Pump ED 101

Daniel Bernoulli – Part 2

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The Bernoulli Principle explains a lot about the flow of fluids and was one of the earliest examples of conservation of energy. It states that, during steady flow, the energy at any point in a conduit is the sum of the velocity head (v), pressure head (P), and elevation head (z). It takes the form of a conservation equation where the sum of the three variables will always remain constant as long as there are no losses or additions.

Energy = v + P + z = Constant

In the example below Bernoulli's equation is expressed in terms of pressure or force per unit area. The first term is dynamic pressure which is a result of the fluid velocity and its density. The second is hydrostatic pressure which is due to any changes in elevation. The third is static pressure which is the actual thermodynamic pressure relative to flow. The sum of the three equals the total pressure and total pressure will remain constant as long as energy is not added or removed from the system.

$1/2\rho v^2 + \rho gz + P = P_{total} = \text{Constant}$

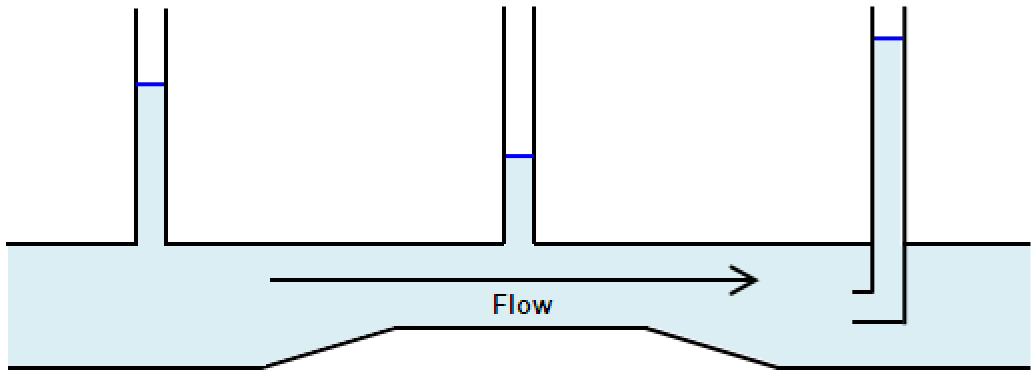
Where: ρ = density, v = flow velocity, P = pressure, g = acceleration due to gravity and z = elevation

Bernoulli's equation can also compare the pressures at any two points in a flowing conduit. Once again, if no energy is added or lost, the sum of the three terms on the left will equal the sum of the terms on the right.

$(1/2\rho v_a^2 + \rho gz_a + P_a) = (1/2\rho v_b^2 + \rho gz_b + P_b)$

Where: a and b are different locations within the conduit

Figure 1 shows the Bernoulli Principle in action and is similar to the one you saw in Part 1 of this series. Here, we have a horizontal pipe that is flowing continuously from left to right and there are no energy losses due to friction. The left and right had diameters are the same but the portion in the center is just two thirds

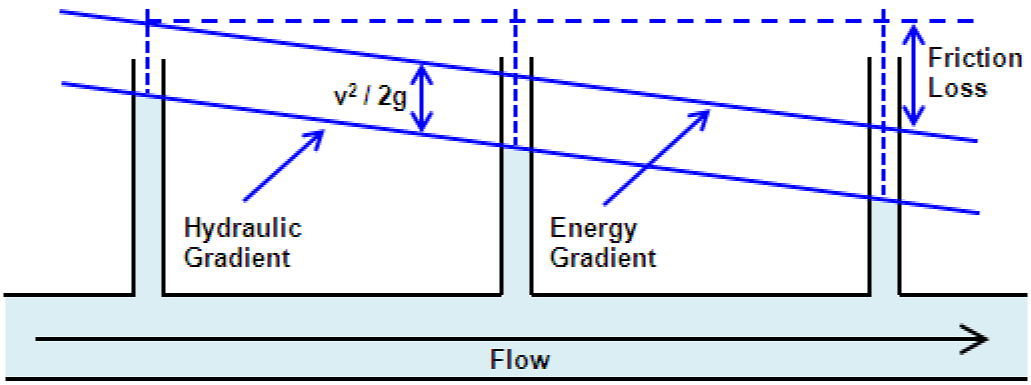


as large. The vertical tubes (piezometers) to the left and in the center are vented to atmosphere and their water levels are proportional to the static pressure in those areas. They measure static pressure in the same manner as a pressure gauge. You will note that the measured pressure in the larger diameter portion is greater than that of the constricted portion. This would be expected since velocity is obviously higher in the center portion and Bernoulli's equation tells us that pressure decreases as velocity increases.

But something seems a little strange about the pressure indicated by the water level in the vertical tube on the far right. One would expect pressure to return to that of far left piezometer if there are no losses due to friction in the constricted area. But, its level indicates a higher pressure and there was no additional energy added to the system. It turns out that the column on the right is a Pitot tube and this device measures pressure in a different manner. In addition to static pressure, it also measures the additional pressure created by the flow velocity.

If a valve on the downstream side was closed and flow ceased, all three vertical tubes would measure the same static pressure regardless of their location and shape. Once flow is resumed the static pressure, measured by the piezometers, will be the static pressure in that particular area. But, unlike the piezometer, the entrance of the Pitot tube faces up stream and allows the flow to push more water into the tube. When water ceases to flow into the tube (stagnation), its vertical level is at its maximum and is equal to the sum of the static and dynamic pressures. The pressure measured by the Pitot tube is the total pressure in the flowing conduit.

Figure 2 is an example of a graphical representation of the Bernoulli equation and is often used during the design of pipelines and open channel systems. It can be used to show the effect on a hydraulic system due to changes in pipe size, elevation and pressure as well as fitting and valve losses. This example illustrates



the pressure at three points in a pipe that is undergoing steady, continuous flow and no changes in elevation. The water levels in the vertical pipes are the static pressures at those points and the angled line connecting them is called the hydraulic gradient or hydraulic grade line. The angled line above that parallels the hydraulic gradient is the energy gradient and is the total pressure in the pipeline. It can be measured by a Pitot tube or it can be calculated using the flow velocity and the equation for velocity head ($v^2/2g$). The energy gradient or grade line is the sum of the velocity head and the static pressure at any point. In this example velocity head remains constant at each point but, static head is reduced based upon the total friction at each point. In more complex examples these two gradients would not parallel one another but would move in both directions depending upon pipe size, elevation and other factors.

The Bernoulli Principle is in action when an airplane flies or a baseball curves. His principle also holds true at sea. The reason that ships must not pass too closely is that the increased velocity of the water passing between them creates a low pressure area that can cause a sideways collision. For this very same reason, large docks tend to have pilings rather than solid walls. And, last but not least - - there is also the "shower curtain" effect.

In a future article we will investigate some similar work performed by Giovanni Venturi and Evangelista Torricelli and how it too, advanced our understanding of hydraulics. Next month we will illustrate the importance of accounting for velocity head when testing pumps in the field.

Joe Evans is responsible for customer and employee education at PumpTech Inc, a pump & packaged systems manufacturer & distributor with branches throughout the Pacific Northwest. He can be reached via his website www.PumpEd101.com. If there are topics that you would like to see discussed in future columns, drop him an email.