RECIRCULATION AND MINIMUM FLOW
ANNOTATED BIBLIOGRAPHY

1. Fraser, W.H., Karassik, I.J., Bush, A.R., "Study of Pump Pulsation, Surge, and Vibration Throws Light on Reliability vs. Efficiency," Power, August, 1977, page 46-49.

Good historic overview of onset of recirculation problems. Competitive pressures in pump industry to achieve higher efficiencies and lower values of NPSH have caused problems from recirculation to be more damaging to pumps than in earlier years. Describes recirculation as vortices which form at low flow. Damage to impeller that this can cause is described. If impeller metal has been eroded, attack occurs on the non-visible side of the inlet vane from suction recirculation, the opposite side as from NPSH. Also, if pressure pulsations have a random frequency, it's more likely recirculation than vane passing frequency or cavitation, which is not random. Article points out problems of choosing highest possible suction specific speed and also problems encountered in oversizing pumps. Discharge recirculation also causes hydraulic surges and cavitation at the impeller tips and may be at higher or lower flows than suction recirculation. The article concludes by indicating that some characteristics of pump applications are mutually contradictory. That is, one cannot achieve maximum reliability and maximum pump efficiency at the same time. Also, a pump which can operate over a wide flow range may not also be the choice for extremely reduced NPSH at higher flows.

2. Fraser, W.H., "Flow Recirculation in Centrifugal Pumps", Proceedings of the 10th Turbomachinery Symposium, 1981,p. 95-100.

Seminal work on the field of recirculation. The article points out that because pumps are running faster and with a lower NPSH, they are likely to have lower costs and higher efficiencies, but are more likely to have recirculation problems. The article summarizes the primary symptoms of suction recirculation to include cavitation damage to the pressure side of the impeller vanes at their inlet, cavitation damage to stationary vanes in the suction, random crackling noises in the suction, and surging of suction flow. Symptoms of discharge recirculation include cavitation damage to the pressure side of the vane at the discharge, axial movement of the shaft including thrust bearing problems, failure of the impeller shrouds at the discharge, shaft failure at the outboard end of double suction and multi-stage pumps, and cavitation damage to the casing tongue or diffuser vanes. A simplified graphic solution (Figure 9 and 10) allows one to predict onset of recirculation. Article concludes that while the charts can be used to predict recirculation flow, the recommended minimum flow can vary widely depending on the size of pump and type of fluid. Lower energy pumps (defined as 2500 gpm or less at heads up to 150 ft.) may not cause damage even though the pump operates in the recirculation zone. For these pumps, the recommended minimum flow is 50% of recirculation flow for continuous operation and 25% for intermittent operation. For hydrocarbons, minimum flow can be 60% of recirculation flow for continuous operation and 25% for intermittent. Pumps with S > 9,000 and N_s >2550, should be evaluated very carefully.

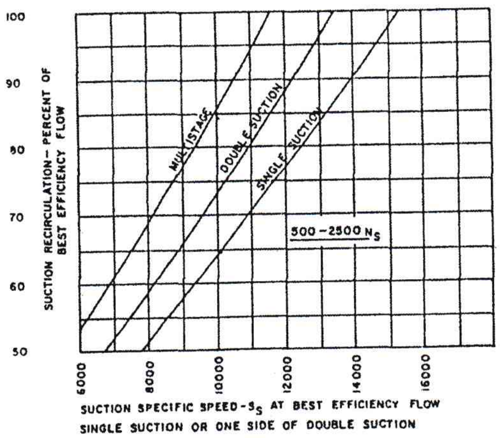


Figure 9. Suction Recirculation — 500 to 2500N_s.

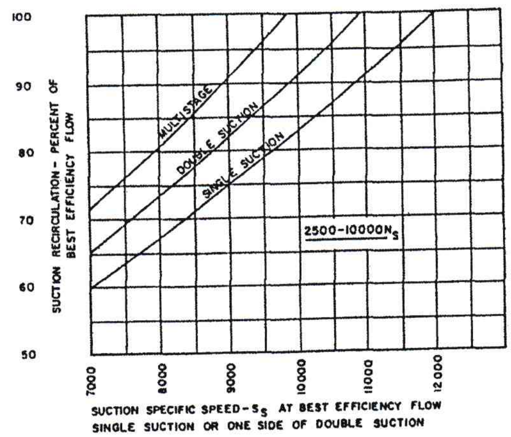


Figure 10. Suction Recirculation — 2500 to 10000N_s.

3. Fraser, W.H., "Avoiding Recirculation in Centrifugal Pumps," <u>Machine Design</u>, June 10, 1982, page 87-91.

This article basically repeats the material given in reference (2), except that the article also includes the formula methods for calculating suction recirculation as well as the graphic solutions. The article gives a detailed procedure to calculate the point as a percentage of best efficiency where recirculation begins. Calculations require knowing elements of the impeller geometry (impeller eye, hub, and outside diameter, and area between vanes at inlet and discharge.)

4. Karassik, I.J., "Flow Recirculation in Centrifugal Pumps: From Theory to Practice," <u>World Pumps</u>, 1983-199, page 119-123.

Article shows calculation method for determining suction and discharge recirculation, using Fraser calculations. Karassik mentions that decreasing impeller diameter moves BEP to a lower flow rate, but doesn't reduce the capacity at which suction recirculation will occur. Article points out that there are two separate periods in the operating life of a pump which should be reviewed during selection. First is full operation when the capacity and head can be predicted with reasonable accuracy. Second is start-up of the system which may actually be long in duration. Recirculation failures commonly occur during this period.

5. Kasztejna, P.J., Heald, C.C., Cooper, Paul, "Experimental Study of the Influence of Backflow Control on Pump Hydraulic-Mechanical Interaction," Proceedings of the Second International Pump Symposium, 1985, page 33-40.

This article describes a device known as a "backflow recirculator" which has been inserted into high suction specific speed pumps. It was found to reduce the strong low frequency fluctuations in suction pressure and axial thrust associated with recirculation.

6. Karassik, I.J., "Centrifugal Pump Clinic, Part 112," World Pumps, October, 1986, page 294-295.

This article again makes use of the Fraser charts to calculate predicted recirculation onset. In the article, a utility company had purchased a boiler feed pump with a high suction specific speed (S=11,300) even though available NPSH was about three times required. Karassik points out if they were to select an impeller with an S value of only 8,500 instead of 11,300, the NPSH required would only have increased by a factor of 1.46. This would have reduced the ratio between available and required NPSH from 3.0 to 2.05, which is still very conservative. And, this would have given a much more stable suction specific speed allowing a wider range of operation without concern about recirculation damage.

7. Karassik, I.J., "Centrifugal Pump Operation at Off-Design Conditions," Chemical Processing Magazine, 1987.

Excellent summary of off-BEP performance. Discussion of what led to greater incidence of problems of off-BEP performance. First, the trend toward increasing impeller suction eye areas for better NPSH brought the onset of internal recirculation closer and closer to the BEP. Secondly, higher heads per stage and larger pump capacities increased the energy levels of individual impellers, making the unfavorable effects of recirculation much worse. Guidelines set by Karassik in this article include:

- Try to keep S at or below 9,000 for water or below 11,000 for hydrocarbons.
- Don't be concerned about suction recirculation in pumps below 100 hp.
- Hydrocarbon services can operate at lower percentages of BEP than equivalent pumps handling cold water.
- Make provisions for expanding minimum flow bypass system size in the field if suction recirculation problems develop, since in many cases the problems don't come to light until after startup.
- If the pump is controlled to operate at a tight range around BEP, higher S value pumps can be chosen.

Article discusses the use of a "bulk-head ring" to reduce suction recirculation. Article also discusses discharge recirculation exhibited by an axial instability of the rotor. It can cause strong pressure pulsations outside the impeller shroud and cause axial movement and thrust bearing failure. Article discusses providing projections from the casing walls to alleviate the effect of discharge recirculation.

8. Gopalakrishnan, S., "A New Method for Computing Minimum Flow," Proceedings of the Fifth International Pump Users Symposium, 1988, page 41-47.

Presents a modification of the Fraser calculations providing less conservative results, and which deviates significantly with Frazer for high N_s and S. Formulas given for calculations, or an estimate of recirculation can be obtained using Figure 8 from the article. From there, minimum flow is equal to recirculation flow times 5 factors, K_1, K_2, K_3, K_4, and K_5. K_1 is a factor to account for power density and comes from Figure 11 below. K_2 accounts for liquid specific gravity and equals the specific gravity. K_3 accounts for margin of $NPSH_a/NPSH_r$, and is obtained from Figure 12. K_4 is a factor to account for intermittency and it is 1.0 for continuous and .7 for intermittent (less than 25%). K_5 accounts for mechanical design margin. If L^3/D^4 is below 100, K_5 is less than 1. Bearing service factor greater than 1.5 and shaft deflection less than .002" may make K^5 greater than 1.

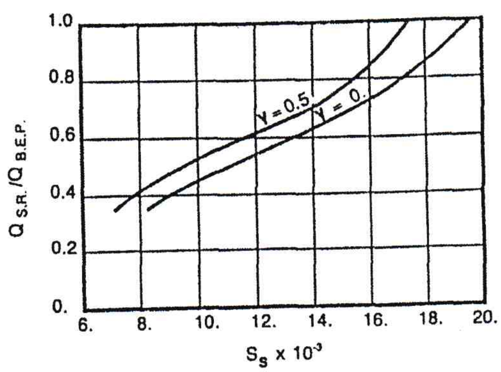


Figure 8. Variation of the Ratio of Suction Recirculation Onset Flow to BEP Flow with Suction Specific Speed.

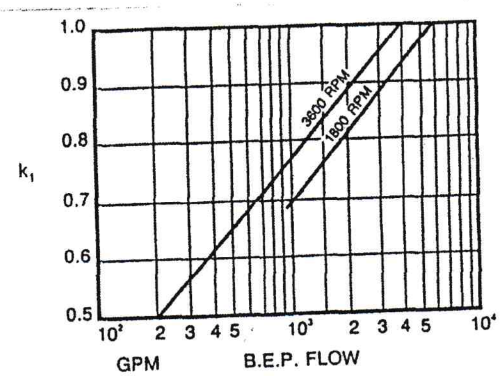
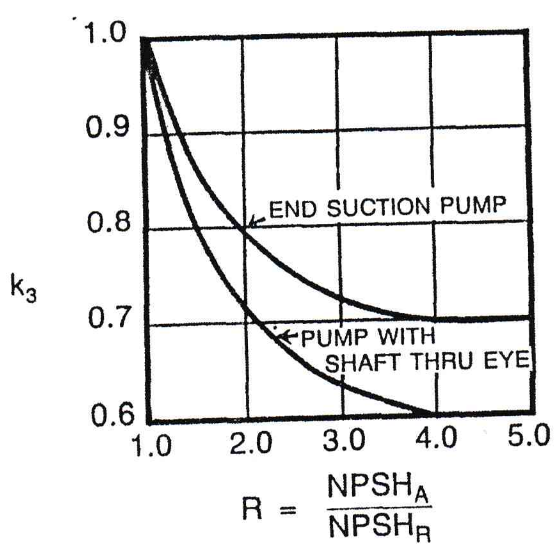


Figure 11. Empirical Factor to Account for Size and Speed Effects.



9. Cooper, Paul, Barrett, James, Steck, Peter, Gopalakrishnan, S., Nelson, W. Ed, Heald, Charles C., Schiavello, Bruno, "Panel Session on Specifying Minimum Flow," Proceedings of the Fifth International Pump Users Symposium, 1988, page 177-192.

Ed Nelson makes a number of practical guidelines and considerations for establishing minimum flow.

- The lower 50-60% of many larger pump operating curves are invalid and cannot be relied upon to guide pump operation.
- Heating of the pumped liquid allows a minimum flow normally 15-20% of BEP, not usually the limiting factor.
- Bearing loads in a well designed pump should set the minimum flow in the same range as the thermal rise, 10-20% of BEP.
- Minimum flow selection depends on time in service. Is the low flow condition almost continuous, a momentary emergency situation, or something in between?
- Recirculation cavitation is most likely to occur in pumps designed for lowest NPSH (high suction specific speed).
- Recirculation is much more damaging with some liquids (eg. water) than with others.
- Double suction pumps are more vulnerable to recirculation than single suction ones and may require minimum flows in the 60-70% of BEP range.
- Energy levels of 600-650 feet of head and 250-300 hp per stage are usually the lower limits of serious instability.
- Pumps should not be oversized in either head or capacity.
- In setting minimum flow, assume that no pump should operate for longer than about 15 minutes below 50% of BEP flow.
- Provide a minimum flow bypass for high energy pumps, including allowances for heat dissipation.
- S above 11,000 require minimum flow of 60-70% of BEP.
- Correction factors that reduce minimum flow when handling hydrocarbons should be used carefully. Some narrow boiling range hydrocarbons tend to react like water.

10. Shiels, S.T., "Centrifugal Pumps Specification and Selection--A Systems Approach--Part I," World Pumps, March, 1990, page 9-18.

This article combines the suction recirculation onset graphs from the Fraser work with the calculation of the five minimum flow factors introduced by Gopalakrishnan in reference (8). Article is good overview of pump/system interaction.

11. Wold, Terry M., "Elements of Minimum Flow," Pumps and Systems Magazine, November, 1993, page 16-20.

Article points out that pumps with a specific speed less than 1,000 that are designed for optimum efficiency have a drooping H-Q curve. Getting rid of this hump requires an impeller redesign that will result in a lower efficiency and a higher NPSHr.

12. Karassik, I.J., "Setting the Minimum Flows for Centrifugal Pumps," Pumps and Systems Magazine, March, 1994, page 14-17.

Despite the passage of 23 years since Fraser's work, Karrasik still continues to recommend this as the procedure for calculating suction recirculation onset. As for determining minimum flow once suction recirculation is computed, Karrasik admits that he does not have a definite and final answer to offer on the subject. He says for high suction specific speeds (which he defines as 10,500 for cold water) the minimum flow should correspond to the onset of recirculation. For more conservative S values such as 8,500-9,500, minimum flow can be set at 25% of BEP. This is a significant difference between these two and it reemphasizes the importance of suction specific speed in the decision of minimum flow.

13. Staff article, "Low Flow Options," Pumps and Systems Magazine, September, 1994, page 20-24.

This article describes some other pump options to consider for low flow services in lieu of throttling centrifugal pumps. These include vertical turbines, regenerative turbines, rotary gear, and metering pumps. Article also presents a chart which can be used in evaluating centrifugal pumps to arrive at a penalty for operation off of BEP, assigning a higher penalty for higher suction specific speed.

14. Bingham-Willamette Minimum Flow Guide, November, 1982

15. Perez, R. and Knight, C., "Hydralically Rerating Centrifugal Pumps to Improve Reliability", Proceedings of the 15th International Pump Users Symposium, 1998, page 41-49.

Two case studies of hydraulic rerating of pumps to correct flow instability. Discusses the many differing guidelines for stable pump flow, including Figure 3 below from Lobanoff and Ross (1992).

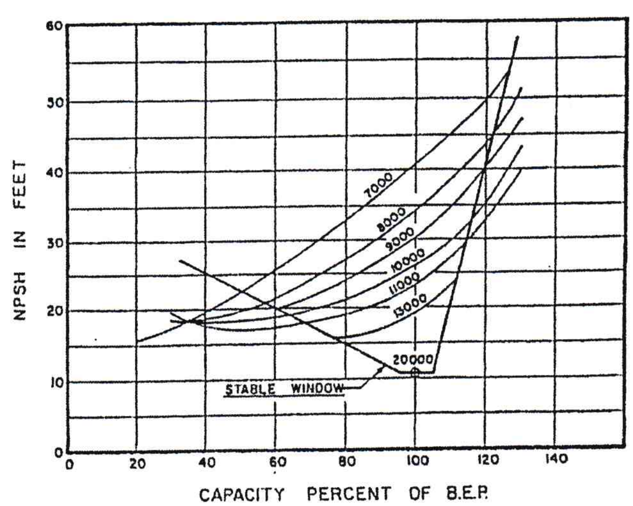


Figure 3. Stable Operating Window Versus Suction Specific Speed.