SECTION 9.2
SEWAGE TREATMENT

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Sewage is defined as the spent water of a community. Although it is more than 99.9% pure water, it contains wastes of almost every form and description. Raw sewage, when fresh, is gray and looks something like dirty dishwater containing bits of floating paper, garbage, rags, sticks, and numerous other items. If allowed to go stale, it turns black and becomes very malodorous. About 25% of the waste matter of normal domestic sewage is in suspension; the remainder is in solution.

Sewage contains many complex organic and mineral compounds. The organic portion of sewage is biochemically degradable and, as such, is responsible for the offensive characteristics usually associated with sewage. Sewage contains large numbers of microorganisms, most of which are bacteria. Fungi, viruses, and protozoa are also found in sewage, but to a lesser extent. Although most of the microorganisms are harmless and can be used to advantage in treating the sewage, the viruses and some of the bacteria are pathogenic and can cause disease.

Sewage flow generally averages between 50 and 200 gallons per capita per day (gpcd) (190 and 760 lpcd). In the absence of better information, an average figure of 100 gpcd (380 lpcd) is generally used for design purposes. The rate of flow usually varies from minimum in the early morning to maximum in the later afternoon. Minimum flow ranges from 50 to 80% and maximum dry-weather flow from 140 to 180% of average flow. The extent of variation decreases as the size of the system increases. Wet-weather flows can be 600 gpcd (2270 lpcd) or more because of the extraneous water entering sewers from roof drains, areaway drains, footing drains, and so on.

SEWAGE SYSTEMS

In most instances, sewage systems are divided into two parts: collection systems and treatment systems.

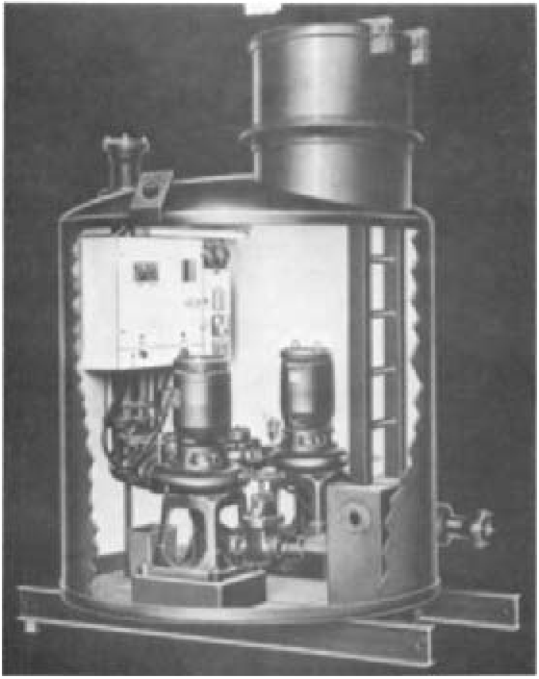

FIGURE 1 Factory-built conventional lift station (Smith & Loveless, Inc.)

Collection Collection systems consist of a network of sewers that collect and convey sewage from individual residences, commercial establishments, and industrial plants to one or more points of disposal. Pumping stations are often needed at various points in the system to pump from one drainage area to another or to the treatment plant. The judicious location of pumping stations enhances the economy of the overall design by eliminating the need for extremely deep sewers.

Small-system pumping stations (Figures 1 and 2) are frequently built underground and may be factory-built. For larger stations, superstructures should be in keeping with surrounding development. It has been said that people smell with their eyes and their ideas as well as their noses, and for this reason aboveground structures should be attractive, with landscaped grounds, to overcome the popular prejudices against sewage works. Stations can be and have been designed and constructed in residential areas where the neighbors apparently are not aware that the stations are not homes.

Treatment Treatment facilities can be many and varied, with the extent and nature of the treatment determined to a large degree by the proposed use of the receiving stream and its ability to assimilate pollutants. Most conventional treatment plants being built today can be classified as either primary, biological, or advanced waste treatment. Other alternatives, such as physical-chemical or chemical-biological treatment, are also used on occasion but on a lesser scale. The treatment needs of smaller communities are sometimes satisfied by package treatment plants or by waste stabilization lagoons.

Primary treatment involves removal of a substantial amount of the suspended solids but little or no colloidal or dissolved matter. Primary treatment facilities normally include screening, grit removal, and primary sedimentation. The sewage is often chlorinated during primary treatment in order to sterilize the wastes.

Biological treatment uses bacteria and other microorganisms to break down and stabilize the organic matter. Trickling filters and the many variations of the activated sludge

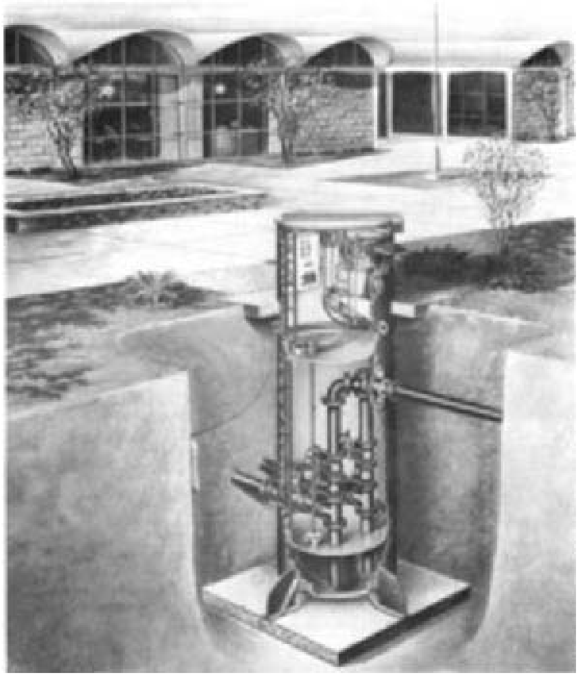

FIGURE 2 Factory-built pneumatic ejector lift station (Smith & Loveless, Inc.)

process are the most popular biological treatment concepts presently in use. Biological treatment is generally followed by final sedimentation of the solids produced by the microorganisms.

Advanced waste treatment is a very complex subject, and it can range from a limited objective, such as phosphate removal, to whatever additional treatment is necessary for water reuse purposes. Advanced waste treatment usually follows conventional primary and biological treatment and can include phosphate removal, nitrate removal, multimedia filtration, carbon absorption, and ion exchange. Where zero discharge is required, it may be necessary to follow advanced waste treatment with spray irrigation of the plant effluent or other methods of disposal.

Combined primary and biological treatment using the activated sludge process is perhaps the most commonly used treatment concept currently in use. A schematic drawing of a typical activated sludge treatment plant is shown in Figure 3. In the example, liquid treatment is accomplished by coarse screening, grit removal, fine screening (or communication), and primary settling, followed by aeration, final settling, and chlorination. Sludge processing includes thickening, dewatering, incineration, and liquid disposal of ash. There are many variations to this layout, but the one shown includes most of the pumping applications normally encountered in treatment plant design. Pumping requirements will of course vary from plant to plant, depending on the process used, the site size and topography, and the relative location of the various structures and equipment.

PUMP APPLICATIONS

Most of the pumping applications associated with the collection and treatment of sewage can be classified according to the general nature of the liquid to be handled. The primary

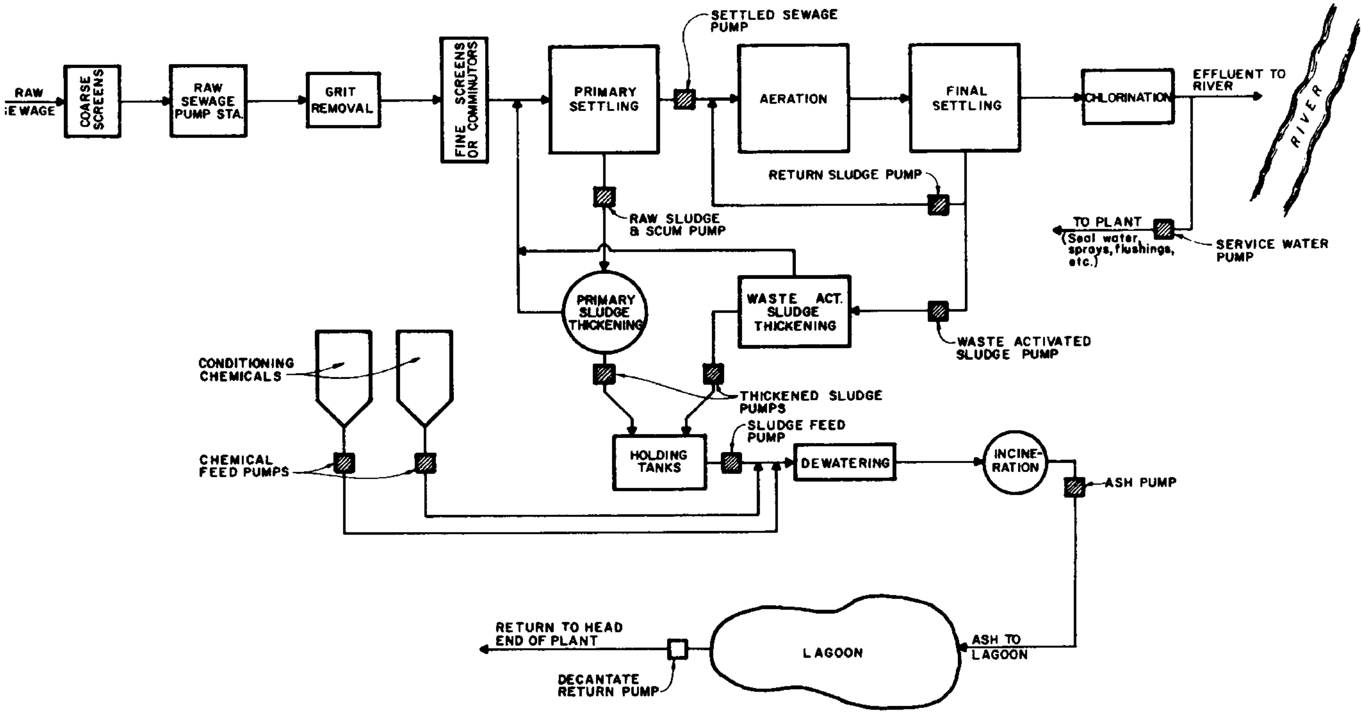

FIGURE 3 Typical activated sludge plant, with dewatering, incineration, and liquid disposal of ash

classifications are (1) raw sewage, (2) settled sewage, (3) service water, and (4) sludge. There are also, however, a number of specialized applications involving the handling of abrasive materials, such as grit and ash. The types of pumps recommended for sewage applications are indicated in Table 1. Although included in the table, chemical pumps are not discussed in this section. They are covered in Section 9.6.

Raw Sewage Raw sewage pumps are used to lift liquid wastes from one level of the collection system to another or to the treatment plant for processing. Regardless of where the pumps are located, the basic design considerations remain the same.

Even though the sewage is normally screened at larger installations before entering the suction wet well, it still contains a large quantity of problem material, such as grit, rags, stringy trash, and miscellaneous solids small enough to pass through the coarse screens. Screens are often omitted from smaller installations because large objects are not as much of a problem because of the smaller size of the incoming sewers.

Raw sewage pumping installations are usually sized so their firm capacity either is equal to a future maximum flow rate of the incoming sewers or can be expanded to accommodate this level. *Firm capacity* is defined as total station capacity with one or more of the largest units out of service.

Pneumatic ejectors (Figure 2) are sometimes used where the required capacity is less than that provided by the smallest conventional sewage pump. This type of unit, however, should not be used where more than 50 connections are expected.

Conventional sewage pumps are, by far, the most common pumps used for the handling of raw sewage. A conventional sewage pump is more specifically described as an end-suction, volute-type centrifugal with an overhung impeller of either the nonclog (Figure 4a) or the radial- or mixed-flow type (Figure 5), depending on capacity and head.

Nonclog pumps are all based on an original development by Wood at New Orleans. Actually, no pump has been developed that cannot clog, either in the pump or at its appurtenances. Experience shows that rope, long stringy rags, sticks, cans, rubber and plastic goods, and grease are most conducive to clogging.

Nonclog impellers are used almost exclusively today for pumps smaller than 10 in (25 cm). These pumps differ from clear-water pumps in that they are designed to pass the largest solids possible for the pump size. The conventional nonclog impeller contains two blades, although some manufacturers are now offering a single-blade ("bladeless") impeller. The two-blade impeller has thick vanes with large fillets between the vanes and the shroud at the vane entrance. The bladeless impeller has no vane tips to catch trash. On the other hand, it is inherently out of balance because of its lack of symmetry.

The larger raw sewage pumps are equipped with either mixed-flow or radial-flow impellers, depending on head conditions. Both have two or more vanes, depending on pump size and the size of solids to be handled. The vane tips are sharper than for the nonclog impeller, resulting in a higher operating efficiency. The heavier vanes are not necessary because the vane openings can be larger than on the smaller pumps. Experience indicates that stringy trash will not clog an impeller with vane openings larger than 4 in (102 mm) in diameter.

Conventional solids handling volute type sewage pumps may be of the dry pit type (Figure 4a), wet pit type (Figure 4b), or submersible type (Figure 4c). Dry pit pumps are by far the most popular and widely used type due to their accessibility for observing mechanical operation and ease of maintenance when necessary.

Wet pit solids handling pumps are gaining in popularity especially on return activated sludge services. They are similar in design to a vertical turbine or mixed-flow diffuser pump except the bowl contains a limited number (usually two) of well-rounded diffusers, the impeller is of the solids handling type, and there is no lower suction bell bearing. Therefore, they are not nearly as likely to clog on the debris normally found in raw sewage. Single-stage models available at the time of this publication are limited to operational total heads under 100 ft (30 m).

Submersible solids handling pumps are commonly used in small raw sewage lift stations. They are most widely used in sizes 12 in (305 mm) and smaller with total heads under 100 ft (30 m) and motor ratings under 150 HP (112 kW).

TABLE 1 Types of pumps generally used in sewage applications

Application	Conventional sewage	Diffuser	Torque flow	Clear-water volute	Ash	Screw	Pneumatic ejector	Air lift	Positive displacement	Chemical
Raw Sewage	X	. . .	. . .	. . .	. . .	X	X	. . .	. . .	. . .
Grit	. . .	. . .	X	. . .	. . .	. . .	. . .	X	. . .	. . .
Primary sludge										
Less than 2% solids	X	. . .	X	. . .	. . .	. . .	. . .	. . .	. . .	. . .
More than 2% solids	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	X	. . .
Normal primary scum	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	X	. . .
Diluted scum	X	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Biological sludge	X	X	. . .	. . .	. . .	X	. . .	X	. . .	. . .
Thickened biological sludge	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	X	. . .
Digested sludge, recirculation	X	. . .	X	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Settled sewage	X	X	. . .	. . .	. . .	X	. . .	. . .	. . .	. . .
Plant effluent	X	X	. . .	. . .	. . .	X	. . .	. . .	. . .	. . .
Service or nonpotable water	X	X	. . .	X	. . .	. . .	. . .	. . .	. . .	. . .
Ash sluice	. . .	. . .	. . .	. . .	X	. . .	. . .	. . .	. . .	. . .
Decantate or supernatant liquor	X	X	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Chemical solution	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	X

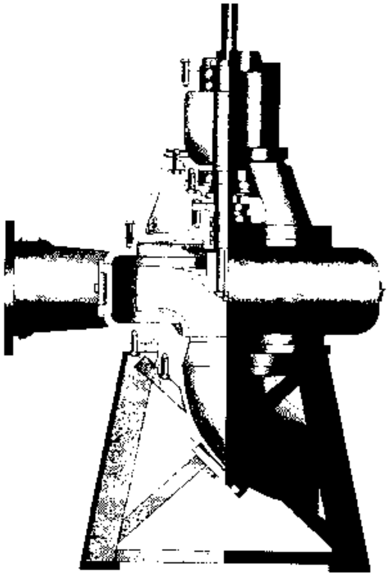

FIGURE 4a Non-clog dry pit sewage pump (Flowserve Corporation)

FIGURE 4b Solids handling wet pit pump (Flowserve Corporation)

FIGURE 4c Non-clog submersible sewage pump (Flowserve Corporation)

Although non-clog pumps 8 in (203 mm) and small are available with self-priming (Section 2.4), most conventional sewage pumps are located so the impeller is always below water level in the suction wet well. This eliminates the need for specialized priming systems.

Self-priming pumps have been used successfully to pump raw unscreened sewage, particularly in the southern part of the United States. The self-priming feature eliminates the

FIGURE 5 Vertical sewage pumping units at the South System Pump Station, Deer Island in Boston, MA containing (8) 36 in (915 mm), 46,300 gpm (10,510 m^3/h) pumps driven by 1250 hp (932 kW) variable speed motors (Flowserve Corporation)

dry-pit cost and gives the centrifugal pump the gas-handling advantage of positive displacement pumps. Operating costs are higher, though, because the design efficiencies generally run about 10 to 15% lower than for the conventional nonclog units.

Archimedean screw pumps (Figure 6) are occasionally used for raw sewage pumping applications. These units are advantageous in that they do not require a conventional wet well, and they are self-compensating in that they automatically pump the liquid received regardless of quantity as long as it does not exceed the design capacity of the pump. This is done without the need for variable speed drive equipment. Also, as shown by Figure 6, the total operating head of a screw pump installation is less than for those pumps that require conventional suction and discharge piping. Screw pumps, however, have a practical limitation as to pumping head. Generally speaking, they are not used for lifts in excess of 25 ft (7.6 m).

Settled Sewage Settled sewage pumps are used to lift partially or completely treated waste from one part of the plant to another or to the receiving stream. In Figure 3, these pumps are the settled sewage pump, service water pump, and decantate return pump.

The liquid to be handled usually contains some solids, but grit and most of the rags and other stringy material have already been removed. Sufficient firm capacity should be provided to meet peak flow requirements. In no case should fewer than two units be provided.

Wet pit solids handling or diffuser pumps (Subsection. 2.2.1) are commonly used for the pumping of settled sewage. Depending on the total head conditions and degree of solids removal, a diffuser pump selection may be of either the propeller or mixed-flow design. However, solids-handling wet pit pumps are gaining in popularity due to their greater freedom from clogging. Although normally installed in wet-pit applications, these units are sometimes mounted on suction piping and installed in a dry pit. Either type of application is acceptable, although economics usually dictates a wet-pit installation. Head and capacity conditions will determine which type of unit is applicable.

Conventional sewage pumps may also be used to pump settled sewage. They may be of the dry pit, wet pit, or submersible type. It is not usually as economical to design a dry pit for this application, but it is acceptable as far as suitability of equipment is concerned.

Archimedean screw pumps can be used to pump settled sewage, provided the lift is not excessive. As previously noted, this type of pump has certain inherent advantages.

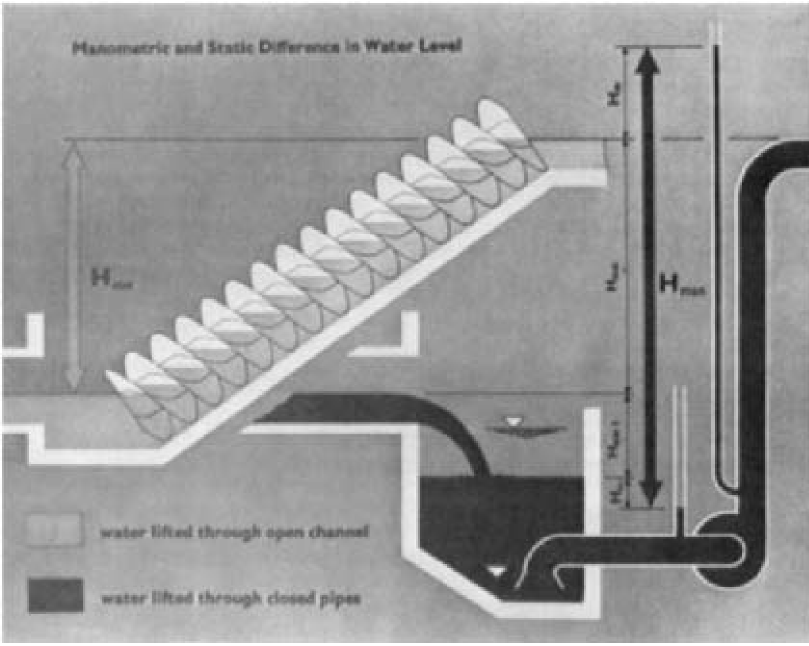

FIGURE 6 Archimedean screw pump (U.S. Filter/Zimpro)

Service Water Plant effluent water is frequently used for flushing, gland seal, foam control sprays, chlorine injector operation, lawn sprinkling, fire protection, and various other services in a waste-water treatment plant. Except for the fact that some solids must be contended with, this application is much the same as that found in building-water supply and small distribution systems.

Screening of solids is normally required; this can be accomplished either before or after the pumps, depending upon various circumstances. Pipeline-type strainers are recommended as they are not only economical but require a minimum of space, can be automatically backflushed, and are much easier to operate than alternative equipment.

Any type of conventional volute or diffuser clear-water pump can be used on service water applications, provided the effluent water is screened prior to entering the pump. Pumps capable of handling some solids should be used in those instances where prescreening is not practical.

Sludge and Scum This classification is divided into two separate categories, based on the concentration of solids in the liquid to be handled. Specialized pumping equipment is required for more concentrated sludges, whereas pumping of dilute sludge and scum is somewhat comparable to the handling of settled sewage.

DILUTE SLUDGE OR SCUM For the purposes of this discussion, *dilute sludge* and *scum* is defined as having less than 2% solids. An exception is digested sludge recirculation, which generally exceeds the 2% limit. This is included along with the more dilute sludges because the same type of pumping equipment is used.

Normally, the handling of dilute sludge is limited to the transfer of biological sludge back to the treatment process or to some other point for further concentration or dewatering and disposal. When digesters are used as part of the treatment facilities, sludge is often recirculated through external heat exchangers in order to maintain temperatures conducive to anaerobic bacterial action. This recirculation also helps keep the contents of the digester mixed. Occasionally, primary sludge and scum are handled in diluted form.

The firm capacity of dilute sludge pumping facilities should be equal to anticipated peak loading. Biological sludge return pumps should have a capacity range from 25 to 100% of average design raw sewage flow to the plant. Digested sludge recirculation pumps should be sized to turn over the contents of the digester frequently enough to maintain the desired temperature. Diluted primary and waste biological sludge pumps should have sufficient capacity to handle peak sludge loading at conservative solids concentrations.

Conventional sewage pumps are suitable for handling dilute sludge and scum. Either the non-clog or mixed-flow impeller may be used, depending upon capacity requirements.

Diffuser pumps are particularly suitable for handling biological sludge that does not contain any appreciable amount of trash or stringy material. They are not recommended, however, for handling diluted scum or for recirculating digested sludge. Depending on capacity requirements, diffuser pumps may be of either the mixed-flow or propeller design. Wet-pit applications are most common, although dry-pit installations are occasionally used.

Torque flow (or vortex) pumps (Figure 7) are often used to handle dilute sludges that contain some grit. These units are particularly suitable for this type of service because their design is such that close running tolerances are not required; this allows the use of specially hardened materials, such as high-nickel iron, which are not easily machined. The most common applications of torque flow pumps are for the pumping of nondegritted dilute primary sludge to gravity thickening and the recirculation of digested sludge.

Screw pumps can be used in certain instances for handling biological sludge. Use of screw pumps is generally limited to low to medium lifts and to those instances where the point of discharge is close to the sludge source.

Air-lift pumps are suitable for transferring biological sludge where the lift is small and the point of discharge nearby. A typical air-lift pump installation is shown in Figure 8. Total head should not exceed 4 to 5 ft (1.2 to 1.5 m). The ability of an air-lift pump to vary capacity is somewhat limited, ranging from about 60 to 100% of the rated amount. These pumps are inexpensive in first cost but have an operating efficiency of only about 30%. They are very easy to install, and maintenance is minimal because there are no moving parts. Air-lift pumps are commonly used to transfer sludge at package treatment plants.

CONCENTRATED SLUDGE OR SCUM Concentrated sludge or scum is defined as having more than 2% solids. The single exception is in the case of the recirculation of digested sludge. As previously discussed, this has been included in the dilute sludge classification.

FIGURE 7 Torque flow pump (EnviroTech Pumpsystems, a Weir Group company)

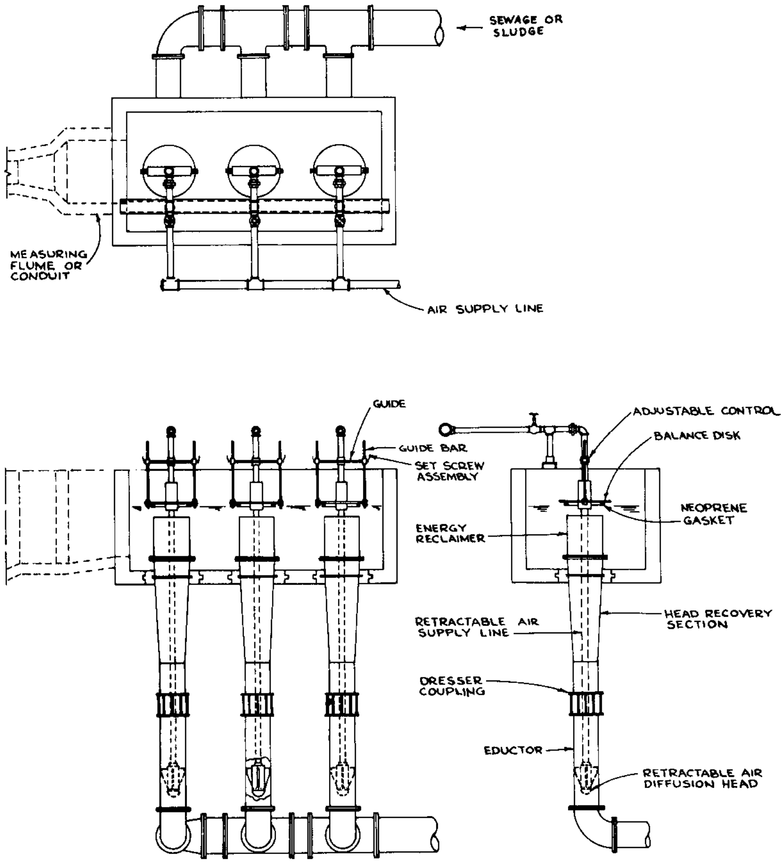

FIGURE 8 Typical air-lift pump installation (Walker Process Equipment Division, McNish Corp.)

Each pumping installation should have enough firm capacity to handle peak design sludge quantities while operating part-time. The proportion of operating time at peak loading should vary from about 25% for primary sludge pumps to close to 80% for pumps feeding dewatering equipment.

Only positive displacement pumps are recommended for handling concentrated sludge and scum, mainly because they can pump viscous liquids containing entrained gas without losing prime. Also, these materials are thixotropic, and conventional formulas for frictional losses are not always valid. An arbitrary allowance of at least 25 lb/in^2 (170 kPa) should be added to the pumping head calculated by conventional methods to allow for changes in viscosity and partial clogging of pipelines. Positive displacement pumps are able to maintain a relatively constant capacity regardless of variations in discharge head.

For most applications, positive displacement pumps may be of either the plunger (Figure 9) or the progressing cavity design (Figure 10). The performance of both depends upon close running clearances; consequently they have a high incidence of maintenance, especially where gritty substances are encountered. Even so, they represent the best pumping equipment currently available, and both designs have been used with success. Lobe-type gear pumps have been used for specialized applications. These are to be avoided, however, where there is any possibility that the material to be pumped will contain even a small amount of grit.

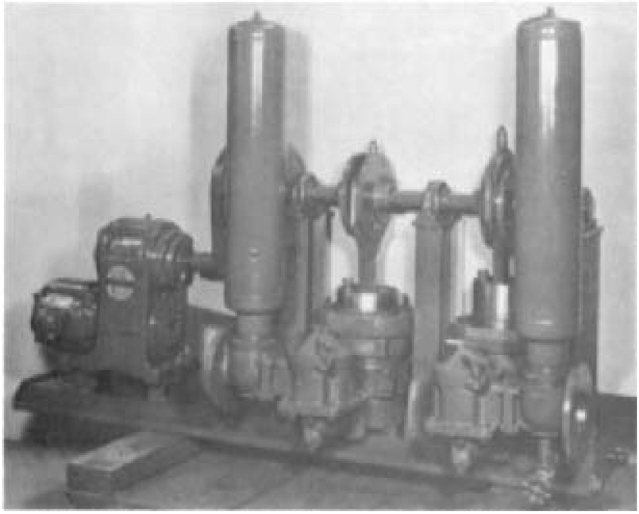

FIGURE 9 Plunger-type sludge pump (ITT Marlow Pumps)

FIGURE 10 Progressing cavity sludge pump (Mono Pumps Ltd.)

Plunger pumps should be of the heaviest design available and should be rated for capacity at about one half of full stroke. The shorter the stroke, the more stable the operation and the less maintenance required. Heads as high as 80 to 100 lb/in^2 (550 to 690 kPa) are available and should be specified in order to give as much flexibility as possible.

Specially designed progressing cavity pumps are available for handling sewage sludges. Wear increases along with pump speed, and so excessive speed should be avoided. Ideally, the maximum speed of a progressing cavity pump should not exceed 350 rpm. These units are readily available with head capabilities up to 50 lb/in^2 (345 kPa) and should be so specified.

Certain of the newer sludge conditioning and dewatering processes, such as heat treatment and pressure filtration, require pumps having a head capability in excess of 500 lb/in^2 (3450 kPa). This is extremely difficult service, and special care should be taken in selecting the type of equipment to be used. So far, this area of application has received very little consideration from pump manufacturers.

Other Uses Grit may be handled with reasonable success with either a torque or an air-lift pump. Considerable flushing water is required with a torque flow pump, and to a

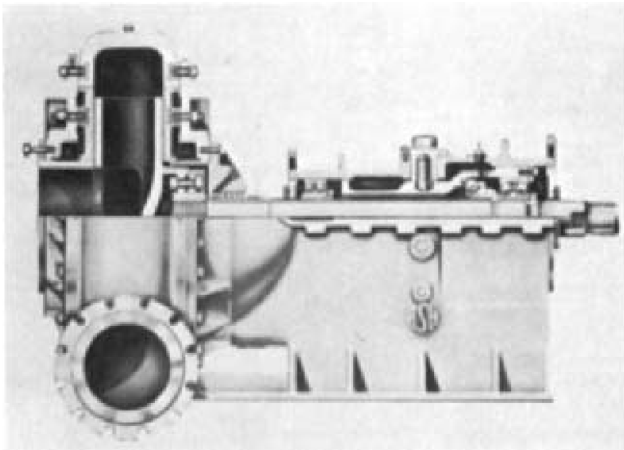

FIGURE 11 Ash pump (EnviroTech Pumpsystems, a Weir Group company)

lesser extent with an air-lift unit. A special ash pump (Figure 11) is required where it is necessary to dispose of incinerator residue in a liquid form. These units are especially designed for ash sluicing service and are made of special hardened metals. No other pump should be considered for this service.

PUMP SELECTION

Various factors should be considered when selecting pumping equipment. These include the number of units to be installed, operating frequency, and station reliability requirements. After these factors have been fully evaluated, head-capacity curves should be prepared in order to match the pumps properly with system requirements. This is necessary because the capacity of most pumps varies with the total head at which the unit operates. When a pump is referred to as having a certain capacity, this capacity applies to only one point on the characteristic curve.

Number of Pumps The number of pumps to be provided at a particular installation depends largely on the required capacity and range of flow. In considering capacity, it is customary to provide a total pumping capability equal to the maximum expected inflow with at least one of the largest pumping units out of service. A minimum of two pumps should be installed in any installation except where pneumatic ejectors are used to serve fewer than 50 houses. Two pumps are customarily installed where the maximum inflow is less than 1.0 mgd (160 m^3/h). At larger installations, the size and number of units should be such that the range of inflow can be met without starting and stopping pumps too frequently and without requiring excessive wet-well storage capacity. Variable-capacity pumps can be used to match pumping rate with inflow rate.

Where variable-capacity pumps are used, a minimum of two units should be installed. In those cases where more than one variable-capacity unit is required to handle peak flow, three units should be installed. In this manner, it is possible to maintain a reasonable rate of flow through each pump. Operation of a single variable-capacity pump in parallel with a constant-capacity pump requires the variable-speed unit to operate at almost no capacity whenever total inflow barely exceeds the rating of the constant-capacity unit. This is extremely difficult service and should be avoided. As a general rule, pumping rates of less than 20% of the rated capacity for which a pump is designed will result in excessive internal recirculation and unstable operation. Recirculation can occur in some pumps at more than 50% of rated capacity. See Subsection 2.3.1.

Operating Frequency Pump size should be coordinated with wet-well design in order to avoid frequent on-off cycling of pumps. Excessive starting will cause undue wear on the starting equipment. Also, standard motors should not be started more than six times an hour. Where more frequent starting is required, special motors should be provided. Inflow into the wet well without pumping should not exceed about 30 minutes if septicity is to be prevented.

Cycle time is defined as the total time between starts of an individual pump. It can be determined by comparing the volume between the on and the off levels in the wet well with the pump capacity. Cycle time is computed as follows:

In USCS units
$$CT = \frac{V}{D - Q} + \frac{V}{Q}$$

In SI units
$$CT = 60\left(\frac{V}{D - Q} + \frac{V}{Q}\right)$$

where CT = cycle time, min
V = wet-well volume between on and off levels, gal (m^3)
D = rated pump capacity, gpm (m^3/h)
Q = wet-well inflow, gpm (m^3/h)

With a given wet-well volume and pumps having a uniform pumping rate, minimum cycle time will occur when the rate of inflow is equal to one-half the discharge rate of the individual pump under consideration. The formula for cycle time simplifies to

in USCS units
$$CT = \frac{2V}{Q}$$

in SI units
$$CT = \frac{120V}{Q}$$

An effective wet-well volume of at least 2.5 times the discharge rate of the pump under consideration is required in order not to exceed the six starts per hour recommended above for pumps having a uniform pumping rate.

Reliability With its increased awareness of and concern for environmental matters, the public has little tolerance for the bypassing of sewage equipment because of power outages, equipment failure, insufficient pumping capacity, or any other reason. Reliability is of extreme importance, and the design of pumping facilities should be premised on providing continuous service. Where electric motors are used, two incoming power lines from separate sources with automatic switching from the preferred source to the standby source are the minimum required for reliability. Standby engine-driven pumps, engine-driven right-angle gear drives, or standby engine-driven generators should be provided where dual electric service cannot be obtained or where the degree of reliability provided by two feeds is not considered adequate. Raw sewage pumping installations are particularly critical. Plant pumping installations usually can be out of service for as long as four hours without adversely affecting the treatment process, provided the liquid will flow by gravity through the plant.

Speed The maximum speed at which a pump should operate is determined by the net positive suction head available at the pump, the quantity of liquid being pumped, and the total head. When specifying pumps, especially those that are to operate with a suction lift, the speed at which the pumps will operate should be checked against limiting suction requirements as set forth by the Hydraulic Institute.

In general, it is not good practice to operate sewage pumping units at speeds in excess of 1750 rpm. This speed is applicable only to smaller units. Larger pumps should operate at lower speeds.

Preparation of Head-Capacity Curves Pump selection generally involves preparation of a system head-capacity curve showing all conditions of head and capacity under which the pumps will be required to operate. Frictional losses can be expected to increase with time, materially affecting the capacity of the pumping units and their operation. For this reason, system curves should reflect the extreme maximum and minimum frictional losses to be expected during the lifetime of the pumping units as well as high and low wet-well levels.

Where two or more pumps discharge into a common header, it is usually advantageous to omit the head losses in individual suction and discharge lines from the system head-capacity curves. This is advisable because the pumping capacity of each unit will vary depending upon which units are in operation. In order to obtain a true picture of the output from a multiple-pump installation, it is better to deduct the individual suction and discharge losses from the pump characteristic curve. This provides a modified curve that represents pump performance at the point of connection to the discharge header. Multiple-pump performance can be determined by adding the capacity for points of equal head from the modified curve. Figure 12 shows a typical set of system curves, together with representative individual pump characteristic curves, modified pump curves, and combined modified curves for multiple-pump operation. Intersection of the modified individual and combined pump curves with the system curves shows total discharge capacity for each of the several possible pumping combinations. A typical set of system curves consists of two curves with a Williams-Hazen coefficient of $C = 100$ (one for maximum and one for minimum static head) and two curves with a Williams-Hazen coefficient of $C = 140$ (for maximum and minimum static head). These coefficients represent the extremes normally found in sewage applications.

Pumps should be selected so the total required capacity of the installation can be delivered with maximum water level in the wet well and maximum friction in the discharge line. Pump efficiency should be maximum at average operating conditions. In the case of Figure 12, assuming that the total capacity of the installation is to be obtained by operating pumps 1, 2, and 3 in parallel, the total head required at the discharge header would be approximately 51 ft (15.5 m). Projecting this point horizontally to the individual modified pump curves and thence vertically to the pump characteristic curves, the required head for pumps 1 and 2 should be 54 ft (16.5 m) and for pump 3 approximately 57 ft (17.4 m). The difference between the head obtained from the pump characteristic curve and the modified curve is the head loss in the suction and discharge piping for the individual pumping units.

Figure 12 also shows the minimum head at which each pump has to operate, approximately 39 ft (11.9 m) for pumps 1 and 2, and about 42 ft (12.8 m) for pump 3. These minimum heads are important and should be made known to the pump manufacturer because they will usually determine the maximum brake power required to drive the pump and the maximum speed at which the pump may operate without cavitation.

PUMP DRIVERS

In the majority of cases, pumps are driven by electric motors. Sometimes, however, they are driven by gasoline, gas, or diesel units where firm power is not available or where pumping is required only at infrequent intervals. Variable-speed drivers are used extensively in sewage applications. These units generally consist of variable-speed motors or constant-speed motors with adjustable slip couplings of either the eddy-current or the fluid coupling type. Selection of the type of variable-speed driver to be used is usually based on space considerations, initial cost, operating cost over the expected life of the equipment, and customer preference. Emphasis is increasingly being placed on operating cost over the expected life due to government and environment requirements. See Section 6.2 for these and other types of speed-varying devices.

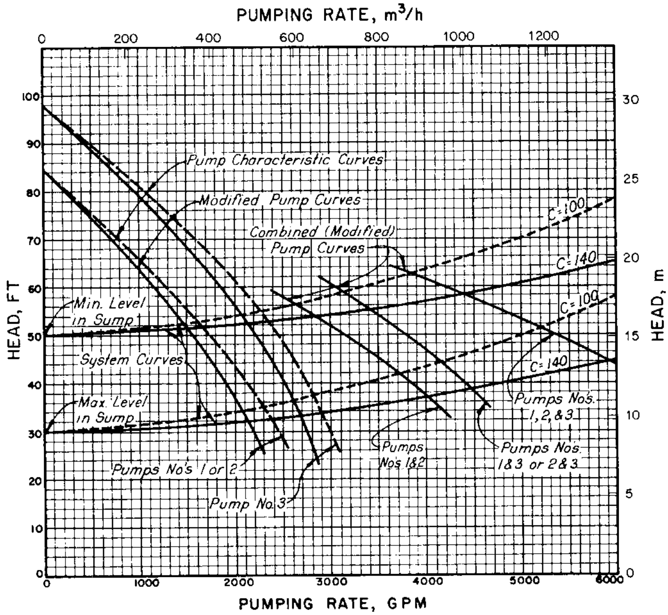

FIGURE 12 Typical head-capacity curves

Variable-speed drivers are particularly appropriate for raw sewage installations that discharge to a treatment plant. Use of this equipment allows the treatment facilities to operate continuously instead of intermittently surging the plant at incremental pumping rates. Variable-speed drivers are used to pump settled sewage and biological sludge where intermittent surging would adversely affect the process. Also, sludge pumps used to feed dewatering equipment are often equipped with variable-speed drives because it is necessary to vary the rate of discharge with the dewatering characteristics of the sludge.

For dry pit applications, the choice between horizontal- and vertical-drive motors depends considerably upon the station arrangement and available space. Horizontal motors are usually preferred, provided there is space and no potential flooding problem. Horizontal pumps are more easily maintained, and they are generally less expensive in first cost. Vertical drivers are generally used, however, for the pumping of raw sewage because of their smaller space requirements. Also, vertical units are advantageous in that the motor is located higher and is less susceptible to flooding.

In vertical dry-pit installations, intermediate shafting is normally preferred. This allows the drivers to be located above a potential flood level in the station. However, the use of intermediate shafting can become quite expensive in terms of initial installation costs and maintenance costs. Additionally, they may be prone to vibration problems if proper precautions are not taken in the design of the station. Vertical drive motor can also be mounted directly above a pump without the use of intermediate shafting. In doing so, it is connected to the pump by means of a suitable coupling. A separate support or bracing of the motor may also be required to provide for adequate installed stiffness.

PUMP CONTROLS

Some means of controlling pump operation is required at most pumping installations. This is usually done from either wet-well level or flow.

Level Control With level control, each pump is turned on and off at specific water levels in the suction wet well; in the case of variable-capacity pumps, the level control attempts to maintain a preset level, once started. Pumps turn on with a rising level and off as the level lowers. Level control is generally used in raw sewage pumping applications. In this manner, it is possible to match discharge with incoming flow.

Flow Control Flow control is used sometimes where there is no limitation on the availability of flow to the pump suction and where it is desirable to maintain a predetermined rate of discharge. Where flow control is used, a flowmeter is used as the primary instrument to measure flow and to serve as a basis for varying pump speed, which in turn controls capacity. The speed can be changed either manually or automatically through closed-loop instrumentation.

Additional Level Control Low-water pump cutoff and high-level alarm are provided on most pumping installations. The low-level cutoff is required to prevent the pumps from running dry, and the high-level alarm notifies the operator in the event the pump should fail to operate. When the pump stops because of low-water cutoff, there is usually some means of indicating this to the operator.

MISCELLANEOUS DESIGN CONSIDERATIONS

In addition to the matters discussed previously, there are certain other items that should be given consideration in the design of pumping installations.

Piping and Valves Suction and discharge piping should normally be sized so the maximum velocities do not exceed 5 and 8 ft/s (1.5 and 2.4 m/s), respectively. Higher velocities, however, may be justified by economic analysis for particular installations. Lines less than 4 in (102 mm) in diameter should not be used for raw sewage. Preferably, sludge lines should be at least 6 in (152 mm) in diameter; 4-in (102-mm) lines are sometimes used for dilute biological sludge.

Valves should be installed as required on the suction and discharge sides of each pump to allow removal and maintenance of individual pumping units without disturbing the function of the remainder of the installation. It is customary to use either ball or plug valves on raw sewage and concentrated sludge applications. Either plug or butterfly valves can be used for settled sewage or for dilute sludge.

Piping should be designed with sufficient flexibility to avoid stress on the pump flanges. Flange-coupling adapters are sometimes used for this purpose on both the suction and discharge sides of the pump.

Surge Control Careful attention should be given to surge control wherever a pump discharges into a force main of appreciable length. Generally this is a problem only in the design of raw sewage pumping stations located within the collection system. Changes in fluid motion caused by starting or stopping of pumps or by power failure can create surge conditions.

Surges caused by normal starting and stopping of pumps driven by electric motors may be controlled (1) by selecting individual pump capacities such that the change in velocity in the system when a single pump starts or stops will not result in excessive surges, (2) by using variable-speed drives to bring pumps gradually on or off line, or (3) by using power-operated valves that are controlled so the pumps are started and stopped against a closed valve.

Surges caused by power failure can be controlled by devices designed to open on an increase in pressure, by devices that will exhaust sewage from the system upon sudden pressure drop in anticipation of surge, or by a surge tank.

Pump Seals Most sewage and sludge pumps can be obtained with either mechanical seals or packed stuffing boxes. Conventional mechanical seals have the disadvantage of requiring a pump to be disassembled so the seal can be repaired. Present mechanical seal technology offers a solution to this in the form of a split mechanical seal. Such a seal can be removed and repaired or replaced without the necessity of disassembling the pumping unit.

Often it is easier to replace the seal rather than repair it, and it is desirable to keep a spare on hand for this purpose. Packed stuffing boxes provided with water-sealed lubrication are still the most common choice for non-submersible sludge and sewage pumps. Grease seals are sometimes used for some of the smaller sewage pumps that do not run continuously.

Water serves multiple purposes as a sealing medium: it seals, lubricates, and flushes. Flushing is particularly important where abrasive material is involved in that it helps prevent this material from entering the seal. Grit and ash are very abrasive, and either will cut the shaft sleeves in a relatively short time. Where pumps are controlled automatically, a solenoid valve interlock with the pump starting circuit should be provided in the seal water connection to each pump. A manual shutoff valve and strainer should be provided on each side of each solenoid valve, and a bypass line should be provided around it.

Mechanical seals are normally lubricated with a clean external water source supplied at a pressure and flow rate as recommended by the seal manufacturer. Seals can be lubricated by the product being pumped provided it is filtered and can provide a reliable pressure and flow rate to the seal cavity. In such cases, a connection is normally provided between the pump discharge and the seal with a 0.10 to 0.20 in (2.5 to 5 mm) in-line filter to prevent foreign material from entering the seal cavity.

Occasionally, a pump station is so remote that sealing water is not readily or economically available. Mechanical seals can be provided constructed of special materials to withstand such adverse conditions. Also, several types of "formed-in-place" packing are available that do not require a smooth surface on which to seal as the packing develops its own sealing surface. However, these packing materials are not normally recommended for temperatures over 130°F (54°C) or pressures over 60 lb/in^2 (4 bar).

Pump Bearings Pump bearings must be adequate for the service and should be designed on the basis of not less than a minimum life of five years in accordance with the Anti-Friction Bearings Manufacturers Association life and thrust values. The larger sewage pumps are usually equipped with both case and impeller rings of bronze or chrome steel.

Cleanout Ports Pumps should be provided, where possible, with cleanout ports on both the suction and discharge sides of the impeller. These are desirable for inspection and maintenance purposes.

Wet-Well Design Raw sewage wet wells should not be so large that sewage is retained long enough to go septic. It is usually desirable to limit storage to a maximum of 30 minutes. Shorter retention time is desirable. With the variable-speed controls now available, many stations can be designed so that the pumping rate matches the inflow rate and the inherent difficulties of frequent pump cycling or long retention times in wet wells can be avoided.

FURTHER READING

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