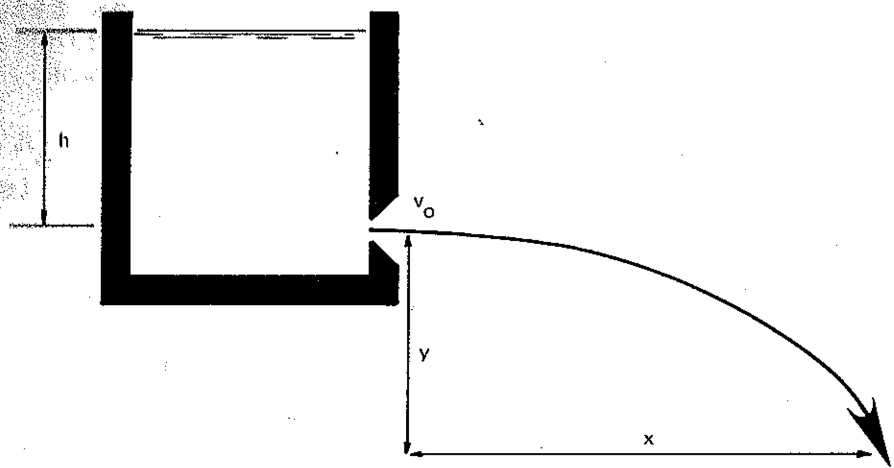


Table 3.4
Orifice Coefficients for Water

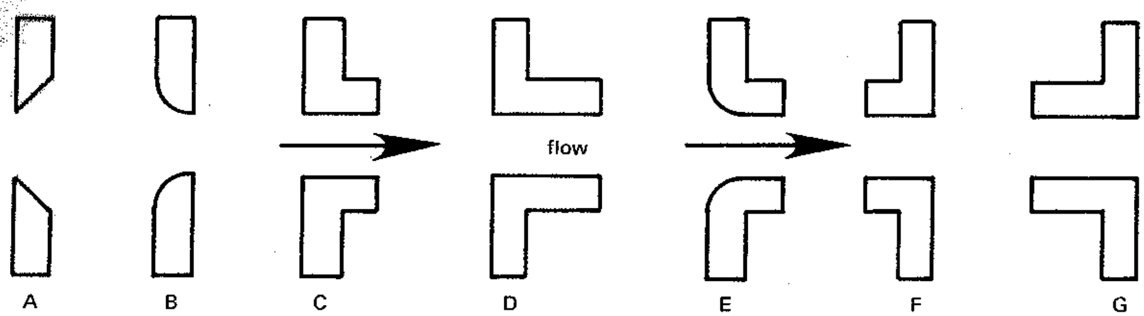


illustration	description	C_d	C_c	C_v
A	sharp-edged	.62	.63	.98
B	round-edged	.98	1.00	.98
C	short tube (fluid separates from walls)	.61	1.00	.61
D	short tube (no separation)	.82	1.00	.82
E	short tube with rounded entrance	.97	.99	.98
F	reentrant tube, length less than one-half of pipe diameter	.54	.55	.99
G	reentrant tube, length 2 to 3 pipe diameters	.72	1.00	.72
not shown	smooth, well-tapered nozzle	.98	.99	.99

The stream coordinates are

$$x = v_o t = v_o\sqrt{2y/g} = 2C_v\sqrt{hy} \qquad 3.55$$

$$y = \frac{gt^2}{2} \qquad 3.56$$

Fluid velocity at a point downstream of the orifice is

$$v_x = v_o \qquad 3.57$$

$$v_y = gt \qquad 3.58$$

B. Time to Empty Tank

If the liquid in a tank is not constantly being replenished, the static head forcing discharge through the orifice will decrease. For a tank with a constant cross-sectional area, the time required to lower the fluid level from level h_1 to h_2 is calculated from equation 3.59.

$$t = \frac{2A_t(\sqrt{h_1} - \sqrt{h_2})}{C_d A_o \sqrt{2g}} \qquad 3.59$$

A_o = ORIFICE

If the tank has a varying cross-section, the following basic relationship holds:

$$Qdt = -A_t dh \qquad 3.60$$

An expression for the tank area, A_t, as a function of h must be determined. Then, the time to empty the tank from height h_1 to h_2 is

$$t = \int_{h_1}^{h_2} \frac{A_t \, dh}{C_d A_o \sqrt{2gh}} \qquad 3.61$$

For a tank being fed at a rate Q_{in}, which is less than the discharge through the orifice, the time to empty expression is

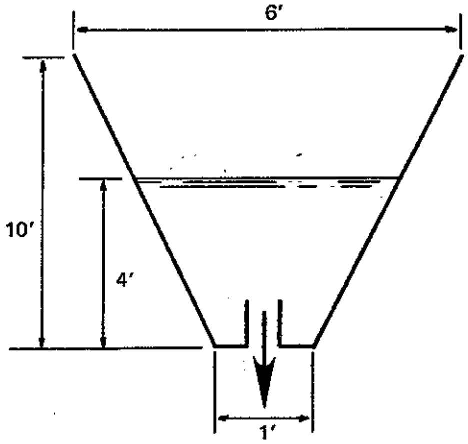
$$t = \int_{h_1}^{h_2} \frac{A_t \, dh}{(C_d A_o \sqrt{2gh}) - Q_{in}}$$

When a tank is being fed at a rate greater than the discharge, the above expression will become positive indicating a rising head. t will then be the time to raise the fluid level from h_1 to h_2.

Example 3.15

A tank constructed as a square-base truncated pyramid is discharging through a 2" re-entrant orifice as illustrated. What is the initial discharge rate? How long will it take to completely drain the tank?

$$A_o = \frac{\pi}{4}\left(\frac{2}{12}\right)^2 = .0218 \text{ ft}^2$$



Using table 3.4 and equation 3.53,

$$Q = .72(.0218)\sqrt{2(32.2)(4)} = .252 \text{ cfs}$$

The expression for A_t in terms of h is

$$A_t = 4\left(\frac{2+h}{4}\right)^2$$

$$t = \int_0^4 \frac{\frac{1}{4}(h^2 + 4h + 4)}{(.72)(.0218)\sqrt{2(32.2)}\ \sqrt{h}}$$

$$= 1.985\left[\tfrac{2}{5}h^{5/2} + \tfrac{8}{3}h^{3/2} + 8h^{.5}\right]_0^4$$

$$= 99.6 \text{ seconds}$$

C. Time to Establish Flow

Consider a tank filled to depth h whose discharge line is controlled by a valve. When this valve is opened, the fluid velocity will increase gradually until it reaches a maximum given by the Bernoulli equation.