Peerless Pump
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Pumping Abrasive Mixtures with Vertical Turbine Pumps

When dealing with abrasive slurries there are several mechanical problems to be considered.

Recent developments and experience show that the vertical turbine pump performs well in many difficult applications, not the least of which is pumping a wide range of slurries. Slurries have been defined as "any liquid with solids present in more than trace amounts".[1] In the vast majority of cases the solids are abrasive to some degree. The abrasive nature of the solid-liquid mixture is often the primary cause of problems related to the useful operating life of the pumping equipment.**

Slurrys and Equipment Life. The life of the equipment is affected by the physical makeup of the slurry. The solid-liquid mixture may be:[2]

(1) Homogeneous as in clays, fine ash, catalytic fines, powdered coal, etc., with particle sizes up to 30 microns (0.0012 in.).
(2) Heterogeneous as in powdered coal, fine sand, catalytic fines, etc., with particle sizes up to 0.2 mm (0.008 in.).
(3) Particles that are transported by saltation (rolling or pushing), such as gravel, pulverized coal, salt crystals, etc., with particle sizes above 2.0 mm (0.080 in.).

The particles may be sharp edged or round edged, soft or extremely hard.

The concentration of solids in the slurry is definitely a factor in the life of the pump. Of all the characteristics, the wear effect due to the concentration of solids is the most predictable. Recent studies by the Research and Development group of Peerless Pump led to categorization of the severity of a pump's duty.[3] The categories as simplified, light service, moderate service and severe service, enable engineers to recommend the materials and features of construction pertinent to a specific application.

**In this discussion, no allowance or consideration of corrosion is made. This factor adds considerable complexity to the problem and is not within the scope of this article.

Materials selection charts are being developed to show the recommendations for basic construction. Options are available if there is anticipation based upon experience with the specific solid-liquid mixture, that a substitute is required. In no way can any chart be considered as a "cure-all" for pump construction. The best possible answers will come from experience with successful installations in the fluids being pumped.

Hydraulics. Hydraulic performance in most cases is the basis for the economic evaluation of equipment. With today's rapid increase in the cost of operation and cost of capital invested, the extended best efficiency of pumping is of considerable economic value. Proper application of materials and design features to obtain optimum equipment effectiveness requires extra effort. Several factors to be considered are discussed below.

Specific gravity: Net effective (average) specific gravity affects the brake horsepower required. Peak or maximum concentration of solids must be considered to prevent the possible damaging overload on the motor and overstress on the pump components.

Viscosity or apparent viscosity: The effect of viscosity in the non-Newtonian fluids and mixtures must be considered. High viscous shear characteristics can easily overload and overstress the pump components to the point of failure.

The life of the equipment is affected by the physical makeup of the slurry.

Particle size or range of sizes: Wear rates and the resultant net reduction in hydraulic pumping efficiency are affected by particle size. Particles too large to get into the close clearance spaces between stationary and rotating components are not too serious a problem in the short term. But they are a serious factor in the erosion due to impingement and in the "sliding" erosion in the fluid passages of the pump assembly.

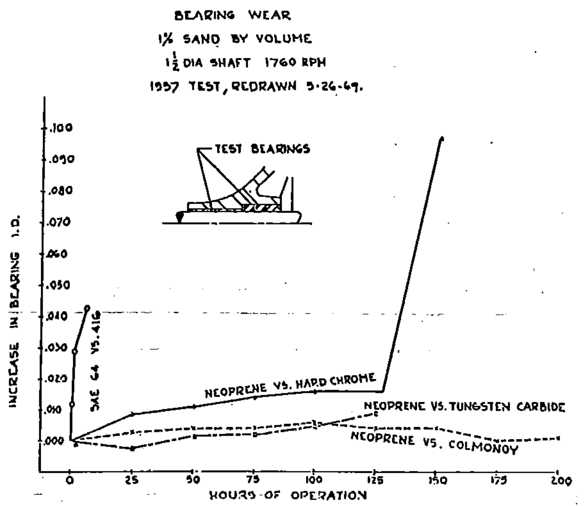

Figure 1a.

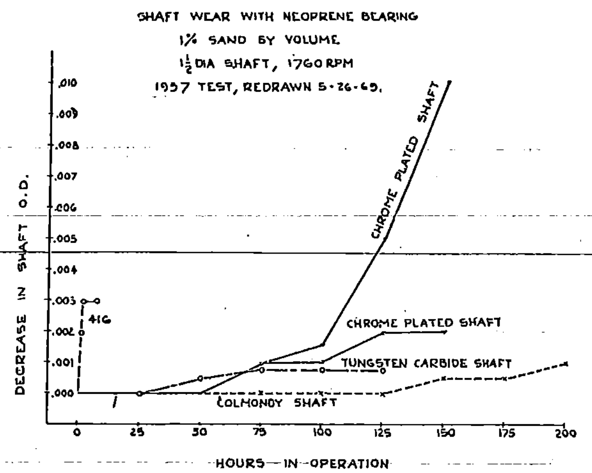

Figure 1b.

Particles of the same size as the running clearances significantly affect the initial wear rates on bearings, shafts, wear rings (enclosed impellers) and vane edges (open impellers). These particles get wedged between the mating parts and cause rapid wear through grinding action.

Particles smaller in their maximum dimension than the running clearances cause wear by erosion only unless the concentration of solids is great enough to cause the particles to pile up and wedge against each other and against the mating surfaces. In that case rapid grinding-type wear will take place.

The most difficult application related to particle size is that in which a wide range of particle sizes exists concurrently. Many pumps have been designed considering the largest particles only, and suffer rapid wear and early failure due to the smaller particles.

The wear due to any form of abrasion usually causes deterioration in the pump hydraulic performance. The most immediate effect is in reduction of the total head developed, or reduced capacity at rated head with the resultant loss in pumping efficiency. This loss is caused by wear ring wear in enclosed impeller construction and by vane edge and bowl seat wear in open impeller construction. The deterioration of performance is compounded by the wear of bearings and shafting. As the bearings wear, the rotating assembly moves off-center, which creates a condition causing further wear of the wear rings or the impeller seat surfaces. The net result is premature maintenance repairs.

Velocity: Wear rates have been estimated to vary as the cube of the velocity up to approximately 100 feet per second flow rates. Therefore, consideration must be given to the pump size and rotating speed, as indicated by the head per stage developed, to avoid excessive wear rates and premature failures.

In many cases a more costly but slower speed pump is a far more economical choice. For instance, on one job, one-stage two-pole pumps were chosen instead of four-pole three-stage units. The service was silty and sandy river water to be raised in several lifts over a mountain. The units were 2,000 horsepower each. After a few months, the customer was faced with extensive and expensive repair costs. Three-stage (lower head per stage) pumps in the same pumping plant were used for six years before repairs were needed.

Enclosed impellers in vertical turbine pumps, though not good for handling fibrous and stringy particles, in pumping other types of particles, can be advantageous. After wear takes place on the side seals (wear rings) and the hydraulic output has fallen off, the performance can be brought back to near normal by utilizing the end seal of the impeller skirt. This is accomplished simply by readjusting the top shaft adjusting nut to lower the impeller to a position with minimum clearance above the lateral wear rings. Many units have had useful and efficient performance extended additional months and years because of this feature. Also, after extensive wear, repair on enclosed construction is usually considerably less costly than the replacement of major components in open impeller construction.

Column pipe velocities: Flow velocity must be high enough to prevent solids from settling to the bottom while within the realm of minimal friction loss for best overall operating efficiency. The optimum velocity will depend on the characteristics of the solids involved.

Pressure: Pressure in itself is not a factor in vertical turbine pumps except in the area of sealing the rotating element from leakage to the atmosphere. Turbine pumps can be "staged" to achieve the desired pressures, thereby keeping internal velocities lower than those required by single stage horizontal centrifugal pumps. This minimizes internal abrasive wear caused by high velocity flow.

Abrasive wear in the packing boxes or in the mechanical seal assemblies is seriously affected by pressure. Clean flushing liquid will protect both the sealing device and the bearing normally found in the assembly.

Mechanics of construction. In addition to the hydraulic performance problems due to abrasive wear there are several mechanical problems to be considered.*

Wear Rings: Wear rings take the wear from abrasion, preventing damage to the major components and minimizing repair costs. But they do wear out. In the applications where the wear ring material is to be the same as its mating component (example: 316 S.S. impeller wear ring and 316 S.S. impeller) wear rings

***The discussion is limited to the effect on the pumping equipment. Side effects must be considered by the purchaser.**

should **not** be included in the original construction. Machining during repair is normally required in any event. Each pump manufacturer will furnish the details for installing wear rings so the original component can be machined to proper dimensions for installing the rings at time of repair. This suggestion, of course, cannot be followed when the original unit is built with wear ring material different than the major component.

Wear ring material hardness varies widely depending on the application. Some examples: 316 S.S. at 200 Brinell may serve well in a very low concentration of small, relatively soft particles; 410 S.S. heat treated to 37Rc (350 Brinell) in silts, sands and similar particles; and tungsten carbide coated rings with a hardness of 90 Ra (in the range of 900 Brinell) for very hard, sharp particles.

Bearings: Wear on the pump shaft occurs concurrently with the bearing wear. This can lead to very early failure and to extensive damage to equipment if proper precautions are not taken. Bearings must be protected if at all possible. Many installations in the field and in abrasion testing facilities continued to operate long after wear rings and major components were virtually destroyed as long as the bearings and shafting remained in good condition.

Erosive Wear: Wear from abrasive erosion is the least difficult to control, but it must not be overlooked. To use extensive precautions on bearings, wear rings, shafting, etc. and then have holes wear through in the pump bowls and impellers would be illogical. Proper materials and/or protective coatings are easily obtainable.

The most frequent failures due to erosion in vertical turbine pumps occur in impellers where velocity is the greatest. Centrifugal separation of the solids from the liquid causes channeling. Channeling occurs in impeller and in the fluid passages of the bowls. Wear takes place both in the vanes and in the shell, or body, of these parts.

Most designs continue to function to some degree even after impeller vanes and diffusor vanes are cut all the way through between passages. Ultimate failure occurs when penetration through the shell of the bowl is complete. Then the additional wear rate opening up the hole is very high and immediate shutdown is required.

Construction Features: Sealing. The most sensitive part of the vertical turbine pump is the area around the shafting where the pump discharge pressure is sealed off from the atmosphere. Several methods of sealing are available depending upon the basic construction of the pump. In the open lineshaft construction possible methods include: (1) a series of labyrinth rings with by-pass bleed-off back to the sump, (2) a packing box with packing rings that rub on the shafting, or (3) a mechanical seal.

Each comes in a variety of forms but is limited in use by the characteristics of the abrasive particles. Very few applications of labyrinths are successful in handling abrasives. The costs of extremely hard materials required will most often defer their use in favor of a more economical system.

Packing boxes are the most common system in use today. Development of hard materials and new techniques to make sleeves and to apply coatings have extended the life of the equipment. Materials such as aluminum oxide, chromium oxide, tungsten carbide, etc., can now be sprayed onto shafts, packing sleeves, and bearing journals in commercial production. An excellent packing box design might include:

1) A tungsten carbide sleeve-type bearing.
2) A ceramic or a tungsten carbide-coated, replaceable sleeve through both the packing and the bearing and
3) A by-pass bleed-off to reduce the pressure on the packing, or,
4) An alternate of clean liquid flushing of the packing and bearing.

Although this construction is not inexpensive, the higher initial investment can often pay off in reduced downtime and longer pump life between repairs.

New materials, improved seal technology, and new auxiliary equipment have made mechanical seals economically feasible in handling abrasives. Virtually all of the seal manufacturers have designs to offer for use in vertical turbine pumps in such service.

Bearings. Another vulnerable part in the vertical turbine pump is the bearings. In the vertical turbine pump the bearings are in the fluid being pumped which subjects them to increased wear especially if there are abrasives in the fluid. If the bearing system can be designed to last, the rest of the pump will continue to function to some degree for a long time. Bearings failure can cause serious damage to the pump or even result in destruction. Many features have been developed to lengthen the life of the bearings in a vertical pump. The aforementioned hard materials, used in bearings, shaft sleeves, shaft coatings, etc., will often add enough to the bearing life to satisfy the job requirements. Solid tungsten carbide sleeve bearings mated with ceramic coated shafting, or even solid tungsten carbide sleeves bonded to the shafting have been known to perform well under rather severe conditions.

The hard materials are used without any flushing or other clean lubricants where a clean filtered liquid is either not available or cannot be tolerated because of contamination of the product being pumped. Figures 1(a) and 1(b) show results of tests of some of the materials used. However, forced lubrication of the bearings with a clean filtered fluid is preferred. In most applications, water is the most economical and available lubricant. A common lubrication system was an individual lubricating line to each bearing of the pump. But in the cases where multistage bowl units were used in conjunction with some length of vertical column pipe with a series of shaft bearings, the plumbing was a nightmare. In close coupled single-stage pumps the plumbing was not quite as difficult. In either application the piping was exposed to the debris and contamination in the pit or sump which often led to damage to or breakage of the lubricant lines with early failure of the affected bearing. Multiple lines also required a complex pressure system to create the different pressure levels required at each stage of the pump.

The number of lines to the pump was reduced by drilling a hole from the bottom end of the bowl shaft up the center of the shaft to a position adjacent to the uppermost bearing in the bowl assembly. Orifice holes were drilled in strategic locations to allow the lubricating or flushing fluid to enter the annulus between the shaft and bearing. The lubricant was then piped by a single pipe to the bottom end of the pump, injected into the tail bearing area of the suction manifold and forced by pressure up the hole in the shaft to each bearing. The single pipe with proper mechanical protection reduced the number of broken pipes. This arrangement requires careful design of the proper radial hole sizes to evenly distribute the lubricant to each bearing. The maximum pressure required must be somewhat higher than the pressure in the uppermost stage to be lubricated.

A further later development is introduction of the lubricant to all of the bearings by use of the enclosed lineshaft tube. The lubricant is injected into the tubing at the surface resulting in elimination of external piping in the pit.

The drilled shafting has been termed "rifle-drilled" because the technique of drilling the long hole in the shaft comes from that used in drilling rifle gun barrels. The shaft size in most pump designs is normally no larger in diameter than required to transmit the maximum anticipated torque and thrust loads. This diameter is often not large enough to allow for "rifle drilling." Hence, most pumps with the "rifle drilling" feature use shafts larger than would otherwise be furnished.

Impellers and bowls. The next area of concern is the wear surfaces of impellers and the mating surfaces in the bowls. For enclosed impeller designs, hard materials, both coatings and solid materials, are used on the expendable and replaceable wear rings. In addition, a flushed wear ring system can be furnished. In open impeller designs the impeller must be made of abrasion resistant materials. The bowl must either be made of similar material or use a coating on the entire impeller seat area.

Last, and not necessarily the least, the bowls and impellers themselves. Some advances have been made recently in metal spraying hard coatings on cast surfaces. For bowls and impellers, this can be accomplished well only on large pumps in which the surfaces to be coated are easily reached with the metalizing spray gun. Some manufacturers offer excellent designs using linings or coatings of soft resilient materials such as rubber, Neoprene, urethanes, nylon, etc. It is difficult to achieve sound coating with no exposed ends or terminations that would allow the coating to peel off in service. Special design and machining modifications are necessary in preparation for coating to insure a successful piece of equipment.

The most common abrasion resistant construction relies simply on proper cast materials. The use of high silicon irons, chromium iron, nickel iron (Ni Hard), hard stainless steels, hard alloy steels, etc., is widespread. Vertical turbine pumps of conventional design can be made in most of the machineable cast materials. Special designs are offered in the extra hard alloys by some manufacturers, but these are normally so much more costly that it is more economical to use less costly construction with a shorter operating life.

Conclusion

The vertical pump industry is perpetually working on developments to meet the needs in the area of pumping abrasives. Service records have been improved, and efforts will continue to be made to employ advancements in technology and metallurgy, as they are developed. ■

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Peerless Pump
A Sterling Company
1200 Sycamore Street, Montebello, California 90640 (213) 726-1232 Telex 67-4156
2005 Northwestern Avenue, Indianapolis, Indiana 46206 (317) 925-9661

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