Run Times

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Minimum continuous flow is the lowest flow rate at which a centrifugal pump may be operated on a continuous basis without exceeding the design constraints of the manufacturer or the equipment specifier.

Thermal stability, mechanical integrity and process control are the three primary factors that contribute to the determination of allowable continuous minimum flow. A minimum continuous flow should be independently determined for each factor. The highest minimum flow rate resulting from this analysis dictates the minimum flow rate for a pump.

This issue will focus on minimum continuous thermal flow, which is defined as: *The lowest flow at which the pump may operate without its operation being impaired by the temperature rise of the pumped fluid.*[1]

Dale B. Andrews

Dale B. Andrews – Editor

Pump efficiency reflects the amount of useful work that is produced by a pump. Useful work is the amount of fluid energy, in the form of flow and head, exiting the pump discharge. The pump's curve, available from the pump manufacturer, provides efficiency information for the flow range of the pump.

The difference between 100% efficiency and the published pump efficiency indicates the percentage of the shaft input power that results in energy losses within the pump. Losses within a pump take the form of heat, noise, and vibration. However, for the purpose of calculating temperature rise in a pump, we make the conservative assumption that all of the losses within the pump are converted to heat.[2]

If the temperature within the pump casing exceeds the saturation temperature[3] of the fluid, the fluid will start to vaporize and the pump will cavitate. In a pump that is

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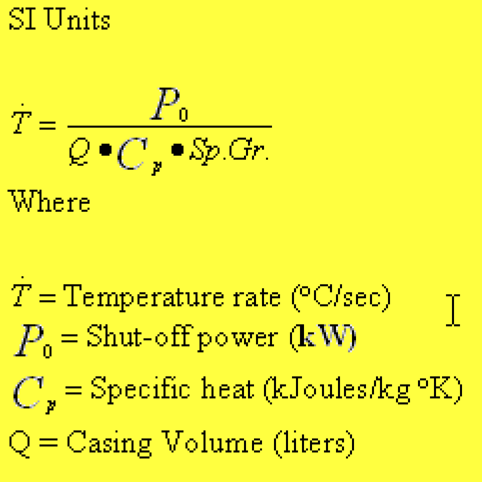
[1] API Standard 610, 8th Edition, Centrifugal Pumps for Petroleum, Heavy Duty Chemical, and Gas Industry services.

[2] This is a reasonable approach to take unless there are very large mechanical parasitic loads in relation to the input power. An example of this might be a small motor driving a pump with a very large bearing or a complex mechanical seal assembly. In that event the parasitic power can be subtracted from the brake power prior to estimating temperature rise.

[3] The temperature at which liquid will boil for a specific pressure. At atmospheric pressure the saturation temperature for water is 100°C (212°F).

at shut-off (zero flow), the temperature and pressure will increase until either the heat losses from the casing balance the heat input, or the pressure is relieved. If the pump is completely blocked in, either by a closed discharge valve or reverse flow check-valve, pressure may rise until it exceeds the material design limits of the pump and a catastrophic failure of the casing or mechanical seal may occur.

The rate at which heat will rise in a blocked in casing can be calculated by the following equation.

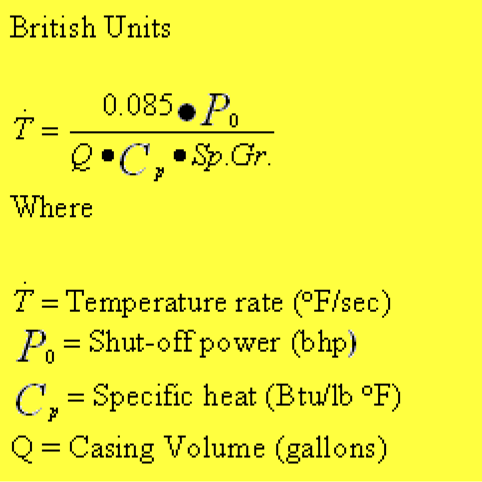


SI Units

$$\dot{T} = \frac{P_0}{Q \bullet C_p \bullet Sp.Gr.}$$

Where

$\dot{T}$ = Temperature rate (°C/sec)
P_0 = Shut-off power (kW)
C_p = Specific heat (kJoules/kg °K)
Q = Casing Volume (liters)



British Units

$$\dot{T} = \frac{0.085 \bullet P_0}{Q \bullet C_p \bullet Sp.Gr.}$$

Where

$\dot{T}$ = Temperature rate (°F/sec)
P_0 = Shut-off power (bhp)
C_p = Specific heat (Btu/lb °F)
Q = Casing Volume (gallons)

For Example:

A pump drawing 25 kW (33.5 hp) at shut-off, with a 20 liter (5.3 gallon) casing volume, handling water[4] would increase in temperature at a rate of 0.3 ^{o}C/sec (.5 ^{o}F/sec).

The time for the liquid to start vaporizing may be calculated by dividing the temperature rate into the difference between the pump inlet fluid temperature and its saturation temperature.

Calculating Minimum Continuous Thermal Flow

First determine the difference between the pump inlet fluid temperature and its saturation temperature. In "The Pump Handbook", Igor Karassik[5] recommends subtracting 9^{o}C (15^{o}F) from this value to arrive at the maximum allowable temperature rise.

Starting at 10% of the best efficiency point flow (BEP)[6], iterate through increasing flow rates, using the following calculation, until the temperature rise through the pump no longer exceeds the maximum allowable temperature rise. If the temperature rise at 10% of BEP flow is less than the maximum allowable temperature rise, then use 10% of BEP as the minimum continuous thermal flow.

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[4] Specific heat of water = 4.19 kJoules/kg ^{o}K or 1.0 Btu/lb ^{o}F

[5] McGraw-Hill 1976

[6] Refer to the pump curve supplied by the manufacturer to obtain the flow and power data, making sure it is corrected for product density and viscosity.

Minimum Continuous Thermal Flow

SI Units

$$\dot{T} = \frac{P_x}{Q \bullet C_p \bullet Sp.Gr.}$$

then

$Q/Q_x * \dot{T} = \Delta T_{pump}$

Where

P_x = Power at the selected Flow (kW)
Q_x = Flow rate through the pump (l/sec)
ΔT_{pump} = Fluid temperature rise (°C)

British Units

$$\dot{T} = \frac{P_x \bullet 5.1}{Q \bullet C_p \bullet Sp.Gr.}$$

then

$Q/Q_x * \dot{T} = \Delta T_{pump}$

Where

P_x = Power at the selected Flow (hp)
Q_x = Flow rate through the pump (gpm)
ΔT_{pump} = Fluid temperature rise (°F)

Example:

Determine the minimum thermal flow for a 100 l/s (1540 gpm), 500 kW (670 hp) multistage pump that at 10% of rated flow draws 375kW (500hp).

The inlet temperature of the water is 70°C (158°F), the inlet pressure is atmospheric pressure 1000 kPa (14.5 psia). The liquid volume of the pump casing is 20 liters (5.3 gallons). Ten Percent of the rated flow is 10 l/s (154 gpm).

The saturation temperature for water at atmospheric pressure is 100°C (212°F). Therefore, the allowable temperature rise is 30°C (54°F) minus a 9°C (15°F) factor of safety, for total allowable temperature rise of 21°C (39°F).

SI Units

$$\dot{T} = \frac{375kW}{20l \bullet 4.19 \bullet 0.975}$$

$\dot{T} = 4.6$°C/sec

The total temperature rise
for the 10 l/s flow rate is

20 liters/10 liters/sec * 4.6 °C/sec = 9.2 °C

British Units

$$\dot{T} = \frac{500hp \bullet 5.1}{5.3gal \bullet 1.0 \bullet 0.975}$$

$\dot{T} = 493$ °F/min

The total temperature rise
for the 154 GPM flow rate is

5.3gal/154gpm * 493°F/min = 17 °F

For this case the 10% flow would satisfy the minimum thermal flow requirements. However, at 500 KW (670BHP), operation of the pump would likely be limited to a much higher flow because of mechanical stability requirements. The lowest flow that a pump can operate at without compromising mechanical reliability is the "Minimum Stable Flow". For most pumps, this is more of a limiting factor than minimum thermal flow. Still, minimum thermal flow often does become a critical factor, especially when dealing with volatile liquids , and it should always be checked when evaluating a pump system. In our next issue we'll discuss the factors that determine "Minimum Stable Flow" and the reliability impact of non-compliance.

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