High Performance Rotary Screw Pumps

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Rotary screw pumps have existed for many years and are manufactured around the world. More demanding service requirements impose challenges on screw pump manufactures to provide higher pressure or flow capability, better wear resistance, improved corrosion resistance and lower leakage emissions. Better materials and more precise machining techniques as well as engineering innovation have led to improvements in all these areas.

The first screw pump built was probably of an Archimedes design used to lift large volumes of water small vertical distances; they are still manufactured and used for this service. Today's three screw high performance pump can deliver liquids to pressures above 300 Bar and flows to 750 m^3/h with long term reliability and excellent efficiency. Twin screw pumps are available for flow rates to 4000 m^3/h, pressures to 100 Bar and can handle corrosive or easily stained materials, again at good efficiencies.

Single screw pumps, also known as progressive cavity pumps use an elastomeric stator and a flexible joint eccentric rotation metallic screw. They are most commonly used for high solids content, viscous flows such as sewage, cement and other difficult slurries. They are not included in this discussion as their design and application bear little resemblance to multiple screw pumps.

THREE SCREW PUMPS–PRINCIPLE APPLICATIONS

Three screw pumps are the largest class of multiple screw pumps in service today. They are commonly used for machinery lubrication, hydraulic elevators, fuel oil transport and burner service, powering hydraulic machinery and in refinery processes for high temperature viscous products such as asphalt, vacuum tower bottoms and residual fuel oils. Three screw pumps also find extensive use in crude oil pipeline service as well as gathering, boosting and loading of barges and ships. They are common in engine rooms on most of the world's commercial marine vessels and many combat ships. Subject to material selection limitations, three screw pumps are also used for polymer pumping in the manufacture of synthetic fibers such as nylon and lycra. Designs are now available in sealless configurations such as magnetic drives and canned arrangements, figure 1. The magnetic drive screw pump is used extensively for pumping isocyanate, a plastic component which is an extremely difficult fluid to seal using conventional technology. Three screw pumps are renowned for their low noise levels, high reliability and long life. They are not, however, very low cost pumps.

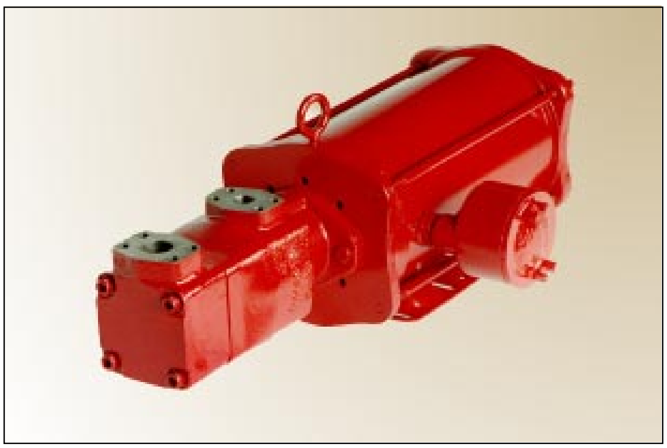

Figure 1 Sealless Canned Three Screw Pump

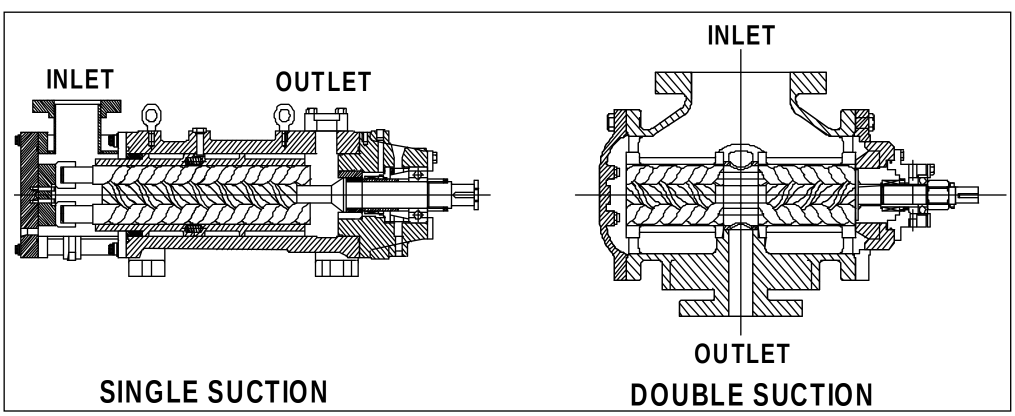

Figure 2 Conventional Three Screw Pump Designs

DESIGN AND OPERATION

Three screw pumps are manufactured in two basic styles, single suction and double suction, figure 2. The single suction design is used for low to medium flow rates and low to very high pressure. The double suction design is really two pumps in parallel in one casing. They are used for medium to high flow rates at low to medium pressure.

Three screw pumps will generally have only one mechanical shaft seal and one, or perhaps two, bearings that locate the shaft axially. Internal hydraulic balance is such that axial and radial hydraulic forces are opposed and cancel each other. Bearing loads are thus very low. Another common characteristic of three screw pumps is that all but the smallest, low pressure designs incorporate replaceable liners in which the pumping screws rotate. Thus, field repair is a simple matter.

The center screw, called the power rotor, performs all the pumping. The meshed outside screws, called idler rotors, cause each liquid-holding chamber to be separated from the adjacent one except for running clearances. This effectively allows staging of the pump pressure rise, figure 3.

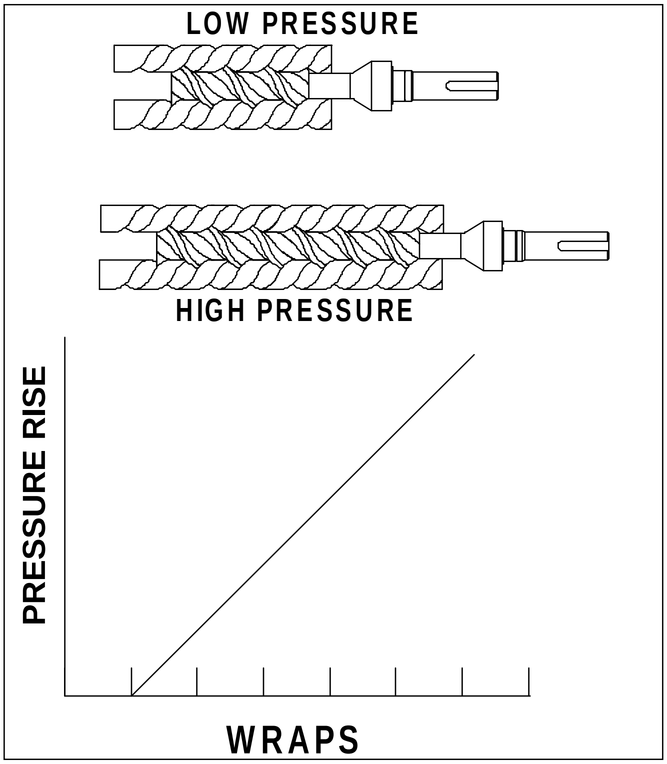

Figure 3   Staging Effects of Screw Pumps

High pressure pumps may have as many as 12 stages while low pressure pumps may have only two or three. Because the center screw is performing all the pumping work, the drive torque transferred to the idler rotors is only that necessary to overcome viscous drag of the cylindrical rotor spinning within its liner clearance. The theoretical flow rate of these pumps is a function of speed, screw set diameter and the lead angle of the threads. Basically, flow rate is a function of the cube of the center screw diameter. Slip flow, the volumetric inefficiency due to clearances, differential pressure and viscosity, is a function of the square of the power rotor diameter. This results in larger pumps being inherently more efficient than smaller pumps, a fact that applies to most rotating machinery.

Speed is ultimately limited by the applications capability to deliver flow to the pump inlet at a sufficient pressure to avoid cavitation. This is true of all pumps. Three screw pumps tend to be high speed pumps, not unlike centrifugal pumps. Two pole and four pole motors are the most common used. When large flows, very high viscosities or low available inlet pressures dictate, slower speed may be necessary. For example, some polymer services handle liquid at 50,000 centistokes or more. Three screw pumps on such service would typically be operated in the 50 to 150 rpm. Gas turbine fuel injection service would more commonly be in the 3000 to 3600 rpm range since the fuels tend to be low in viscosity, 1 to 20 centistokes, and the pump inlet is normally boosted to a positive pressure from a fuel treatment skid pump. The high speed operation is desirable when handling low viscosity liquids since the idler rotors generate a hydrodynamic liquid film in their load zones that resists radial hydraulic loads, very similar to hydrodynamic sleeve bearings found in turbomachinery.

In order to achieve the highest pressure capability from three screw pumps, it is necessary to control the shape of the screws while under hydraulic load. This is best achieved by the use of five axis NC profile grinding which allows complete dimensional control and a high degree of repeatability. Opposed loading of the idler rotor outside diameters on the power rotor root diameter dictate that these surfaces be heat treated to withstand the cyclic stress. Again, profile thread grinding allows the final screw contour to be produced while leaving the rotors quite hard, in the order of 58R (58 on the Rockwell C scale). This hard surface better resists abrasive wear from contaminants, typical of crude oil transport.

As versatile as three screw pumps are, there are some applications for which they are not suitable. While many advances in materials engineering are taking place, the state of the art for three screw pumps is such that very corrosion resistant materials such as high nickel steels have too great a galling tendency. The rotors of three screw pumps touch and thus any materials that tend to gall are unsuitable. Unfortunately, this includes many corrosion resistant materials. Viscosities too low to allow hydrodynamic film support generation are also application areas for which the three screw pump is not optimal.

TWO SCREW PUMPS – PRINCIPLE APPLICATIONS

Generally, two screw or twin screw pumps are more costly to produce than three screw pumps and thus are not in as extensive use. They can, however, handle applications that are well beyond many types of pumps including three screw designs. Twin screw pumps are especially suited to very low available inlet pressure applications and more so if the required flow rates are high. Services similar to three screw pumps include crude oil pipelining, refinery hot, viscous product processing, synthetic fiber processing, barge unloading, fuel oil burner and transfer as well as unique applications such as adhesive manufacture, nitrocellulose explosive processing, high water cut crude oil, multiphase (gas/oil mixtures) pumping, light oil flush of hot process pumping, cargo off-loading with ballast water as one of the fluids, tank stripping service where air content can be high and paper pulp production needing to pump over about 10% solids.

DESIGN AND OPERATION

The vast majority of twin screw pumps are of the double suction design, figure 4. The opposed thread arrangement provides inherent axial hydraulic balance due to its symmetry. The pumping screws do not touch each other and thus lend

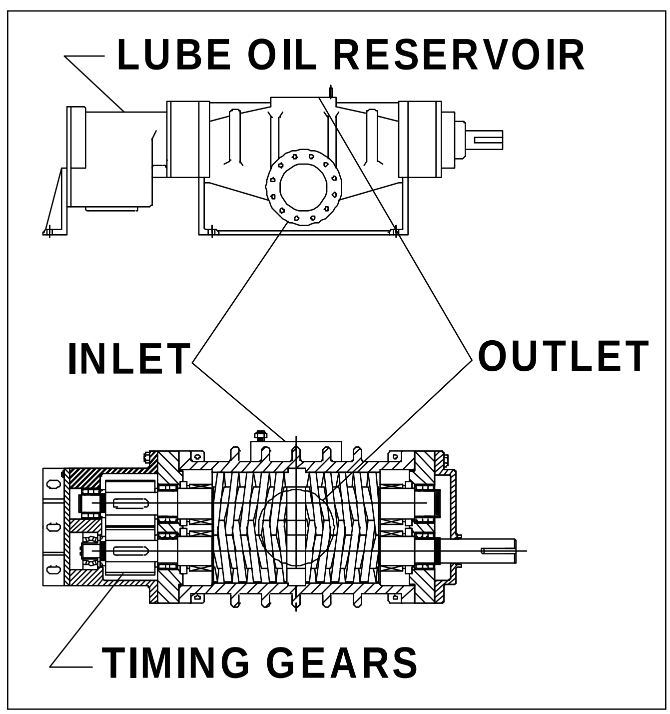

Figure 4   Twin Screw Pump Construction

Figure 5   Hard Faced Twin Screw Outside Diameter

themselves well to manufacture from corrosion resistant materials. The timing gears serve to both synchronize the screw mesh as well as to transmit half the total power input from the drive shaft to the driven shaft. Each shaft effectively handles half the flow and thus half the power. Each end of each shaft has a support bearing to react the radial hydraulic loads which are not otherwise balanced. A few designs leave the bearings and timing gears operating in the liquid pumped. While this results in a significantly lower cost pump design, it defeats much of the value that twin screw pumps bring to applications. The more common and better design keeps the timing gears and bearings external to the liquid pumped. They need not rely upon the lubricating qualities of the pumped liquid nor its cleanliness. Four mechanical shaft seals keep these bearings and timing gears isolated and operating in a controlled environment.

Twin screw pumps are manufactured from a broader range of materials including 316 stainless steel. When extreme galling tendencies exist between adjacent running components, a slight increase in clearance is provided to minimize potential for contact. In addition, the stationary bores in which the screws rotate can be provided with a thick industrial hard chrome coating which further reduces the likelihood of galling as well as providing a very hard, durable surface for wear resistance. Such coatings do, however, require the capability of inside diameter grinding to achieve finished geometry within tolerances. For highly abrasive services, the outside diameter of the screws can be coated with various hard facings to better resist wear. Among these coatings are tungsten carbide, stellite, chrome oxide, alumina titanium dioxide and others. Figure 5 shows a finished screw with a hard surfaced outside diameter. Note the balance holes drilled into the screw. This is a single thread start rotor and requires dynamic balance to keep vibration levels low. Double thread start rotors are in nearly perfect dynamic balance due to their symmetry and such pumps do not normally require dynamic balance. Both single and double thread starts are used depending on pump displacement and number of stages. As in three screw pumps, twin screw pumps use the staging effect to both minimize rotor deflection under pressure and to provide a longer leak path for internal slip to maintain good efficiencies.

Typical multiple screw pump performance is illustrated in figure 8. The high efficiency performance is a clear advantage over centrifugal pumps where liquid viscosity exceeds 20 centistokes. For pressures requiring two or more stages in a centrifugal pump, multiple screw pumps will frequently be very competitive on a first cost basis as well. Operating liquid temperatures as high as 315 ^{0}C have been achieved in twin screw pumps for the ROSE® deasphalting process, figure 9. Timing gears and bearings are force cooled while the pump body is jacketed for a hot oil circulating system to bring the pump to process temperature in a gradual, controlled manner. Three screw pumps have been applied to the same elevated temperature, more commonly on asphalt or vacuum

Figure 6 Final Inspection of Stainless Steel Adhesive Process Pump with Thermal Compensation Mounts

Figure 7 Diesel Engine Driver 100 Bar Crude Oil Pipeline Screw Pump in Guatemala, Central America

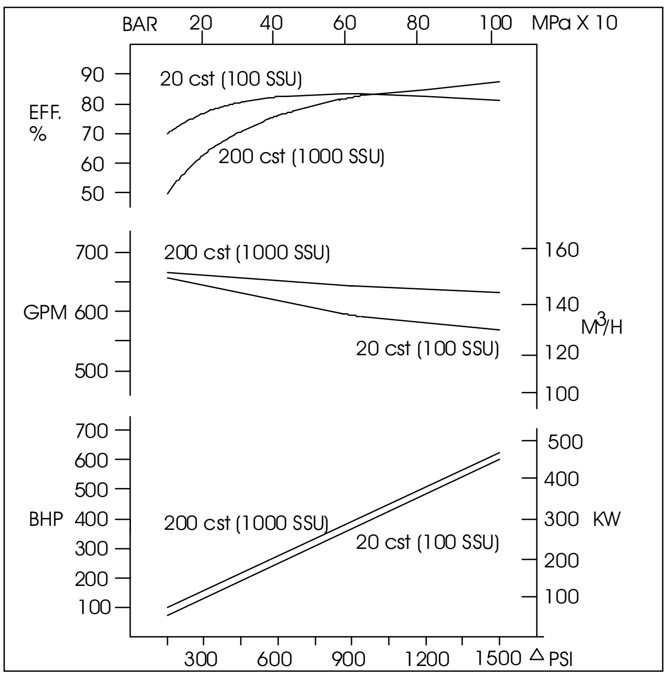

Figure 8 Typical Multiple Screw Pump Performance

tower bottoms services in refineries. Multiple screw pumps for virtually all refinery or petrochemical services are provided in general accordance with API (American Petroleum Institute) standards, frequently modified to suit the end user or engineer/constructor specifications.

Medium and high viscosity operation are not the only regions where multiple screw pumps bring advantages to the end user. Low viscosity combined with high pressure and flows less than approximately 100 m^3/h are excellent screw pump applications. Continuous, non-pulsating flow is required, for example, in high pressure atomizers for fuel combustion.

Combustion gas turbines frequently burn distillate fuels, naphtha and other low viscosity petroleum liquids that may reach 1 centistoke or less and require pumping pressures in the 65 to 90 Bar range. The combination of modest flow, low viscosity and high pressure is a difficult service for all but reciprocating pumps. the pressure and flow pulsation from reciprocating pumps usually cannot be tolerated in fuel burning systems, especially combustion gas turbines.

Figure 9 Rose® Process Twin Screw Pump for 315°C Asphaltene Service

Ongoing research and development efforts will further extend the capabilities of these machines allowing better performance over a broader range of applications. Multiple screw pumps are uniquely suited to many of the applications described herein and offer long term benefits to their users.

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