A Design Guide to Ensuring Pump Reliability and Safety for High-Temperature Process Fluids

technical bulletin

Background

Although pump specifications such as API 610 and ISO 5199 cover some of the requirements for when process fluids are at high temperatures, such as in some hydrocarbon, plastics, or resin processes, experience has shown that when temperatures start to reach or exceed 400°C careful selection of components and materials are required in addition to other design considerations.

Using standard design methods for high temperature duties may lead to leaking seals, failed lubrication, stalled drives, or even seizure of the pump, and so special consideration needs to be given to various parts of the pumps in addition to guarding against high temperatures for operatives.

Minimum Thermal Flow

When fluids are pumped their temperature is increased. This occurs because of recirculation of the fluid in the pump and as energy from the driver equipment is converted to heat which transfers to the process fluid.

For fluids where the operating temperature is much lower than its saturation temperature (boiling point), this rise in temperature does not usually cause a problem, but when the fluid is close to its saturation temperature any additional increase in temperature can be problematic and the Minimum Thermal Flow (MTF) must be considered. MTF is defined as "The lowest flow at which the pump can operate without its operation being impaired by the temperature rise of the pumped fluid."

The temperature of the process fluid in the pump must be always kept below its saturation temperature otherwise the liquid starts to vaporise causing cavitation in the pump which can result in vibration, mechanical damage, seal and bearing failure and catastrophic failure of the pump.

If there is a risk that MTF cannot be maintained during the process, design changes must be introduced in the pump such as spill back flow, control valves, and automatic recirculation valves.

Allowable working pressure

It is worth noting that the maximum allowable working pressure will decrease as the pump temperature increases and this can be significant when high temperatures are considered, and so appropriate allowances must be made in the in the hydrodynamic calculations.

Casings

Casings are both in contact with the process fluid on the inside and exposed to ambient conditions on the outside. The selection of suitable materials will depend on the following:

- Dimensional changes due to thermal expansion.
- Resistance to corrosion (typically, heat increases a liquid's corrosiveness).
- Maximum practical temperature limit for use as determined by thermal shock resistance, loss of strength, or other factors.

Centreline mounted casings are preferred as thermal expansion is uniform in all directions, therefore halving the thermal expansion forces exerted vertically through the flange and pipework.

Clearances in the pump, such as the impeller to casing clearance, are critical to the pump's reliable operation and efficiency. Heat causes the metal parts to expand, decreasing the internal clearances. Clearances must therefore be increased to ensure that the pump does not seize due to thermal growth. Typically, clearances need to be increased when fluid temperatures exceed 260°C.

Thermal shock must be considered when processing high temperature fluids. Thermal shock occurs whenever sudden changes in the temperature of the metal take place, such as when the hot fluid first enters a pump that is at ambient temperature. Thermal shock can cause cracks in the material and so should always be avoided. For casings, low carbon steel is usually the preferred material as this has high thermal shock resistance, although if corrosion resistant is required, duplex / super duplex stainless-steel can be used at relatively lower fluid temperatures, but at more extreme temperatures C6 steel must be used throughout.

Jacketing and heat tracing

In addition to minimising thermal shock, for process fluids that increase in viscosity as the temperature decreases, pump temperatures should be maintained wherever possible to prevent clogging and potential failure. This could be through:

- Jacketing the pump pipework whilst the pump is off.
- Trace heating the pump and pipework whilst the pump is off.
- Using using trace heating to bring the cold pump and pipework up to operating temperature before the pump is started.

Alignment

Different materials expand at different rates as the temperature changes and so during commissioning pumps must be carefully aligned when running at operating temperature (for alignment when hot, reference should be made to API 686 Recommended Practice for Machinery Installation and Installation Design).

Motors and couplings

There are no special requirements for motors or couplings other than undertaking alignment at operating temperature when the pump is commissioned.

Seal systems

The use of mechanical seals is crucial for high temperature fluids, however simple 'O' rings are not suitable and more complex seals arrangements are required.

To maintain a suitable operating temperature for the seal system to operate reliably will require external flush or air/forced convection. Incorporating heat sinks into the design can also help reduce heat soak along the shaft and additionally assist in maintaining MTF.

Gaskets

Low melting point materials must be avoided. Graphite is often selected as this can better withstand very high temperatures.

Bearings and lubrication

High temperature pumps are designed to use mineral oil for lubrication. However, mineral oil works best at around 100°C and so its temperature needs to be managed, usually through a combination of heat sinks, fans on the bearing bracket or water cooling of an oil sump.

Condensation in the oil also needs to be considered, especially in a hot or humid environment, and so a breather or condensate collection and drain point in the sump may be required.

Temperature probes in bearings are worth considering to ensure that bearings do not exceed a pre-set temperature for the lubrication system employed.

Bolts

At relatively lower temperatures, low carbon or stainless-steel bolts can be used, but at higher temperatures the bolt material must be selected carefully.

Paint systems

High temperature paint systems must be used on all external surfaces as per the paint manufacturers' recommendations and limitations.

Guarding

Guarding against temperature comes under the "Essential health and safety requirements of the Machinery Directive". As part of the Machinery Directive, it is a requirement that all machinery should be protected against known hazards such as mechanical breakage or liquid ejection. The necessary guarding required is based upon a risk assessment of the machine and guarding is then designed to mitigate those hazards.

EN ISO 14120 will ensure compliance with general guarding, but with regards to high temperatures it is the end-user's responsibility to ensure the equipment is safe to operate. However, manufacturers have a responsibility to take reasonable steps to protect, and if required, to warn the operator and installer.

To this end, a risk assessment would be carried out before the pump is manufactured considering points depending on the temperature extremes and customer actions, for example:

- Low risk: including relatively low temperature fluid, location in ATEX Zone 1 area, customer has confirmed they are fitting thermal jacketing/using barriers.
- Medium risk: including relatively medium temperature fluid, location in ATEX Zone 2 area, customer has confirmed they are considering fitting thermal jacketing/using barriers.
- High risk: including relatively high temperature fluid, location is not in a restricted area, customer has not confirmed they are fitting thermal jacketing/using barriers.

Based on the risk assessment, appropriate warning labels, guards and jackets would be provided with the pump by the manufacturer along with formal communication to the customer of the risks, which would be recorded within the contract file as risk documents and photographs for future reference.

On-site, the end-user is responsible for steps to eliminate any risk of injury arising from contact with or proximity to machinery parts or materials at high temperatures. The necessary steps must also be taken to avoid or protect against the risk of hot material being ejected.

Pumps when operating aren't "hands on" equipment and so are usually located in industrial environments, and so prevention may be as simple as restricted zones. It should be noted however, that even though a pump may not be operating that it could still be dangerously hot and so appropriate guarding and warnings should be applied.

▼ Revision history

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