High Temperature Molten Salt Pumps

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There is probably no other class of industrial pumps that require such a high degree of coordination between the design, materials of construction and intelligent application as these do. Here's why.

Fully understanding the requirements of the application, temperatures and the materials being handled is only the beginning when selecting the type of pump that will best meet all of the criteria for a successful high temperature molten salt system.

Meeting the flow and head demands for a given system is a very small portion of understanding the broader specifications for a high temperature pumping system. Many details must be reviewed, researched, tested and retested, because this single piece of equipment is the heart of the system – if it does not run properly, the system will not operate satisfactorily and may even fail.

It is crucial that the design and materials of construction support and strengthen each other, because extremely high temperature applications extend both of these elements to their limits. From a design standpoint, these critical pumps require simplicity and ruggedness, plus flexibility, to meet longevity in life. The conditions under which high temperature pumps are installed in industrial and process plants are recognized to be highly variable. No single design is adaptable to all of them.

The experience gained through building and testing high temperature molten salt pumps for various applications provides a keen knowledge of the intricate requirements needed for this type of equipment. It also ensures that successful research and development will lead to the commercialization of such equipment.

Everything – from how the pump is installed to the maintenance that will be required – must be evaluated before purchasing it. Understanding the total system requirements will ensure a safe and long life between rebuilds of a molten salt pump.

Materials and Temperatures

The temperature is the starting point for selecting the materials of construction used for the pump. Operating temperature ranges for molten salt start just above their melting point, about 238-deg C (435-deg F), and can run as high as 1200-deg C (2192-deg F).

The salt chemistry must also be considered, because it is absolutely necessary to understand the temperature at which the molten salt will decompose. Many salts will form hazardous gases and may become more aggressively corrosive at the liquid/atmospheric line of the pump or attack the welds.

Because temperature weakens the strength of all materials, the correct materials and designs are reviewed together. The materials used can often compensate for inherently weaker designs being dictated by space limitations or the type of pump used. The reverse is also true, when the design will compensate for weaknesses in the materials due to high temperatures. Understanding this relationship is crucial to selecting the right pump for a given application.

The length of the pump and the operating temperature of the molten salt greatly affect the basic design and material selection of the pump. Selecting a material that falls into the marginal range, or even at the extreme high end of the temperature range, can be very dangerous. The risk of a weak

Table 1

Temperature	240-350 deg C	350-600 deg C	700-930 deg C	930-1100 deg C
Basic Materials	Carbon Steel	316, 321, 347SS	600,625 Inconel	TZM Moly.
	304,316 SS	Haynes 242	Haynes 263	Waspaloy
		718 Inconel	Haynes 25, 188	Haynes 214

structure that will cause a maintenance nightmare must be avoided at all cost. Purchasing the wrong combination of materials and equipment design will create a catastrophic failure of the molten salt system.

High temperatures and basic materials can be divided into four major categories, as shown in Table 1. This is only a guideline and not respective of a specific application.

Before selecting a material, the correlation between the type of salt, temperature range or ranges, velocities within the pump volute and discharge, thermal expansion of the pump shaft, column and discharge assemblies, and mounting arrangement of the pump must be evaluated. Each of these factors influence the type of materials used to best meet the application.

The type of salts used in molten salt applications varies widely, from simple compound salts like sodium nitrates and potassium nitrates to blended complexes, such as fluoride-based salts like FLiNaK. Understanding their melting points, decomposition temperatures, corrosion characteristics, need for agitation, fluid density at different temperatures and freezing points all help in selecting the proper materials.

Temperature ranges that vary can cause distortion and binding in the rotating elements of the pump. For this reason, calculations of each range must be performed to determine the thermal expansion effects on the pump's rotating assembly and stationary components to ensure the proper materials are used in case these temperature changes occur.

The thermal expansion of the rotating assembly and stationary components of the pump must be matched to prevent distortion and binding of the rotating assembly. Materials of each that have similar thermal expansion rates will simplify the pump design. Both lateral and diametrical dimensions must be calculated to ensure that the pump rotates freely and there is no distortion in the column and discharge assemblies.

Fluid velocities and temperature can cause high erosion of impeller vane tips, volute cut waters and discharge elbows. Fluid relative velocity should be kept in a range of 10-fps to 12-fps. Erosion/corrosion damage is usually proportional to the tip-speed to the 6th power – the higher the tip speed, the more severe the erosion/corrosion damage becomes.

The mounting plate serves two major design functions. First, the strength of the mounting plate plays a critical role in pump stability and performance. It supports the pump and motor and keeps everything in alignment. The movement that a pump generates can damage the discharge piping if the mounting plate flexes.

Second, vibration levels can be very high if the mounting plate is weakened by the heat. Both axial and radial vibration can cause severe damage to the pump if the mounting plate is weak. The mounting plate normally has an insulation barrier that prevents the high temperature of the salt from deforming and weakening it. Again, selecting the proper material is critical.

Standard High Temperature Pump Designs

When dealing with high temperature molten salt applications, pumps can be categorized into four different styles. There are other types of high temperature liquids, such as molten metals, which use the same type of pump or even several other types, such as EM (Electro-Magnetic) pumps which cannot be used on molten salts.

Table 2

Temperature Ranges	240-350 deg C	350-600 deg C	600-930 deg C	930-1100 deg C
Vertical Cantilever	Setting: 2m Med. Flow Med. Head Design: Std.	Setting: 2m Med. Flow Med. Head Design: Mod. Std	Setting: 1m Med. Flow Med. Head Design: Mod.	Setting: .5m Low Flow Low Head Design: Custom
Vertical	Setting: 3m High/Med. Flow High/Med. Head Design: Std.	Setting: 3m High/Med. Flow High/Med. Head Design: Mod. Std	Setting: 2m Med. Flow Med. Head Design: Mod.	Setting: 1.5m Med. Flow Med. Head Design: Custom
Vertical Submerged Bearing	Setting: 20m High/Med. Flow High/Med. Head Design: Custom	Setting: 18m High/Med. Flow High/Med. Head Design: Custom	Setting: 15m Med. Flow Med. Head Design: Custom	Consult Factory
Axial Flow Propeller	Setting: 4m High Flow Low Head Design: Custom	Setting: 3m High Flow Low Head Design: Custom	N/A	N/A

Table 2 lists standard vertical pumps for molten salt applications and gives general data that is not related to any specific application.

Vertical cantilever pumps offer many different features, such as several types of mounting arrangements. System designers have great flexibility in tank mounting, as well as mounting the pump outside of the tank. Vertical cantilever pumps have no bearings below the main mounting plate. Cantilever pumps only offer single volute designs. The disassembly of a vertical cantilever pump is the easiest of all four designs.

Vertical pumps can be single stage or multi-stage wet end designs. Applications requiring high heads will use multi-staged wet end. Multi-staged wet end designs are custom manufactured for molten salt applications. These pumps have a lower radial bearing. They also have several mounting arrangements, both inside the tank and outside of the tank. Vertical pumps can offer multi stage volutes as an option. They have longer settings than the cantilever, but are more difficult to disassemble.

Vertical submerged bearing pumps offer the longest design. They can only be mounted in the tank. Vertical submerged bearing pumps can offer multi-staged volutes. These pumps are the most difficult to disassemble.

Axial flow pumps are special in design. Their applications are limited to low heads and high flows. Chemical reactors are one of the main applications for this type of pump. Their special design permits the rotating assembly to be removed from the pump shell without removing the suction and discharge piping. Axial flow pumps can only be mounted with the shaft in a vertical up position. The disassembly of this pump makes it one of the easiest pumps to rebuild.

A vertical sump pump for sulfuric acid applications.

Mounting and Sealing Molten Salt Pumps

Understanding how to seal a molten salt pump to either a tank flange or a structure mounted above the tank is very critical for several reasons.

First, because this seal area becomes part of the cool down transition section of the pump, it can grow into a major problem if not designed properly. Molten salt will climb the shaft and work its way into this seal area, solidifying and freezing up the rotating assembly if this area is too cool, or spraying dangerous molten salt outside of the tank to create an unsafe situation if it is too hot.

A vertical cantilever pump illustration showing stuffing box diagram.

A vertical cantilever sump pump.

This area can be 4-in to 6-in in long for tank mounted pumps, and as much as 4-ft to10-ft long for pumps mounted on structures above the tank. The shaft must be cooled down before the heat reaches the main thrust bearings. This seal area is the first cooling zone, but it must maintain a temperature just above the melting point of the salt.

If molten salt is not stopped from migrating up the shaft prior to the first cooling zone, major failures can occur. The use of salt flingers and a counter flow screw machined into the main shaft will reduce the salt migration up the shaft. Based on the shaft speed and liquid levels in the tank, a secondary screw may be required. The size and design of the screws and flingers will vary based upon the temperatures and type of salt being used.

In the second cooling zone, just above the seal area, heat fans are used to reduce the shaft temperature to 65-deg C before reaching the thrust bearings. The design of this area may require external fans for cooling the shaft if the pump sets idle for long periods of time.

A vertical sump pump.

Failure Mode Analysis

Identifying the primary failure modes of the molten salt pump will help define the predictive maintenance program requirements needed to ensure a trouble-free system.

All systems are different. An evaluation of the pump design used in the system, what the operational sequence is and the general site condition will define the failure modes. The major areas needing to be evaluated are the bare pump, coupling, motor, VFD drive, discharge assembly above the mounting plate, and the sealing area of the pump to the tank. Once failure modes for each of these areas are identified, a stocking program should be put into place so that spare parts are on-site to minimize repair time and lost production.

It is important to evaluate each of these components for their ease of maintenance. One example on the bare pump is the thrust bearings. A well designed molten salt pump will permit the thrust bearings to be replaced without removing the hot pump to save many hours of lost production.

Monitoring Molten Salt Pumps

Monitoring molten salt pumps plays a critical role in a predictive maintenance program. These programs are a cost effective option since action is only taken when the equipment shows a progression of failure. Equipment may be shut down before severe and/or secondary damage occurs to the system. Required maintenance work can be scheduled or planned for normal plant shutdowns.

A multi-technology approach to condition monitoring offers the best analysis of this critical equipment. Vibration analysis, thermal analysis of bearings, oil or grease analysis, alignment, horsepower and visual inspections all provide necessary input to condition monitoring.

Any successful predictive maintenance program includes more than just a technical element. It also involves a human element that is capable of utilizing experience and knowledge in evaluating the technical data so that they work together in maintaining a trouble-free molten salt system.

Important Things to Remember

When designing a molten salt system, involving the pump manufacturer as part of the design team as early as possible can effectively eliminate costly mistakes. The experience of the pump manufacturer in handling molten salt applications is the key to applying the proper design and proven technology to the system.

Be sure that the manufacturer selected has experience in evaluating the chemical reactions between the type of salt, temperatures and materials used in the pump, CFD and FEA analysis design capabilities, specialized manufacturing techniques and can provide support with the correct condition monitoring systems, predictive maintenance programs and proven repair procedures.

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