Centrifugal Pump Efficiency – Part 1 What is Efficiency?

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Introduction

In this multi part series, we will investigate several aspects of centrifugal pump efficiency. First I will define efficiency and give some examples. Next we will examine some of the design criteria that ultimately dictate the efficiency exhibited by a particular pump. We will also try to make that somewhat nebulas quantity, known as specific speed, more meaningful. I will also illustrate its effect on the shape of a pump's performance curve and overall pump efficiency. Next we will look at the contributions of individual pump components to its overall efficiency. I will also show you why the combined efficiency of a pump and its driver is the product, not the average, of the two efficiencies. We will also see how pump efficiency can be preserved by changing impeller speed rather than reducing it diameter. Next we will compare the value of peak efficiency versus the breadth of efficiency over a range of flow. We will end with a discussion of the importance, or sometimes unimportance, of efficiency as it relates to a particular application or process.

What is Pump Efficiency?

When we speak of the efficiency of any machine we are simply referring to how well it can convert one form of energy into another. If one unit of energy is supplied to a machine and its output, in the same units of measure, is one-half unit its efficiency is 50%. As simple as this may seem, it can still get a bit complex because the units used by our English system of measurement can be quite different for each form of energy. Fortunately, the use of constants brings equivalency to these, otherwise, diverse quantities.

A common example of such a machine is the "heat engine" which uses energy in the form of heat to produce mechanical energy. This family includes many members but, the internal combustion engine is one with which we are all familiar. Although this machine is an integral part of our everyday lives, its effectiveness in converting energy is far less than we might expect. The efficiency of the typical automobile engine is around 20%. To put it another way, 80% of the heat energy in a gallon of gasoline does no useful work. Although gas mileage has increased somewhat over the years, that increase has as much to do with increased mechanical efficiency as increases in engine efficiency itself. Diesel engines do a better job, but still max out around 40%. This increase is due, primarily, to its higher compression ratio and the fact that the fuel, under high pressure, is injected directly into the cylinder.

In the pump industry much our work involves two extremely simple, yet efficient machines - - the centrifugal pump and the AC induction motor. The centrifugal pump converts mechanical energy into hydraulic energy (flow, velocity, and pressure) and the AC motor converts electrical energy into mechanical energy. Many medium and larger centrifugals offer efficiencies of 75 – 93% and even the smaller ones usually fall into the 50 – 70% range. Large AC motors, on the other hand, approach an efficiency of 97% and any motor, ten horsepower and above, can be designed to break the 90% barrier.

The overall efficiency of a centrifugal pump is simply the ratio of the water (output) power to the shaft (input) power and is illustrated by the equation below.

$$E_f = P_W / P_S$$

Where Ef is efficiency, Pw is the water power, and Ps is the shaft power. In the US, Ps is the power provided to the pump shaft in brake horsepower and Pw is:

$$P_W = (Q \times H) / 3960$$

Where Q is flow in GPM and H is head in feet. The constant, 3960, converts the product of flow and head (GPM-feet) into BHP. These equations predict that a pump that produces 100 GPM at 30' of head and requires 1 BHP will have an overall efficiency is 75.7% at that that flow point. An extension of the second equation also allows us to compute the BHP required at any point on a pump's performance curve if we know its hydraulic efficiency. I will show some examples of this later on in this series.

How is Pump Efficiency Attained?

The overall efficiency of a centrifugal pump is the product of three individual efficiencies - - mechanical, volumetric and hydraulic. Mechanical efficiency includes losses in the bearing frame, stuffing box and mechanical seals. Volumetric efficiency includes losses due to leakage through the wear rings, balancing holes and vane clearances in the case of semi-open impellers. Hydraulic efficiency includes liquid friction and other losses in the volute and impeller. Although mechanical and volumetric losses are important components, hydraulic efficiency is the largest factor. If you think about it, the centrifugal pump has a lot in common the induction motor when it comes to the design phase. That commonality is that both have only two major components that can be modified by the designer. In the case of the motor it is the rotor and the stator and for the pump it is the impeller and the volute (or diffuser). Let's start our investigation of centrifugal pump efficiency with the impeller.

The affinity laws tell us quite a bit about the inner workings of an impeller. We know that, for any given impeller, the head it produces varies as the square of a change in speed. Double the speed and the head increases by a factor of four. If you keep speed constant, the same rule holds true for small changes in its diameter. The flow through an impeller follows a similar rule but, in this case, its change is directly proportional to the speed or diameter change - - double the speed or diameter and flow doubles. Actually, when we talk about a change in rotational speed or impeller diameter, we are really referring to its peripheral speed or the speed, in feet per second, of a point at its periphery. It is this speed that determines the maximum head and flow attainable by any impeller.

The head produced by an impeller is almost entirely dependent upon its peripheral velocity but, flow is influenced by several other factors. Obviously, the width and depth (cross sectional area) of the flow passages (vanes) and the diameter of the impeller eye are important considerations as they determine the ease with which some volume of water can pass through the impeller. Other factors such as vane shape also influence an impeller's performance. But, if you wanted to design an impeller from scratch where the heck do you start? Do you just take a wild guess about dimensions and shapes, make some samples, and then test them? Well, in the early days that is exactly what we did. Today, however, we can draw on years of experience and, at a minimum, find a suitable starting point for our design. And, that starting point is something called Specific Speed. Next month we will investigate specific speed and how it can predict the performance of a particular impeller.

There are many great pump books available today but, one of the classics is now available as a free download at Google Books. "Pumping Machinery" was authored by Arthur M. Green, a professor of mechanical engineering at Rensselaer Polytechnic Institute and was published by John Wiley & Sons over one hundred years ago. It begins with a comprehensive history of pumps and ends with a detailed review of centrifugal pumps and their advances over the previous twenty years. You will be impressed at the level of knowledge possessed by the author. The number of illustrations is absolutely amazing and accounts for a significant portion of its 725 pages. This one gets an A+ rating from me.

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.