Understanding Pump Minimum Flow

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Abstract

Early in the relatively brief history of centrifugal pumps, manufacturers provided a single 'minimum flow' value intended to prevent users from running their machines to destruction. Over time, the demanding realities of plant operations coupled with wear and tear of pumps operating at reduced flows, drove various 're-evaluations' and 'refinements' in specifying and defining pump 'minimum flow.' Today, depending upon the application, the pump type, the pump physical size, its developed pressure, the rate of flow, suction conditions, and the input power, we can have different minimum flow values for continuous operation, for intermittent operation, for maximum permissible temperature rise and for impeller cavitation erosion life. This tutorial will explore minimum flow concepts, definitions, and how these apply to the operation of pumps.

Pump Phenomena versus Flow

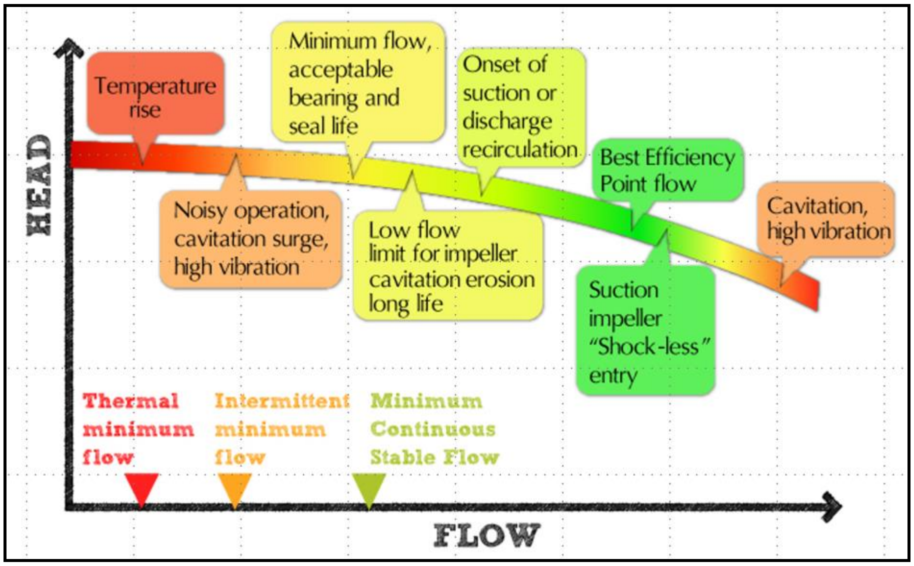

Figure 1. Pump phenomena versus flow

Figure 1. shows the relationships among the various off-design pump phenomena and minimum flow conditions. The head versus rate of flow curve with indicated phenomena is a variation of S. Gopalakrishnan's from his well-cited paper titled, "A New Method for Computing Minimum Flow," *Proceedings of the 5th International Pump Users Symposium*; Texas A&M University, May 1988, pp. 41-47. As an aside, I recall Gopal (everyone knew him by that name) had made a local technical

presentation using the now well-known chart, before it was published. Evidently the chart was copied from a handout of the overhead slides and was quickly pirated by another, and then others. Copies or variants of this chart appear widely in papers and presentations on pumps.

Principal Factors for Specifying Minimum Flow

Here are the principal factors for establishing minimum flow for a centrifugal pump:

- Permissible vibration
- Operating stability
- Impeller cavitation erosion life
- Radial loading
- Temperature rise
- System related

Vibration and operating stability, and radial loading when it is unsteady, are primarily hydraulic effects related to the onset of flow separation and internal recirculation. Cavitation erosion may become excessive, particularly at reduced operating flow conditions. Temperature rise can lead to vaporization and a 'run dry' condition. System related conditions such as cooling flow requirements are application specific.

Minimum Continuous Stable Flow

The quoted minimum flow for continuous operation is usually called "Minimum Continuous Stable Flow" or its common abbreviation "MCSF." It is the flow below which the pump should not be operated continuously. The usual purpose of MCSF is to achieve satisfactory bearing and seal life; however MCSF may be based on other considerations.

For hydrocarbon process industry API 610 specification pumps, the value of MCSF is normally coincident with the lower flow limit of the "Acceptable Operating Range" (refer to Figure 2.), where a specified vibration limit is not to be exceeded.

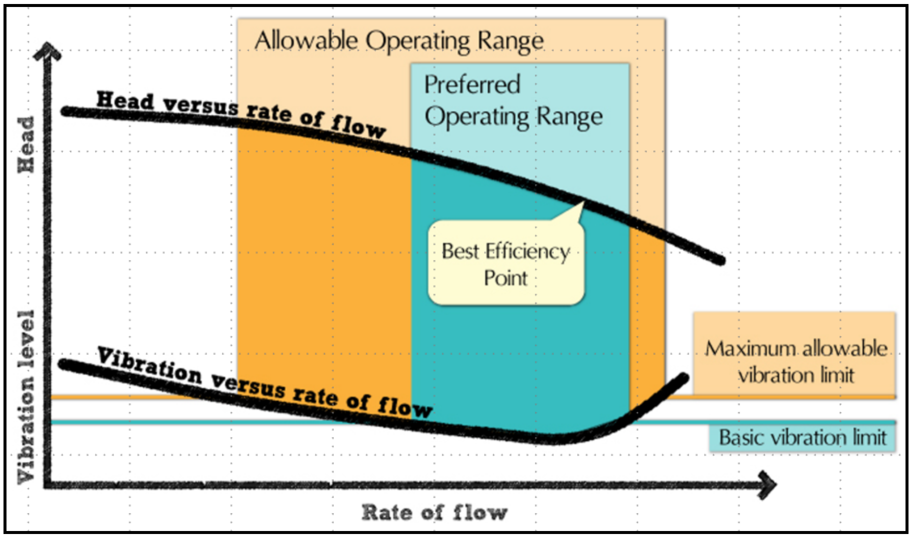

Figure 2. Vibration characteristic

MCSF is a value that can range from roughly 10% to 80% of Best Efficiency Point flow depending on pump size and type, operating speed, impeller suction geometry, liquid density, and other factors. A size 2” (50mm) discharge single-stage process pump may have an MCSF as low as 10% of BEP flow. MCSF is often in the range of 30% to 60% of BEP flow for process pumps with discharge sizes 3” (75 mm) and larger. Large mixed flow vertical pumps and very high head-per-stage centrifugal pumps may have an MCSF greater than 60% of BEP flow. Axial flow pumps have a power curve that rises toward shutoff and minimum flow may be limited by the power rating of its driver.

Operating Stability

A dip or discontinuity in the H-Q rise to shutoff, see Figure 3., may result in quasi-stable pump operation wherein there are two possible rates of flow along the pump curve at the same head.

Cavitation bubble voids, sometimes resulting from suction or discharge recirculation, or from blade cavitation, or both, can result in unsteady or unstable pump operation.

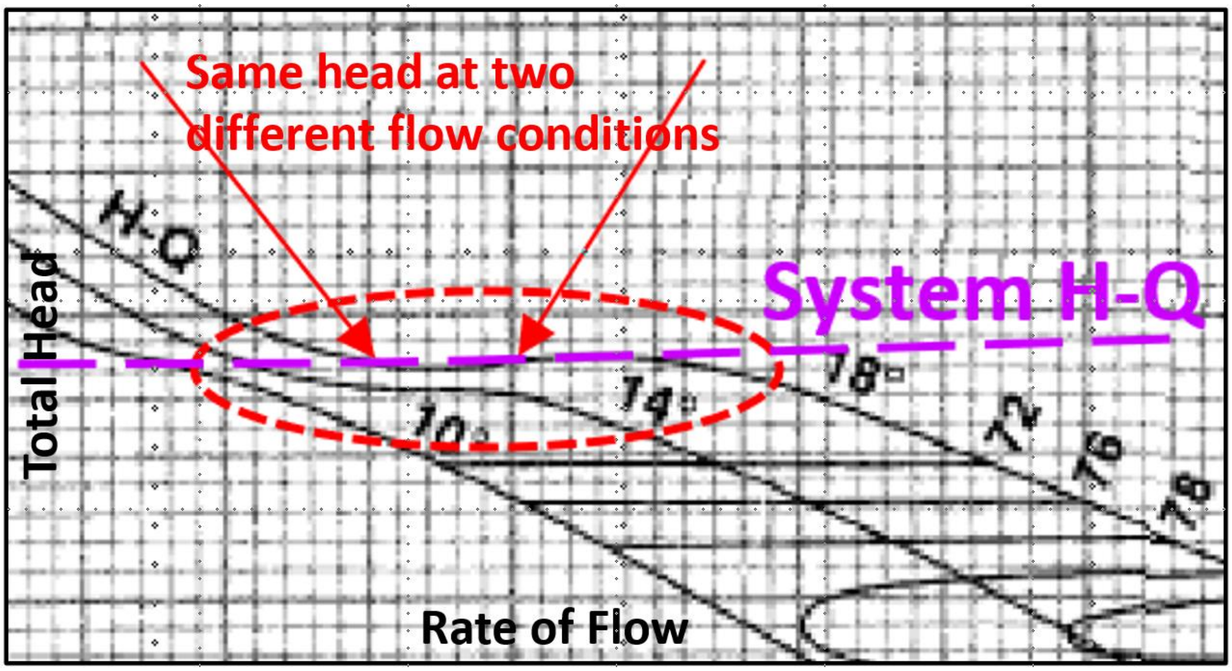

Figure 3. A dip in the head rise curve may lead to operating instability

Impeller cavitation erosion life

On certain applications and with high energy pumps the minimum flow is governed by cavitation erosion damage and a minimum continuous flow for achieving impeller long life or a specified 40,000-hour impeller erosion life would be established by the manufacturer.

Figure 4. Cavitation erosion

Intermittent minimum flow

Intermittent minimum flow, when specified, is usually given as a percentage of MCSF. On some applications the governing intermittent value may be based on temperature rise rather than vibration. On large high energy pumps the value of intermittent minimum flow could be, for example, “70% of MCSF and not to exceed 100 hours per year.”

Radial loading

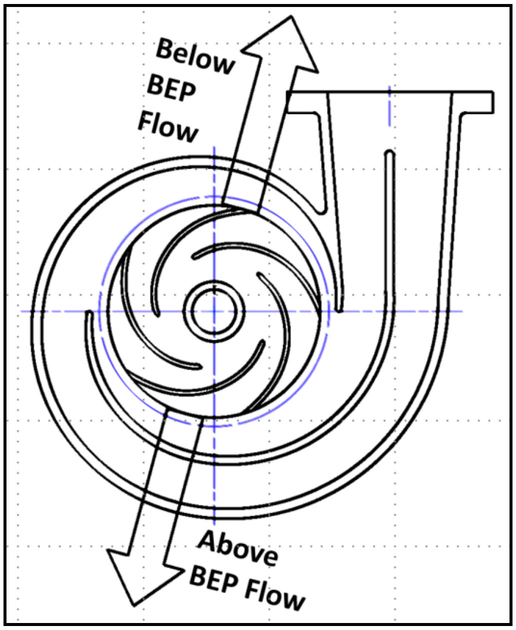

Figure 5. Volute pump radial loading

For some types of pumps, off-peak radial loading could result in excessive shaft deflection, fatigue, excessive bearing loading, reduced seal life, and early failure. With these pumps, placing a lower limit on flow may be necessary.

Minimum Continuous Thermal Flow

For some applications a thermal minimum flow or “Minimum Continuous Thermal Flow” is specified based on permissible liquid temperature rise. MCTF is usually, but not necessarily, lower than MCSF. While a pump thermal minimum flow is not always specified, the end user can readily calculate its value based on input mechanical power heating up the liquid. The limiting temperature rise is based on a safe margin to prevent flashing of the pumped liquid to vapor, potentially causing pump seizure.

Thermal minimum flow is not normally a concern at pump start-up as long as the closed discharge valve is set to begin opening right away. If the margin of system NPSHA above pump NPSHR is minimal, then the temperature rise conditions at pump start-up should be checked carefully.

Multi-stage pumps can be susceptible to heating and liquid flashing across the balance device, particularly with low NPSH Available applications.

Care must be exercised in the operation of centrifugal pumps, particularly high energy pumps, at low flow or shutoff because heating of the liquid is rapid, vibration levels can be severe, and the risk of destructive 'dry run' incident is high.

A few pump applications, such as a vertical turbine jockey pump for maintaining pressure in a large fire sprinkler system, can potentially operate continuously at shutoff while pump suction recirculation mixes with the water in the sump in which it operates. The sump acts as a heat sink and a minimal water temperature rise is not a problem. This example is a rare exception to an almost invariable stricture on operating the pump continuously at shutoff.

Minimum Flow Methods Used

Any of the following factors may be considered in establishing minimum flow values:

- Rule of thumb
- Temperature rise
- Manufacturer specific rules
- Published methods
- Vibration limits
- System and pump performance evaluation
- System pressure limitations
- Onset of suction recirculation or discharge recirculation
- Radial thrust
- Cavitation erosion intensity
- Maximum permissible power rise (high specific speed and axial flow pumps)
- Any combination of the above factors or others not listed

Resources include: the industry standards from the Hydraulic Institute, Europump, ISO, API, etc. and various online resources.

Authors who have written on the subject or developed methodologies include: Heald and Palgrave, Fraser, Gülich, Neumann, Lobanoff & Ross, Bloch, Grist, Schiavello, Visser, Budris, Karassik, Messina, Cooper, Gopalakrishnan, and others

Manufacturers often publish product specific guidelines.

‘K’ Factor method for computing minimum flow (Q_{MIN}) or (*MCSF*)

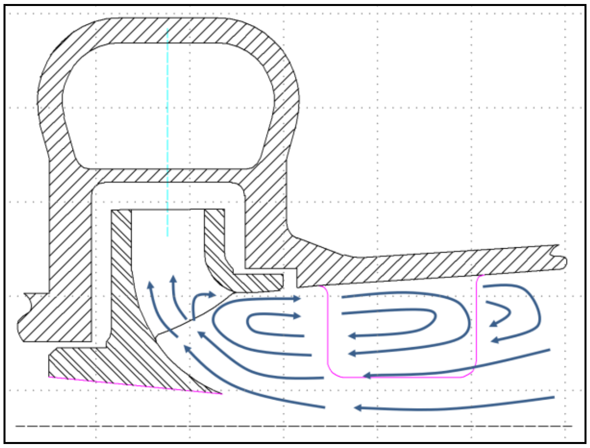

Figure 6. Suction recirculation

The ‘K’ Factor equation:

$$Q_{MIN} = Q_R \cdot K_1 \cdot K_2 \cdot K_3 \cdot K_4 \cdot K_5$$

Where:

Q_R = Onset of recirculation (the greater value of discharge or suction recirculation)

Factors:

- K_1 – Based on power density
- K_2 – Specific gravity
- K_3 – Based on ratio of NPSHa/NPSHr
- K_4 – Intermittency of operation
- K_5 – Specific to mechanical design

The ‘K’ Factor method was developed by Gopalakrishnan of Byron Jackson Products / BW/IP International and the work is cited in the above section on ‘Pump Phenomena versus Flow.’ It is arguably the best published methodology available. The basis for the ‘K’ Factor method stems from earlier work on of Worthington Chief Hydraulic Engineer Warren Fraser (Fraser, W.H., *Recirculation in Centrifugal Pumps*, ASME Winter Annual Meeting, 1981, Washington D.C.)

Conclusion

The purpose of minimum flow is generally to prevent undue wear and tear or damage to a centrifugal pump. In the real environment of a process or utility plant, a pump is operated at just about any condition demanded by the immediate or the ongoing circumstances. Thus there are different pump minimum flow definitions, evaluation criteria, and values to accommodate various modes of operation.