Variable Speed Pumping

An Online Continuing Education Course for Engineers

Course Number: M-2035

Credit: 2 Hours / 2 PDH / 2 CPD

Variable Speed Pumping

Introduction

Pumping systems account for nearly 20% of the world's energy used by electric motors and 25% to 50% of the total electrical energy usage in certain industrial facilities. Significant opportunities exist to reduce pumping system energy consumption through smart design, retrofitting, and operating practices. In particular, the many pumping applications with variable-duty requirements offer great potential for savings. The savings often go well beyond energy, and may include improved performance, improved reliability, and reduced life cycle costs.

Most existing systems requiring flow control make use of bypass lines, throttling valves, or pump speed adjustments. The most efficient of these is pump speed control. When a pump's speed is reduced, less energy is imparted to the fluid and less energy needs to be throttled or bypassed. Speed can be controlled in a number of ways, with the most popular type of variable speed drive (VSD) being the variable frequency drive (VFD).

Pumping applications with variable duty requirements offer great potential for energy savings, improved performance, and reduced life cycle costs. Pump speed adjustment is not appropriate for all pumping systems, however.

Pumping Systems

A proper discussion of pumping considers not just the pump, but the entire pumping "system" and how the system components interact. The recommended systems approach to evaluation and analysis includes both the supply and demand sides of the system.

Pumping System Hydraulic Characteristics

In a pumping system, the objective, in most cases, is either to transfer a liquid from a source to a required destination, e.g., filling a high-level reservoir, or to circulate liquid around a system, e.g., as a means of heat transfer. Pressure is needed to make the liquid flow at the required rate and this must overcome losses in the system. Losses are of two types: static and friction head.

The ratio of static to friction head over the operating range influences the benefits achievable from VSDs.

Static head, in its most simple form, is the difference in height of the supply and destination of the liquid being moved, or the pressure in a vessel into which the pump is discharging, if it is independent of flow rate. Friction head (sometimes called dynamic head loss), is the friction loss on the liquid being moved, in pipes, valves, and other equipment in the system. This loss is proportional to the square of the flow rate. A closed-loop circulating system, without a surface open to atmospheric pressure, would exhibit only friction losses.

Most systems have a combination of static and friction head. The ratio of static to friction head over the operating range influences the benefits achievable from VSDs. Static head is a characteristic of the specific installation. Reducing this head whenever possible generally reduces both the cost of the installation and the cost of pumping the liquid. Friction head losses must be minimized to reduce pumping cost, but after eliminating unnecessary pipe fittings and length, further reduction in friction head will require larger diameter pipes, which adds to installation cost.

Pump Types

Proper selection of pumps, motors, and controls to meet the process requirements is essential to ensure that a pumping system operates effectively, reliably, and efficiently. All pumps are divided into the two major categories of positive displacement (PD) and rotodynamic.

PD pumps can be classified into two main groups: rotary and reciprocating.

Rotary pumps typically work at pressures up to 25 Bar (360 pounds per square inch [psi]). These pumps transfer liquid from suction to discharge through the action of rotating screws, lobes, gears, rollers, etc., which operate within a rigid casing.

Reciprocating pumps typically work at pressures up to 500 Bar. These pumps discharge liquid by changing the internal volume. Reciprocating pumps can generally be classified as having a piston, plunger, or diaphragm, displacing a discrete volume of liquid between an inlet valve and a discharge valve. The rotary motion of the driver, such as an electric motor, is converted to the reciprocating motion by a crankshaft, camshaft, or swash-plate.

The performance of a pump can be expressed graphically as head against flow rate. The rotodynamic pump has a curve where the head falls gradually with increasing flow. However, for a PD pump, the flow is almost constant whatever the head. It is customary to draw the curve for PD pumps with the axes reversed, but for comparison, a common presentation is used here for the two pump types.

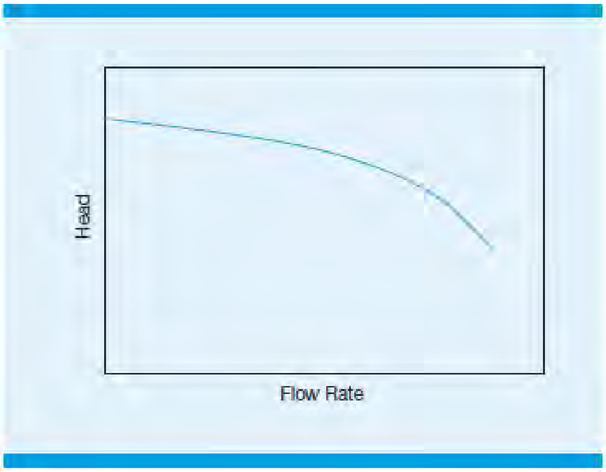

Figure ES-1.
Performance curve for a rotodynamic pump

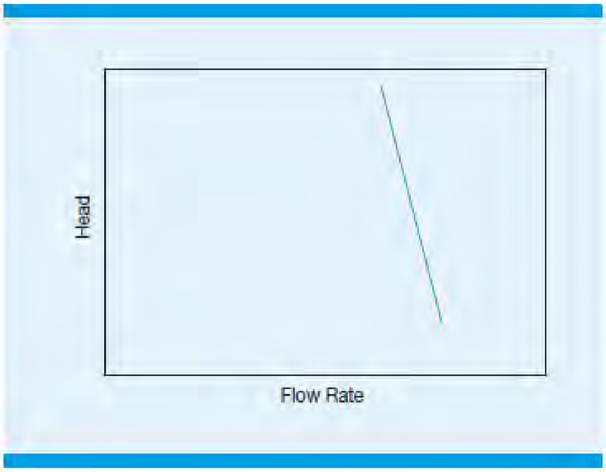

Figure ES-2.
Performance curve for a positive displacement pump

Interaction of Pumps and Systems

When a pump is installed in a system, the effect can be illustrated graphically by superimposing pump and system curves. The operating point will always be where the two curves intersect.

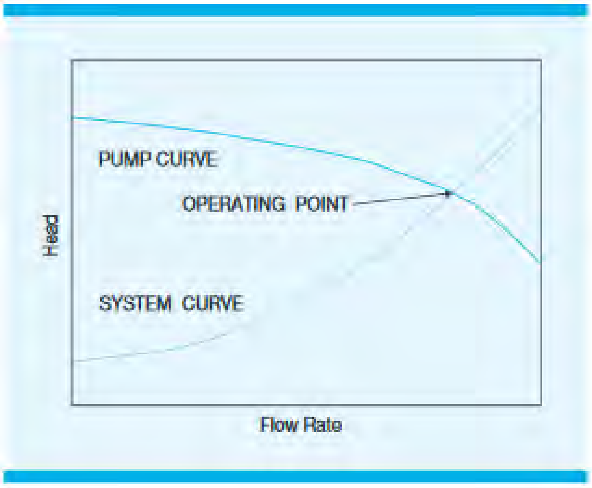

Figure ES-3.
System curve and a performance curve for a rotodynamic pump

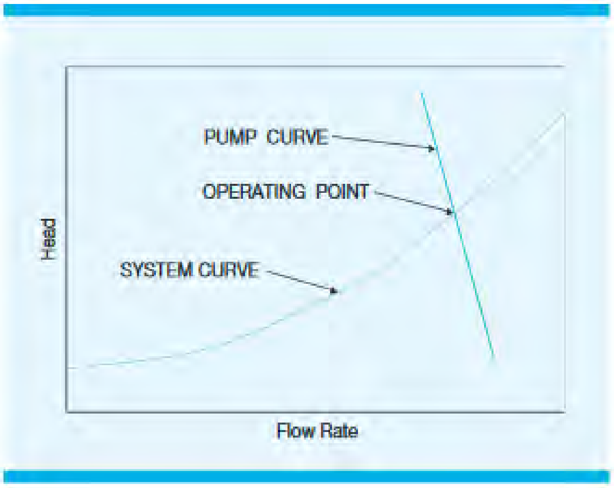

Figure ES-4.
System curve and a performance curve for a positive displacement pump

For a PD pump, if the system resistance increases, i.e., the system curve is moved upwards, the pump will increase its discharge pressure and maintain a fairly constant flow rate, dependent on viscosity and pump type. Unsafe pressure levels can occur without relief valves. For a rotodynamic pump, an increasing system resistance will reduce the flow, eventually to zero, but the maximum head is limited. Even so, this condition is only acceptable for a short period without causing problems. Adding comfort margins to the calculated system curve to ensure that a sufficiently large pump is selected will generally result in installing an oversized pump. The pump will operate at an excessive flow rate or will need to be throttled, leading to increased energy use and reduced pump life.

Many pumping systems require a variation of flow or pressure. Either the system curve or the pump curve must be changed to get a different operating point. Where a single pump has been installed for a range of duties, it will have been sized to meet the greatest output demand. It will therefore usually be oversized, and will be operating inefficiently for other duties. Consequently, there is an opportunity to achieve an energy cost savings by using control methods, such as variable speed, which reduce the power to drive the pump during the periods of reduced demand.

Effects of Speed Variation on Rotodynamic Pumps

Varying the rotational speed has a direct effect on the pump’s performance.

A roto-dynamic pump is a dynamic device with the head generated by a rotating impeller. Thus, there is a relationship between impeller peripheral velocity and generated head. Peripheral velocity is directly related to shaft rotational speed, for a fixed impeller diameter. Varying the rotational speed therefore has a direct effect on the pump’s performance. The equations relating roto-dynamic pump performance parameters of flow to speed, and head and power absorbed to speed, are known as the Affinity Laws.

Changing pump impeller diameter also effectively changes the duty point in a given system, and at low cost, but this can be used only for permanent adjustment to the pump curve and is not discussed further as a control method.

For systems where friction loss predominates, reducing pump speed moves the intersection point on the system curve along a line of constant efficiency (see Figure ES-5). The operating point of the pump, relative to its best efficiency point, remains constant and the pump continues to operate in its ideal region. The Affinity Laws are obeyed, which means that there is a substantial reduction in power absorbed accompanying the reduction in flow and head, making variable speed the ideal control method.

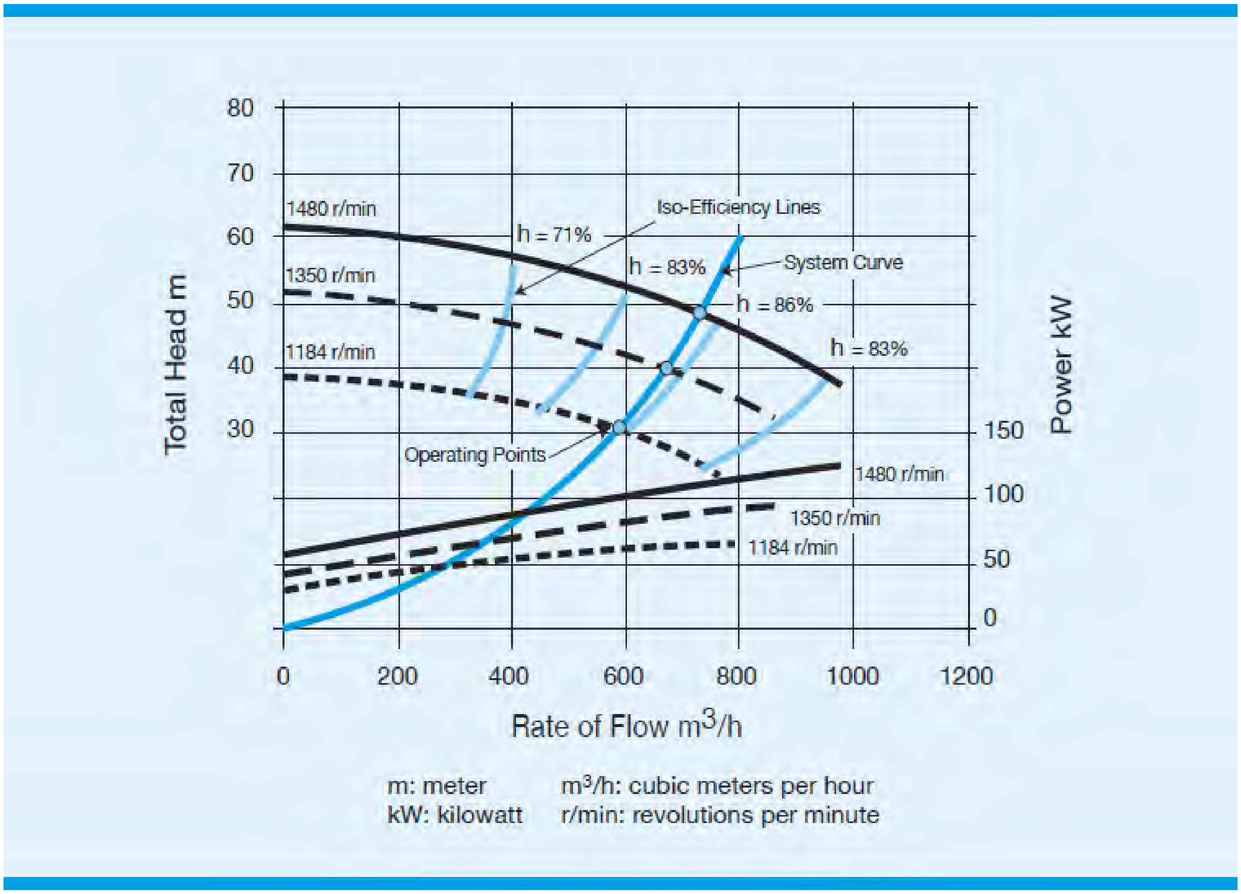

Figure ES-5.
Example of the effect of pump speed change in a system with only friction loss

However, in systems with high static head, the system curve does not start from the origin but at some non-zero value on the y-axis corresponding to the static head. Hence, the system curve does not follow the curves of constant efficiency. Instead, it intersects them (see Figure ES-6). The reduction in flow is no longer proportional to speed; a small turn down in speed greatly reduces flow rate and pump efficiency. A common mistake is to also use the Affinity Laws to calculate energy savings in systems with static head. Although this may be done as an approximation, it can also lead to major errors.

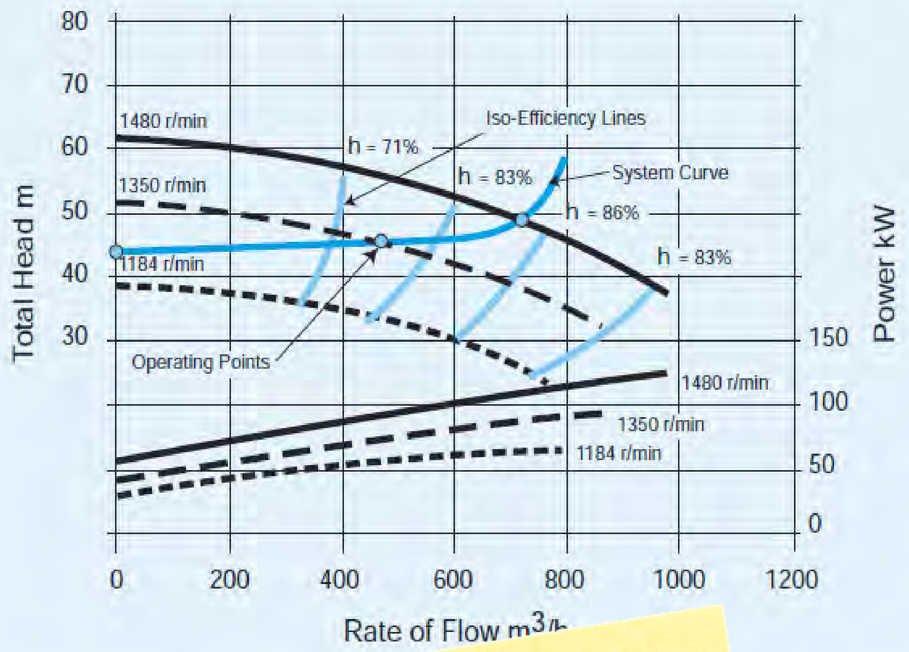

Figure ES-6.
Example of the effe tatic head

It is relevant to note tl e efficient than by a control valve. In addit to lower speed. The hydraulic forces on the pump casing, reduce approximately with the ump bearings, and so reducing speed increase nic pump, bearing life is proportional to the se ise are reduced and seal life is increased, pr able operating range.

Increasing pump speed hile reducing speed will have a positive effe