HIGH TEMPERATURE TWIN SCREW PUMPS

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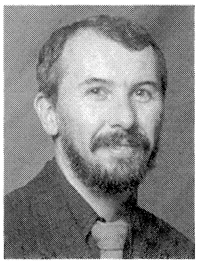

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ABSTRACT

High temperature applications present many engineering problems. Thermal growth of piping and vessels, coupled with typically lower viscosities at high temperature, has made centerline mounted centrifugal pumps the primary choice in hot applications. Two screw pumps offer extended viscosity ranges, can handle entrained gases, and require less inlet pressure than centrifugal pumps. Two screw pumps have earned a reputation of reliability over several decades of high temperature service in demanding applications.

CENTRIFUGAL PUMPS

Centerline mounted centrifugal pumps are designed to grow radially from their shaft centerline outwards. Internal operating clearances are large relative to the thermal expansion. These pumps have a good reputation for being reliable performers and work well in many installations.

Centrifugal pumps can handle a wide range of operating conditions. They can run on viscosities ranging from less than one centipoise solvents to several hundred centipoise. Single stage pumps can handle high flowrates at relatively low heads, and multistage pumps can handle high head applications. These pumps are relatively inexpensive and should be the first choice when application requirements can be met.

Centrifugal pumps do become limited when viscosities rise above a few hundred centipoise. The pump head, capacity, and efficiency all fall until the pump can no longer get fluid into the impeller. Conditions at startup may include viscosities beyond the capability of a centrifugal pump, even though the centrifugal could handle the normal operating mode. On systems that have very few shutdowns, it may be practical to have an auxiliary system dedicated to bringing the main system on line.

Centrifugal pumps operate on a head-capacity curve. When system pressures change, the flowrate changes. For transfer services this is acceptable, but it leads to difficulty in controlling exothermic reactions. The ability to control flow independent of pressure adds safety and control to batch reactor operations.

Net positive suction head limitations are common in high temperature applications due to boiling points of some constituents. In tower or reactor applications, the NPSH available may only be the static height of the liquid. If there is any viscosity to the fluid, centrifugal pumps may not be able to operate without cavitation. Positive displacement pumps typically have much lower inlet requirements than centrifugal pumps.

Entrained gas can cause problems for centrifugal pumps. As the fluid enters the eye of the impeller, the pressure drops and the entrained gas expands. The gas has a low density, so the impeller cannot add enough kinetic energy to exit the impeller and enter the volute. The impeller becomes vapor bound and the pump stops pumping. Screw pumps can operate successfully with entrained gas because they move a volume by enclosing it rather than accelerating it.

TWO SCREW PUMPS

When the above limitations are encountered, a centrifugal pump can no longer meet the application demands. At that point, a two screw pump should be considered. Two screw pumps are a more complex piece of machinery than single stage centrifugal pumps, but when the above limitations are encountered, the system is already a fairly complex environment. The addition of a two screw pump can simplify the operation of the system by maintaining a constant flowrate while other variables change.

Two screw pumps have been around since the early 1950s. They have been used in high temperature applications for almost as long. Asphalt transfer was one of the early applications. As the chemical industry expanded in the 1970s, new applications arose. Polymers, rubbers, and adhesives were manufactured in many locations and by many different methods. Currently, there is a move toward large facilities devoted to individual products. This requires large scale equipment with greater reliability. The foreseeable future includes more exotic materials and greater environmental controls.

TYPICAL REFINERY SERVICES

Asphalt transfer is a typical high temperature two screw pump application. Temperatures range from 300°F to 500°F (150°C to 260°C) and viscosities range from 100 to 5000 SSU (20 to 1000 cp). Flowrates are from a few hundred to a few thousand gallons per minute at discharge pressures of 100 to 200 psig. Two screw pumps can handle the normal range of operations and also the upset conditions encountered when the asphalt starts to cool down. As the temperature drops, the viscosity rises rapidly. If the asphalt cannot be pumped out, the vessel or container is at risk of having the asphalt solidify. Two screw pumps become more efficient as the viscosity increases and the discharge pressure increases, whereas a centrifugal pump would lose capacity, efficiency, and start cavitating.

Hydrocarbon processing utilizes two screw pump technology at the end of the refining process. Vacuum tower bottoms is a service characterized by very low net positive inlet pressure available ($NPIP_A$), low to moderate viscosities, and the potential for entrained gases. During steady state operation, the available suction pressure is only the static height of fluid in the tower. Viscosity is low and discharge pressure is low. When the viscosity increases, either due to lower temperature or heavier crude oil, more gas is entrained in the higher viscosity fluid. Discharge pressure also rises due to additional pipe friction loss at the higher viscosity. Startup conditions can include low or high viscosity depending on the system, and upset conditions can encompass very high viscosities. Two screw pumps often have drivers sized for the worst upset condition so the system can be restarted even at ambient temperatures.

The Rose process is an asphaltene process that operates at relatively high temperature, viscosity, flowrate, and pressure. Typical values are 550°F, 1000 to 4000 cp viscosity, 2000 gpm, and 500 psi pressure. These conditions are well suited to two screw pumps, and mechanical efficiencies at these conditions are typically 70 to 80 percent overall efficiency.

TYPICAL CHEMICAL SERVICES

High viscosity polymers dominate the chemical applications for high temperature two screw pumps. Many polymers have low viscosity solvents in the reaction, and these solvents have high vapor pressures at elevated temperature. The inlet pressure may be substantial, but the $NPIP_A$ is only the static height of fluid in the reactor. The reactions are frequently exothermic and require a pump to circulate the product from the reactor vessel, through a heat exchanger, and back to the reactor vessel. The pump must be capable of handling very low to very high viscosities with very low $NPIP_A$. Batch reactors also need to be pumped out after each batch so the pump must be able to strip the vessel and run dry. Solvent or caustic cleaning cycles are required. All wetted components are usually stainless steel or other corrosion resistant materials.

Polymers that are manufactured with solvents frequently have an evaporator draw off service. This process involves subjecting the product to high temperature and high vacuum in an attempt to boil the solvent phase out of the polymer. The polymer product is removed from this process by a two screw pump operating on high viscosity polymer with very low $NPIP_A$. Center suction, hopper style pump suction inlets have handled inlet pressures below one psia.

Many polymers are shear sensitive. If the product is exposed to high shear rates, the desired physical properties may be changed. Emulsions are sensitive to droplet size and dispersion. Two screw pumps are successful in these applications due to the laminar flow of the product within the pumping cavities. There is very little mixing in the pumping action so the physical properties of the product are not altered.

Polyester manufacturing plants are being designed with higher capacities, but they still require constant flowrates as variables change. Larger pumps have been designed to accommodate these services with flowrates of several thousand gallons per minute of hot, viscous product. Due to the nature of the system, component reliability was the primary concern in the design of the pump and pump systems. One pass flow through a system also means that failure of any one component in that system stops the entire system.

The hot melt adhesives industry uses two screw pumps to manufacture and convey their products. The ability to operate on a wide range of viscosities makes the system less sensitive to variations in temperatures.

Nylon manufacturers use two screw pumps in the extrusion process. Hot nylon is pumped against a die head and extruded into a cooling system. The pumps are required to operate at a constant flowrate, although the viscosity varies and the resistance from the die head decreases with time, as the extrusion ports wear and open up.

DESIGN CONSIDERATIONS FOR HIGH TEMPERATURES

High temperatures, usually considered to be above 300°F, require consideration to thermal expansion. The piping system must be supported in such a manner as to minimize suction and discharge flange loading forces and moments. In systems that have large expansions, the pump baseplate is mounted on constant force supports that allow the baseplate to free float with the piping. This not only reduces piping strain, but adds the feature of lowering the pump baseplate to allow for easier pump removal. Spring supports can be used in place of constant force supports, if the spring load is within flange loading limits.

The pump is mounted on the baseplate with a locating pin on the coupling end and slot mounted feet on the outboard end. This allows the pump to expand axially without imposing a buckling force on the pump body. The locating pin is mounted on the pump centerline, and all growth is from that fixed location. The rear feet are mounted with a slot and guide and secured with clearanced bolts that allow the feet to slide along the slot as the body lengthens.

Internally, the drive shaft is retained axially by a double row ball bearing type thrust bearing. This bearing establishes the axial position of the drive shaft within the body and all growth of the shaft is from that fixed location. This thrust bearing is at the outboard end of the pump, so there is an axial growth toward the pump coupling. The coupling has sufficient gap to accommodate the growth.

The driven shaft is positioned within the body by the use of herringbone timing gears. These gears establish both the rotational relationship between the two shafts and also the axial positioning of the driven shaft relative to the drive shaft. The driven shaft is supported by roller bearings and all axial growth is from the center of the timing gear. The timing gears are positioned adjacent to the thrust bearing on the drive shaft.

Radial growth due to thermal expansion requires adjustment of the screw outer diameters and the shaft hub diameters. The parallel shafts are supported in bearing brackets. The bearing brackets are cooled by a lubrication system that cools and circulates the lube oil to the gears and bearings. This keeps the shafts at a constant distance between shaft centerlines. Both shafts grow radially from their centerlines, so the outer diameter of one shaft grows toward the hub of the other shaft. The hub is also growing outwards so the clearance between the hub and outer diameter of the other screw (root clearance) needs to be increased for the required clearance at maximum temperature.

The body bore is a figure eight shaped bore that houses the two meshed screws. When the body bores are heated, the diameter of each bore increases and the distance between the centers of each bore increases. This is different from the screw shafts that are supported in cooled bearings. As the temperature increases, the overall clearance between the screws and the bores increases due to the growth of the bore center distances relative to the shaft center distances. The bore diameter and the screw diameter both grow at similar rates (if similar materials are used), but the total amount of area between the screws and bores increases.

The screws are completely surrounded by the pumped fluid and stabilize dimensionally at that temperature. The screws will attain the temperature of the pumped fluid very rapidly due to the high heat capacity of most fluids and the high flowrate around the screws. Changes in the temperature of the pumped fluid will affect the screw dimensions more rapidly than they would affect the body bore dimensions. The body is only bounded by the pumped fluid on one side, and that has a relatively small wetted area compared to the wetted area of the screw. The outer side of the body bores is either surrounded by a heating jacket or insulation. If there is a difference in temperature between the jacket heating fluid and the pumped fluid, the body will stabilize dimensionally at an intermediate temperature.

OPERATIONAL CONSIDERATIONS

The startup procedure for most high temperature systems needs to define how the system is brought up to temperature and how quickly it is brought up to temperature. Some systems can be started at ambient temperature, and then create their own heat. This is frequently the case with batch reactors designed for exothermic reactions. There is enough mass circulating in the system that the changes in temperature occur gradually, and all components of the system heat at the same rate. At the end of the batch, the procedure should address the rate and means of cooling prior to the start of the next batch.

Systems that are designed to operate at a steady state hot condition usually require a system preheat prior to starting the system. In these systems, the preheating is frequently done with steam or hot oil. The entire system needs to be heated uniformly to avoid any thermal stresses in unheated or overheated areas. The process fluid should be as close to preheat temperature as possible to avoid any thermal shock at startup.

One system at a large chemical plant was designed to preheat the sections of the system where high temperatures were encountered. The system was steam heated for several hours to allow a thorough heat soak. Before the system was started, the mechanical seals were hydrotested and held pressure as required. At startup, the mechanical seals rapidly started leaking, causing the system to be shut down. After a short time, the seals were again hydrotested and again held pressure as required. The system was restarted with identical results. A review of the startup procedure revealed that the upstream portion of the system was preheated with hot oil rather than steam. The two sections of the system were preheated to different temperatures. The upstream portion was considerably cooler than the steam heated section. When the cooler process fluid entered the screws, the shafts contracted, pulling the mechanical seal faces open and causing the leak. As soon as the system was stopped, the process fluid in the pump was heated to the surrounding steam temperature, the shafts grew to their previous length, and the mechanical seal leak disappeared. The solution to this problem was to preheat both portions of the system with the same preheat source so that the entire system would be at the same temperature. When this change was implemented, the system was started successfully.

Shut down procedures need to address the possibility of products solidifying at ambient temperatures. If the system can be preheated thoroughly, it may be acceptable to let the system solidify and just allow sufficient preheat before startup. Other systems may require some form of emptying or diluting to reduce viscosities to acceptable ranges when the system is at ambient temperature. Mechanical seals may require a flush, quench, or both; or double mechanical seals with a separate barrier system may be required.

PUMP PERFORMANCE EFFECTS

The operating temperature will affect the hydraulic performance of two screw pumps. As previously noted, there is a change in clearance area between the screw outer diameter and the bore inner diameter and the change in center distances. This change in clearance area affects the slip or internal recirculation within the pump. The internal recirculation or slip is a function of clearance area, viscosity, and differential pressure. When pumping high viscosity fluids, this change in area will not significantly impact pump performance. The difference in performance is evident on low viscosities, such as solvents, or on high pressures. When a pump is intended to operate under several different sets of conditions at different temperatures, the operating conditions should be identified and defined such that operational guidelines can be established.

Refinery services, where the highest viscosities are encountered at ambient temperature startup, may require a low speed start at low pressure to get the product moving and heating. Once the system is started and warmed, the speed may be increased to normal. This can be done with two speed motors, gears, or variable speed drivers.

Chemical services, where solvents are frequently used in cleaning cycles, may have reduced pressure limits for operating on solvents. This is normally not a problem as pressure is a function of piping loss, which is reduced at low viscosities.

CONCLUSIONS

Two screw pumps have capabilities beyond the operating range of centerline mounted centrifugal pumps. Two screw pumps can handle the high viscosity, entrained gas, and low $NPIP_A$ conditions of many high temperature applications. The advantage of constant flow under varying operating conditions gives greater control to already complex systems.

The system designer and the pump manufacturer need to understand the full range of requirements and capabilities. The startup, operating, and shut down procedures need to be established and reviewed to assure reliable operation.

Two screw pumps have been operating in high temperature environments for several decades. They have proven to be reliable components of complex systems and have given greater latitude to system designers through greater process capabilities.

NOMENCLATURE

Bore	=	The figure eight shape housing that the screws are in. The bore is located between the suction and discharge.
Clearance	=	The area between moving components.
Entrained gas	=	Bubbles of gas that are trapped in a liquid due to the viscosity of the fluid. This is different from bubbles of vapor that form when pressure falls below the vapor pressure. Entrained gas does not collapse back to liquid as pressure increases, it only compresses.
Flank clearance	=	The area between the helical flights of the two screws when meshed.
$NPIP_A$	=	Net positive inlet pressure available. This is the total pressure at the pump inlet, minus piping friction losses at rated flowrate, minus the vapor pressure. It is the same as net positive suction head available ($NPSH_A$), but is reported in units of psi instead of feet of liquid.
$NPIP_R$	=	Net positive inlet pressure required. This is the minimum pressure required to avoid cavitation and reduction of capacity.
OD clearance	=	The area between the outer diameter of the screw and the inner diameter of the bore. It can be expressed as total (diametral) or radial.
Root clearance	=	The area between the outer diameter of one screw and the hub of the other screw when the two screws are meshed.
Screw	=	The helical thread portion on the shaft. The two screws mesh together in the bore.

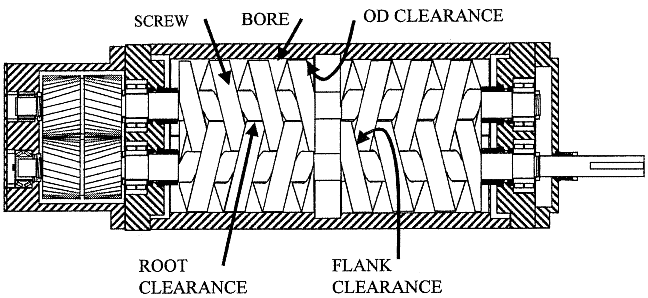

Figure 1. Screw Pump Nomenclature.

APPENDIX

Performance at Different Operating Temperatures

The graphs in Figures 2, 3, and 4 show the change in performance for operating at different temperatures. The pump is designed for operating at 700°F, and clearances have been adjusted accordingly. The top line in each graph represents a pump with standard clearances operating at 80˚F for comparison. The change in performance is most noticeable at lower viscosities and higher pressures. Note the change in scale on the vertical axis. Figure 2 is low viscosity (10 cp), Figure 3 is at 200 cp, and Figure 4 is at 20,000 cp. Viscosities of several million cp are possible with two screw pumps.

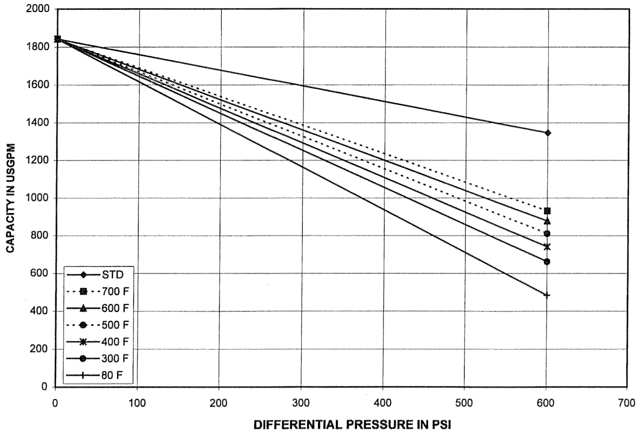

Figure 2. Pump Performance at 10 CP.

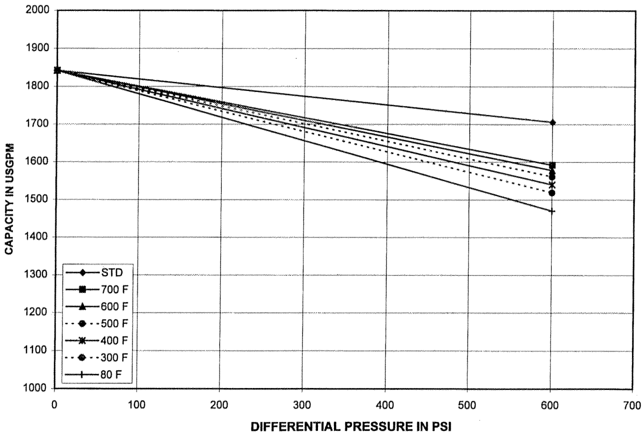

Figure 3. Pump Performance at 200 CP.

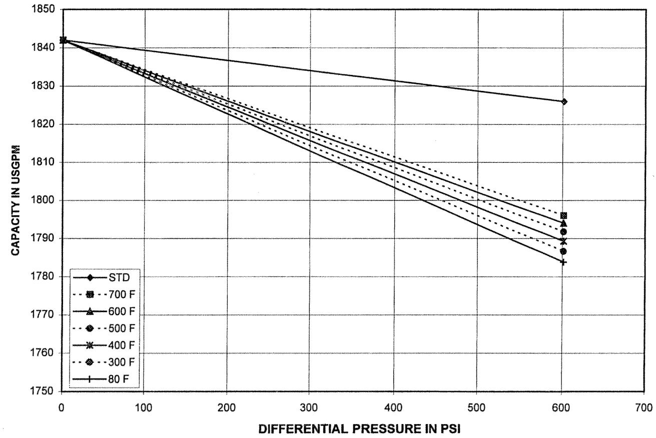

Figure 4. Pump Performance at 20,000 CP.