Efflux From a Tank

Aimee Pierce

INTRODUCTION

The *Efflux From a Tank* experiment explores concepts of material and energy balance through pipes. Calculating mass balances requires calculating the fluid mass entering and exiting the system by applying a “black box” conservation equation. Mechanical energy balances are used to account for the potential and kinetic energy flowing into and out of the system, which relate the fluid efflux velocity to a change in height.

Combining material and energy balances is important whenever making calculations of fluids in pipes. This is relevant in plant design as well as day-to-day plant operations in plug flow reactors, heat exchangers, and overall process flow design decisions when fluids are being transferred.

The purpose of the Efflux From a Tank experiment was to calculate the amount of time it took for a fluid in a tank to decrease in height, as the fluid flows out of the tank through a pipe. This time was used to compare and contrast findings through various pipe sizes with two different fluids: water and ethylene glycol.

It was predicted that decreasing pipe length, increasing pipe velocity, and decreasing fluid viscosity would increase fluid velocity. As viscosity and pipe length increases, and as pipe diameter decreases, the effect of the fluid’s friction factor becomes more dominant, leading to fluid flowing slower through the pipe.

THEORY

Material and energy balances play crucial roles in calculating fluid efflux, or the flow of fluids to, from, and between tanks. Accounting for those energy flows is done using mechanical energy balances [1]; a generalized mechanical energy balance is given in Equation 1.

$$\Delta(v)^2/2 + \Delta P/\rho + g\Delta z + F + W_s = 0 \qquad (1)$$

Where:

v = velocity of liquid in the pipe

P = pressure
g = gravitational constant
H = height
W = work
hf = friction losses

The generalized mechanical energy balance in Equation 1 can be reduced to Equation 2 with the assumption that frictional losses are only due to skin friction in the pipe. This equation yields a function for the velocity as it relates to the change in height of liquid flowing out of a tank.

$$-\square(\square + \square) + \square\square(\square_{\square})^{2}/\square_{\square} = 0$$
(2)

Where:
L = pipe length
h = liquid height
f = friction factor
vp = velocity
Rp = pipe radius

The friction factor term used in Equation 2 is dependent on the type of flow in the pipe. Laminar flow in pipes allows any momentum exchange in the pipe to occur between microscopic adjacent layers of the fluid. Turbulent flow exists when inertial forces dominate viscous forces, and contains eddies, which randomly mix the fluid. Flow in a pipe is characterized by a dimensionless quantity of density, viscosity, velocity, and pipe diameter. This quantity is called the Reynolds number, and is shown in Equation 5. A Reynolds number of less than 2300 yields laminar flow, a value above 2300 yields turbulent flow. Equation 6 is used for the friction factor

$$\square\square = (\square\square\square)/\square \quad (5)$$
$$\square = 16\square/2\square_{\square}\square\square \quad (6)$$
$$\square = 0.0791/\square\square^{1/4} \quad (7)$$

Where:
f = friction factor
□ = density
L = length

v = velocity
μ = viscosity

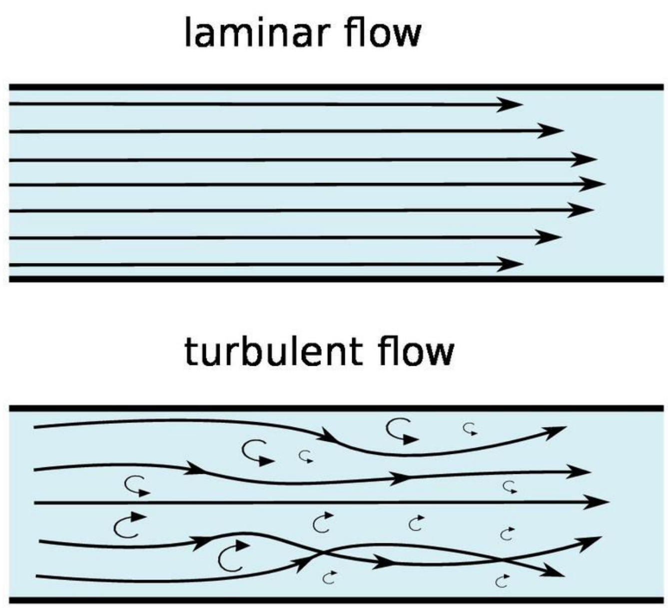

Figure 1: Diagram comparing laminar and turbulent flow [4]

For mechanical energy balances assumed to be frictionless, the Bernoulli equation, shown in Equation 8.

$$\Delta P/\rho + \Delta v^2/2 + g\Delta z = 0 \quad (8)$$

Where:

P = pressure
g = gravitational coefficient
Δz = change in process height

Understanding of material balances is also important when studying the flow of fluids in pipes. Mass balances are represented by conservation equations of the system; a general conservation equation is shown in Equation 9. Because total mass is a conserved quantity if there is no chemical reaction occurring in a system, the conservation equation for the transfer of fluid through a pipe can be reduced to Equation 10.

$$\square\square\square\square\square\square\square\square\square\square\square\square = \square\square - \square\square\square + \square\square\square\square\square\square\square\square\square\square - \square\square\square\square\square\square\square\square\square\square\square$$

(9)

$$0 = \square\square - \square\square\square \qquad (10)$$

The mass balance of a fluid flowing through a pipe is shown in Equation 11, where the total mass of the system is represented in Equation 12. The total mass of the system, $\square_{\square\square\square}$, is substituted into equation 11 to yield Equation 13, assuming constant density. The material balance of a fluid flowing through a pipe out of a tank, is represented by Equation 13. This equation can be integrated to calculate the time required for the height in a tank to change by a specified amount.

$$\square\square_{\square\square\square}/\square\square = \square\square\square_{\square}{}^{2}\square \qquad (11)$$

$$\square_{\square\square\square} = \square\square(\square_{\square}{}^{2}\square + \square_{\square}{}^{2}\square) \qquad (12)$$

$$\square\square/\square\square = -(\square_{\square}/\square_{\square})^{2}\square \qquad (13)$$

Where:

Ro = density of liquid
Rp = pipe radius
Rt = tank radius
h = height of liquid in tank
v = fluid velocity

An expression that relates the change in height in a tank to the time for laminar and turbulent flows respectively is shown in Equations 14 and 15. The material balance shown in Equation 13 along with the reduced mechanical energy balance in Equation 2 and the correct friction factor equation applied for laminar/turbulent flow (Equations 6 and 7) are used to create the equations.

$$\square\square[(\square + \square_{0})/(\square + \square(\square))] = (\square\square\square_{\square}{}^{4}/8\square\square\square_{\square}{}^{2})\square$$

(14)

$$[(\square + \square(\square))/(\square + \square_{0})^{3/7}]^{3/7} = 1 - (3\square_{\square}{}^{2}\square)/(7\square_{\square}{}^{2}\square^{4/7}(\square + \square_{0})^{3/7}$$

(15)

Where:

$$\square = [(0.0791)\square\square^{1/4}/2^{1/4}\square\square^{1/4}\square_{\square}{}^{5/4}]$$

Fluid efflux time can be calculated using Equations 14 and 15.

MATERIALS AND METHODS

APPARATUS

The apparatus used in the Efflux in a Tank experiment consists of a clear plastic holding tank with an attached metal pipe leading to a plastic receiving tank below. A diagram of the apparatus is shown in Figure 2. The holding tank contains the fluid during the experimental run, and is emptied through the metal pipe into the receiving tank. The receiving tank stores the fluid when the experiment is not being run. At the bottom of the clear holding tank is a threaded entrance to attach/detach a threaded metal pipe. Each fluid used in the Efflux in a Tank experiment has a separate identical apparatus.

Preparing the apparatus requires screwing on a threaded metal pipe (with a cap on the bottom) to the bottom of the holding tank. Transferring the fluid from the receiving tank to the holding tank is also part of the experimental preparation. This requires opening a valve - to allow for the fluid to exit the receiving tank - and turning on a mechanical pump to transfer the water from the receiving tank to the holding tank. The fluid is pumped to the holding tank to a fill line of 12” or 7.5” for water and ethylene glycol respectively. The pump is turned off and the valve is closed once the fill line is reached, and the apparatus is prepared to run.

PROCESS

During the Efflux From a Tank experiment, fluid flowed from the holding tank, through the attached metal pipe, to the receiving tank. At the start of a run, the cap on the bottom of the metal pipe was released and a stopwatch was started. As the fluid left the holding tank, time was recorded for every inch the fluid height in the tank decreased, using the fluid meniscus and a ruler applied to the tank. A delta of six inches was recorded for each fluid in each run, meaning that six data points were recorded for each pipe used. This process was repeated for each pipe used.

A variety of pipe lengths and diameters were used to conduct this experiment, shown in Figure 2.

Length			

		3”	6”	12”	24”
Diameter	.125”				X
	.188”	X	X	X	X
	.250”				X
	.314”				X
	.375”				X

Limitations to the process for the Efflux From a Tank experiment include operator error in measuring the time for a one inch delta of fluid. The nature of the time recordings was solely based on the experimenter's view of the fluid in the tank, where inconsistency can cause errors in the data.

RESULTS

DISCUSSION

CONCLUSION

SOURCES

[1] R. M. Felder, R. W. Rousseau. “Mechanical energy balances,” *Elementary Principles of Chemical Processes*,

[2] Lab manual

[3] http://www-mdp.eng.cam.ac.uk/web/library/enginfo/aerothermal_dvd_only/aero/fprops/introvisc/node8.html

[4] http://www.cfdsupport.com/OpenFOAM-Training-by-CFD-Support/node263.html