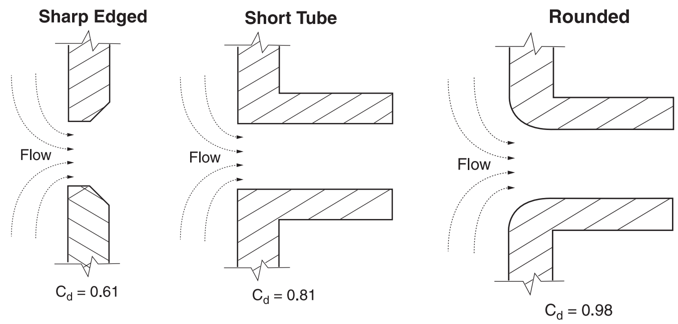
Calculating the Time Required to Empty a Vessel

The following formulas are based on turbulent flow of a Newtonian fluid through an outlet (orifice) in a tank. The discharge coefficient C_d depends on the configuration of the outlet. Some typical values for discharge coefficient are shown at right.

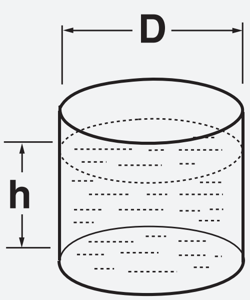
Variables:
- h = elevation of tank
- D = diameter of tank
- A = orifice area (ft^2)
- G = gravitational acceleration = 32.2 ft/sec^2
- Δt = time required to empty tank (sec)



EXAMPLES

EXAMPLE ONE
VERTICAL CYLINDRICAL TANK

$$\Delta t = \frac{\pi D^2}{C_d A}\sqrt{\frac{h}{8G}}$$



A vertical cylindrical tank 12' in diameter is fitted with a 2" Hayward bulkhead fitting (comparable to a short tube outlet). The area of the outlet is:

$$\Delta t = \frac{\pi D^2_{orf}}{4\,(144)} = \frac{\pi\, 2^2}{4\,(144)} = 0.0218 \text{ ft}^2$$

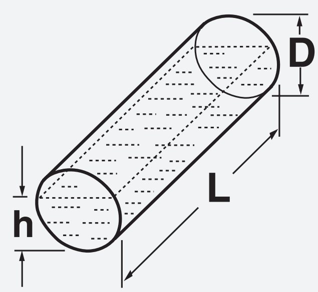
If the tank is filled with water to a height of 20', and we assume turbulent flow, the approximate time to empty the tank is given by:

$$\Delta t = \frac{\pi\, 12^2}{0.81\,(0.0218)}\sqrt{\frac{20}{8\,(32.2)}} = 7{,}139 \text{ sec}$$

The tank should be empty in about 2 hours.

EXAMPLE TWO
HORIZONTAL CYLINDRICAL TANK

$$\Delta t = \frac{L\{D^{3/2} - (D-h)^{3/2}\}}{3\,C_d A}\sqrt{\frac{8}{G}}$$



A 7' diameter by 9' long horizontal cylindrical tank has a 4" diameter sharp edged orifice outlet. The area of the outlet is:

$$\Delta t = \frac{\pi D^2_{orf}}{4\,(144)} = \frac{\pi\, 4^2}{4\,(144)} = 0.0873 \text{ ft}^2$$

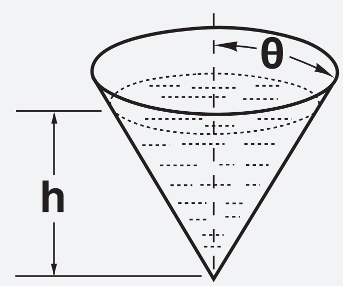
If the tank is filled with water to a height of 5', and we assume turbulent flow, the approximate time to empty the tank is given by:

$$\Delta t = \frac{9\{7^{3/2} - (7-5)^{3/2}\}}{3\,(0.61)\,0.0873}\sqrt{\frac{8}{(32.2)}} = 440 \text{ sec}$$

The tank should be empty in about 7 minutes.

EXAMPLE THREE
CONICAL TANK

$$\Delta t = \frac{\pi\, h^{5/2} \tan^2\theta}{5\,C_d A}\sqrt{\frac{8}{G}}$$



A conical tank with a taper angle of 25° is fitted with a 2" diameter short tube type outlet. The area of the outlet is:

$$\Delta t = \frac{\pi D^2_{orf}}{4\,(144)} = \frac{\pi\, 2^2}{4\,(144)} = 0.0218 \text{ ft}^2$$

If the tank is filled with water to a height of 28', and we assume turbulent flow, the approximate time to empty the tank is given by:

$$\Delta t = \frac{\pi\,(28^{5/2})\tan^2 25°}{5\,(0.81)\,0.0128}\sqrt{\frac{2}{32.2}} = 8{,}000 \text{ sec}$$

The tank should be empty in about 2-1/4 hours.