YORK®

Centrifugal Chiller Minimum and Maximum Flow Limits

Form Number: 160.00-AD9 (522)
New Release
Issue Date: 2022-05-31

Application data

The information in this document is for systems that use water for the evaporator and condenser water loops. For other fluids, for example a brine type fluid such as glycol, contact your Johnson Controls representative for detailed flow limits for that fluid. This information is based on evaporator temperature limits defined as Leaving chilled water temperature (LCHWT) ≥ 40°F (4.4°C). At conditions below 40°F (4.4°C) for water, the minimum velocity increases to avoid the risk of freezing.

Chiller considerations

To ensure maximum turndown is available, select an evaporator design point where the flow rate is greater than 3 ft/s (0.9 m/s). In many variable primary flow (VPF) piping arrangements, the evaporator pressure drop is set higher than normal. As a result, more turndown is available in the evaporator flow rate without the need to pump large amounts of water through the de-coupler or bypass line.

All heat exchangers have operating limits that can change the range of control for any given heat exchanger. Similarly, chillers have operating limits that are defined in terms of minimum and maximum flow rates. The flow rates are determined by the velocity that a fluid can travel through the tube in the heat exchanger and effect the efficiency of the intended heat transfer. In some cases, these limits can be affected by other operating characteristics of the system.

The use of VPF in chilled water plant systems plays an increasingly popular role in the management of chiller plant operating costs. Although these opportunities provide significant savings, they do have limitations. As with any system that involves heat exchangers and liquid flow for heat exchange, plant operators must be aware of these limitations. Operators can then develop their control methodology to ensure optimal operating schedules that use these flow limits as part of the process to prevent negative impacts to the unit operation. The key factors that impact the unit operation are the following:

- Tube water velocity
- Waterbox pressure drop
- Flow rate of change limits

To prevent negative impacts to the plant performance, plant operators must not use flow values and rate of change limits that exceed published limits for chillers.

Flow rate limits

The published minimum and maximum flow rates from Johnson Controls are based on water-filled systems. For all other fluids, special engineering ratings are required to establish the minimum and maximum flow rates. Contact your local Johnson Controls representative for these details.

The chiller minimum and maximum flow limits are determined by the following key factors:

- Internal tube water velocities (heat transfer and tube fouling mitigation)
- Waterbox pressure drop (mechanical divider gasket failure) limits

The limits in chiller literature from Johnson Controls relate to a fully loaded evaporator at 100% chilled water load for a chiller using water as the chilled liquid fluid. The part load limits are calculated based on the load available at the evaporator.

Tube water velocity

Tube water velocity limits are based on the loading of the evaporator. At full load evaporator at 100% rated capacity conditions, the tube water velocity must be in the range of 3 ft/s (0.9 m/s) to 12 ft/s (3.7 m/s) at LCHWT ≥ 40°F (4.4°C). Below 40°F (4.4°C) for water, the minimum velocity increases to avoid the risk of freezing. To ensure efficient heat transfer, the correct water velocity must be maintained through the tubes. If the flow rate decreases below or increases above the tube water velocity limits, the turbulence of the chilled liquid changes and this then reduces heat transfer efficiency.

Tube water velocity is designed to minimize the effects of fouling of the waterside of the tubes. If the water velocity falls too low, for a condenser with an open loop cooling tower, the risk of deposits on the tubes increases. This can affect the overall thermal efficiency and can lead to internal surface defects. To recover efficiency and to prevent additional operating costs, clean the tubes more frequently.

Chillers can operate at any operating point from the minimum velocity limit up to the maximum velocity limit that is published. When the water tube velocity limits are exceeded, the heat transfer capability of the chiller drops off because the flow profile is not fully turbulent.

Turbulence ensures that water contacts the tube wall for sufficient time for the heat transfer process to occur and to reject the heat either into the evaporator or out of the condenser. At the minimum flow, the water velocity can be too slow to generate fully turbulent flow. Above 12 ft/s (3.7 m/s), high water velocities can result in tube erosion. For optimal heat transfer between the water and the tubes, and to protect the integrity of the tubes, keep the tube water velocity in the published limits.

The following conditions indicate that the tube water velocity is not in the correct limits:

- Higher-than-design approach temperatures in both shells
- Apparent lack of capacity in the evaporator that appears as low evaporator pressure
- Change in capacity in the condenser that appears as high condensing pressure

Waterbox pressure drop

If waterbox pressure drop is too high, it increases the pumping costs because of the greater high pressure requirement at the pump. This system pressure drop must be considered during the customer pump selection process because of these additional costs.

The pressure drop is a mechanical limit determined by the gasketing that is used to separate the water passes in a multiple-pass chiller waterbox. Every pass change requires a divider plate and gasketing. When the flow rate and tube water velocity increases, the differential pressure at the divider plate gasket increases. If the pressure drop across this gasket is exceeded, it can lead to failure of the gasket.

A single-pass unit does not have a mechanical limit resulting from the gasketing because it has no divider plate or gasket. A single-pass unit is limited only by tube water velocity and design system water pressure.

When the gasket fails, the water can bypass the individual passes of the tube bundle, which reduces the overall thermal efficiency and the chiller efficiency. Gasket failure can be initiated during the chiller commissioning process where the flows for the chiller are trimmed by the plant controls.

Note: To prevent gasket failure of the main waterbox gasket, for all single-pass and multiple waterbox options, do not exceed the maximum rated system operating pressure of the waterbox.

As a chiller barrel moves into multiple-pass selections, the limit becomes 22.5 ft H_2O (67.3 kPa) per pass. For example, the maximum pressure drop on a two-pass machine is 45 ft H_2O (134.5 kPa) and on a three-pass machine, it is 67.5 ft H_2O (201.8 kPa).

Flow rate of change limits

The chilled water flow rates for VPF systems are designed to change to reflect variable changes in the chilled water load to the chiller. The limiting factors to the flow rate of change are the site system or the chiller control devices. The fastest rate of allowable change is based on the slowest reacting control device. To determine this rate, evaluate each control device to find the slowest time that each device requires to control to the setpoint value.

Johnson Controls chillers use different chiller capacity control devices that vary in the timing required to control to changes in the load based on the difference to the setpoint. This is also true for the site chiller system controls. All systems must be tested to establish the control to setpoint timing.

In some cases, it can be defined as up to a 10% or less reduction in load, either flow rate or temperature, over a 60 s period. This period might need to increase or decrease based on the response time of the chiller controls. In addition, the change must be modulated during that 60 s period and not completed in large steps of reduction, for example, by closing a valve suddenly.

The limit for the rate of change has the following benefits:

- Sudden flow or load reduction can result in nuisance faults as discussed in the Chiller staging section.
- The chiller controls can have time to respond and maintain stable control during any rate of change of the flow rate or load.

Plant operation at or near the limits

To reduce the risk of nuisance flow drops or loss when the chiller plant operation requires multiple chiller operation and staging to occur, it is important to recognize several key steps. Implement effective control logic to avoid operating characteristics that can cause the flows to exceed the limits that include flow rate of change. Use the flow rate limits to develop the plant operation control scheme to avoid nuisance warnings, faults, and trips.

Chiller staging

When more than one chiller is brought online, the pump operation must be modified to support the required additional flow. Change the pump operation to raise the flow while the chiller water isolation valves, if present, are opened. Failure to do so can cause flow reductions for the operating chiller and lead to the following issues:

- Heat transfer reductions in the evaporator, resulting in low pressure or surging
- Heat transfer reductions in the condenser, resulting in higher pressure, high motor current, or surging

When a chiller is shut down while other chillers remain online, keep both chiller pumps operating until the chiller is in a stopped state. Failure to do so can result in the same symptoms noted previously.

Actuated valves

An important system control factor is the rate that any actuated valves open or close. Adjust the valve operator timing to accommodate this rate. Controls that cause a valve to close too quickly, exceeding the flow rate of change limit, can result in the same issues noted previously in regards to flow loss during chiller staging. An example of an acceptable valve stroke time to manage the rate of change is 1.5 min to 2 min for a full stroke of the valve that is controlled.

Calculation of the minimum flow values

Refer to the appropriate chiller *Engineering Guide manual* for the minimum flow rate for all heat exchangers for each chiller model. That minimum flow rate is based on the evaporator tube velocity at 3 ft/s (0.9 m/s). This is true for a fully loaded (100% evaporator load) barrel. The actual minimum flow is defined as 1.5 ft/s (0.5 m/s) minimum tube velocity at 50% or lower evaporator load point and no lower than that value no matter how low the evaporator load goes. So at 60% evaporator load, the minimum flow is 60% of the published full load minimum flow, and at 70% evaporator load, the minimum flow is 70% of the published full load minimum flow. See Table 1 for example.

To aid in determining the minimum flow limits, generate a VPF/Constant Delta T report to provide minimum flows as evaporator load is reduced. The information in Table 1 can be used to calculate the minimum flow values when the VPF/Constant Delta T report is not available.

In the following example, the published minimum flow is 320 gpm. So for every 10% in load reduction, you get a 10% flow reduction of 32 gpm (2.0 L/s) until you get to the 50% load minimum flow values, which is the absolute minimum flow for the given evaporator.

Table 1: Example of minimum flow values at part load conditions

Evaporator load, %	Minimum flow, gpm (L/s)	Minimum flow, ft/s (m/s)
100	320 (20.2)	3.0 (0.91)
90	288 (18.2)	2.7 (0.82)
80	256 (16.1)	2.4 (0.73)
70	224 (14.1)	2.1 (0.64)
60	192 (12.1)	1.8 (0.55)
50	157 (9.9)	1.5 (0.46)
40	157 (9.9)	1.5 (0.46)
30	157 (9.9)	1.5 (0.46)
20	157 (9.9)	1.5 (0.46)

For the most stable operation in a chiller plant that is designed to use a VPF pumping scheme, the minimum evaporator flow rate is 1.5 ft/s (0.5 m/s). Ensure that any flow rate of change occurs at the slowest speed possible. Slow changes to the flow rate ensures stable operation with minimal impact to steady state chiller operation. Control changes of this nature must use the site device limits to increase and decrease control commands and response times.

For additional information, contact your local Johnson Controls representative.