SECTION 13
DRAINAGE OF MINES

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<table>
<thead>
<tr>
<th>ART</th>
<th>PAGE</th>
<th>ART</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.</td>
<td>Drainage Tunnels</td>
<td>10</td>
<td>12.</td>
</tr>
<tr>
<td>7.</td>
<td>Steam Pumps</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

Note.—Numbers in parentheses in text refer to Bibliography at end of this section.
DRAINAGE OF MINES

1. SOURCES AND CONTROL OF MINE WATER

Surface inflow through outcrops is the chief source of mine water in regions of heavy or moderate rainfall, especially where mines are worked to the outcrop, and large drainage areas are above or tributary to extensive outcrop workings. In such cases, mines may be subject to sudden floods, which usually require definite times to reach the workings. Hence records of quantity and character of precipitation, and time and extent of resulting extra inflow, should be kept for their value in giving warning. Deposits overtopping under water-bearing surface wash, as in alluvial valleys, while not exposed to similar flooding, are subject to continuous percolation through the strata, the amount dependent upon the character of the measures and closeness of mine workings to buried outcrop. In case of a coal seam in contact with a bed of fire-clay, the latter may be washed out over areas sufficient to cause disastrous inflow. Surface flood water may also find its way into mine openings or open crop-falls (1).

Surface water through cracked or broken measures may be more dangerous and troublesome than that from open outcrops. Where a deposit has been extensively worked by open or by shrinkage stopes under fissured rock cover, cracks and crevices may admit large quantities of both surface and ground water, combining serious permanent flow with periodic flooding from rainfall.

Flooding may also come from caves extending into water-bearing wash or water-soaked deposits, from mining under too thin a rock cover, or cutting into "pot-holes" or buried valleys. At Nanticoke, Penn, 26 men were buried in quicksand from a pot-hole over 100 feet deeper than the surrounding rock.

Water from permeable measures is always possible, and in formations like soft massive sandstones may be expected. It may enter as seepage, or under pressure, often from large areas, resulting in persistent inflows. Relief can be obtained only by draining entire basins, or by general lowering of ground-water level. WATER FROM CREVICES OR UNDERGROUND CHANNELS is sometimes encountered in shaft sinking or in mining itself, coming in unexpectedly and in large volume. It may persist to the complete drainage of territory tapped. Water from uninspected underground cavities, either natural caves or abandoned workings, is fortunately rare. Its serious aspect, aside from quantity of water, is suddenness of inflow, which may endanger life and quickly flood lower workings.

2. PREVENTION OF INFLOW

Surface. It is generally cheaper to keep water out of mines than to remove it after it has entered. While it may be impossible to prevent the entrance of all water, the amount can usually be decreased by attention to sources of inflow. In impervious soil, entrance of surface water can be minimized by well-planned ditching around outcrop or fractured areas. In permeable soil, ditches should be lined, or wooden or concrete flumes installed. If streams or drainage channels cross outcrops or fractured areas they should be flumed, or diverted by canals, designed to take maximum flood volumes, and located to minimise danger of rupture from surface settlement often occurring during flood periods.

Drainage works are sometimes built through extensive districts by a combination of interests, as in Hazleton region, Penn, where Black Creek has been diverted outside of the coal measures for miles, relieving the drainage situation in a number of collieries, each of which formerly pumped practically the entire creek flow.

Besides diverting surface water, the discharge of mine pumps must be delivered outside of drainage area of mine. This may cause contamination of streams. Some state courts have ruled that discharge of mine water into its natural drainage channels is permissible, but that damages may be recovered for its discharge into streams not reached by gravity in case the mine should fill. Thus, drainage tunnels discharging onto unpolluted watersheds may furnish ground for damages.

Entrance of flood water through openings other than crop-falls or cracked measures should be impossible. If there are openings below flood level, along creeks or in alluvial flood plains, shut-off doors or temporary dams should be installed. In planning new openings flood records should be obtained, and openings placed well above danger line. Damage from flooding may be so serious as to warrant considerable expenditure to avoid it. In case of shafts, the cost of extending waterproof curbs above possible flood level is small, and the shaft spoil may be economically used for
filling necessary to raise plant above high-water mark. This has been done at many shafts in the flood plain of Susquehanna River, Penn., shaft curbs being at least 5 ft above highest recorded flood mark; also, provision is made for shutting openings promptly in case of possible higher floods.

Underground. In mining under heavy water-bearing wash or quicksand, it is imperative to leave sufficient rock cover, and to keep workings far enough below buried outcrops to avoid danger. Preliminary exploration of rock surface should be done by borings sufficiently close together for making a fairly reliable contour map of the buried rock surface.

Fig 1 is a map of a small area of the buried valley of Susquehanna River, showing the great irregularities of rock surface revealed by borings. The wash varies from less than 100 to nearly 300 ft deep, and without borings the workings might easily have been extended into unsuspected deep recesses in the rock. In such boring, especially in stratified measures, some holes must be continued into the rock, to determine its nature. These holes should be grouted to the rock surface, to prevent entrance of water through them to subsequent mine workings.

![Map of Rock Surface of Buried Valley](image)

**Fig 1.** Map of Rock Surface of Buried Valley

Rock thickness required between workings and overlying wash depends so largely on character of deposit, nature of overlying rock and method of mining, that no general rule is possible. In the Wyoming Anthracite Field, Penn., under the Susquehanna Valley and under the river itself, the rock cover varies from 100 to 50 ft minimum; under deeper wash, from 20 to 100% of thickness of wash. Under aver conditions, with sandstones and slates overlying mine openings, and with ample pillars, a rock thickness above workings equal to 1/3 of total cover is a reasonable minimum. In steeply-pitching measures, thickness of cover is determined by the distance from outcrop required to prevent inflow along bedding planes; best determined by test openings toward outcrop.

Douglas Bunting gives the following relations for 24 ft width of mine openings:

- \( T = 1.5 \sqrt{d} + 5 \) (strong measures, rock surface fully explored).
- \( T = 1.5 \sqrt{d} + 15 \) (softer measures, liable to disintegration, rock surface fully explored).
- \( T = 1.5 \sqrt{d} + 40 \) (strong measures, rock surface imperfectly explored).
- \( T = 1.5 \sqrt{d} + 50 \) (softer measures, liable to disintegration, rock surface imperfectly explored).

In these formulas: \( T \) = thickness of rock cover, \( d \) = depth of surface wash, ft.

Grouting and waterproof linings. Inflow from water-bearing strata is avoidable by waterproof linings of shafts and other openings, or by grouting under pressure into surrounding rocks.
DRAINAGE OF MINES

In approaching known or possible old workings, and when mining in limestone where cavities may be expected, drill holes, preferably bored through gate valves previously secured, should be kept well in advance of all workings, to avoid disastrous intrushes of water, and to control flow from any orebody which may be tapped by holes, letting water out only in such quantities and at such times as may be suitable for capacity of the pumps.

No means have yet been devised for materially diminishing the inflow of deep ground water, as encountered in porous formations of some western mines. An adequate pumping plant is the sole safeguard. Grouting in advance of sinking may be done through bore holes surrounding proposed shaft location; or during sinking through radiating drill holes; or subsequently behind shaft lining of steel, brick, stone or concrete (Sec 7, 8).

In case of fissured or broken ground the flow may be reduced and sometimes entirely cut off by cement grouting under pressure through bore holes, or by the Kirby (patented) process, consisting of injection through drill holes or into partly-plugged cracks of chopped straw, sawdust or other finely divided material, followed by clay, slimes or mud (first used at the Flat River, Mo, mines of Federal Lead Co, where it practically stopped the flow from a network of fissures previously unconquerable).

Sometimes, when water pressure in cracks or fissures is so great that plugging in preparation for grouting or mudding only results in spreading the water through considerable areas of fractured or permeable rock, the pressure may be relieved by drilling diagonal holes into the cracks, and plugging and grouting cracks, after which the drill holes which have taken the flow temporarily are permanently closed.

Tapping underground reservoirs. When approaching suspected bodies of water under pressure, bore holes should be kept in advance of the face, and bored in such manner as to permit withdrawal of drill rods and closing of hole when water is encountered. One hole (better 2 holes) should be bored straight ahead of face, 10 to 20 ft in hard rock, 75 to 100 ft in soft rock or bituminous coal. Other holes, of about same depth, should be drilled obliquely forward (about 30° from center line) at intervals of 8 to 12 ft. If water be tapped unexpectedly, insert a dry soft-wood plug of diam small enough to enter freely; push to bottom of hole, and hold there by a rod or pipe of suitable length, and a larger plug driven into neck of hole. In several hours the inner plug will have swollen tight, when outer plug can be removed; then enlarge outer 5 or 6 ft of hole. To a piece of heavy pipe screw a sleeve coupling at one end and a straight-way gate valve at other. Insert coupling end into enlarged hole, and wedge with oakum and dry soft-wood wedges; also brace outer end of pipe against timbering, if pressure be great. Insert drill through gate valve, bore through inner plug, withdraw drill, and regulate flow of water by gate valve. If position of water body be known with certainty, the above preparations can be made in advance, and boring finished through a stuffing box attached to end of valve.

Water rings. If complete waterproofing of a shaft be too costly, water rings may be built into the lining, to lead water entering above them into sumps excavated in sides of shaft, whence it may be pumped to surface, saving a material vertical lift, or piped down the shaft, and power thus obtained utilized. Such rings and intermediate sumps are especially desirable for very deep shafts, where pumping is done in two or more lifts, the intermediate sumps then serving for upper pumps.

Chain pillars. In deposits opened by drift or tunnel, and later worked below water level, a chain pillar sufficient to retain permanently all surface water should be left on the water level. Openings to dip are so arranged that water can be led past them and out through tunnel. A chain pillar ties up part of the mineral, which, however, is recoverable before final abandonment of the property, and by reducing pumping throughout life of mine may pay for itself many times over.

3. SUMPS, UNDERGROUND DAMS, BOREHOLES AND PIPING

Drainage levels. In general, water should be intercepted at as high a point in the workings as possible, to avoid unnecessary height of pumping lift. But this principle is modified by considerations as to the best points for locating sumps and installing pumping plant, even at cost of increasing the head for a portion of the water. The main collection point should be determined early in the development of a mine, and all openings driven from it should have a grade of at least 0.25% (0.5% being sometimes adopted, to make haulage resistance nearly equal for both empty and loaded cars. See Sec 11). Water ditches, excavated below or on one side of track, in entries, drifts or tunnels, should be kept clean and open. If main drainage levels are in broken or fissured ground, ditches should be lined with concrete; or wooden flumes, half-round terra cotta tiles, or even pipe, may be used, to prevent water from permeating into lower workings.

For proper drainage, chain pillars should be maintained as long as possible under drainage levels. An exception is where exhausted workings may be allowed to fill with water without detriment to
the mine, as in small local basins in a flat deposit. Workings in wet ground should not be extended to the dip, if this would require installation of a number of small, scattered pumps. In such case, water may sometimes be drained off through bore holes to the lower workings. By similar means, water troubles may be avoided in sinking shafts and winzes.

Size of sump is chiefly dependent upon quantity of inflow. It should be large enough to take care of inflow while pumps are stopped for ordinary repairs. A sump capacity of

![Diagram of Sump and Pump Room](image)

Fig 2. Plan of Sumps and Pump Room, No 6 Mine, Lehigh Nav Coal Co, Lansford, Pa

8 hr max inflow, without submerging the pump, may be considered a minimum; capacities of 24 hr or more are not unusual.

Location of sumps should be carefully considered in layout of mine workings. Since haulage ways, with their drains, gravitate towards shafts, the main sump is usually placed near foot of shaft or slope. Where conditions permit, a good sump is obtained at low cost

![Diagram of Underground Dam](image)

Fig 3. Details of Underground Dam, Hazleton Shaft Colliery

by working out an area of the deposit to the dip, adjacent to shaft station, leaving chain pillars to isolate sump from lower workings. Sumps should be arranged so that they can be easily cleaned out.

In pitching deposits, where several veins are worked, the sump is sometimes placed in main workings and pumps in an overlying or underlying vein, the two being connected on main level by a tunnel closed by a dam (Fig 8). The pipe from dam to pump has a shut-off valve, so that if necessary, main workings can be flooded to considerable depths without affecting operation of pumps.
Fig 2 shows a well designed sump at Lanford No 6 mine, Lehigh Navigation Coal Co. There are two centrifugal pumps, each of 2,000 gal per min, and 2 sumps holding 118,000 and 114,000 gal. The sumps are connected, to maintain same water level in both; this is important, as the pumps operate automatically, and are started and stopped by float switches. Switches are so arranged that when pump No 1 can not alone handle the inflow, pump No 2 starts automatically.

![Diagram of a sump system]

Fig 4. Emergency Flood Dam (for 45-ft Head), Lehigh Nav Coal Co, Tamaqua, Pa

For cleaning one sump, the connecting tunnel is closed and all water from the main tunnel diverted to the other sump. The sump to be cleaned is then pumped out as far as practicable with the main pump, the rest being removed with a small plunger pump. The sediment removed is loaded into mine cars, and pulled out by a motor through the rock slope. Low-water level in the sump should be not more than 20 ft below center line of pump, and end of suction pipe not less than 2 ft from bottom of sump.

![Diagram of an emergency flood dam]

Underground dams (4) must often hold water under heavy heads, and should be backed by masonry, calculated to resist max possible head of water. They are usually of brick or concrete (Fig 3). Solid abutments are essential; all soft adjacent material must be cut away to insure against bodily movement of the dam. Manholes of ample strength must be provided to drain off water and permit entrance and inspection. Timber dams, single, or better double bulkheaded, with a clay core may be used in case of emergency. Fig 4 and 5 show steel emergency dams which can be readily closed in times of high water. A flat rubber 1/4-in gasket, between frame and door, provides an effective seal.

As mine dams are subject to heavy strains, their strength is a vital matter and careful calculations are necessary. The following formula is for arch dams (Fig 3):

\[
t = \frac{\sqrt{0.4r} - 1}{4e}
\]
in which: \( t = \) thickness, in; \( r = \) shorter or external radius, in; \( w = \) width of opening or span, in; \( p = \) maximum water pressure, lb per sq in; \( s = \) safe compressive strength of material used, lb per sq in; \( f = \) factor of safety, not less than 8.

A. Faulds gives (4), quoting W. S. Aldis, using same notation, but with factor of safety 10:

\[
t = r \left( 1 - \sqrt{1 - \frac{2p}{s}} \right) \text{ for arch dams}; \quad t = r \left( 1 - \frac{3}{1} \sqrt{1 - \frac{1.5p}{s}} \right) \text{ for spherical dams.}
\]

Factors \( \frac{2p}{s} \) and \( \frac{1.5p}{s} \) must be less than unity, or proposed material will be too weak.

A straight or flat concrete dam, necessary where strata will not safely stand thrust of an arch dam, is practically a plate supported on 4 sides, a condition requiring an intricate calculation. For such a plate tests have shown an increase in strength of fully one third over that of a beam supported at both ends. It is safe to calculate a straight dam as a beam having its shortest length loaded uniformly and supported at both ends, using the formula:

\[
s = \frac{wl}{2bd^2} \quad \text{whence,} \quad d = \sqrt{\frac{wl}{2bs}}
\]

in which: \( s = \) unit stress in extreme fibers; \( b = \) breadth, in; \( d = \) thickness, in; \( w = \) total load, lb; \( l = \) length, in. In this case the strength of plain concrete in tension should be taken at not over 60 lb per sq in, whence for a dam with span of 7 ft (= 84 in), built to withstand 500 ft head (= 216.6 lb per sq in):

\[
w = 84 \times 216.6 = 18 208 \text{ lb per linear in, and } d = \sqrt{\frac{18 208 \times 84}{2 \times 50}} = 126 \text{ in}
\]

A saving in material can be made by building a flat dam of reinforced concrete. If the rock formation be of doubtful strength to stand direct thrust of either arched or flat dam, a larger surface of abutment may be obtained by stepping the notch (Fig 6). In a large Schuylkill County, Penn, colliery, a special method was employed (Fig 7) to drown out a fire in upper levels without complete flooding. As the pillars were not considered safe to support the pressure which would be brought on the lower dams, these were relieved by flooding behind auxiliary dams, thus building up a series of counterbalanced pressures. Hence the coal in each pillar took no more pressure than that due to a single lift on any one dam. Fig 8 shows an underground dam and pumping plant in the Hazleton Shaft mine, Lehigh Valley Coal Co.

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![Fig 6. Stepped Abutment, Concrete Dam](image1)

![Fig 7. Series of Dams, with Counterbalanced Pressures](image2)

![Fig 8. Underground Dam and Pumping Plant, Hazleton Shaft Colliery](image3)

Pumping through boreholes is a common practice in both coal and metal mines, the pump delivering directly into holes drilled from surface to mine workings (33). In weak strata the holes are lined with W-1 pipe, around which rich cement mortar is poured. If the water is very acid the pipe should be wood-lined, or the boreholes lined with terra-cotta piping. In hard rock no lining is necessary.
By using boreholes the pumping plant can be located to suit the position and shape of the mine openings. They often reduce the lift, save cost of providing space for and installing column pipe, and avoid possibility of damage to mine workings from broken column pipe. Boreholes are 8–24 in diam, drilled by churn or shot drill (Sec 9). Objections to them are the possibility that the holes will be closed by caving or settlement of the strata and the difficulty of renewing worn out pipe lining. In water-bearing, porous strata, boreholes with use of air-lift pumping have successfully lowered water levels in advance of sinking.

Boreholes are sometimes used for dropping water from an upper to a lower level. Quantity of water discharged can be determined from a friction chart (Fig 9). If there were no pipe friction, the water would flow through borehole with increasing speed and
be discharged at a velocity $V = 2gH$, where $H$ is the vertical distance between upper and lower basin. Pipe friction retards flow, which becomes uniform when the total friction in borehole equals the head $H$; that is, when the friction becomes 100 ft for every 100 ft of borehole. The capacities causing a friction loss of 100 ft per 100 ft of pipe can be taken from the chart.

Example. A vert borehole 3 in diam will discharge approx 500 gal per min, and a 6-in hole, 3,000 gal per min, regardless of their length, provided there is a sufficient head of water over the inlet to produce the velocity required in the pipe and that the borehole is smooth (37).

For a sloping hole or pipe 3 in diam, 100 ft long, on a grade of 1 in 10, the effective head is 100 divided by 10, or 10 ft. The friction loss per 100 ft of borehole or pipe can not, therefore, be more than 10 ft, corresponding to a max flow of approx 160 gal per min. (See Sec 38.)

Pump piping. Suction pipe should be short as possible, with few bends and should dip directly into the water (Fig 20, Art 11), so that it can be raised from the sump by the crane which should be installed in every pump room. Suction piping must not be wood-lined, as the staves may become loose and block the strainer. For acid water, it is cement-lined, by a mixture of 1 part finely sieved Portland cement and 2 parts sharp silica sand, applied by a long handle trowel, to form a layer about 0.5 in thick; after which, both ends of the pipe are closed with damp canvas to keep out the air until cement has set. If wet cement is exposed to air it will crack. Good cement linings should last for years. Discharge piping must be well supported and braced, so that any water hammer caused by closing of the check valve is not transmitted to the pump. Fig 10 shows proper method of supporting column pipe in the shaft. Size of column pipe should be calculated to minimize friction head; increased power due to frictional resistance may cost more than the larger piping.

As elbows increase resistance, they should be of long radius. Always use $Y$ branches with long bends; avoid tees. C-I flanged pipe is generally in 10- or 12-ft lengths, without male and female joints, as these are troublesome when piping is renewed. Present practice leans to straight flanges, with concentric $Y$-grooves to retain the gasket. A W-I ring, 1/8-1/4 in by 1 in wide, wrapped with
DRAINAGE OF MINES

tarred hemp, makes a good gasket. Composition fiber gaskets have also been successful. Minor
bends in piping may be made with bevel-ring joints (either the iron-ring built-up gasket, or the
composition fiber gasket), thus avoiding necessity for lengths of special curved pipe. Column pipe,
ot otherwise protected, should be coated inside and out by hot asphalt or tar.

Lining for acid water (31, 32). Cement lining for suction piping is satisfactory; lead lining is
good, but wears rapidly in gritty water; wood lining is cheap and simple, with excellent wearing
and acid-resisting qualities. Wood lining is best of narrow, sawed strips with radial joints, driven
dry and swelled with pure water; strips should not be planed, because sawed surfaces, when swelled,
interlock and form better joints. For pipes to 8 in diam, liners 0.5 in thick are ample, 8½-in strips
are sometimes used; for 8 to 14-in pipe, 0.75-in liners are sufficient; for over 14 in, usually 1 in.

When column pipes become blocked with incrustations, the sections are disconnected and
cleaned by hand, or a cleaner is drawn through the entire line to cut loose the scale. There are
various types of cleaners. The "Go-Devil," a wooden ball with a large number of spikes driven
into it and protruding 1 to 1½ in, is generally used in the anthracite region for removing "Yellow-
Boy" (FeS). The balls are sometimes of stainless steel, with spikes or knives welded onto them.
As incrustations increase pipe friction and consequently the pumping head, resulting in decreased
capacity and efficiency, pipe lines should be cleaned at regular intervals. "Go-Devil" housings (Fig 11)
permit introduction of the ball into the pipe line while the pump is in operation. The ball is placed
in the upper chamber, and the by-pass is opened, equalising the pressure on both sides of the flap.
The flap is then lowered, the ball falls into the column line and the pump pressure drives it through
to the surface.

4. DRAINAGE TUNNELS

These are advantageous where location and topography permit. Though first cost is
large, the elimination of pumping charges and freedom from possibility of flooding the mine,
due either to accident to pumps or power plant, or to labor troubles, may warrant the
investment. In most cases, local conditions are such that only the upper levels of a mine
can thus be unwatered by gravity. When workings extend below tunnel level, pumps
must be installed. But, drainage tunnels still have the advantage of saving cost of raising
the entire volume of water through a height equal to distance below surface at which
tunnel intersects deposit. An estimate of length of tunnel justified in comparison with a
pumping plant must be made with careful consideration of: cost of driving, maximum
quantity of water possible for short periods, and height of lift for which the pumps and
power plant must be designed.

Cost of drainage tunnels, and their design, cross-sectional dimensions and speed of
driving under different conditions, are given in detail in Sec 6.

Should the tunnel serve also for haulage and ventilation, all of its cost is not chargeable to
drainage. To justify driving a tunnel for drainage only, the interest on first cost, plus annual
allowance for amortisation, must be less than operating expense of pumping, plus allowance for
amortisation of pumps and power plant. The amortisation allowance must be based on a con-
servative estimate of life of mine. If a tunnel replaces a pumping plant, the final value of plant is
its second-hand, or its scrap value, less cost of removal.

5. SIPHONS

Siphons have a limited use as adjuncts of main drainage systems, in conveying water
from one part of a mine to another; for example, from a place which, though higher than
main sump, is separated from it by still higher intervening ground. A siphon will work
only when highest point of pipe is less than 34 ft above water level at inlet end. Joints
must be tight, because leakage and presence of entrained air reduce practical limit of suc-
tion height, and siphons are unsatisfactory when a (Fig 12) exceeds, say, 20 ft. The
working height is proportionately less at altitudes above sea level. The longer or dis-
charge leg of the siphon must fall through a greater height than the short leg, or draft pipe.

The difference between these heights is the effective head, $h$, which causes flow and over-
comes pipe friction. If the pipe friction were zero, the water would run down the dis-
charge pipe at increasing velocity, and have a velocity at the outlet of $V = 2gh$. The pipe
friction retards the flow and the chart (Fig 9) should be used for calculating siphons.

Example. For a siphon of 2 in diam, 200 ft long, with $a = 10$ ft and $b = 18$ ft, the effective head
$h = b - a = 8$ ft. The friction loss in 200 ft of 2-in pipe, therefore, can not exceed 8 ft, or 4 ft per
100 ft, which, according to the chart, corresponds to a flow of approx 30 gal per min. Actual flow is
COMPRESSED-AIR DRIVEN PUMPS

20% to 40% less, depending on losses at entrance and in bends, and leakage of air into the draft pipe. To charge the siphon for starting, a short stand-pipe is placed at the summit and gate valves at each end of the pipe. The discharge valve is used to regulate the flow if the discharge valve becomes so great that a vacuum forms at the crown of the siphon.

6. HOISTING WATER IN TANKS

Water hoisting, though less economical than pumping with electric or centrifugal pumps, is useful for unwatering flooded mines. For this emergency service it usually replaces the hoisting of ore or coal, which presumably can not be raised while hoisting water. The mineral hoist of a shaft subject to sudden inrushes of water should be convertible to a water hoist in the least possible time. A water tank is designed either to be attached under each cage or is put on in its place. The shaft should extend at least 30 ft below the bottom level, at which there is a platform with doors (Fig 13). When water is to be hoisted the doors are removed, thus allowing the tank to be lowered into the sump. The false bottom should be tight, so that solid matter can not enter, the sump. A small pump should be installed to pump out the sump occasionally.

Readers desiring further information regarding water hoisting by tanks are referred to the previous editions of this book, in which full details of the tanks are given, with costs. See also Bib 27, 28.

7. STEAM PUMPS (4-7)

Current practice tends toward complete electrification of mines. Steam pumps are now rarely installed, most of them having been replaced by centrifugals. But, at mines where there is an excess of boiler fuel and pump and boiler plant are in good condition, it is advisable to maintain steam pumps. If the boiler plant is near the pumproom, and pumps are of compound condensing type, pumping cost compares favorably with that of the best motor-driven centrifugals. New steam-driven units are generally centrifugals, driven by steam turbines, with or without speed reduction gearing. Their advantage over motor drive is that speed can be regulated and capacity adjusted to inflow, but they can not be operated safely without an attendant; a decided disadvantage. See Sec 40 for details of pumps and their design.

8. COMPRESSED-AIR DRIVEN PUMPS (see Sec 15) (20)

Though pumping by compressed air is less efficient than by steam or electricity, its use is sometimes warranted: (a) in gassy collieries, where electricity is dangerous, and pumps are too far from boiler plant for economical steam transmission; (b) in mines where heat from steam pipes is objectionable, or heat combined with moisture would injure roof rock; (c) where there is no electric plant and amount of current required would not warrant an installation. It is common to use compressed air in pumps built for steam, and in cylinders not properly proportioned for the pressure employed. Under these conditions it is rare that more than 20% of indicated power at compressor is represented by actual water pumped; with reheated air, the efficiency may rise to about 30%. The chief difficulties are, that ordinary direct-acting pumps fail to make full stroke, and their clearance volume is too great for compressed-air operation. Better results are obtainable from larger flywheel pumps, designed for the service. In absence of reheating, trouble from freezing in exhaust ports may be minimised by use of separators and traps in air lines close to the pumps, and by directing a small stream of water, taken under column-pipe pressure, into the exhaust passages below the valves.
9. AIR-LIFT PUMPS (see Sec 15) (Bib, 19–24)

Details are omitted here, as the construction and operation of air-lifts are treated at length in Sec 15, wherein are given also examples embodying results obtained from a number of mine installations. Efficiency is low, rarely exceeding 45% and often much smaller; but this defect is offset by their efficacy under certain conditions, especially for pumping out flooded shafts and mines.

10. ELECTRICALLY-DRIVEN PUMPS (see also Sec 16, 40)

Electric pumps comprise station pumps, and portable pumps used for gathering purposes. Station pumps are generally centrifugals, recent installations having automatic control for starting and stopping. They can be operated safely without an attendant and great savings are thus possible. Plunger pumps must have an attendant, as there is always danger that solid matter will lodge on the valve seats, causing slippage and water-hammer, and broken pipes or valve chambers. Plunger pumps are used only when small volumes are pumped against very high heads; for instance, 100 gal per min against 800 ft.

This condition would require a high-speed centrifugal, with 6 or more stages and high upkeep cost, especially when the water is acidulous. High upkeep would be somewhat offset by saving in first cost and maintenance of the column pipe, due to the smooth, non-pulsating discharge from a centrifugal pump. Actual figures are lacking, but practice proves that these savings are considerable.

Centrifugal pumps. Operating conditions differ entirely from those of plunger pumps. When the discharge pressure of a plunger pump is reduced, the power required falls off; when the head on a centrifugal is reduced, the power increases. The delivery volume of a plunger pump running at constant speed is invariable, regardless of the lift; whereas a centrifugal at constant speed delivers more water at low heads than at high (14, 15).

Performance. Water entering a centrifugal pump is set in rotation by the impellers and issues at the periphery at high veloci. This veloci is gradually reduced in the pump casing and converted into pressure, which in turn overcomes the resistance in the column pipe. Obviously, the volume delivered increases as resistance decreases. The high veloci at which the water leaves the impeller should be reduced in the casing gradually, without shock, and transformed into press with minimum loss. This is effected in a volute casing, or in one having a diffusion ring between impeller and outer casing. Volute casings are the rule for single-stage pumps, and are common also for multi-stage pumps, especially when the water is acid. To obtain high effic in a diffusion-ring pump, the tips of the diffusion vanes must be rather thin, so that acid water soon destroys them. The volute pump has higher effic over a wider range than diffusion-ring pumps. Fig 14 shows the
approx performance of volute pumps. If the head and capac at which a pump is most efficient be taken as unity, by increasing the head 15%, the capac decreases about 40%, power decreases 24%, and effic is reduced 9%. If the head decreases 12%, the capac increases 20%, power increases 10%, while effic decreases 4%. An average pump will deliver no water whatever against a head approx 20% higher than that at which the pump shows its best effic.

Centrifugals are usually driven by constant-speed motors. If driven by variable-speed motors, it should be noted that the capac increases or decreases directly as the speed. Head increases or decreases as the square of this ratio, the hp increasing or decreasing as the third power. Thus, if a pump driven by a 1203-rpm motor, delivering 1000 gal against 100 ft head, and requiring 35 hp, were connected to an 1800-rpm motor, the results would be: capac, \((1800 + 1200) \times 1000 = 1500 \text{ gal per min}\); head, \((1800 + 1200)^2 \times 100 = 225 \text{ ft}\); power required, \((1800 + 1200)^3 \times 35 = 118 \text{ hp}\).

Before changing speed of a centrifugal pump, the maker should be consulted. Performance
curves of different makes vary. If a centrifugal is to work against a fixed head, as in case of a station pump, the shape of the head capacity curve and the efficiency curve are of little importance, and the pump giving highest efficiency for the specified conditions should be selected. But, if the pump be used for unwatering purposes, or if it may be used in different locations underground, that pump should be selected which gives good efficiency over a wide range, and does not overload the motor to a dangerous point when the head is reduced. Fig 15 shows the characteristic curves of a pump with efficiency of 70% and over, for any condition between 700 gal per min against 120 ft head and 1,800 gal against 80 ft head. Maximum efficiency occurs when delivering 2,200 gal against 105 ft head.

Single-stage centrifugal pumps can be built for heads up to 600 or 700 ft, but this involves very high speeds. For mine service the head is limited, as a rule, to about 250 ft, and such heads are recommended only if the water is clean and not acid. In general, the head per stage should be limited to about 100 ft for acid water. Single-stage pumps are usually of the double-suction volute type. Water enters the impeller from both sides, eliminating end thrust. A thrust bearing should, however, be provided, and insisted upon for large-diameter impellers.

Multi-stage centrifugal pumps are balanced by opposing the impellers, so that the thrust of one impeller is counterbalanced by the thrust of the next. If they are balanced by a balancing disk, the latter relieves the discharge stuffing box of the high pressure, and puts it under suction pressure; a great advantage with high heads. These disks are generally used for fresh water pumps, but are not recommended for very gritty or acid water, which soon cuts out the disk faces.

Centrifugal pumps are now used almost exclusively for unwatering flooded mines. Single-stage pumps driven by high-speed motors are mounted on trucks, and have large capacity. To facilitate moving these pumps, it is advisable to use a metal-stiffened rubber suction hose, with 10-15 ft of ordinary hose on discharge side. A strainer basket should be attached to the end of the suction hose, and a check valve on the discharge hose, so that water hammer cannot burst the hose. Workings that were considered hopeless lost years ago, have been pumped out with high-speed centrifugals at relatively low cost.

Floods in 1936 inundated many coal mines, forcing them to shut down. To return thousands of men to work, the State of Pennsylvania agreed to assist in de-watering mines by paying for pumps, pipes and power, but not for labor. The volume of flood water to be handled in the Wyoming Valley was estimated at 8 to 18 billion gal, and the state purchased 18 Harston sinking pumps. They were of the single-stage, double-suction type, capable of delivering 4,000 gal per min, against 350 ft head; driven by 400-hp, 4,000-volt, 3-phase, 60-cycle line-start motors, running at 1,750 rpm. The units can be installed either vertically or horizontally and are operated without being bolted down or secured by props, as there is no vibration. The impellers are non-overloading, and the switch can be thrown in regardless of the head. Fig 10 shows two of these pumps mounted vertically on a cage.

In the Uniontown Bituminous Basin, approx 3 billion gal were impounded. The State purchased 3 Deep-well Turbine pumps, each having a capacity of 4,000 gal per min, against a head of 450 ft, and driven by 700-hp, 1,100 rpm, 2,300-volt, 3-phase, 60-cycle motors, with reduced voltage starters. Each pump required approx 420 ft of 4-in shafting, running in a 6-in enclosing tube and guided by 85 bearings, which also acted as couplings for the tube. The shaft, with enclosing tube, was placed inside the 20-in column pipe, at the end of which the 6-stage pump was mounted. The entire 20-in column pipe was vulcanized on the inside with rubber compound, and the tube enclosing the shaft was vulcanized on the outside to protect against corrosion.
11. PUMP ROOMS

Fig 20 shows an up-to-date pump room, containing 3 4-stage centrifugal pumps, each of 2 000 gal per min, against a head of 800 ft. The pumps work automatically, requiring no attendance.

This pump room is provided with an 8-ton traveling crane, to facilitate repairs. The suction pipes drop directly into the sump, and can be lifted out by the crane. Each pump has 2 strainers, one near the pump, the other (a "basket") at end of suction pipe. The basket strainers have liberal openings, but must prevent large floating objects from entering the intake. Each pump has a check valve, and there is another check valve in the discharge line. There are also 3 priming pumps of the dry vacuum type (Art 12), each of a capacity of 50 cu ft per min.

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Fig 18. Hasleton Auto Station Pump

Foundations. For station pumps, solid concrete foundations are well worth while. They should be true, of good materials, and only one end of pump bed-frame should be bolted down, the other being left free, to allow for expansion.

Gathering pumps, designed to be moved frequently from place to place, are preferably of the self-priming centrifugal type. Generally, the types capable of pumping continuously a mixture of air and water are less effic and more subject to wear than those pumping water only.

The La Bour pump (Fig 17) is primed by trapping water within the pump and utilizing the velocity of expulsion of pockets of water discharged by the impeller, which entrain air and carry it out of the casing. The pump can handle a mixture of air and water, and draw from several sumps simultaneously.

In the Hasleton Station pump (Fig 18) air is trapped in a vessel connected to the suction line, and pushed directly into the discharge line by a return flow of water caused by stopping the pump. Repeated starts and stops, made automatically, may be required to prime the pump if
suction line is long. This pump handles water only and can draw from one sump only. It is
started by an electrode (Fig 19), which is suspended over the ditch. When water reaches its high
level, contact through the water is established between the electrode and its casing, whereupon the

![Diagram of Electrode for Starting Hasleton Pump](image)

pump starts, and runs until the water is pumped down and air enters the suction line. Then the
pump stands idle until the ditch has filled again. Power consumption and wear are thus kept at
a minimum.

12. CHECK VALVES AND STRAINERS

Check valves should be carefully selected, since their failure may ruin the pump. They are of the single-flap or multiple-flap type. Experience shows that when a single-flap valve is liberally proportioned it will close without shock. Its construction should be simple and all parts exceptionally heavy, as indicated in Fig 21. Noisy seating of a check valve is sometimes caused by breaking (or separating) of the water column in the
discharge pipe, when the pump is being shut down. As momentum keeps the water
moving in the discharge faster than the pump delivers, the column is broken, resulting
Three pumps, each having a capacity of 2000 GPM against 300 ft head, operating automatically without attendant.

Fig 20. Pumping Station, 5th Level, No 12 Slope, Greenwood Colliery, Lehigh Navigation Coal Co, Lansford, Pa
in a water hammer when the flow is reversed. This can be averted by slowing down the motor before cutting off the current entirely. If the motor is of the slip-ring type, a

speed reduction of about 10% can be effected, reducing the capacity of the pump more than 50%; and if the motor runs for approx 15 seconds at this lower speed the flow in the column pipe will usually be reduced enough to eliminate water hammer.

Strainers. A screen should be placed at the end of suction line, or in the ditch feeding the sump, to prevent large pieces of wood from entering the pump. A strainer should be installed near the pump, in an easily accessible place, to catch smaller foreign matter which has passed through the screen, and which would block the impeller passages. The strainer should not form an air pocket; the free area of the screen should be approx 4 times as large as the area of suction pipe, and the direction of the flow through the strainer should change only slightly, to avoid disturbance and friction loss.

Fig 22 shows a large capacity (7,000 gal per min), streamlined strainer in which air, separating in upper part of strainer, is automatically withdrawn. Fig 23 shows a small capacity strainer of simple and effic construction. Large particles of foreign matter drop into the dirt catcher; the screen and dirt catcher can readily be removed. Strainers should be inspected and cleaned at regular intervals, to keep frictional resistance at a minimum. Frictional resistance increases the suction lift, which in turn decreases the capacity and effic of the pump.
13. AUTOMATIC OPERATION OF CENTRIFUGAL PUMPS

This is rapidly coming into use, and has been so perfected that the largest units can be run with absolute safety without an attendant. Pump runners' wages are thus saved. Automatically controlled pumps keep the water in the sump at a predetermined level; they are protected against accidents caused by loss of water due to air leaks in the suction line, or to choked strainers, and stop automatically in case of breakage of the column.

Fig 24. Arrangement of Primer and Accessories for Automatic Control of Centrifugal Pump, with Diagram of Wiring

Fig 25. Centrifugal Pump with Suction-line Primer

Priming centrifugal pumps. There are 3 methods: (a) installing a foot valve and filling the suction pipe and pump casing with water from the discharge column; (b) using a vacuum pump, or other means of exhausting air from the suction line and pump casing, and filling them with water from the sump; (c) providing a head on the suction, when a pump takes water from a dam. Foot valves are widely used for small pumps, but are not reliable, as they are apt to leak and wear out rapidly in acid water. A pump with a foot valve will operate automatically with safety, but often fails to start when the valve becomes leaky. Hence, foot valves are not recommended for mine service.

A priming-pump is used for most centrifugals. It is started by a switch operated by a float in the sump, and exhausting the air from the centrifugal, thus drawing water from the sump through the suction pipe and pump casing, and thence through a valve into a priming chamber, which contains a float. When water enters the chamber, the float
rises and closes the priming switch, which starts the centrifugal pump motor. The motor having been accelerated a contact is automatically opened, stopping the priming pump. When the centrifugal begins to run, the priming valve is closed by the pressure from the pump, the water from the priming chamber drains out, and the priming switch opens. Protective devices are shunted around the priming switch, and the current flows through them when the switch is open. These devices consist of a vacuum regulator, which opens the circuit if the vacuum exceeds a predetermined value, and a pressure regulator, opening the circuit when the pressure in the discharge line falls below a predetermined pressure. Fig 24 shows arrangement of pumps and accessories, and the elementary wiring diagram.

Pumps with capacities not exceeding 1,500 gal per min, and working against a head of not more than 250 ft, can be made to work automatically by installing a suction-line primer close to the pump (Fig 25). The primer, shown in Fig 26, combines in one casting a strainer, check valve seat, and air-removing device. To prime the pump, the priming chamber is filled with water and the pump started. It draws the water from the priming tank, and in doing so creates a vacuum in the tank and suction line, which causes water to rise in the suction line and flow through the check valve into the passage leading to the pump inlet, whence it is pumped into the discharge line. The air filling the tank is drawn through eductors into the stream and forced into the discharge line. Repeated starts and stops may be required to prime a long suction line. Starting and stopping may be automatically controlled by an electrode fitted in the tank.

Priming-pumps may be either wet or dry. Wet priming-pumps are in common use, but the water must be clean and free of acid. Dry priming-pumps require less power. A trap must be interposed, to prevent the water from entering the cylinder; a barometric loop serves the same purpose. The most efficient trap, widely used with
connected to top of the casing of a single-stage pump, or to top of the first stage of a multi-stage pump. The remaining stages need not be primed.

When a centrifugal takes water from a dam (Fig 27), no priming is required. As the water rises behind the dam, it also rises in the suction line and pump casing, and raises the float in the priming chamber, thus closing the priming switch and starting the pump. The protective devices are shunted as described above. The pump is stopped by the vacuum regulator switch, which opens when the water behind the dam has receded to the low level.

14. NEUTRALIZING ACID MINE WATER (30)

Acid water is sometimes neutralized before pumping, thus avoiding damage to pumps and column pipe. In many mines the quantity of water is so great that it can not be economically neutralized before pumping. Sometimes part of the water used for the preparation of coal is neutralized to prevent rapid wear of the breaker equipment.

A computation based on actual conditions is necessary to determine the advisability of this procedure, dependent as it is on character and quantity of water, type and cost of pumping plant, and price of the alkali required. Milk of lime may be added to sump water in measured quantity at regular intervals, as in coal mines and in metal mines at Butte, Mont., and elsewhere.

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