SECTION 9.10
MINING

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It might be asked why pumps used in mining services receive a separate classification when the types involved do not differ in principle or in general appearance from those used in fresh-water service. The answer is the need for utmost reliability and an ability to withstand both corrosive and abrasive waters. Not all mine waters are corrosive, but almost all mine waters from active mines are abrasive because of the suspended solids from the mining operations. Much can be done to limit the amount of solids handled, but the solution generally requires a compromise based on economics. Removal of most coarse solids is usually justified but removal of fine solids is generally impractical. Thus, a heavy-duty pump has evolved that warrants the classification of mine pump.

PUMPING CONDITIONS AND PUMP TYPES

Pumping conditions in mining services can be determined from a consideration of the types of mines and the material being mined. For example, the broadest category would be a division between open-pit and underground or deep mines. Open pit mines seldom exceed 600 ft (183 m) in depth so the pumping heads generally are not much greater than this unless very long discharge lines are required. For many open-pit mines, the greatest pumping load does not result from groundwater but from rainfall. Unless a certain increase in water level can be tolerated at the bottom of the pit, the maximum rainfall rate and the drainage area involved will determine the required pumping capacity.

As mining progresses, the pumps generally must move with the operator. This suggests the use of barge-mounted vertical pumps. A practical cost-effective way of achieving dewatering under this scenario is the use of a pond system with barge-mounted vertical cantilevered shaft pumps. Barge mounting adds a great deal of flexibility. Simple barges, as in Figure 1, illustrate the simplicity of this mounting. Except for occasional greasing of the bearings, there is little maintenance, as these pumps do not require a stuffing box or

FIGURE 1 A simple barge (Hazleton Pumps, Inc.)

mechanical seal. Almost any size can be barge mounted. Figure 2 shows one of three 1500 HP (1119 kW) vertical cantilevered shaft pumps that are installed on one barge. Each pump is rated at 14,000 gpm (3180 m^3/h).

Where there is significant rainfall, the flow rates are generally large and the combination of large capacities with moderate heads may suggest a double suction pump. The selection of a double suction pump may permit the use of a higher speed pump; however, the selection may not be based on hydraulic considerations alone. An examination of hydraulic design for a double suction pump may show it is ideal for a barge-mounted vertical pump, providing there is ample water level in the pit. On the other hand, minimum water levels may be required to facilitate mining operations. If these conditions exist, which commonly occurs, selection of a top inlet single stage pump may be better. Top inlet barge mounted vertical pumps can pump the water level down without drawing the mud from the bottom. This is the conflict, as the desirable features of the double inlet pump are lost.

Comparative features can be readily seen from an examination of the net positive suction head (*NPSH*) requirements. High-capacity moderate head pumps have a specific speed (N_S) which may require a greater *NPSH*; that is, a greater submergence. This may alter the pump length and the ability to utilize a cantilevered shaft pump. Such pumps are ideal for barge mounting if the *NPSH* (required submergence) conditions exist.

Figures 3 and 4 are reproductions of charts published by the Hydraulic Institute. An example will highlight the available design choices. Calculations may show that some combinations of flow, head, and pump speed are not feasible. This is an important consideration before proceeding with design. Assuming we have a possible floating pump station with a pumping requirement of 7500 gpm (1700 m^3/h) and a calculated discharge head of 300 ft (91m), Table 1 shows the calculation of the required absolute suction conditions. Converting from absolute pressure to submergence from the water level to the impeller centerline, under standard atmospheric conditions, the table shows how much submergence is required for a given operating speed. The table shows that a single inlet pump at 1800 rpm is not practical, and a pump designed for 1200 rpm is barely acceptable. A dou-

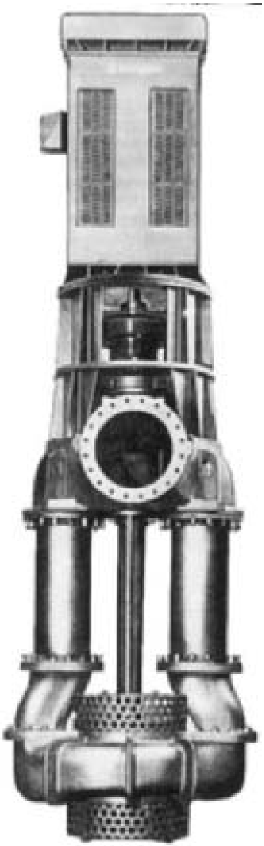

FIGURE 2 Vertical cantilevered shaft pumps used for barge mounting (Hazleton Pumps, Inc.)

ble suction pump at 1800 rpm is also barely acceptable if there is to be a cushion for low barometer days. A double suction pump at 1200 prm is fully acceptable. We are not locked into this selection, as a lower flow rate with more pumps may be fully acceptable at a higher speed.

The calculation for *NPSH* shows that the 1800 rpm double suction pump and the 1200 rpm single suction pump have about the same *NPSH* requirement. Although both are for the same hydraulic conditions, they are substantially different pumps. If the *NPSH* requirements can be met with a simple single inlet higher-speed barge mounted pump installation, a substantial reduction in cost and weight is possible.

Technically, other solutions are possible when the *NPSH* is marginal. If the *NPSH* requirement is only a few additional feet, it may be possible to lengthen the pump to increase the submerged depth. In comparing available *NPSH* and required *NPSH*, the altitude of the installation and the temperature of the liquid should be considered. Altitude correction can be simply applied as 1 ft (0.3 m) for each 1000 ft (305 m) of elevation in the calculation of *NPSH* available.

The development of large overhung vertical shaft pumps has been a boon to mining operations. Figure 5 shows the installation of four floats, each with a 400 HP (300 kW) top inlet cantilevered shaft pump. The type of mining operation frequently dictates the pump design and particularly the installation. Figure 6 shows float mounted pumps designed to

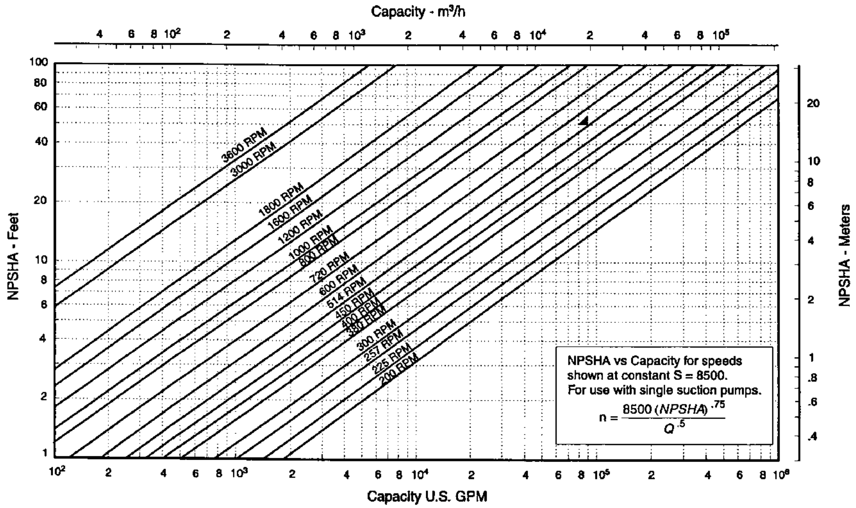

FIGURE 3 Recommended maximum operating speeds for single suction pumps (Hydraulic Institute ANSI/HI 2000 Edition Pump Standards, Reference 1)

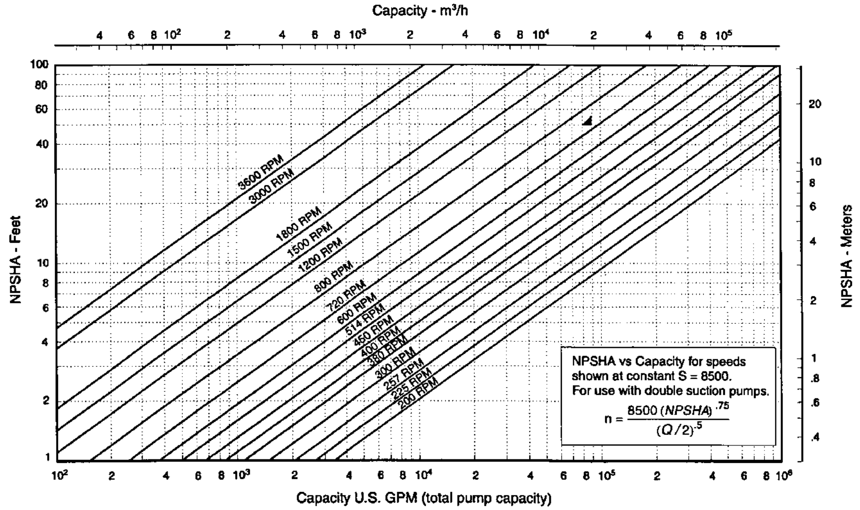

FIGURE 4 Recommended maximum operating speeds for double suction pumps (Hydraulic Institute ANSI/HI 2000 Edition Pump Standards, Reference 1)

skim the clean liquid in a settling pond. The float construction acts as a weir so only the cleanest liquid is returned to the plant. The float mounts 250 HP (185 kW) top inlet vertical cantilevered shaft pumps. An interesting feature is the hydraulic thrust balancing by the use of opposed flexible hose discharge lines. Note that these forces also exist in steel pipeline and must be adequately restrained.

TABLE 1 Calculation of required absolute suction conditions

Pump Type	Operating Speed—rpm	Specific Speed	*NPSH* Required Ft (m)	Submergence Ft (m)
Single Suction*	1800	2163	48 (14.6)	18 (5.5)
Single Suction*	1200	1529	30 (9.1)	0**
Double Suction	1800	1442	31 (9.5)	1 (0.3)***
Double Suction	1200	1019	18 (5.5)	0***

*Can be top or bottom inlet
**Barely acceptable with submergence sufficient to prevent vortexing at inlet
***Very safe

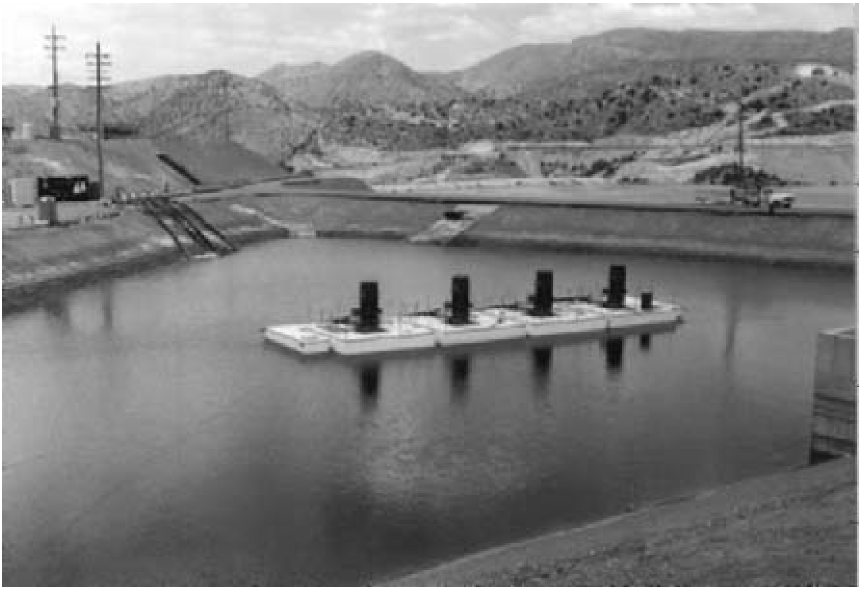

FIGURE 5 An installation of four floats with top inlet cantilevered shaft pumps (Hazleton Pumps, Inc.)

Figure 7 illustrates an interesting installation of a float-mounted pump of unique design. The pump is of cantilevered shaft design (no submerged bearings) with the pump utilizing the motor bearings. Pump construction is shown in Figure 8. This is ideal for barge mounting. It involves a special motor, but the lower center of gravity permits a smaller barge and readily compensates for the extra cost of the motor. No submerged shaft bearing is required, so dirty water can be handled with little maintenance. A double discharge design also provides balanced hydraulic side thrust and eliminates the need for a shaft seal.

If floats are to be used for pump mounting, considerations in addition to hydraulics must be examined. Floats must be designed for safe operation in all circumstances. Floats for individual pumps are simple and readily moved about a mining operation; however, there are other factors beside the weight of the pump and motor. A portion of the discharge line (usually a hose on floats) must be supported by the pump float. Consideration must be given to the possibility that a number of workmen might gather at one side of the float and overturn it. Stability calculations must be made by considering

FIGURE 6 Float-mounted pumps designed to skim the clean liquid in a settling pond (Hazleton Pumps, Inc.)

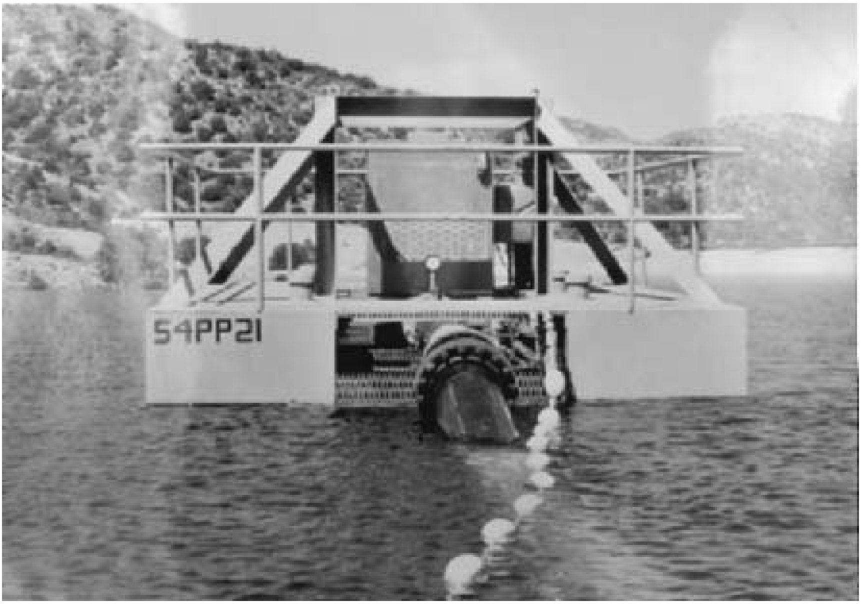

FIGURE 7 Unique design float-mounted pump (Hazleton Pumps, Inc.)

lateral rotation of the float and the uprighting forces due to the additional buoyancy on one side (or end). The center of gravity must be within the center of buoyancy. If the center of gravity moves beyond the center of buoyancy, the float will overturn. It must also be remembered that, after a pontoon is submerged, that is the limit of buoyancy. In addition to these factors, wind effects must be considered. If the climate is not too severe,

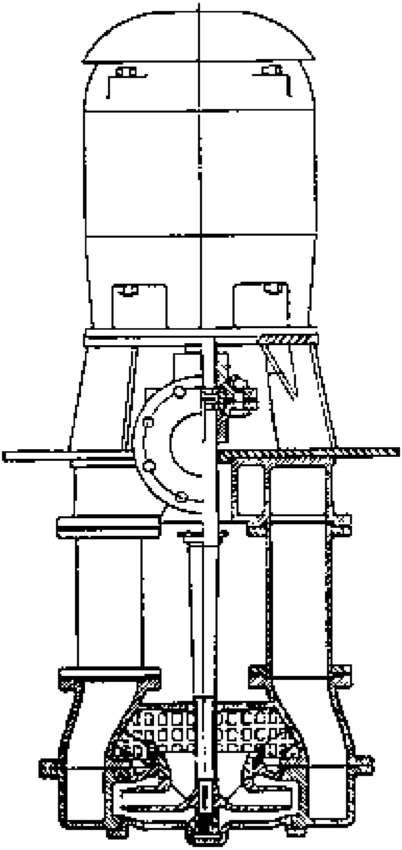

FIGURE 8 Cantilevered shaft design utilizing motor bearings (Hazleton Pumps, Inc.)

pumps on simple floats can be protected from ice damage if the float is surrounded with a simple air bubble system.

As the pump flow rates increase, fixed installations become more manageable. Figure 9 shows four 24 in (610 mm) discharge, 1250 horsepower (750 kW) vertical pumps. The pumps are of stainless steel in a mining operation. This is an ideal installation as a structure is in place for pump maintenance.

The selection of the discharge line will have a significant effect on the total pumping output. If selected for normal pumping conditions, the pipeline may not add significant capacity to the system by the use of an additional pump. As an example, examine an installation utilizing a 14 in (355 mm) Schedule 40 steel pipe discharge line for a normal flow of about 5000 gpm (1135 m^3/h). Assume a friction head of 70 ft (21.3 m) and a static head of 180 ft (54.9 m), for a total pumping head of 250 ft (76.2 m). Figure 10 shows that adding a second pump to the system will not double the pumping capacity as the two pump characteristics are added to the system head curve. In this exaggerated example, adding a second pump will increase the total flow by less than 1000 gpm (227 m^3/h). Note that each pump now will discharge less than 3000 gpm (680 m^3/h). The obvious answer is to either use a larger discharge line and a different pump selection, or the use of a separate discharge line for each pump. In that case, the total capacity would be 10,000 gpm

FIGURE 9 24 in (610 mm) discharge, 1250 HP (750 kW) vertical pumps (Hazleton Pumps, Inc.)

(2270 m^3/h). This becomes a study in economics for each installation. In the above example, this installation is obviously poorly designed. As pipeline velocities increase, discharge line transients may present problems on shutdown. The author is aware of one long pipeline that failed in 17 places on the first shutdown. Other factors must also be considered, such as the projected life of the project and the cost if the project is flooded.

Much has been said about pumping from mines. Obviously, the least costly method is to keep the water from entering the mining operation. It is not always applicable, but a ring of "deep-well" turbine pumps, on the periphery of the operation, can lower the water table sufficiently to keep the mining pit relatively dry. A typical large turbine pump with submersible motor is shown in Figure 11.

Pumps for operation in deep mines have different considerations. If a mine is not more than approximately 1200 ft (365 m) deep, Schedule 40 pipe is generally satisfactory for the pressure involved. For example, 12 in (305 mm) seamless Schedule 40 steel pipe is listed as 1200 lb/in^2 (82.75 bar) hydrotest pressure. However, if the water is corrosive, wall thickness allowance must be made, or stainless steel pipe used. 1200 lb/in^2 converts to approximately 2700 ft of water. Allowance must also be made for water hammer if the line velocity is high. Generally, average line velocities of 10 ft/s (3.1 m/s) will produce high tran-

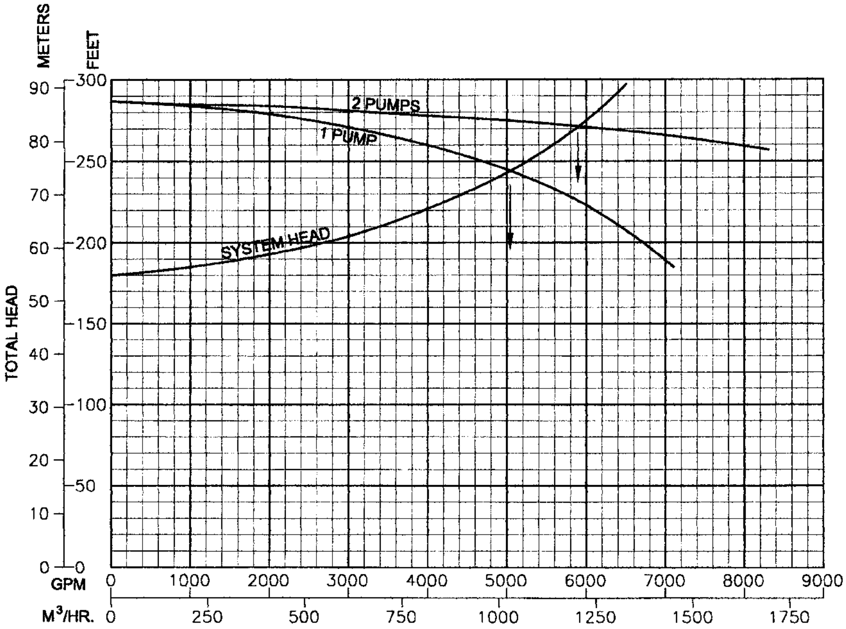

FIGURE 10 One and two pump operation on a system curve

sient pressures upon pump shutdown, so more conservative velocities should be selected. As these installations are generally long term, considerable savings can be obtained by reduced power requirements if the pipeline velocities are near 5 ft/s (1.5 m/s).

In designing a mine pumping system, an analysis must be made where the water is coming from. It is generally not practical to put the main pump station at the bottom of the mine if the bulk of the water is occurring at an upper level. If this is the case, a decision must be made for the pumping condition of the mine bottom pumps. Should they simply pump to the upper level or directly to the surface? Both financial and safety considerations are essential. Failure of upper level pumps may jeopardize the mine safety. These are decisions that involve much more than basic equipment selection. One solution to the problem of a possible power failure is the use of submersible pumps at the shaft bottom. Single-stage submersible pumps, as shown in Figure 12, are available to 600 HP (448 kW) and can readily pump to upper levels in case of flooding at the bottom level.

If the mine is deeper than 1200 ft (365 m), other approaches must be considered. Consideration of Class 250 or 300 valves and pipefittings may show that the cost warrants pumping only to an upper level to stay within the limits of the Class 150 fittings. This does not necessarily mean a duplicate pumping station as series pumps can safely be installed at an upper level. This is practical only if the bulk of the water occurs at or near the bottom level. Because there are mines deeper than 2000 ft (365 m), the problems become more acute. In any event, the main consideration is to conduct a study to determine at what level the greatest flow of water occurs.

A very old but interesting photo (see Figure 13) shows a sealed pump-room housing three 1000 HP (746 kW) bronze constructed pumps in a coal mine. This pump room had access only from an upper level so water could rise in the mine by approximately 200 ft (36.5 m) before flooding the pump room.

Not all mines suffer from ingress of a great deal of water, but many of those that do have closed because the cost of pumping was too great. An example is shown in Figure 14. There were three 2000 HP (1490 kW) pumps in one pump room in a zinc mine. Note in this

FIGURE 11 A typical large turbine pump with submersible motor (Hazleton Pumps, Inc.)

photograph that these large pumps are in segments so they can be lowered into the mine and reassembled.

Pump discharge line forces must be calculated for all installations. The reactive forces from the piping must be isolated from the pump. Underground pumps generally operate at high pressure and the forces generated are high. Failure to adequately support and restrain the piping can cause pipe failure and result in severe pump misalignment.

MATERIALS OF CONSTRUCTION

Most water pumps perform quite satisfactorily with bronze impellers, wearing rings, and shaft sleeves, but the dirty or corrosive waters in mine service require superior materials. Because mine waters range from neutral (pH of approximately 7) to severely acidic (as low as pH 1.5 in some coal mines) and to very basic (as occurs in limestone mines and so on), there is no universally best material. The choice obviously is the lowest-priced material that gives satisfactory service life.

Many times, the decision must be made not on the basis of the best available materials, but on the basis of which material will best withstand the abrasive conditions during the intended life of the project. If there is a five-year anticipated life of the mine, there is little advantage in selecting materials that will last twice as long. Conversely, a mine with

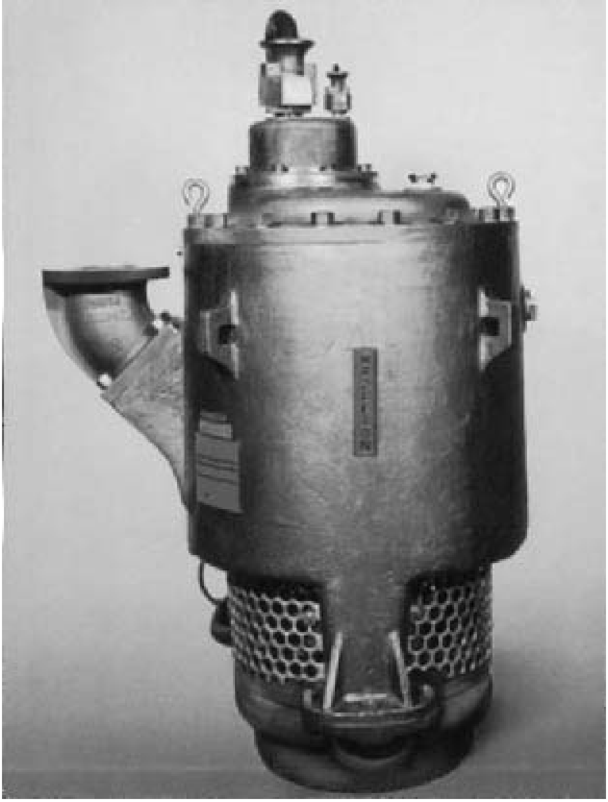

FIGURE 12 Single stage submersible pump (Hazleton Pumps, Inc.)

a projected life of 25 years would require the best commercially available materials. There are also the exotic alloys, but their use is seldom justified.

Assuming that there will always be a slight amount of solids present, the metallurgy given in Table 2 should be considered.

Care should be exercised when selecting alloys because many stainless steels do not have as great a strength as carbon steel. The same applies to bolting. Thus, a pump rated for high-pressure service with a carbon steel or alloy steel casing and bolting may not be suitable when made of bronze or stainless steel.

Although ceramic-coated shaft sleeves are excellent in many applications, remember that ceramic coatings are porous and that the base metal must be able to withstand the environment. Also, some ceramics will not be suitable in strongly basic water. Others, however, are suitable, and so a general specification for ceramic coating should never be made. A plasma-applied ceramic is generally denser and more serviceable than one applied by a simple flame spray.

HYDRAULIC CONDITIONS

Low-Head Pumps For low-head pumps, up to approximately 150 ft (46 m), the installation must be carefully checked to prevent cavitation during periods of low-head operation. This is particularly important during one-pump operation on a parallel system. For

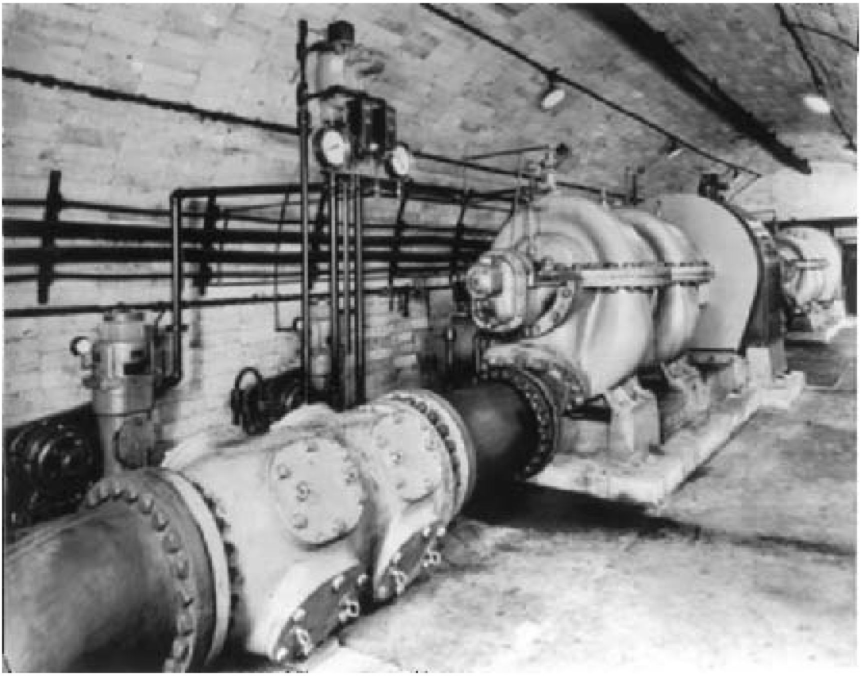

FIGURE 13 A sealed room in a coal mine housing three 1000 HP (746 kW) bronze constructed pumps (Hazleton Pumps, Inc.)

example, if two 5000-gpm (1136-m^3/h) pumps are discharging into a common discharge line against a static head of 80 ft (24 m) and a frictional head of 60 ft (18 m), the frictional head will be only 15 ft (4.6 m) when one pump operates alone at 5000 gpm (1136 m^3/h). The total head will now be only 95 ft (69 m), and the single pump will carry out to a much higher capacity. Unless sufficient *NPSH* is available for the single-pump runout point, the pump will cavitate. Although the two pumps should be selected for 5000 gpm (1136 m^3/h) at 140 ft (43 m) total head, the required *NPSH* should be determined not at 5000 gpm (1186 m^3/h) but at the capacity corresponding to the intersection of the pump and system curves.

High-Head Pumps For high-head pumps, 1000 ft (305 m) head or more, the risk of cavitation for single-pump operation on a parallel system is less than for low-head pumps. For example, if the static head is 1000 ft (305 m) and the frictional head is 60 ft (18 m) when two 5000-gpm (1136-m^3/h) pumps are operating, the total head will decrease from 1060 ft (323 m) to only 1015 ft (309 m) when one pump operates at 5000 gpm (1136 m^3/h). This means that, for either one- or two-pump operation, the capacity of each pump will be approximately the same and the risk of runout cavitation is minimal.

Waterhammer and Pressure Pulsations A waterhammer analysis should be made of both high- and low-pressure pumping systems. Although the transient pressure pulsations are related to the rate of change of velocity rather than the magnitude of the steady-state condition, mine experience indicates that waterhammer problems can be anticipated when pipe velocities exceed 10 ft/s (3 m/s). In high-pressure pumping systems, it is not unusual for transient pressure pulsations to be as high as 300 lb/in^2 (2068 kPa) above or below the steady-state pressure.

FIGURE 14 Three 2000 HP (1490 kW) pumps in one room in a zinc mine (Hazleton Pumps, Inc.)

Transient pressure pulsations have been experienced in low-pressure pumping systems. The danger here is that the low-pressure portion of the cycle will fall below atmospheric pressure and the pipe will collapse.

Although any pumping system for mine service should be analyzed in detail for transient pressure pulsations, experience has shown that adequate air bottles have proved to be one of the most effective and least expensive means of surge suppression. Slow-closing valves and flywheels have been used, but they must be sized correctly. This is especially true with high-speed pumps because these units possess little rotational inertia and will decelerate very rapidly on shutdown, with accompanying high-pressure surge.

SUMPS

Permanent sumps are seldom used in open-pit mines because the sump area generally moves as the mining operation progresses. This means that the pump station must be portable, and the installation of the pumps on a barge provides the most convenient arrangement. Either horizontal or vertical pumps may be used, but vertical pumps eliminate the need for priming equipment. If the vertical pumps are of the overhung-shaft design, the stuffing box may be eliminated. This is important if the water is dirty. Although small cyclones can be used to clarify the water for pumps that have stuffing boxes, care must be taken to prevent leaves and other trash from blocking the gland water line. In freezing climates, special provision must be made to prevent the suction line, pump, and even the barge itself from freezing in place.

Underground mine sumps present special problems because they function not only as sumps but also as clarifiers. A well-designed sump is a good clarifier, but all too frequently

TABLE 2 Materials of construction for mine pumps

	Neutral waters		Acidic waters		Basic waters	
	Moderate heads	High heads	Moderate heads	High heads	Moderate heads	High heads
Casing	Cast iron	Ductile iron/ cast steel	316 S.S./ alloy 20	17-4 PH	Cast iron	Ductile iron/ cast steel
Impeller	28% Cr	28% Cr	PH55A/ 17-4PH CD-4MCu	PH55A/ 17-4PH CD4-MCu	28% Cr	28% Cr
Wear rings	28% Cr	28% Cr	Same as impeller	Same as impeller	28% Cr	28% Cr
Shaft sleeve	28% Cr or 303 S.S. ceramic-coated	28% Cr or 303 S.S. ceramic-coated	316 or alloy 20 ceramic-coated PH55A, etc.	316 or alloy 20 ceramic-coated PH55A, etc.	28% Cr or 303 S.S. ceramic-coated	28% Cr or 303 S.S. ceramic-coated
Shaft	Carbon steel	High-tensile alloy steel	316 S.S./ alloy 20	17-4 PH	Carbon steel	High-tensile alloy steel
	Alloy 20	21% Cr	29% Ni	2.5% Mo		
	CD4-MCu	26% Cr	5% Ni	2.0% Mo		
	28% Cr	28% Cr	—	—		
	304 S.S.	19% Cr	10% Ni	—		
	316 S.S.	19% Cr	10% Ni	2.5% Mo		
	17-4 PH	17% Cr	4% Ni	—		Hardenable
	PH55A	20% Cr	10% Ni	3.5% Mo		Hardenable

inadequate provisions are made for cleaning the sump. If it is not cleaned at regular intervals, the loss of storage capacity may be critical in the event of a power failure. Furthermore, a sump partially filled with solids does not give the proper retention time for clarification, and the solids are directed into the pump. Although few sumps can economically be made large enough for complete clarification, it is important that a large portion of the solids be removed. This is particularly true for 3600-rpm pumps because the high-speed generally produces a high head per stage and the high differential pressure between stages causes severe wear if abrasive solids are present. Some mines use conventional thickeners and flocculating agents in an attempt to keep a high concentration of solids from reaching the pump.

Some general rules should be considered in designing sumps for underground pump rooms:

1. Attempt to get a complete analysis of the water (from another portion of the mine or from an adjacent mine if necessary).
2. Analyze the sample for corrosive properties to determine the proper materials of construction for the pump.
3. Analyze the sample for possible scale buildup in the pipeline and pumps. Check the velocity effect, if any, on the buildup rate.
4. Determine the percentage of suspended solids in the sample, its screen analysis, and the settling rate for various fractions. Determine the sump dimensions necessary for removal of all solids and then for progressively larger solids in order to select the most economical size.

5. Compare the sump size as determined in rule 4 with the size required for physical storage capacity for *(a)* continuous pumping, (*b*) off-peak power pumping, (*c*) programmed pumping, and *(d)* storage during estimated maximum length of power interruption.
6. Calculate practical sump dimensions, considering the geologic conditions.
7. Install grit traps ahead of the sump to remove large, heavy solids. Consider methods for cleaning the grit traps.
8. Install trash screens to prevent wooden wedges, and so on from entering the sump.
9. Review sump cleaning methods and program. The best-designed sump is of no value if it is not cleaned. Compare mechanical cleaning methods with cost of parallel sumps.
10. Review the suction requirements of the pumps to be used. Because of altitude, temperature, distance from low water level to pump centerline, and suction line loss, the available *NPSH* may be inadequate for even an 1800-rpm pump. If a decision as to pump size, type, and speed has been made and an *NPSH* problem does exist, a decision must be made either to use low-speed booster pumps or to lower the pump room level to below the sump level. From a safety standpoint, the use of a booster pump is preferable, although it does add another piece of equipment.
11. Where the storage capacity is inadequate to meet possible power failures, consider either vertical pumps—possibly up to 100 ft (30 m)—for the shaft bottom pumping up to the main pump station level, or sealed pump rooms that can operate over wide variations in the sump level from a 15-ft (4.6-m) suction lift to a positive head of several hundred feet.
12. Determine the final design based on a compromise between the mine engineer (who wants maximum output), the electrical engineer (who wants small starting load), the geologist (who wants small sump dimensions), and the mechanical engineer (who wants the most reliable and easily maintained equipment).

AUTOMATIC PUMP CONTROL

With proper instrumentation, almost all pump stations can be operated automatically. Remote monitoring is simple, relatively inexpensive, and can provide safe operation and signaling of nearly all operating conditions. Equipment is presently available to measure, record, and transmit the operating conditions to remote locations. The proper equipment can thus relieve worry about the operation of the facility even if it is many miles from the operation's headquarters. Automatic control can be a simple float switch or a pressure switch, or it can be sufficiently complex to provide reliable operation under the most critical or adverse conditions. Automatic control can provide greater reliability, and its cost can depreciate over only a few years. Furthermore, the automatic recording of flow rate, flow totalizing, and periods of operation provides valuable data for analyzing the performance of the pumping installation as well as the possible cost savings in pumping during off-peak power periods.

Where the safety of a mine is dependent on the reliable operation of the dewatering pumps and controls, the following minimum requirements should be considered:

1. There should be a sump level alarm for high water, both local and remote (at the surface).
2. Sump level control should be dependable. For example, electrodes are generally unreliable in waters that leave a conducting film.
3. The control should be programmed where more than one pump is installed. However, the use of an alternator is not always desirable because all pumps are exposed to the same degree of wear. It is preferable to have one standby pump programmed through a sequence selection switch to operate at least once per week.

4. Pump priming should be positive. Hydraulic devices should be combined with electric controls so complete dependence is not on the electric control. The presence of water in the pump should be detected to prevent the starting of a dry pump.
5. A delay circuit should be provided to ensure complete priming.
6. The control should provide for at least three starting attempts (unless an overload has occurred).
7. The priming time should be limited (if under a suction lift system).
8. The control should provide for a restart in the event of a false loss of prime on start-up (suction lift system).
9. Pump and motor bearings should have thermostats to stop pumps in the event of bearing failure.
10. Vibration monitoring may be important. This is particularly true for vertical pumps.
11. Pressure controls should indicate normal pressure and fail-safe in the event of a loss of pressure (broken column line, and so on).
12. Flow indication (check valve flow switch) is needed to signal a shaft failure.
13. Remote indication (generally at the mine office) should provide at least an indication of operation and signal pump failure or high water. More detailed information may be transmitted.
14. For long distances, investigate the use of carrier-current indication schemes, together with signal multiplexing, and so on.
15. Provide a method to test the control and alarm system.

DRIVERS

Open-pit mines use electrically driven mining equipment, such as drag lines and shovels, and the availability of power has permitted the use of electrically driven pumps. There are still many gasoline-driven or diesel-driven units, but the convenience of electric power, particularly for automatically controlled units, has increased the trend to electric drive. The availability of reliable high-voltage cable has made portable high-voltage equipment safe and economical. Pumps in open-pit service are seldom provided with sophisticated control or drive mechanisms. The primary requirements are reliability, portability, and wear resistance.

In locations where rainfall may be heavy and there is danger of power failure, a combination of electric drive and engine drive is used. The engine can be direct-coupled to the pump through a motor with a double-extended shaft or with a clutch between the engine and the motor. Automatic control is simple and reliable.

Although some steam-driven pumps still exist in underground service, their number is rapidly decreasing. Electric motor drive is the simplest for automatic control. Variable-speed units, however, are seldom used in underground service because the ratio of static head to total dynamic head is quite high. Thus the frictional loss is not a large percentage of the total head loss and not much advantage is gained by variable speed. The solution is usually a multiple-pump installation. This must be designed with care because it is possible to raise the frictional head to a point where an additional pump produces little additional capacity. Multiple discharge lines are the answer and are frequently used for safety reasons. In normal service, all discharge lines are used in parallel, although conservative design allows each line to handle the required capacity.

As with all pumping installations, a complete set of system-head curves must be prepared to analyze the power requirements under all conditions.

Motor enclosures are important in underground service. Because of the high humidity, special insulation (epoxy encapsulated, and so on) should be specified. Dripproof enclosures are the minimum requirement, with weather-protected Type I the preferred construction. Heaters should also be provided. Screens should be installed to prevent the entrance of rats. Winding temperature detectors, bearing thermostats, and ground-fault detectors are recommended in mine service and should be incorporated in the pump-control and alarm circuits.

Although the starting torque of a centrifugal pump is low, the available torque may have to be checked in some cases. A normal-torque motor should be suitable for pumps in the range of 500 to 3000 (10 to 60) specific speed. High-specific-speed pumps, however, have the highest power at shutoff, and it will be necessary to examine the starting arrangements for such pumps.

Starting a pump against a long empty pipeline may present overload problems, and repeated starts may be necessary. In such cases, the number of permissible starts per hour should be checked. Winding temperature detectors are important in such applications.

Although reduced-voltage starters may be required in some instances, most modern mines have electrical facilities designed for across-the-line starting. This is preferable because the starting equipment is cheaper. Before deciding on a reduced-voltage starter, the effect of the starting load on the transformer and line impedance should be checked. It may be that the voltage drop will eliminate the requirement for reduced-voltage starters. On the other hand, the effect on the primary side should be checked so the voltage drop is not so large as to drop out other equipment.

Synchronous-motor drives are seldom used unless they are large (generally at least 1000 hp) (750 kW) and then only if they are in relatively continuous service. Under such conditions, they can be operated under “leading current” conditions for power factor correction. Smaller installations frequently provide capacitors at the pump installation to provide the necessary correction for a particular installation.

Surge protection from lightning should not be overlooked. Some locations are particularly susceptible to lightning damage, especially to long surface lines. Lightning arresters should be provided at the surface, and surge arresters should be mounted at the motor location.

REFERENCES

1. American National Standard for Centrifugal Pumps for Design and Application, ANSI/HI 1.3-2000, Hydraulic Institute, Parsippany, NJ www.pumps.org.