Elements of Minimum Flow

BY TERRY M. WOLD

Minimum flow can be determined by examining each of the factors that affect it. There are five elements that can be quantified and evaluated:

1. Temperature rise (minimum thermal flow)
2. Minimum stable flow
3. Thrust capacity
4. NPSH requirements
5. Recirculation

The highest flow calculated using these parameters is considered the minimum flow.

TEMPERATURE RISE

Temperature rise comes from energy imparted to the liquid through hydraulic and mechanical losses within the pump. These losses are converted to heat, which can be assumed to be entirely absorbed by the liquid pumped. Based on this assumption, temperature rise ΔT in °F is expressed as:

$$\Delta T = \frac{H}{778 \times C_p} \times \frac{1}{\eta - 1}$$

where

H = total head in feet

C_p = specific heat of the liquid, Btu/lb x °F

η = pump efficiency in decimal form

778 ft–lbs = energy to raise the temperature of one pound of water 1°F

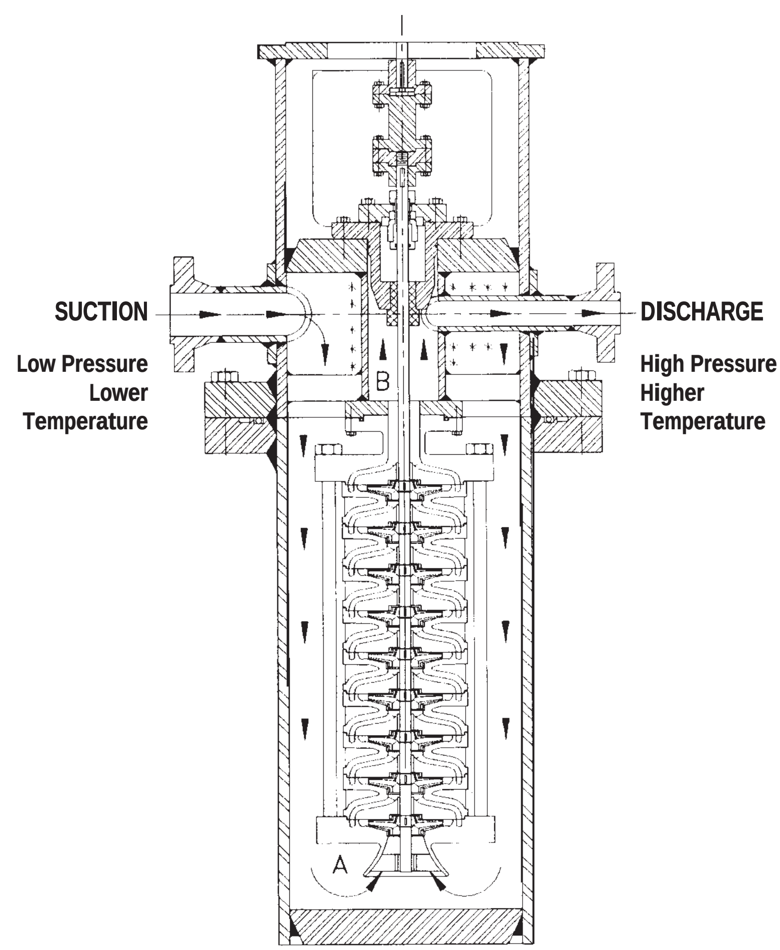
To calculate this, the specific heat and allowable temperature rise must be known.

The specific heat for water is 1.0, and other specific heats can be as low as 0.5. The specific heats for a number of liquids can be found in many chemical and mechanical handbooks.

What is the maximum allowable temperature rise? Pump manufacturers usually limit it to 15°F. However, this can be disastrous in certain situations. A comparison of the vapor pressure to the lowest expected suction pressure plus NPSH required ($NPSH_R$) by the pump must be made. The temperature where the vapor pressure equals the suction pressure plus the $NPSH_R$ is the maximum allowable temperature. The difference between the allowable temperature and the temperature at the pump inlet is the maximum allowable temperature rise. Knowing ΔT and C_p, the minimum flow can be determined by finding the corresponding head and efficiency.

When calculating the maximum allowable temperature rise, look at the pump geometry. For instance, examine the vertical can

FIGURE 1



A high-pressure vertical pump. Asterisks (*) denote where low-temperature fluid is exposed to higher temperatures. Flashing and vaporization can occur here. Temperature increases as fluid travels from A towards B.

pump in Figure 1. Although pressure increases as the fluid is pumped upward through the stages, consider the pump inlet. The fluid at the inlet (low pressure, low temperature) is exposed to the temperature of the fluid in the discharge riser in the head (higher pressure, higher temperature). This means that the vapor pressure of the fluid at the pump inlet must be high enough to accommodate the total temperature rise through all the stages. If this condition is discovered during the pump design phase, a thermal barrier can be designed to reduce the temperature that the inlet fluid is exposed to.

Some books, such as the *Pump Handbook* (Ref. 5), contain a typical chart based on water (C_p = 1.0) that can be used with the manufacturer's performance curve to determine temperature rise. If the maximum allowable temperature rise exceeds the previously determined allowable temperature rise, a heat shield can be designed and fitted to the pump during the design stage. This requirement must be recognized during the design stage, because once the pump is built, options for retrofitting the pump with a heat shield are greatly reduced.

MINIMUM STABLE FLOW

Minimum stable flow can be defined as the flow corresponding to the head that equals shutoff head. In other words, outside the "droop" in the head capacity curve. In general, pumps with a specific speed less than 1,000 that are designed for optimum efficiency have a drooping curve. Getting rid of this "hump" requires an impeller redesign; however, note that there will be a loss of efficiency and an increase in $NPSH_R$.

What's wrong with a drooping head/capacity curve? A drooping curve has corresponding heads for two different flows. The pump reacts to the system requirements, and there are two flows where the pump can meet the system requirements. As a result, it "hunts" or "shuttles" between these two flows. This can damage the pump and other equipment, but it will happen only under certain circumstances:

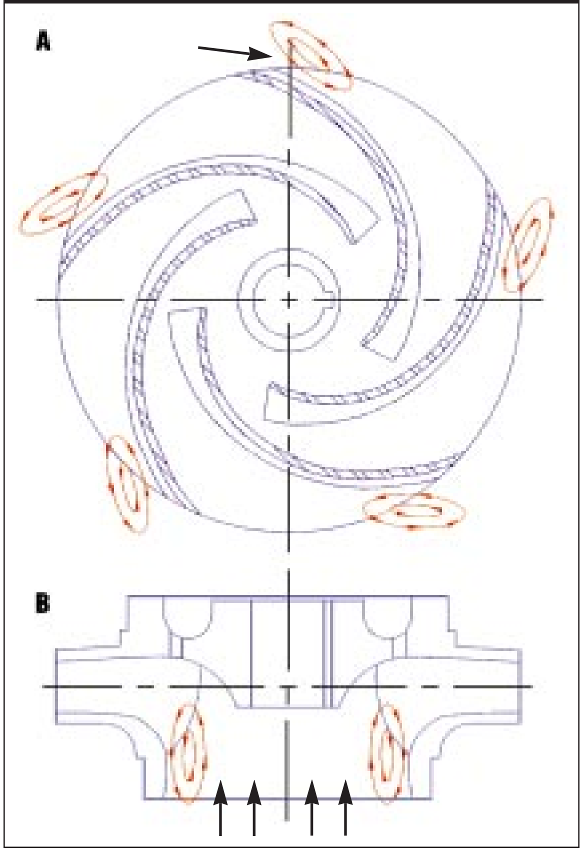
1. The liquid pumped must be uninhibited at both the suction and discharge vessels.
2. One element in the system must be able to store and return energy, i.e., a water column or trapped gas.
3. Something must upset the system to make it start hunting, i.e., starting another pump in parallel or throttling a valve.

Note: All of these must be present at the same time to cause the pump to hunt.

Minimum flow based on the shape of the performance curve is not so much a function of the pump as it is a function of the system where the pump is placed. A pump in a system where the above criteria are present should not have a drooping curve in the zone of operation.

Because pumps with a drooping head/capacity curve have higher efficiency and a lower operating cost, it would seem prudent to investigate the installation of a minimum flow bypass.

FIGURE 2



Recirculation zones are always on the pressure side of the vane. A shows discharge recirculation (the front shroud has been left out for clarity). B shows inlet recirculation.

THRUST LOADING

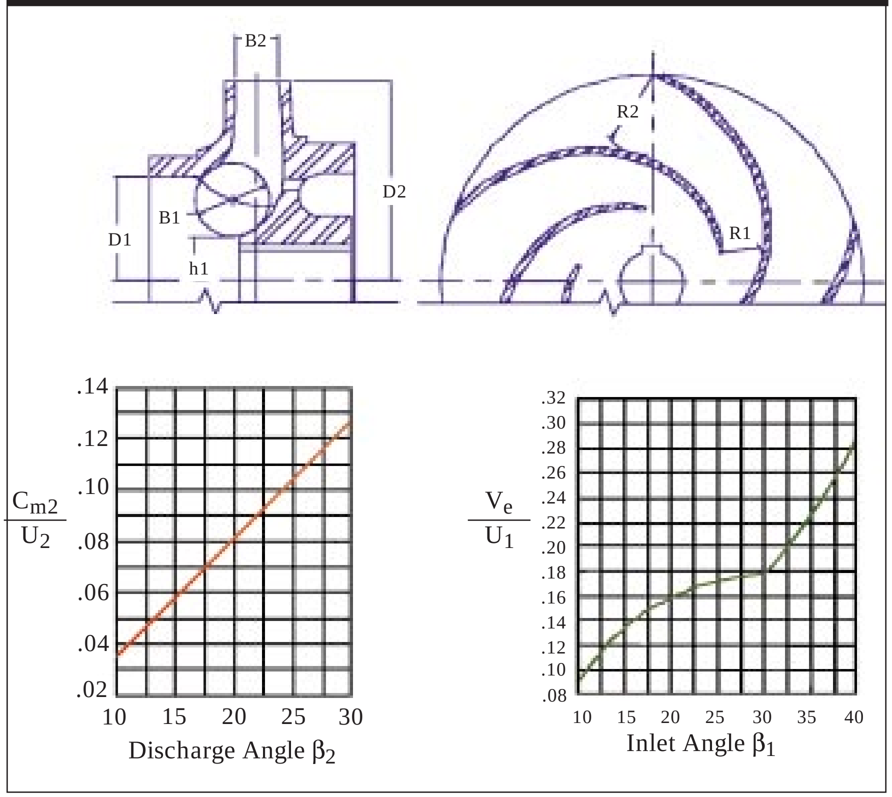
Axial thrust in a vertical turbine pump increases rapidly as flows are reduced and head increased. Based on the limitations of the driver bearings, flow must be maintained at a value where thrust developed by the pump does not impair bearing life. Find out what your bearing life is and ask the pump manufacturer to give specific thrust values based on actual tests.

If a problem exists that cannot be handled by the driver bearings, contact the pump manufacturer. There are many designs available today for vertical pumps (both single and multistage) with integral bearings. These bearings can be sized to handle the thrust. Thrust can be balanced by the use of balanced and unbalanced stages or adding a balance drum, if necessary. These techniques for thrust balancing are used when high thrust motors are not available. It is worth noting that balanced stages incorporate wear rings and balance holes to achieve lower thrust; therefore, a slight reduction in pump efficiency can be expected, and energy costs become a factor.

NPSH REQUIREMENTS

How many pumps have been oversized because of NPSH available ($NPSH_A$)? It seems the easiest solution to an NPSH problem is to go to the next size pump with a larger suc-

FIGURE 3



Incipient recirculation. Minimum flow is approximately 50% of incipient flow, while minimum intermittent flow is approximately 25% of incipient flow. See text under "Recirculation Calculations" for details

tion, thereby reducing the inlet losses. A couple of factors become entangled when this is done. A larger pump means operating back on the pump curve. Minimum flow must be considered. Is the curve stable? What about temperature rise? If there is already an NPSH problem, an extra few degrees of temperature rise will not help the situation. The thrust and eye diameter will increase, possibly causing damaging recirculation. When trying to solve an NPSH problem, don't take the easiest way out. Look at other options that may solve a long-term problem and reduce operating costs.

RECIRCULATION

Every pump has a point where recirculation begins. But if this is the case, why don't more pumps have problems?

Recirculation is caused by oversized flow channels that allow liquid to turn around or reverse flow while pumping is going on (Figure 2 shows recirculation zones). This reversal causes a vortex that attaches itself to the pressure side of the vane. If there is enough energy available and the velocities are high enough, damage will occur. Suction recirculation is reduced by lowering the peripheral velocity, which in turn increases NPSH. To avoid this it is better to recognize the problem in the design stage and opt for a lower-speed pump, two smaller pumps, or an increase in $NPSH_A$.

Discharge recirculation is caused by flow reversal and high velocities producing damaging vortices on the pressure side of the vane at the outlet (Figure 2). The solution to this problem lies in the impeller design. The problem is the result of a mismatched case and impeller, too little vane overlap in the impeller design, or trimming the impeller below the minimum diameter for which it was designed.

Recirculation is one of the most difficult problems to understand and document. Many studies on the topic have been done over the years. Mr. Fraser's paper (Ref. 1) is one of the most useful tools for determining where recirculation begins. In it he describes how to calculate the inception of recirculation based on specific design characteristics of the impeller and he includes charts that can be used with a minimum amount of information. An example of Fraser calculations, which show the requirements to calculate the inception of suction and discharge recirculation, is shown in Figure 3.

RECIRCULATION CALCULATIONS

Figure 3 indicates the user-defined variables and charts required to make the Fraser calculations for minimum flow. Information to do the detailed calculations include:

- Q = capacity at the best efficiency point
- H = head at the best efficiency point
- $NPSH_R$ = net positive suction head required at the pump suction
- N = pump speed
- N_S = pump specific speed
- N_{SS} = suction specific speed
- Z = number of impeller vanes
- h_1 = hub diameter (h_1 = 0 for single suction pumps)
- D_1 = impeller eye diameter
- D_2 = impeller outside diameter
- B_1 = impeller inlet width
- B_2 = impeller outlet width
- R_1 = impeller inlet radius
- R_2 = impeller outlet radius
- F_1 = impeller inlet area
- F_2 = impeller outlet area
- β_1 = impeller inlet angle
- β_2 = impeller outlet angle

The above information is obtained from the pump manufacturer curves or impeller design files. The impeller design values are usually considered proprietary information.

K_{Ve} and K_{Cm2} can be determined from the charts in Figure 3.

With all of the above information at hand, suction recirculation and the two modes of discharge recirculation can be determined.

As previously mentioned, Fraser has some empirical charts at the end of his paper that can be used to estimate the minimum flow for recirculation. A few of the design factors of the impeller are still required. It is best to discuss recirculation with your pump manufacturer before purchasing a pump, in order to reduce the possibility of problems with your pump and system after installation and start-up.

SUMMARY

Minimum flow can be accurately determined if the elements described above are reviewed by the user and the manufacturer. Neither has all the information to determine a minimum flow that is economical, efficient, and insures a trouble-free pump life. It takes a coordinated effort by the user and the manufacturer to come up with an optimum system for pump selection, design, and installation.

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Terry Wold has been the engineering manager for Afton Pumps for the last four years. He has been involved in pump design for 25 years. Mr. Wold graduated from Lamar Tech in 1968 with a bachelor's degree in mechanical engineering and is currently a registered engineer in the State of Texas.

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