Pressure Drop in Piping and Pump Applications

An Online Continuing Education Course for Engineers

Course Number: M-5019

Credit: 5 Hours / 5 PDH / 5 CPD

Pressure Drop in Piping and Pump Applications

Manuel Calzada, P.E.

OBJECTIVE

The objective of this course is to familiarize the student with the material necessary to adequately and quickly:

- Estimate pressure drop of incompressible fluids inside pipes
- Select pumps and understand the impact of different configurations
- Determine flows, pressure drops, and power requirements across parallel pipes in a system
- Estimate NPSHa for pumps

Equations are developed throughout the course to solve problems analytically. In addition, a Microsoft Excel computerized pressure drop calculator program is included in the course. The calculator is designed so that no macros are used and, in most cases, can be used with Google Sheets and Excel Online applications. These options provide the student with the opportunity to use these calculators without the need to purchase the Microsoft software. However, if the student wants to automate these sheets, it would require the full Excel software.

This course includes a simple review of some essential and basic concepts from the previous course in fluids "**Pipe Selection and Friction Loss Calculation**," without which the student may not be able to follow the sequence of this course.

Once these basic concepts are covered, then the new material will cover the following concepts:

- System Curves
- Parallel pipes. Flows and pressure drops and power requirements across systems
- Pump curves
- Combination Pump/Pipe system
- Pump affinity laws
- Impact of these laws on the complete pump/pipe system
- Pumps in parallel and pumps in series
- Evaluation of available NPSH values for pumps

In this course, we will cover problem solutions to more complex problems using some basic excel tools. These tools allow the student to experiment with the problem variables and gain a better understanding of the whole system.

In the previous course, "**Pipe Selection and Friction Loss Calculation,**" the focus was to be able to understand and calculate pressure drops and power requirements across **only** *single pipes* under different situations. An Excel calculator program was provided in the previous course to facilitate the understanding of the course and speed up the calculation time. This new course expands on the same concepts and adds new pipe/pump systems, which are a better representation of real case scenarios.

PRESSURE DROP CALCULATIONS AND POWER REQUIREMENT

BASIC FLUID DYNAMICS IN PIPES

As an incompressible fluid flows through a pipe, a friction force along the pipe wall is created against the fluid that will decrease the pressure of the fluid as it moves through the pipe.

The following figure represents a section of fluid inside the pipe. As the fluid flows from left to right, there are a series of forces that act on the element or section of fluid of area A and thickness dx. The conservation of momentum requires that the sum of all the forces equal the change in momentum.

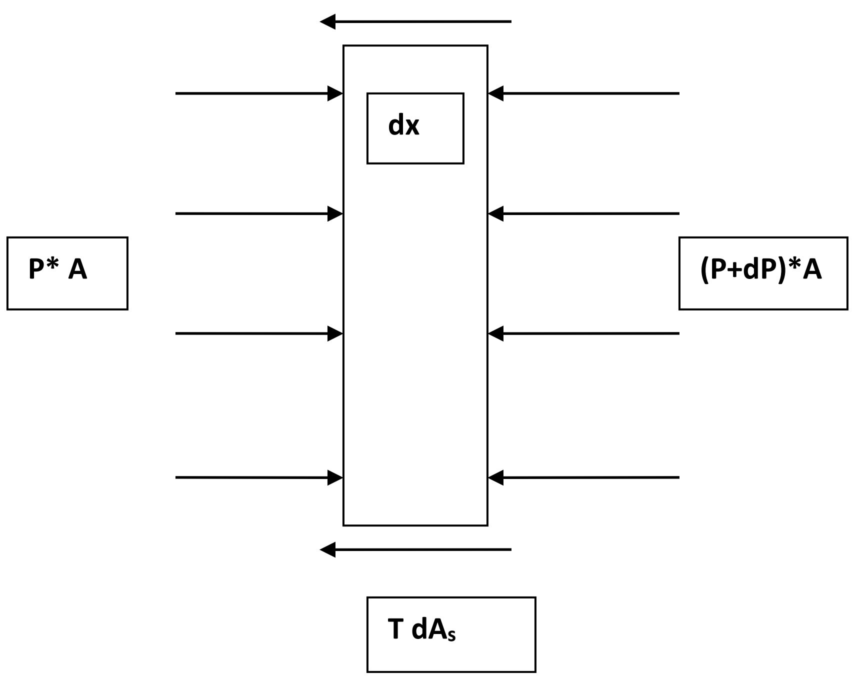

Figure 1

Since the velocity of an incompressible fluid inside the pipe of a constant diameter is constant, the following equation can be written:

$$P\,A - (P+dP)\,A - T\,dA_s = 0 \qquad \text{eqn. 1}$$

Where:

P is the initial pressure acting on the fluid element
P+dP is the pressure acting on the other side of the fluid element
A is the cross-sectional area of the element
T is the wall shear stress due to friction acting on the fluid
A_s is the peripheral area over which the shear stress acts.

Equation 1 can be written as:

$$A\,dP + T\,dA_s = 0$$

Where:

$$A = \pi D^2 / 4$$
$$A_s = \pi D\,dx$$

Where **D** is the element diameter, and d**x** is the width of the element.

From here, we get the following expression:

$$dP + T\,(4\,dx / D) = 0 \qquad \text{eqn 2}$$

Equation 2 represents the forces acting on the fluid element. In order to represent **T** as a variable in terms of other flow variables and in terms of the friction f, we will use the expression:

$$T = (f / 4)\,(\rho V^2) / (2\,g_c) \qquad \text{eqn 3}$$

Where

V is the mean average velocity of the fluid inside the pipe (ft/sec)
ρ is the fluid density (Lbm/ft^3)
f is the friction coefficient of the fluid in the pipe (dimensionless)
g_c is the gravity constant

Using these expressions (eqn 2 and eqn 3) we can develop an equation to calculate the pressure drop across a fluid inside a pipe:

$$dP + (f / 4)\,(\rho V^2) / (2\,g_c)\,(4\,dx / D) = 0 \qquad \text{eqn 4}$$

By integrating this equation over the length of the pipe, it can be rearranged as:

$$P_2 - P_1 = -\,(\rho V^2)\,(f\,L) / (2\,g_c\,D_h) \qquad \text{eqn 5}$$

Where

L is the pipe length (ft)

So far in this development, we have used only the effect of the friction of the pipe over the element. If, in addition, there is an elevation difference between point 1 and point 2 or there is a difference in velocity between those same points, this needs to be taken into account.

The final expression developed, which takes into account the difference in elevation and changes in velocity between any two points, is known as the Bernoulli's equation where no work or heat is produced or introduced into the system. It is expressed as follows:

$$((P_2 - P_1)/\rho) + ((V_2^2 - V_1^2)/(2g_c)) + ((g(Z_2 - Z_1))/g_c) + ((V^2 f L)/(2g_c D_h)) = 0 \qquad \textbf{eqn 6}$$

Example 1
If a water flow of 20 cubic feet of water per minute is flowing through a 3-inch pipe, 50 feet long and horizontal, calculate the pressure drop of the water if the friction coefficient of the fluid in the pipe is 0.02 and the water density is 62.4 lbm/ft^3.

Solution
The first thing that we need to do is calculate the velocity of the flow.

$$V = Q / A = 20 / ((1/16)(\pi/4)) = 408 \text{ ft/min or } 6.8 \text{ ft/sec}$$

Once we know the velocity of the fluid in the pipe, we can replace it in eqn 5

$$P_2 - P_1 = -(\rho V^2)(f L) / (2 g_c D_h)$$

$$P2 - P1 = -(62.4 * 6.8^2)(0.02 * 50) / (2 * 32.2 * ¼)$$
$$= -179.2 \text{ Lbs/ft\^{}2} \qquad \text{answer}$$

Now, assume that there is an incline on the pipe and the discharge point is 5 ft higher than the intake point. To calculate the pressure differential between these two points, we need to include the difference in elevation in the pipe. The formula that we need to use now is Bernoulli's equation, equation 6. Notice that the velocity in point 1 and 2 are the same since the pipe diameter has not changed.

$$((P_2 - P_1)/\rho) + ((V_2^2 - V_1^2)./(2 g_c)) + ((g Z_2 - g Z_1)/g_c) + ((V^2 f L)/(2 g_c D_h)) = 0$$

since $V_1 = V_2$ the above equation is simplified to:

$$((P_2 - P_1)/\rho) + ((g Z_2 - g Z_1)/g_c) + ((V^2 f L)/(2 g_c D_h)) = 0$$

$$P_2 - P_1 = -\rho((V^2 f L)/(2 g_c D_h)) - \rho((g Z_2 - g Z_1)/g_c)$$

$$= -62.4((6.8^2 * 0.02 * 50)/(2 * 32.2 * ¼)) - 62.4((32.2 * 5)/32.2)$$

$$= -179.2 - 312 = -491.2 \text{ Lbs/ft\^{}2} \qquad \text{answer}$$

ENERGY REQUIREMENTS TO PUMP A FLUID THROUGH A PIPE

Again, up to this point, we have only considered the pressure drops in a fluid as it flows inside a pipe. The question that we need to address now is: What is the power required to pump the liquid through the pipe? To answer this question, we need to look at the conservation of energy equation, which states that the energy applied into a system (thermal, mechanical, electrical, etc.) minus the energy from the system is equal to the energy stored by the system.

Graphically we can represent this principle in the following figure

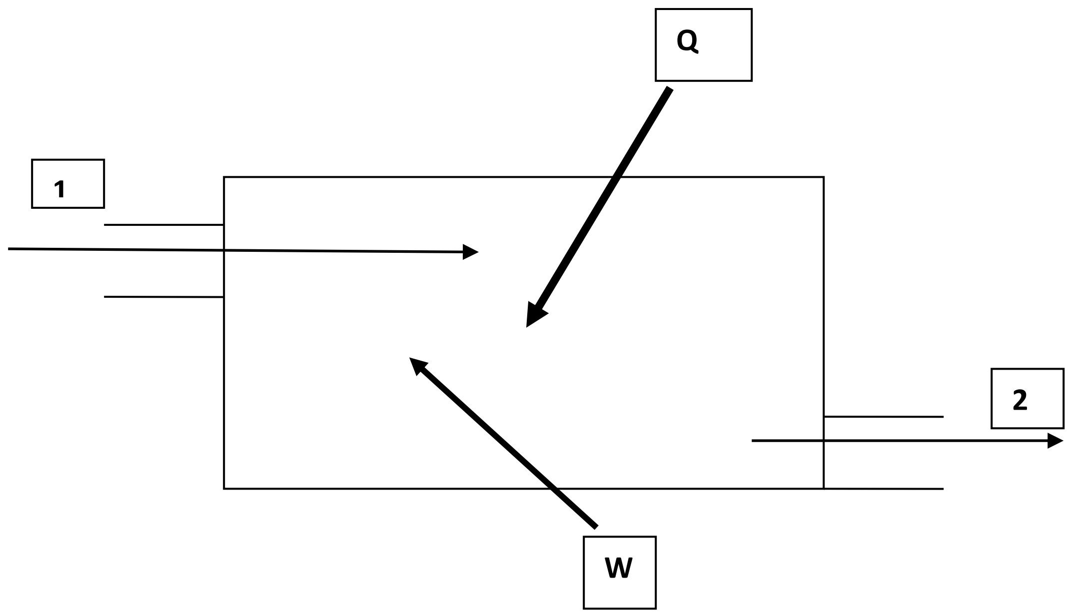

Figure 2. Box represents a pump where fluid flows in and out, and heat and work are added or taken away from it.

In this figure, we have that a fluid is entering the system through port 1 and leaving through port 2. The velocities at 1 and 2 do not need to be the same. In addition, Heat (represented by Q) is introduced into the system, and Work (represented by W) is also introduced into the system. Also, we can see that there is an elevation difference between port 1 and port 2.

The energy balance for this equation can be represented as:

$$\mathbf{d(Q+W)/dt = m\left((h2+V2^2/2g_c+Z2(g/g_c)) - (h1+V1^2/2g_c+Z1(g/g_c))\right)} \qquad \textbf{eqn 7}$$

Where
dQ/dt is the heat rate into the system
dW/dt is the work rate into the system
$\mathbf{h_2}$ is the enthalpy of the flow at point 2
$\mathbf{h_1}$ is the enthalpy of the flow at point 1

V_1 is the velocity of the flow at point 1
V_2 is the velocity of the flow at point 2
Z_1 is the elevation of port 1
Z_2 is the elevation of port 2
m is the mass flow rate. Notice that $\rho A_1 V_1 = \rho A_2 V_2$ since the mass flow rate is constant through the system, and we are studying incompressible fluids only.

h (enthalpy) = u + P/ ρ

Where

u is the internal energy of the fluid. This energy is dependent on the temperature; therefore in an isothermal process u1 = u2.

When we apply the definition of enthalpy to eqn 7, and assuming an isothermal process, it becomes:

$$d(Q+W)/dt = \rho AV \left((P2/\rho + V^2_2/2gc + Z2(g/gc)) - (P1/\rho + V^2_1/2gc + Z1(g/gc))\right) \quad \textbf{Eqn 8}$$

Example 2
Calculate the power requi… r minute from a lake to the top of a building a… he length of the pipe is 700 ft, the density of th… t is 0.02. Neglect the internal energy abs… ed at the surface of the lake.

Solution
This problem will be … direct ways are possible, but it is important to … problem is very simple, using the software in…

As a first step, we wil… heat introduced by the pump is negligible, d… et of the pump as points 1 and 2. If the inlet are… nts 1 and 2 are the same, and the equation…

From the lake to the pu…

$$((P_e-P_2)/\rho)+((V \ldots \ldots)/(2g_c D_h)) = 0$$