High Temperature Molten Salt Pumps

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There is probably no class of equipment for industrial application requires such a high degree of coordination between the design, materials of construction and intelligent application as do pumps used in High Temperature Molten Salt Applications. It is only through lengthy experience and close observation that these three elements can be satisfactorily associated.

Fully understanding the requirements of the application, temperatures and the materials being pumped will be the starting point for selecting the type of pump that will best meet all of the criteria needed for a successful High Temperature Molten Salt System. Meeting the flow and head requirements for a given system is only a very small part of understanding the requirements for a High Temperature Pumping System. There are many details that must be reviewed, researched, tested and retested as this single piece of equipment is the Heart of your system, if it does not run properly, your system will not operate satisfactorily and may even fail.

It is critical that the design and materials of construction support and strengthen each other. Extremely High Temperature applications take both of these elements to their limits. From the standpoint of design, we need simplicity and ruggedness, plus flexibility to meet the longevity in life that these critical pumps require.

It is recognized that the conditions under which High Temperature Pumps are installed in industrial and process plants are highly variable and that no single design is adaptable to all of them. The combined experience and knowledge from building and testing of High Temperature Molten Salt pumps for various applications has given us a very broad understanding of the special requirements needed for this type of equipment. The use of such resources insures a successful R&D program as well as Commercialization of such equipment.

Molten Salt Pumps must be designed to meet the individual requirements of the system that they are used in. Many aspects must be considered when selecting a pump to handle high temperature molten salt. 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 insure a Safe and Long Life between rebuilds of your Molten Salt Pumps.

Materials and Temperatures

The operating temperature ranges for molten salt start just above their melting point, about 238 deg C (435 deg F) and can be as high as 1200 deg C (2192 deg F).
The temperature is the starting point for selecting the materials of construction used for the pump. The salt chemistry must also consider when selecting the type of materials used. It is critical 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.

Temperature will weaken the strength of all materials. It is critical that the correct materials and designs are looked at together. Many times the materials used can compensate for weaker designs, which have been required due to the space or type of pump used. The reverse is also true. There are times when the design will compensate for weaknesses in the materials due to high temperatures. Understanding this relationship is critical in selecting the right pump for your application.

The basic design and material selection of pumps is greatly affected by the length of the pump and the operating temperature of the molten salt. 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 structure that will cause a maintenance nightmare must be avoided at all cost. Purchasing the wrong combination of materials and design, of this critical equipment will crate a catastrophic failure of your molten salt system.

High Temperatures and Basic Materials can be divided into four (4) major categories. The following chart is only a guideline and not respective of a specific application.

Temperature	240-350deg C	350-600deg C	700-930deg C	930-1100deg 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

Many questions must be answered 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 your application.

The type of Salts used in molten salt applications varies widely. They can be 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 will help in making a selection of materials.

Temperature ranges that vary can cause distortion and binding in the rotating elements of the pump. It is important that calculations of each range is done to determine the thermal expansion effects on the pumps rotating assemble and the stationary components so that the proper materials are used for when these temperature changes occur.

The 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 10-12 feet per second.

Erosion/corrosion damage is usually proportional to the tip-speed to the 6^{th} power; the higher the tip speed, the more severe the erosion/corrosion damage becomes.

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. Selecting material that have similar thermal expansion rates, will simplify the pump design, which will talk about later. Both lateral and diametrical dimension must be calculated to insure that the pump rotates freely and that there is no distortion in the column and discharge assemblies.

The strength of the mounting plate is very critical to the pumps stability and performance. Normally the mounting plate has an insulation barrier that reduces the high temperature of the salt from deforming and weakening the mounting plate. The mounting plate provides several major design features. First it supports the pump and motor and keep everything in alignment. The movement that a pump can generate can damage the discharge piping if the mounting plate flexes. Secondly, the vibration levels can be very high it the mounting plate is weakened by the heat. Vibration in both the axial and radial directions can cause severe damage to the pump if the mounting plate is weak. Selecting the proper material is critical.

When dealing with high temperature molten salt applications, the type of pumps offered can be categorized into four (4) different pump 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 a EM (Electro-Magnetic) pumps which cannot be used on molten salts. The following is an outline of standard vertical pumps for molten salt applications. It will give general data but it is not related to any specific application.

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.

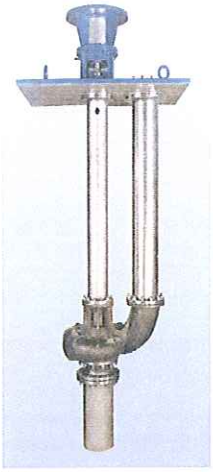
Temperature Ranges	240-350deg C	350-600deg C	600-930deg C	930-1100deg C
Vertical Cantilever	Setting: 2m Med. Flow Med. Head Design: Std.	Setting: 2m Med. Flow Med. Head Design: Mod. Std	Setting: 1m Med. Flow Med. Head Design: Mod.	Setting: .5m Low Flow Low Head Design: Custom
Vertical	Setting: 3m High/Med. 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

Standard High Temperature Pumps Designs

GVSN

RCEV

GVRN

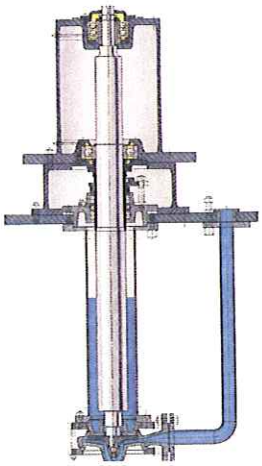


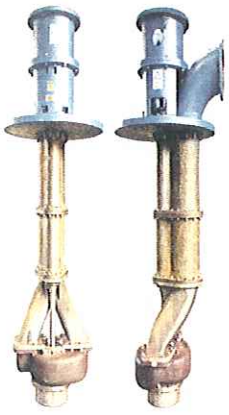
Vertical Cantilever Pumps offer many different features such as several types of mounting arrangements. In tank mounting as well as mounting the pump outside of the tank gives system designers great flexibility. Vertical Cantilever pumps have no bearings below the main mounting plate. Cantilever pumps only offer single volute designs. Disassemble of the vertical cantilever pumps is the easiest of all four designs.

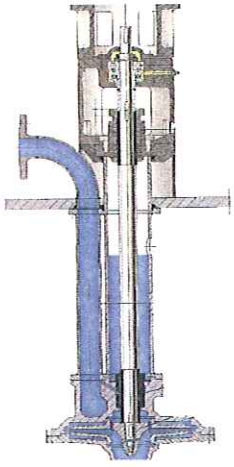
Vertical Pumps have a lower radial bearing. They also have several mounting arrangements, both inside the tank and outside of the tank. Vertical pumps can offer multi-stage volutes as an option. They have longer settings than the cantilever but are more difficult to disassemble.

Vertical Submerged Bearing Pumps are the longest design offered. They can only be mounted in the tank. Vertical Submerged Bearing pumps can offer multi-staged volutes. They 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 with out removing the suction and discharge piping. Axial Flow pumps of this type can only be mounted with the shaft in a vertical up position. Disassembly of this pump is one of the easiest pumps to rebuild.







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 reason. The first is that this area becomes part of the cool down transition section of the pump. This area can become a major problem if it is not design properly. Molten salt will climb the shaft and work its' way into this area, solidifing and freezing up the rotating assemble if this area is too cool or spraying molten outside of the tank creating an unsafe and danagerous situation if the area is too hot. This area can be 4-6 inches in length for tank mounted pumps and as much as 4-10 feet for pump 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 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 maybe required. The size and design of the screws and flingers will vary based on the temperatures and type of salt 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 to be used to cool the shaft if the pump sets idle for long periods of time.

Failure Mode Analysis

Identifing the primary failure modes of your molten salt pumps will help define the Predictive Maintenance Program requirements needed to insure a trouble free system.
All systems are different. An evaluation of the design of pump used in your system, what the operational secquence is and the general site condition will define the failure modes. The major areas that need 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 needs to 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. This will save many hours of lost production.

Monitoring of Molten Salt Pumps

Monitoring of Molten Salt Pumps is a critical part of a predictive maintenance program. Predictive Maintenance programs are 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, horse power and visual inspections all provide necessary input to condition monitoring. Any successful predictive maintenance program, not only has a technical element, but also has a

human element where experience and knowledge in evaluating the techical data work together to maintain a trouble free molten salt system.

Important Things to Remember

When designing your molten Salt System, keep in mind that the pump will be the Heart of your system. This single piece of equipment is one of the most critical components of your system, if it does not operate properly, your system will have major problems or even fail. Having the pump manufacturer as part of your design team as early as possible will be very effective in eliminating costly mistakes. The experience of the pump manufacturer in handling various molten salt applications is the key to applying the proper design and proven technology to your system. Both the selection of materials of construction and the design must be based on actual experience and proven design features. Be sure that the pump manufacturer that you select has the 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 support you with the correct condition monitoring systems, predictive maintenance programs and proven repair procedures.

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