Low Flow Options

This service range demands an innovative approach.

Process requirements often demand capacities below those achievable with a conventional centrifugal pump. Figure 1 illustrates the range of service conditions considered to be low flow. The minimum continuous stable flow of a typical 1"x2"x7" overhung pump at 1800 rpm is approximately 7 gpm, while at 3550 rpm the minimum continuous stable flow is about 13 gpm. A pump of this size will produce about 240 ft. of head. As the head requirement increases to 5000 ft., the minimum continuous stable flow will increase to about 190 gpm.

Conventional centrifugal pumps will not handle these low capacities very well for two main reasons:

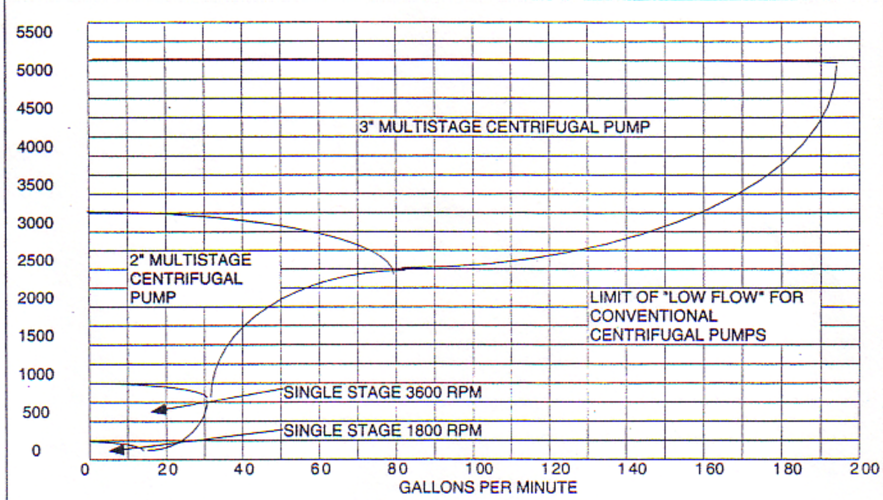
Suction recirculation

The minimum continuous stable flow is usually set by the pump manufacturer to avoid suction recirculation. Suction recirculation results in increased vibration and imparts continuous axial movement to the shaft, decreasing the life of bearings and mechanical seals. The point at which suction recirculation begins may be calculated as described by Dr. S. Gopalakrishnan in his presentation at the 5th International Pump Users Symposium in 1988. The pump manufacturer should perform these calculations and set the pump minimum continuous stable flow at a capacity greater than the calculated capacity.

Temperature rise

The ultimate limitation on low capacity is minimum continuous thermal flow. Temperature rise through a pump determines the minimum flow rate. The maximum safe temperature rise through a pump should be limited to 10°F. The formula for determining thermal rise through a pump is:

FIGURE 1



RANGE CONSIDERED LOW FLOW

$$\delta T = \frac{H}{778C_p} \times \frac{1}{(Eff - 1)}$$

H = total head in feet

C_p = specific heat of the liquid in $\frac{Btu}{lb}$ x °F

788 ft-lbs = the energy to raise the temperature of one pound of water by 1°F

PARTIAL EMISSION PUMPS

The type of pump most frequently applied to fulfill low flow requirements is a single port diffuser pump with a "Barske" straight vane impeller close coupled to an electric motor, also known as a partial emission pump (Figure 2). Theoretically, in this kind of pump, the only liquid discharged as each chamber passes the diffuser port is the liquid between the impeller vanes. In reality, however, due to the clearance between the case and impeller, some additional liquid also gets swept out the diffuser port. Unfortunately, this pump has a head capacity that droops at shutoff which inhibits the ability to control the pump capacity by increasing pressure with decreasing flow (Figure 3). As a result, installation of a flowmeter is necessary to effectively control this type of pump.

BY PUMPS AND SYSTEMS STAFF

FIGURE 2. BARSKE STRAIGHT VANE IMPELLER WITH SINGLE PORT DIFFUSER PARTIAL EMISSION PUMP

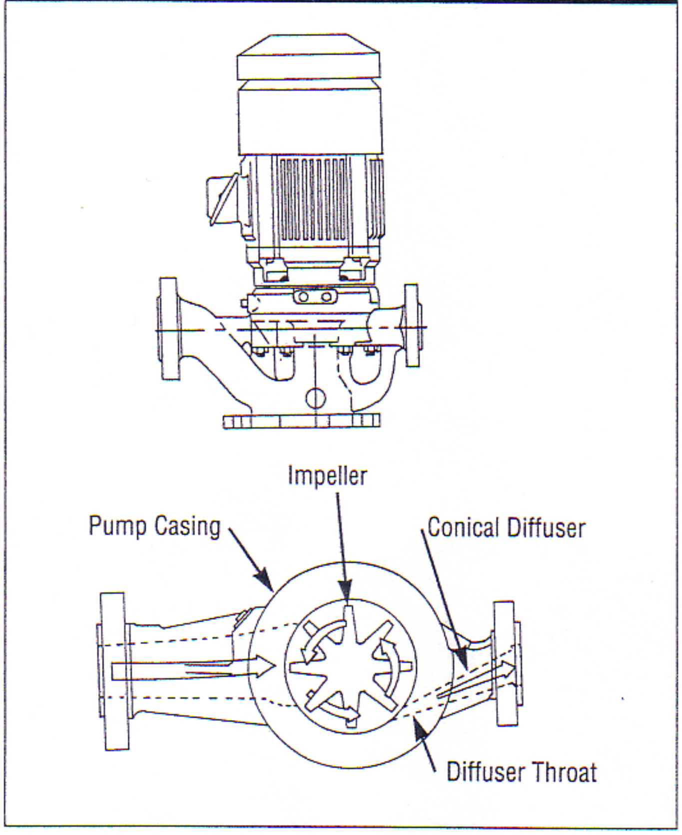
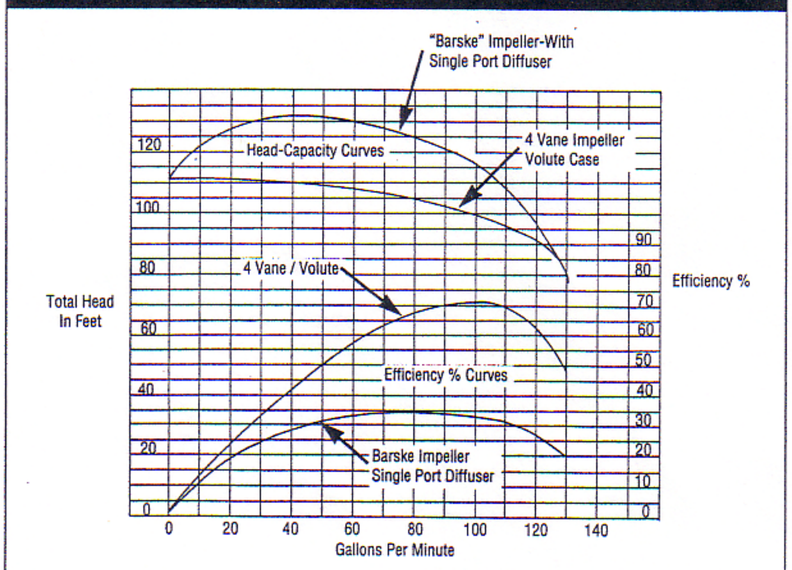


FIGURE 3. TYPICAL CURVE SHAPES



Because the characteristic curve for the "Barske" impeller, also referred to as a high solidity impeller, is exactly the opposite of a centrifugal pump (where increasing the number of impeller vanes will flatten the curve and eventually cause a droop), the droop of the head capacity curve towards shutoff can be minimized in a single port diffuser pump by increasing the number of impeller vanes.

Another method of eliminating head capacity droop is to install a discharge orifice. Since the friction across an orifice increases as the flow increases, the pressure of a discharge orifice will increase the pump curve slope so that the pump can be pressure controlled. Unfortunately, a discharge orifice decreases the pump efficiency.

The partial emission pump is also available with an integral gear (either single or double increaser) to produce a higher pressure head than a single stage pump. Since high head application with the integral gear may call for speeds up to 20,000 rpm, an axial flow inducer is often employed in conjunction with this gear to lower the net positive suction head (NPSH).

Another means to achieve low flow combined with high head requirements is to drive the pump with a special motor capable of high speed. Application of a variable frequency drive will produce speeds nearing 7200 rpm. With this type of construction a partial emission pump may also be coupled to a canned motor for sealless pump construction.

One manufacturer builds the partial emission type pump with an in-line configuration, giving the pump its own bearing frame. In this configuration the pump is flexibly coupled to a standard vertical solid shaft motor. This same manufacturer also builds this pump in a horizontal centerline-mounted configuration.

FLOW RESTRICTION DEVICES

Conventional centrifugal pumps can handle low flow conditions with the incorporation of a restriction device on the discharge to shift the best efficiency point (BEP) capacity back toward shutoff and increase the pump curve slope. Unlike the partial emission pumps which employ a construction requiring removal of a motor with a special shaft extension for mounting the impeller, or in the case of high speed applications removal of the motor and gear, the application of flow restriction devices on conventional API or ANSI pumps provides the benefit of an easily maintained single stage pump.

Even though a restriction device reduces the efficiency by a considerable amount, low flow pumps are generally low horsepower machines, so consuming a little more horsepower to obtain a steep curve rise previous to shutoff is a small price to pay for the more desirable performance. Moreover, the required motor horsepower for the restricted pump is less than that for a non-restricted pump, as the restriction will not allow the pump to run to the extended portion of the curve.

The use of an orifice to restrict flow will produce the desired performance. However, if the orifice diameter is considerably smaller than the pump discharge and discharge piping, cavitation and noise may occur on the downstream side of the orifice.

For this reason one pump manufacturer incorporates a venturi to modify pump performance. The advantage of the venturi is that the gradual taper down to the required hole size then back up to the discharge pipe size effectively eliminates the cavitation, noise and vibration. Pumps equipped with venturi have been observed to run smoother and quieter as they approach shutoff.

OTHER PUMP OPTIONS

- Another type of centrifugal pump that will operate effectively in the low flow range is a vertical can pump. A 5-6 in. diameter bowl assembly will experience its BEP capacity in the 60-120 gpm range at 3600 rpm. At these operating conditions the pump will produce heads up to about 1000 ft. A primary advantage of the vertical pump is the ability to stack many stages so that a low capacity impeller of fairly good efficiency will produce a high head. These pumps usually incorporate two, sometimes three or four, impeller designs of various capacities. Mixing impellers will result in a rated point capacity very near BEP. There is a limit, of course, to how many stages a vertical can pump may have. The limiting factors are shaft diameter size required to transmit the horsepower and torque and the availability of shafting in long sections (usually 20 feet). Another limitation is dependent on the machining tolerances of the register fittings of the bowl assembly. Since the tolerances are additive as the bowl is assembled, they may cause shaft binding if they are not tight enough.

  Regenerative turbine pumps will also fulfill low flow requirements. These pumps, available in single and multistage construction, have a very steep head characteristic and will operate on pressure control. The regenerative turbine does not demonstrate any apparent problems with minimum continuous stable flow, so the only limiting factor to set minimum flow is temperature rise. The formula for temperature rise through these pumps is identical to that for centrifugal pumps. The disadvantage of a regenerative turbine is the close internal clearances required to produce the pumping action. To accommodate this close clearance, the pumpage must be very clean.

- Gear or other rotary positive displacement pumps also will operate in the low flow range without difficulty. These pumps do not, however, operate well in low viscosity services.

- Controlled volume metering pumps can be applied for low flow services and are one of the few types of pumps that will operate at flow rates below 1 gpm. The disadvantages of using a metering pump are the inherent pulsations which may damage downstream piping and instruments. Pulsation dampeners help to smooth out pulsations but never entirely eliminate them.

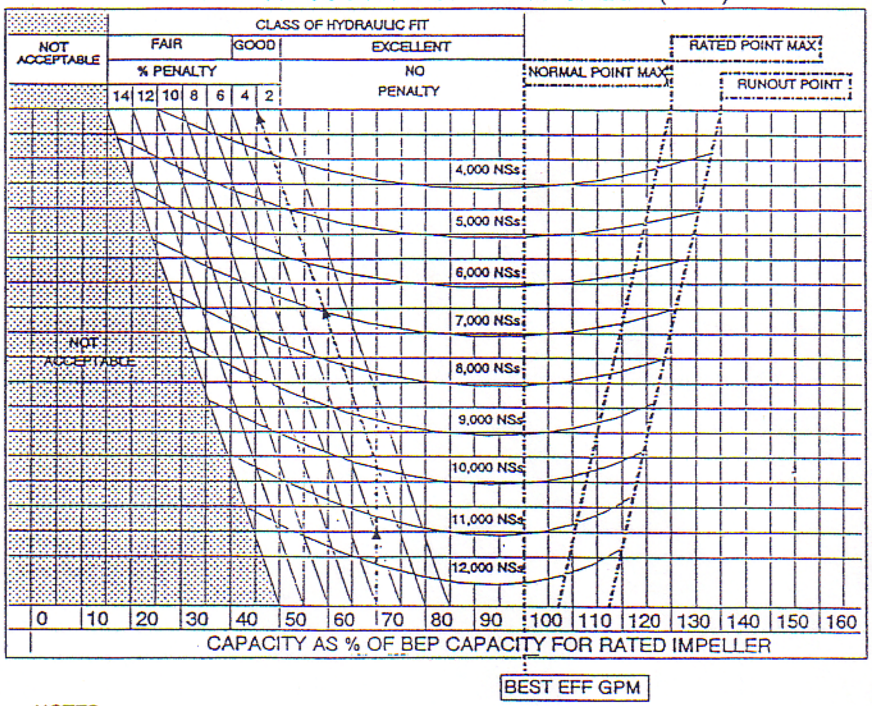
CASTING LIMITATIONS

Development of a truly efficient low capacity centrifugal pump requires prohibitively small liquid passages. These small passages are troublesome to produce in the casting process because the sand mold is prone to collapse at such small sizes and small interior passages are difficult to clean to the degree required for good efficiency in operation.

A semi-open impeller is easier to cast and clean. This design is, however, in violation of API 610, which calls for an enclosed impeller cast in one piece. If sufficient advantages of the semi-open configuration are demonstrated, this standard might be changed. Very small

FIGURE 4

CENTRIFUGAL PUMP HYDRAULIC FIT EVALUATION
STABLE WINDOW OF OPERATION
BASED ON SUCTION SPECIFIC SPEED (NSS)



NOTES:

1. NSS FORMULA $\dfrac{RPM\ (GPM)^{0.5}}{(NPSHR)^{0.75}}$
2. CALCULATE NSS AT BEP CAPACITY AT MAXIMUM DIAMETER IMPELLER AND NPSHr AT THAT POINT.
3. FOR DOUBLE SUCTION IMPELLERS USE GPM/2
4. APPLY PENALTY TO PUMP PRICE (EXCLUDING DRIVER).
5. EXAMPLE:
   NORMAL CAPACITY IS 700 GPM.
   BEP AT RATED IMPELLER DIAMETER IS 1000 GPM.
   SUCTION SPECIFIC SPEED (NSS) IS 10,000.
   PENALTY IS 3% OF PUMP PRICE.
   (SEE EXAMPLE ARROWS ON CHART)

impellers might even be machined from billet stock (similar to some centrifugal compressor impellers), thus eliminating all of the casting problems.

Similarly, the casing of a low flow pump is difficult to cast and clean, requiring very small passageways which must have a smooth surface in order to produce good efficiency. This obstacle to producing a low flow pump case might be overcome by eliminating the need for a case casting in favor of a machined and fabricated construction.

EVALUATING HYDRAULIC FIT

The fact of the matter is most manufacturers usually make little profit on their small model pumps. To convince manufacturers that quality low flow pumps are actually in demand, users must let them know that their quotations for pumps in the low flow area are being evaluated for hydraulic fit. One method of evaluating hydraulic fit is shown in Figure 4. This evaluating tool adds a penalty, as a percentage multiplier, to the pump price for rated capacity to the left of BEP capacity. This tool is based on the fact that a higher suction specific speed correlates with a smaller stable window of operation.

Applying this tool consistently and sending it along with your request for quotations will convince pump manufacturers that low flow performance is an area of hydraulic design that needs to be addressed. ■

REFERENCES

F. H. Fraser, *Recirculation in Centrifugal Pumps*, presented at the ASME Winter Annual Meeting (1981).

S. Gopalakrishnan, *A New Method for Computing Minimum Flow*, presented at 5th International Pump Users Symposium (1988).

U. M. Barske, *Design of Open Impeller Centrifugal Pumps*, Royal Aircraft Establishment, Farnborough, Technical Note No. RPD 77 (January, 1953).

Trygve Dahl, *Centrifugal Pump Hydraulics for Low Specific Speed Applications*, presented at 6th International Pump Users Symposium (1989).

ACKNOWLEDGMENTS

Pumps and Systems would like to thank the members of its User Advisory Team for their assistance in preparing this article.