WATER PUMPING STATION

AND

PUMPING MACHINERY

-By-

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Contents

INTRODUCTION

The pumping station, the most important part in a water supply system, acts as the heart in a human body, controlling the working of the whole system. In this paper is given a little further study of the general installation of a pump-station. The first part is concerned with the selection of a location for the pumping station, beautification of the grounds, buildings, interior design, station piping, fire demand, etc.

In the second part of this paper is given different kinds of pumps that serve in water work systems, their advantages and disadvantages, methods of installation, and standards of selection.

Any pumping station design is governed by the local conditions. This paper gives the general idea and principles of designing only. All different conditions cannot be covered and individual problems must depend upon the judgements of the engineer, who is responsible for the design of the particular pumping station.

I. LOCATION OF PUMPING STATION

The location of a pumping station is established according to the conditions of use to which a pumping is to be put. There are several kinds of services which will be mentioned below; however, the general services of a pumping station are where the impounding reservoir, stream, or lake forming the source of supply to irrigated or the highest building to be supplied thereby, the water must be raised to such elevation, if the excess is not sufficient to overcome the friction in the conduit, pumping must be resorted to. Ground waters are occasionally, found at such elevations that pumping is unnecessary; but in most cases they must be raised from beneath the ground-surface, in some instances several hundred feet even. As a general statement, subject to many exceptions, however, impound surface-supplied do not need pumping while river, lake, and ground-water do. The majority of exceptions to the later statement are found among irrigation systems, where the water is not required above the surface of the ground.

II. CLASS OF SERVICE

Pumping stations should be established according to the conditions of use to which a pumping is to be put and the place where it is to be installed, may be grouped into the following classes of service:

"(1) Deep-well pumps must operate in drilled wells from six to twenty-six inches in diameter which limits the size of pump castings. Yet the pump may be required to discharge from 10 to 9,000 g.p.m. under the heads varying from a few feet up to 1000 ft. Fortunately the flow of under ground water is and discharge are so related that a pump can be selected for operation with small variation of head and discharge and designed to operate at best efficiency for the given conditions. Gradual lowering of the ground necessitate later changes. Deep-well pumps may be arranged to discharge the water into a low-level reservoir or directly into the distributing system.

(2) Low-lift service involves the pumping of water from the source, lake or stream, into a low-lever reservoir or purification plant.

(3) High-lift service involves the pumping of water from a purification plant or low service reservoir or from the source itself into the distributing system. This part of a pumping system is the most expensive both in first cost

and cost of operation and demands the most careful consideration of economy and dependability.

(4) Booster pumps are used to increase the pressure in certain parts of the system due to high elevation or inadequate pressure arising from excessive loss in long distributing pipes. Booster pumps are also used to provide water in the upper stories of tall buildings.

(5) Fire Service. In modern fire protection the municipal water supply is brought to the hydrant nearest the fire, but the special fire pumps which boost the pressure to that required for efficient fire fighting are located in the tall buildings, factories, or portable apparatus.

In many cities located adjacent to a surface supply special high pressure mains have been built serving highly congested areas. The pumps for this class of service must be absolutely dependable with a dependable prime mover.

(6) Small water supplies at low head must be provided for parks, farms, and small estates. Pumps for this class of service are sometimes difficult to build at low cost, but special pumps have been developed to meet this demand.

(7) Stand by pumps for use when other ordinary pumps fail are extremely important in certain industrial plants and hospitals as well as in municipal pumping stations for fire protection. Prime specifications for this service are dependability of power supply, prime mover, pump, pipes, and

controls. Economy is a secondary consideration. It should be located so that coal may be readily transported to it. In general, pump-stations located in residential districts should be operated by electricity, as it is difficult and expensive to suppress all of the nuisances in connection with the operation of a steam plant."

AUXILIARY PUMP

Auxiliary pumping stations are sometimes installed on large distribution systems to increase the pressure which might otherwise be too low. Low pressures in a district may be caused by inadequate sizes of pipe; a large localized consumption, as in an industrial section; or high elevation above the main pumping station. Auxiliary stations are sometimes equipped with automatically operated devices which may be remotely controlled at a central station. Steam power is not suited to automatic control; and an automatically controlled internal-combustion engine should not be left operating without attention. Electric motors and equipment are most suitable to unattended automatic operation or remote control. The purpose of adding additional auxiliary station is to increase the work efficiency ofnlarge distribution systems. The location is selected according to the local situation.

The location of a modern water-work pumping station should be carefully selected. A desirable site should be chosen where there is no unreasonable hinderance to public activities. With regard to the distribution system; to secure an even distribution of pressure throughout the system, the site of the pumping station should be located as centrally as possible. The hydraulics of the system are important in determining the most desirable location of main and auxiliary pumping stations.

Most of the public opinions are not quite interesting of the location of a pumping station, and would not be paid any attention about this most important public affair. They would not be thought that water, food, and protection, now as then, are the three prime necessities of life, and of this water is of first importance. Cities or towns can only exist where water is available or can be procured to quench thirst for the preparation of food, sanitation and fire protection. Without water all other considerations may be set aside, and nothing is of more serious consequence than the failure of the water supply. Pumping station is the most important part of a water supply system. Some like the operations of a heart in a human body. How could we leave it behind the other business.

It is argued that in many cases the source of supply is so located that the pumping station and allied works may not be placed in the better section of the community; that it is frequently remote, or in the worst section; that to expend money for ornamental purposes in such locations would be a waste. That is an open question. It may be true in some cases, but in general there is no spot in any city or town so humble that it cannot be improved. Why add to existing ugliness? Left alone, nature is seldom ugly, but man makes it so. He should restore it either to its natural condition or artificially make it no less beautiful than nature left it. Having restored it, let him make his work pleasing thereafter. It has also been repeatedly found that the poorer quarters of a city can be improved; that the inhabitants will lend a helping hand if given an example and shown the way. All such improvements lead to better citizenship.

It sometimes happens, due to a too prevalent idea that a waterworks building must be of an objectionable factory type, that no structure should be located in the residence districts, for fear it would spoil the neighborhood. There is, of course, no real reason why such an idea should prevail, nor why such a construction should be objectionable in fact, other than a rather unfortunate precedent for just such objectionable structures actually built. It is just as possible to make such a building in keeping with its surroundings, as to do it with any other sort of building. A gully in a park, in a beautiful residence district, but difficult and expensive to fill up, might be utilized for a filter plant and pumping station, the superstructures of which might be made as attractive as any park pavilion. There are many ways of doing it. For instance, the new pumping station of Saginaw, Michigan, is located in a residence district, and in planning buildings and grounds exceptional care was exercised that it should add to, rather than detract from, the attractiveness of its surroundings, while providing all up-to-date means for improving the sanitary, portable and industrial qualities of the City's water supply. Costing over $2,500,000, it was dedicated and put into operation to serve the 100,000 inhabitants. The water is taken from Lake Linton, a bayou dredged to 20 ft. to serve as a faw water storage reservoir, and communicating with the Saginaw River. The new pumping and water treatment plant, which replaces two antiquated steam pumping plants and an electric booster station from which raw water was formerly distributed through the mains, was decided upon only after a long series of campaigns and referendums, in which not only questions relating to bond issues, but also four different water supplies, were voted upon. In the final effort, an essay contest by high school students was used with good effect in arousing public interest.

The beautification of the ground of pumping station depends a great deal on local conditions that is climate, rainfall, moisture of ground and richness of soil. The attractive grounds can be created and maintained without excessive cost and without the assistance of a professional or landscape architect, anyway it would not cost a great deal for beautification even having architectural design. In the meantime, the appearance of all structures or buildings in the plant should be constructed beautifully, because the beautification of the grounds and buildings shows tangible evidence of prosperity and cleanliness. If we only selected the suitable location but neglected the appearance of all buildings disease and bad morals are most frequently bred in filthy surroundings A dirty and ill-kept water plant should at once be under suspicion, not only as to the sanitary quality of its supply, but also as to the morals of its management. Furthermore, beautification has in it also a wonderful advertising feature both at home and abroad. Most people ardently love what is clean and beautiful. A feeling of beauty in its highest sense is undoubtedly a gift, but who shall say that it is not often unexpectedly latent and but needs development. It is recognized that the opening of many private gardens for public inspection will go a long way to develop a general desire on the part of every home owner to do something to make his home more attractive. The desire to do something of the same kind, even in a modest way, makes for better character and better citizenship. Beautification will make a water works which will foster good will, fair dealing, confidence and win the praise of the people.

A pumping station should be avoided the danger from interruption of the operation through fire, either from within or from neighboring structures, so that the station should be

constructed a fire-proof building surrounded by sufficient spaces to avoid possibility of the over-heating of any part of the pumping station by fire in neighboring buildings. It shall be constructed preferably in an isolated location. For the purposes of fire-proof, the station and all buildings should be constructed in reinforced concrete which gives high safety of protection of fire from neighboring buildings. The pumping station and other buildings of the plant should contain no combustible materials in their construction. Combustible wainscoting, roof, shealting and floors are objectionable, as in some instance, they add enough fuel to allow a small fire to injure machinery. Wooden lockers and partitions for offices should be entirely eliminated. Non-fireproof buildings should have incombustible roof covering. Cornices and gutters should be metal flashed; the several sections, particularly any with high-potential generating or transforming equipment should be separated by parapeted fire walls and the openings between the several sections should be protected by fire doors or wired glass in metal frame. In most cases, it is not practicable to remodel an existing building so that it will be fire-proof at a reasonable cost, but for any frame station, the installation of a complete sprinkler equipment with the removal of as much wood work as possible, will render the building reasonably safe.
All stations should have their exposed window and door openings protected, which can be esthetically and economically done with

wired glass in metal frame. Where a plant is in a closely built-up section or seriously exposed, it is desirable to add farther protection by installing a water curtain and in serious cases metals or tin clod shutters should also be added. This protection against exterior fires applies just as much to the mutually exposing buildings of the plant as to some outside buildings.

Because of the fire hazard, electrical wiring should be installed in conduit, in accordance with the National Electric Code. Gasoline standby engines for driving pumps are often placed in separate buildings, but this is sometimes difficult or inconvenient to do if the storage of gasoline within the building to a small amount and proper ventilation will make the pumping station safe.

<u>FUTURE GROWTH</u>: For the purpose of designing a modern or complete pumping station should be arranged with the idea of future expansion or future growth, also for the preparation of future improvement, additional pumps will be installed. Water works construction is now sufficiently standardized, so that it is possible to lay out pumping plants subject to enlargement in such manner that the station and buildings may be useful indefinitely. With the increasing of population and water consumption demand, and the concentration of population in large centers, pumping stations of much greater

capacity than those now in use will be required, and engineers must look forward to the future growth or probable ultimate capacity of the station in selecting the size and type of pumping units, and in constructing buildings. It is usually practicable to build only for a moderate time in the future, but it costs little to lay down the indefinite future additions on paper, and so to locate the building so to arrange the equipment that extensions may be made without destroying the usefulness of important parts of the plant. It is all too common to find layouts that have expanded piecemeal according to the path of least expense, which must be torn out and rebuilt, because further expansion is impracticable. We can see farther into the future today than was possible a generation ago. There may be radical improvements in water works equipment hereafter, but, if the general plan of expansion has sufficient elasticity, the probable future can be accomodated. Therefore, in order to avoid the loss in the future improvement due to increasing of capacity and pumping units will be required, better increase a little at present for future expansion of station than will decrease the loss at future.

In the ordinary water work pumping station, steam operated, there is, first, the heart of the plant, so to speak, consisting of the main entrance, offices, and possibly a laboratory which may be grouped, and will need the space of future expansion. The most important spaces for future growth expansion, is the engine room and the boiler room, after providing for the present and the immediate future, may be expanded along parallel lines without necessarily spoiling the architectural symmetry. It is wise to be liberal in selecting dimensions. This tends toward permanency.

In order to keep the service to meet the maximum demand. Any station should be at least capable of meeting the maximum domestic demand plus fire draft with the largest pump out of service, some of the stations may be have two or three spare pumps, which should be served suitable capacity of the other due to out of service. When the increasing of water demand, those spare pumps will take the places of the other, and the additional new pumps will be easily installed. If the water is filtered, it is desirable in small pumping stations to centralize the business end of all the station operation on account of facility in supervision. This complicates the design, especially the provision for future expansion, andcentralization is not always possible when filtration is added to an old water works. In the layout of a new plant, however, it is practicable so to coordinate, the expansion of pump room, boiler room, filter plant, coagulation basin, and clear well, that each may be enlarged in an orderly manner with convenience of access between the operating parts and the administrative center of the group. Plants in cities up to 100,000 population, or somewhat more, may thus be designed without the necessity for separating the pumping station and filtration plants.

In the growth and development of the pumping station, refinement in machinery, and reduction in cost of manufacture, through better and more appropriate designing, coupled with more efficient and economical shop management, gradually led to higher and higher duties in steam economy, and this gradually changed designs and consequently sizes and farms of buildings. The old fight between low first cost and low duty and high first cost and high duty, gradually quieted down by the great advocate of low duty and low interest accounts finally being forced to enter the field of a higher economy or retire to the back ground. He entered it and kept his colors well to the front for many years, but the simplification of the crank and fly wheel engine and the increasing complication of the direct acting engine from the very nature of the common aim of both towards high steam expansion, has gradually placed them upon equal footing, so far as cost of construction is concerned and there are undoubtedly certain items in the designing of machinery like close clearance space.

The higher steam pressure which go hand in hand with greater and greater steam economy, changed ideas on boilers, brought greater horse power boiler by enlarging the units and gross demands, and lead to restricting the dimensions of boiler plant so far as practicable. Probably for regular good every day efficiency the horizontal return tabular is as good as any, andbetter than most. But where large power are involved the room required, and the size of necessary buildings place a limit upon the consistent size of boilers and unit of this type. The boiler for high pressure made up of parts of comparatively small diameters upon the unit principle, seem to economize space, buildings, first cost of complete plant and other important particulars in that line, to a very satisfactory degree.

For the future growth of designing plant, the engineers should be kept his eyes to the possible enlargement of buildings, pumping locations etc. without destroying the plant, so to speak, much lost time, trouble, and money will be saved.

<u>FIRE DEMAND</u>: A pumping station should be provided an adequate supply for a maximum fire demand plus maximum draft is a matter which must be decided on the ground. There are so many varying conditions that may enter into the situation that each locality should be treated by itself. One thing should be carefully paid attention is the hydrant flow-tests which must be made frequently and results noted. So far as we know, there are no portion of the occupied areas of the system should be omitted as it might be that particular locality that

would furnish a demand that could not for some reason or other be satisfied.

There is one thing should be borne in mind, in connection with combining accelerated pumping with a gravity supply during periods of extraordinary demand in party of where the pressure is ordinarily low by reason of its elevation, its remoteness, or absence of connection with a primary feeder, and that is the fact that, in order to meet a demand for more pressure in one particular sect of the system, the pressure has to be correspondingly raised throughout the entire system, that means a dissipation of force. So that the pumping station should be taken care of this serious happening.

The amount of water required for extinguishing fires is not very large in the aggregate, but when fires occur it is wanted at a high rate, and pipes must therefore be provided of large capacity to meet this demand. Pipe sizes required for fire protection in American cities are always larger than those required for other uses, and the size of pipe to be selected within the area of the distribution system, and between it and the distributing reservoir or pumping station where direct pumping is used, is mainly controlled by question of fire protection.

"The amount of water to be provided for fire service depends upon many matters; among others, the size of buildings, the materials and methods of construction; upon how near the buildings are together; the pressure at which the water is available; upon whether auxiliary fire systems are available; upon how great a loss of life and property might result from a bad fire, and upon the cost of making a given quantity of water available and the financial ability of the system or community to pay for doing it.

For average American conditions, take the square root of the population in thousands and this indicates the rate in millions of gallons of water per day at which water should be provided for fire service. For example: if the population is 9 thousand, allow water at a rate of 3 million gallons per day for fire service. If the population is 25 thousand allow five million gallons per day, and if 100 thousand allow 10 million gallons of water per day."

In the case of cities up to 100,000 inhabitants it is generally necessary to provide pipe capacity so that the whole amount of water provided for fire protection can be delivered with some loss of pressure in the neighborhood of the closest, largest, highest and most valuable buildings, and at each of such points if there are several; elsewhere piping capable of delivering smaller quantities varying with the kind and value of construction and the proximity of the various buildings.

Pressure for fire service: If steam fire engines are used and depended upon as in many American cities, the only requirement for pressure is that during fires and with the heaviest draft the pipes shall have sufficient capacity to supply water to the steam fire engines and at the same time retain as much pressure as is needed for domestic service. If the pressure is higher, hose streams can be obtained from the hydrants without the use of the fire engines. The additional pressure to permit this to be done is very desirable. A pressure of 70 pounds during the fire is the lowest pressure that permits effective hose streams to be obtained for use on buildings of moderate size. If only residences are involved, 50 or 60 pounds will give a fair stream. In business districts with large buildings better hose streams are obtained with higher pressures, and in general the higher the pressure the better the fire service. 100 pounds gives a good working service without steam fire engines. Higher pressures up to 150 pounds and more are available in some cities.

INTERIOR DESIGN

The design of the interior of the building includes the consideration of such factors as space requirements for each piece of equipment; the proper location of the equipment; the heating, lighting, ventilation, and drainage of the building; and the interior decoration. Space requirements of equipment must be determined from its design or, in the case of "stock" equipment, from catalogue descriptions or similar information. The net space requirements will be determined in this manner. The total space allowed should provide for accessibility and convenience. Equipment in a small, dark, unpleasant location is more easily neglected than equipment accessible for observation, operation, and repairs. The location of a piece of equipment is more directly affected by the requirements of accessibility and convenience than it is by space requirements. Equipment should be located so as to provide short, well laid-out steam piping, electric wiring, belt connections, or other methods of power transmission. Each piece of equipment should be accessible to an overhead crane or so located that it can be removed or replaced without disturbing other pieces of equipment.

Provision should be made for adequate heating for the comfort of the operators and for the safety of the equipment. The ventilation and lighting of all parts of the building should be generous so as to assure that no equipment shall be neglected, to serve as an incentive to careful operation, and to create pride on the part of the operators in the appearance and maintenance of the equipment. A dark, dusty, gas-filled boiler room or a damp, poorly lighted engine room is unnecessary and avoidable.

The interior decoration should be simple, light colored and dignified. in keeping with the important nature of the service being rendered. Interior walls of white or light colored glazed tile with dull colored floors of tile or other ceramic material are frequently used and are satisfactory. The following statements are supposed for reciprocating pump.

The location of pumps: A pump should be located as near the source of supply as circumstances will permit, particularly if the water or other fluid is to be drawn into the pump by suction; as the first requisite is that a full and steady supply must be furnished to allow the pump chamber to fill, in order to effect a steady motion of, and constand delivery from the pump. This is important as no pump can work satisfactorily that does not have a full supply of water. Place the pump on a masonry foundation in preference to a wooden floor; the latter is liable to rot and bring undue strain on the pipes, causing leaky jounts.

Suction pipe: The suction pipe should in no case be smaller than the size given in the manufacturer's table; if long, it must be larger, as the friction caused by the unusual length will partly overcome the head due to the vacuum, and prevent a full supply from entering the pump; it must be as free as possible from elbows and valves, as they retard flow of water much more than the length does. Avoid the possibility of air pockets. The pipe should be air-tight, as a small leak will greatly impair the working of the pump. A foot-valve should be used on long or high suctions, and if used, its net opening should be somewhat in excess of the area of the pipe.

If there is danger of foreign substances entering the pipe, a strainer is necessary, which should have an aggregate area of openings, according to the speed at which the pump is to run, from 3 to 6 times the area of the pipe.

Suction air chamber: A large air chamber on the suction line close, or connected, to the suction chamber of the pump is always an advantage where the suction is great, as it tends to equalize the flow and to prevent concussion in the pump. It is necessary for high-speed pumps. It should be so located as to relieve pulsation in the suction line in the most efficient manner. If the water cylinder has suction openings on both sides, place the air chamber opposite the suction pipe; but if the cylinder has a suction opening on one side only, the suction pipe may be placed on the same side of the cylinder as the air chamber. The suction air chamber is made from a piece of pipe of the same size as the suction pipe, and from 2 to 3 feet long, capped on the top and fastened to the water cylinder by short nipple and an elbow or T.

Delivery pipes: Should not be smaller than given in the manufacturer's tables, unless for temporary use and short distances, if the distance is great, use a size larger; the difference in first cost will be more than compensated for by a reduced friction, and consequent economy of power. Run every pipe in as direct a line as practicable, and where turns are necessary, use full round bends or elbows, of as large radius as convenient. Use Y-branches in preference to T's, Gate, or straight-way, valves should always be used for water.

Steam and exhaust pipes: should be straight and as free as possible, and as large as the sizes given in the manufacturer's tables. Before connecting a pump (or engine) blow out the steam pipe thoroughly. Any dirt carried into a steam cylinder will injure it seriously. In connecting make due allowance for expansion of steam pipes when heated by steam. A throttle valve should be placed in a steam pipe as close to the pump as possible. Means should be proveded for draining this pipe before starting the pump. Placing a small feed-water heater in exhaust pipe from pump, or putting a three-way cock in exhaust piping and connecting the exhaust piping to the suction pipe of the pump is sometimes suggested but is inadvisable on account of presence of oil in steam. Steam and exhaust pipes should be connected so that they may be drained of the water of condensation.

Graphite pipe joint compound: is the best to use where-ever there is any possibility of the joint being taken apart at some future time. It contains flake graphite. Due to its lubricating properties, a screwed joint may be made much tighter than with a cement-like preparation. It is equally valuable for threaded or flanged joints of steam, water, gas and air piping, for bolts, nuts, stay-bolts, studs, caps, boiler plugs, hand-hole and man-hole plates of boilers, doors of gas retorts, metal gaskets, flanges, ground joints, etc. It makes the tightest joints, prevents rusting, or corrosion, does not get hard or brittle, but allows the parts to be opened at ease any time. Flake graphite compound is about $2\frac{1}{2}$ times greater in bulk than red or white lead, mixed, and is therefore, pound for pound, much more economical.

Care: If the pump is to be left idle for some time, fill the oil cup, then open the cock from the oil cup so that oil can flow into the steam chest; then let the pump make half a dozen quick strokes to distribute the oil well over the inside of the steam end, and so prevent rusting while the pump is standing. In cold weather open all cocks and drain plugs to prevent freezing when the pump is not in use. Use good cylinder oil only. Keep the stuffing boxes clean, full of good packing, well oiled, and just tight enough to prevent leakage without excessive friction. Don't screw the glands too tightly, and don't allow the same packing to remain in the stuffing boxes too long or it will become hard and scratches the piston. If the pump runs badly make sure that the water valves and pipes are all right, before examining the steam end. Always see that the pump has a full and steady supply of water. All parts of stock pumps by best manufacturers are made to standard gages and templates and are interchangeable.

Starting: After pump has made a few strokes exhausting to the atmosphere, three-way cock on exhaust may be turned and exhaust conducted to condenser. In the case of a light suction lift, a piston or plunger pump will readily pick up water in the suction pipe. Before starting a pump when first set up, see that it is not packed too tight; test the valve motion to see that it is free. If the movement of the pump should not be uniform, one stroke with the other, or different parts of a stroke, or refuse to take water from the suction, it will be found that either some substance has lodged under the valves to prevent their closing, or that the pump gets air through some leak in the suction, or the suction pipe is obstructed.

Sweating of hydraulic machinery is prevented by E. Jersey Water Company, Paterson, New Jersey, as follows: Clean the iron surface with wire brush; give two coats of red lead, then apply heavy coat of litharge and put on as many cork chips as will stick. Apply second coat of litharge and again dust on as many cork chips as will stick.

Foundation of engine house: The engine beds, pump chambers is basement, pipe culverts and all foundations and external walls for the engine house should be constructed in mass concrete or reinforced concrete, prepared over the site with concrete mixers, and dropped into position.

The foundation should be substantial and level. If the pump is very large, the foundation should not be connected with the building. If the foundation is of concrete, anchor bolts should be set in a templet with anchor plates at the lower ends. Place sheet iron pipe around each bolt so that the bolt can be moved about ½ inch to conform the bed plate when placed on the foundation. The bed plate should be carefully leveled on the foundation, and be grouted so that it will not be deflected and throw the pump out of alignment. The pump should be protected from injury including the action of the elements. It should be accessible so that parts may be easily removed for repairs.

ENGINES

Most pumping engines are driven by steam and boiler, it is essential that the water works engineers consider the design of the boiler plant, auxiliary equipment and selection of plant auxiliaries in a most careful manner in order to obtain the full benefits from the use of high steam pressures and temperatures. The use of the regenerative cycle of operation with the feed water heated by means of steam bled from the main units has been adopted by nearly all large power stations placed in operation in the last few years. It is felt that two-stage bleeding of main unit will prove the most economical for water works practice. In a great many cases the use of both economizers and air preheaters will be fully justified in water work stations, as they have in central power stations. All auxiliaries should be driven by either electric or water motors, or possibly a combination of the two steam driven auxiliaries are fast disappearing as they are not necessary, since sufficient steam for feed water heating can be bled from the main units at a more economical rate. Electric driven auxiliaries are preferable, in view of their ease in installation and operation and the elimination of a great deal of small piping which would be necessary with the water motors.

Since the tendency in pumping station design is to follow along the practice of large central power stations, it is believed that the future large pumping station will have pumping units of around 150 m.g.d. capacity. Steam turbines have already been developed for capacities far in excess of any horse power that might be required for operating a pump of this size and it will be up to the pump designers to develop pumps that will meet this requirement. Also the reduction gears will necessarily have to be developed for such large capacities. The future unit will have mounted on the main shaft a direct current generator capable of driving all plant auxiliaries required for the particular unit, as well as the boiler room auxiliaries operating in connection with each main pumping unit. The boilers will be equipped with an preheaters, economizers, both radiant and connection type superheaters and the furnaces entirely enclosed with water colled surface forming a part of boiler circulation. The probable stéam pressure will be 400 pounds gauge with 255^{o} superheat, making a total steam temperature of 700^{o}F. The unit type pulverized fuel equipment will be installed in connection with each boiler. Evaporators for make up water and deaerators will be used for feed water purification, and feed water heating will be done by the use of the regenerative cycle, using two-stage bleeding from the main unit. Emergency power supply for plant auxiliaries or for starting up the plant will be proveded by a small house steam turbine, and in additional electrical energy will be supplied from the central power station. The overall duty of the pumping unit will be around 250 million foot pounds per thousand pounds of steam. The overall thermal efficiency of the will be approximately 20 per cent.

STATION PIPING

HEADER LAYOUTS: There were plenty discussion for pipes laying which concerned service pipes and main pipes of a water work system, but most of the stations they were neglected the most valuable work of header layouts. That is the piping arrangements of used to connect the pumps with out-going main pipes. It was suffered a great damage in many existing stations when one of the headers was broken not only kept the whole station out of service, flooded over the plant, injured all machines and pumps, but also lost faith to the public. If such header layout system is installed by experimental design and good arrangement, it will receive safety service, and obtain maximum reliability consistent with the number of valves and fittings used.

There are no certain rules or methods in laying of header systems, because it is various to different conditions of different stations. The soil and other local influences, such as availability, cost, labor conditions and requirements of the service enter largely into the selection of the pipe, the method of its installation, and also what kind of pump in service. The soil may be anything from quick-sand in aqueous suspension to solid granite. Something like this would be occurred ordinarily. The pumps should be operated for the demand of public. The header must lay out in the idea working conditions in connection to the mains and pumps. In order to meet the maximum demand, most of the pump stations are installed one or two spare largest pumps with capacity should be available to other pumps, due to the various conditions, such as routine repairs, lubrication, breaks in steam piping or values or things of that sort to be expected, then the spare pump should be come to serve of presenting the value of demand. In other words, the spare pump should be served to meet the maximum domestic demand plus fire draft when the other out of service, but no matter how many spare pumps are installed, if one of the main or header breaks it would be suffered a great damage in the poor arrangement layout.

Mr. F. G. Cuningham, was given some general functions of good discharge header as follows:

a. To permit any or all pumps to deliver to any or all supply mains, or at least reasonable flexibility in this respect.

b. To permit any pump, pipe or valve to be isolated for repairs without crippling service.

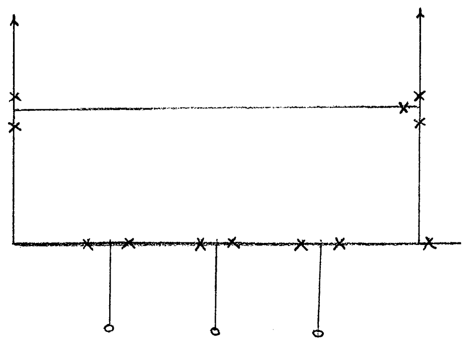
c. To allow of ready operation of essential control valves, especially in emergencies.

d. To provide convenient access for inspection and repair of control valves and connecting pipes.

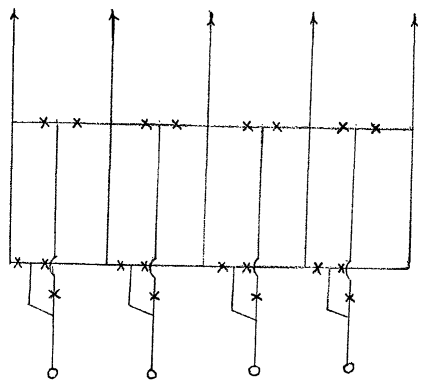
e. To provide reliable and multiple points of connection for essential small water pipes for station service.

The above functions are very important to header arrangement.

In the new pumping station of Kansas City, they designed the header system; it was very good, and satisfied the general functions required.

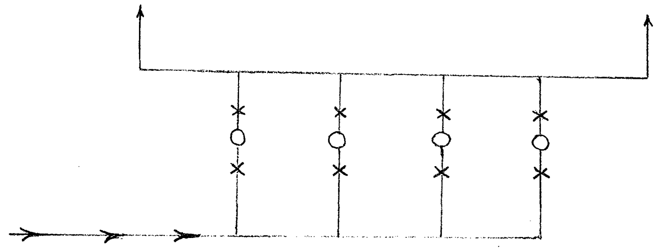


The above figure shows the new header system in the new pumping station in Kansas City; the effect of the most serious single break or repair would be put only one pump out of service, and the other two pumps still keep on working.



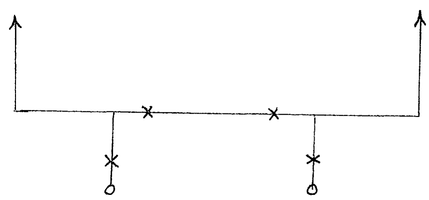
Header system of the new pumping station of Chicago

In this new designing system, no matter what happens to one single pump, main, or header, they can maintain service without any trouble. Mr. F. G. Gunningham has had much experience in the designing and the arrangement of header layout. In an article whose title is "Pump Discharge Headers and Pump Piping for Water Works Station," he gives a discussion of header layout. The substance of the discussion is as follows:



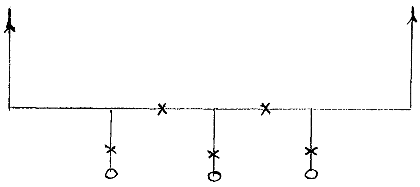
(1)

Figure (1) shows a flagrant case of poor arrangement actually installed in a recent project. The entire battery of pumps is connected to a single suction main and a single discharge main without valves except on the branch connections to the pumps. The repair of any piece of pipe in suction or discharge lines or of any valve would put the entire station out of service.



(2)

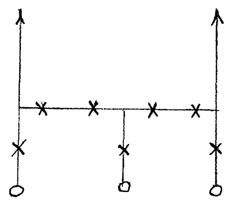
Figure (2) shows two pumps and two lines with two valves between pumps. One pump and one line would be shut down by any break or any valve repair. If it were not for the valves between the pumps the entire station would be shut down. This layout is of interest principally in showing that the number of pumps and of lines is too small.



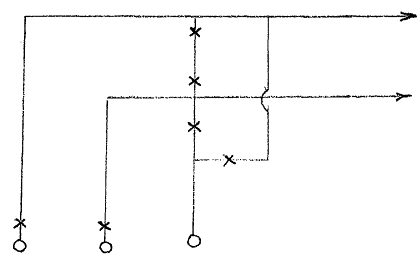
(3)

Figure (3) shows three pumps and two lines of which two pumps and one line would be put out of service by repairs to valves "A" or "B".

Figure (4) shows the same thing except that there are two valves between adjoining pumps making it unnecessary to shut down more than one pump and one line with a single break.

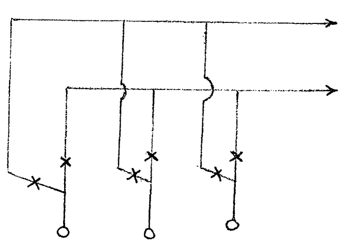


(4)

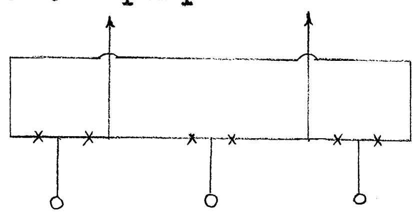


(5)

Figure (5) shows a three pump layout containing six valves and with a poorly arranged cross connection. Repair to valve "A" would put out of service two pumps and one line.



(6)

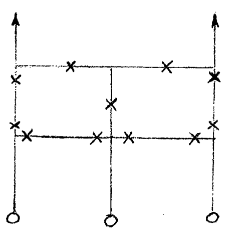


(7)

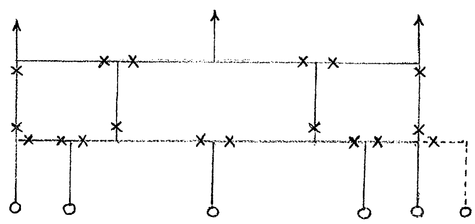
Figure (6) is shown a good layout having the same number of pumps as Figure (5), lines and valves, and with each pump discharge split into a separate valved connection leading to each main. With this arrangement the most that one pump and one supply main, which result would occur through the repair of any one of the six valves.

Figure (7) shows another way of accomplishing the same results as in Figure (6) with the same of valves. The consequences of the most serious valve repair are the same as the Figure (6), except that the chances of such occurrence are somewhat less since there are only four valves that can produce that result instead of six.

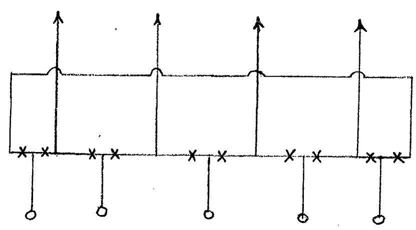
Figure (8) shows substantially the same arrangement as Figure (7) except that additional valves are inserted bringing the total number up to 11. Under this arrangement two advantages are gained as compared with the others. First, while the repair of certain valves can shut down either one pump or one supply main, no single repair can shut down both a pump and a supply main. Second, connections are such that there is less likelihood of emergencies requiring the stopping of one pumping unit and the starting of another, which operation might be embarrassing.



(8)

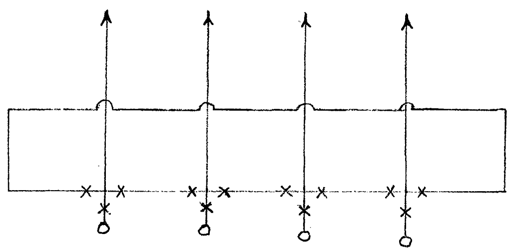


(9)

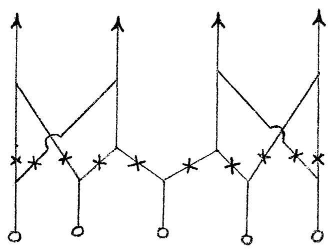


(10)

Figure (9) and Figure (10) show the leader layout designed by Mr. F. G. Gunningham. In Figure (9), the effect of the most serious single break or repair would be to put one pump supply main out of service. Due to the arrangement of cross connections it is possible in this layout to continue pumping to all of the mains with all pumps except by a break, thus cutting down the chance of having suddenly to start up a new unit as above mentioned. Figure (10), it can be expanded or contracted indefinitely to fit any number of pumps or supply lines. It is founded upon the reasonable basis that two pumps or two mains may be put out of service simultaneously without impairing service. The features of this arrangement are the way in which the pump discharges and the supply mains alternate in their point of connection to the header and the use of the run-around pipe which may be placed under or above the supply mains or discharge mains. For the number of valves and fittings required this arrangement provides at least as much reliability and flexibility as any arrangement the writer has so far encountered. As compared with Figure (9) it provides for the same number of pumps and one additional supply main and requires only ten valves and nine tees instead of 18 valves and 12 tees. By adding eight more valves, that is placing two valves, instead of one between each pump connection, the most serious break would shut down only one pump or one supply main instead of both the pump and supply main, giving substantially the same result as Figure (9). Both of these arrangements make unnecessary the providing of valves in the individual discharge pipes from the various pumps, because any pump can be isolated by closing the header valves lying on either side of the tee for the pump connection.

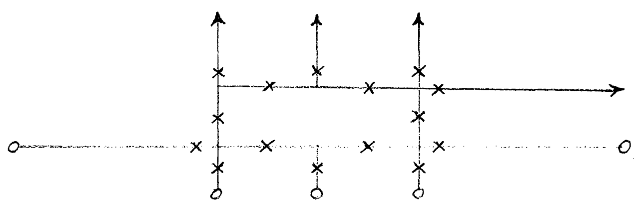


(11)



(12)

Figure (11) differs from Figure (10) in that the pump discharges and supply mains are in line, doing away with the offset at the header. Without the offset higher velocities and smaller valves and pipes might be used with distinct advantage. The valves in the individual pump discharge pipes are more necessary in this case than in Figure (10) because without them a supply main would be shut down whenever a pump was opened for repair or inspection. This arrangement is at its best when the number of pumps and the number of supply mains can be made equal, as they often can be by a little planning.



(13)

Figure (12) shows another application of the idea already illustrated in Figure (6), that is of splitting each pump discharge into two pipes each leading to a different supply main. Figure (12) is equivalent, as regards the number of valves and results produced by the repair of a valve, to Figure (10) or to Figure (11) if the valves in the pump leads of the latter be omitted. It might be more convenient or economical than either of these in some cases.

Figure (13) shows the header arrangement actually installed in a large city having the same number of pumps and supply mains as illustrated in Figures (10) and (12). The interesting points about this layout are the unskilled use which has been made of the number of valves and fittings installed and the failure to provide adequately for maintaining service. Thus repair to valve "A" would shut down three pumps which comprise 75 per cent of the station capacity. Repair to valve "B" would shut down three of the four supply mains. Other combinations would shut down one pump and two supply mains or vice versa. It is interesting to note that by using one of the arrangements shown in Figures (9) to (12) much better results would have been secured with five less valves and fewer fittings. Or stated in another way, by using three more valves than were actually used and by changing the arrangement it would have been possible to have kept everything in service except one pump or one supply main in the event of the most serious break of a valve.

From the above discussions, we can compare the systems of header layout and understand them more easily, especially those students who are interested in sanitation but experience about this point of design.

FITTING: In fitting of headers, it should be considered the fitting conditions during selecting locations of header lines. The final location should be selected after a thorough study of its effect on the hygranlic gradient of the line, and the nature of the difficulties encountered. Great care should be taken to provide a firm and uniform foundation for the headers, even all pipes. No matter what may be its materials, as settlement is bad for any pipe. By far the larger part of the breaks which have occurred in cast iron pipes have been due to settlement rather than to internal pressure. All bends should be firmly braces. The materials for backfilling under and around the pipe should be carefully selected, and should be so compacted as to prevent unequal external pressures. However, the foundation of fitting header even water mains should be very carefully selected and installed.

CENTRIFUGAL PUMPS

DEVELOPMENT: The early centrifugal pumps were suitable only for low head and low speed, and for this reason found very little use in water works where heads above 150 feet are the rule. This type of pump first designed and constructed in the United States a little over a century ago. In 1899, Dr. De Laval, built a single stage centrifugal pump which, running at 15,400 r.p.m., developed 590 feet head and delivered 185 g.p.m. Those early developments were prophetic of the modern application of high steam pressures and also of the recent use of single stage boiler feed pumps on naval vessels and of high pressures per stage in multistage pumps.

As this development of centrifugal pump were given a new idea to water works engineers, and the the De Laval Company began building centrifugal pumps and steam turbines in the United States in the year of 1901. The following figures show the total capacity of centrifugal pumps supplied to municipal water works at successive periods by the De Laval Steam Turbine Company:

Year	Total Capacity m.g.d.
1907	25
1910	150
1915	1350
1920	3500
1930	14,000

From this data, it will be seen that the application of centrifugal pumps in the water works field has increased tremendously. It is certainly a great improvement of its long progressing history of centrifugal pump. Such as the changing of mechanical construction, materials, operating characteristics, and efficiency, etc., it seems not necessary to mention it in paper. We might have a general idea of developments of centrifugal pumps from the "Simmaries of important development of centrifugal pumps during last 20 years," It was written by Mr. A. Peterson in 1933.

"(1) Efficiencies of small pumps have been improved from 15 to 20 per cent and of large pumps from 8 to 10 per cent.

(2) 20 years ago, single stage pumps were seldom used for heads higher than 100 to 125 feet, while today (1933) they are used for heads as high as 250 feet and high efficiencies are obtained at such heads.

(3) Due to a greater knowledge of factors affecting noise and cavitation, which has resulted in placing limitation on inlet tip speed of impeller vanes, and thus revolutions, the useful range of centrifugal pumps, particularly in regard to suction lifts, has been extended.

(4) By proper selection of pump size and speed more satisfactory operation at high suction lifts can now be obtained than was the case 20 years ago.

(5) The efficiency of the driver of centrifugal water works pumps has also been improved during the last 20 years, and this applies particularly to steam turbines and more so to the comparatively small turbines as generally used for

driving water works pumps.

I am probably not far wrong in stating that the Rankine cycle efficiency of the average present-day water works turbine is about 20 per cent higher than it was 20 years ago, and this coupled with the modern high steam pressures and temperatures results in duties that make steam turbine drive for water works pumps a very attractive and economical proposition."

These summaries of the development of centrifugal pumps presented a good knowledge in studying the development of centrifugal pumps. The only change in recent years of centrifugal pumps is the driving power. Modern electric motors increased the usefulness of centrifugal pumps, but even with motors they can be used as main pumps only where the electric power is available at low cost, or where service is too intermittant to warrant maintaining a steam plant. With the advent of the steam turbine, centrifugal pumps really came into usefulness as main pumping units as well as auxiliaries, and although the steam turbine is a later machine in development, it may be said that efficient electric and steam turbine drives were developed simultaneously.

TYPES: There are two essential and they may be subdivided into classes according to details of construction. The stationary casing and revolving impeller. The water enters one part of the casing, which directs it to the center of the impeller which it enters and is given great velocity and then enters the discharge part of the casing, where a large part of the velocity is transformed into pressure. If the water enters an impeller from one side only, it is called a single-suction impeller, if from both sides, a double-suction. In practically all large pumps, the water enters the bottom part of the casing. In some single suction pumps 4" and smaller, the suction is in the center of one side, the water passing directly from suction pipe to impeller. In most side-suction and some other pumps the discharge pipe connects with the top of the casing; but in the most efficient and practically all large pumps the discharge and suction pipes both connect to the bottom part of the casing.

Volute pumps are lower than turbine pumps in first cost, and they are more suitable to the handling of liquids containing grit and large particles of suspended matter. Higher efficiencies can be secured from turbine than from volute pumps, but their greater cost and greater wear on diffusion vanes, combines with other reasons, are diminishing their use in water works practice.

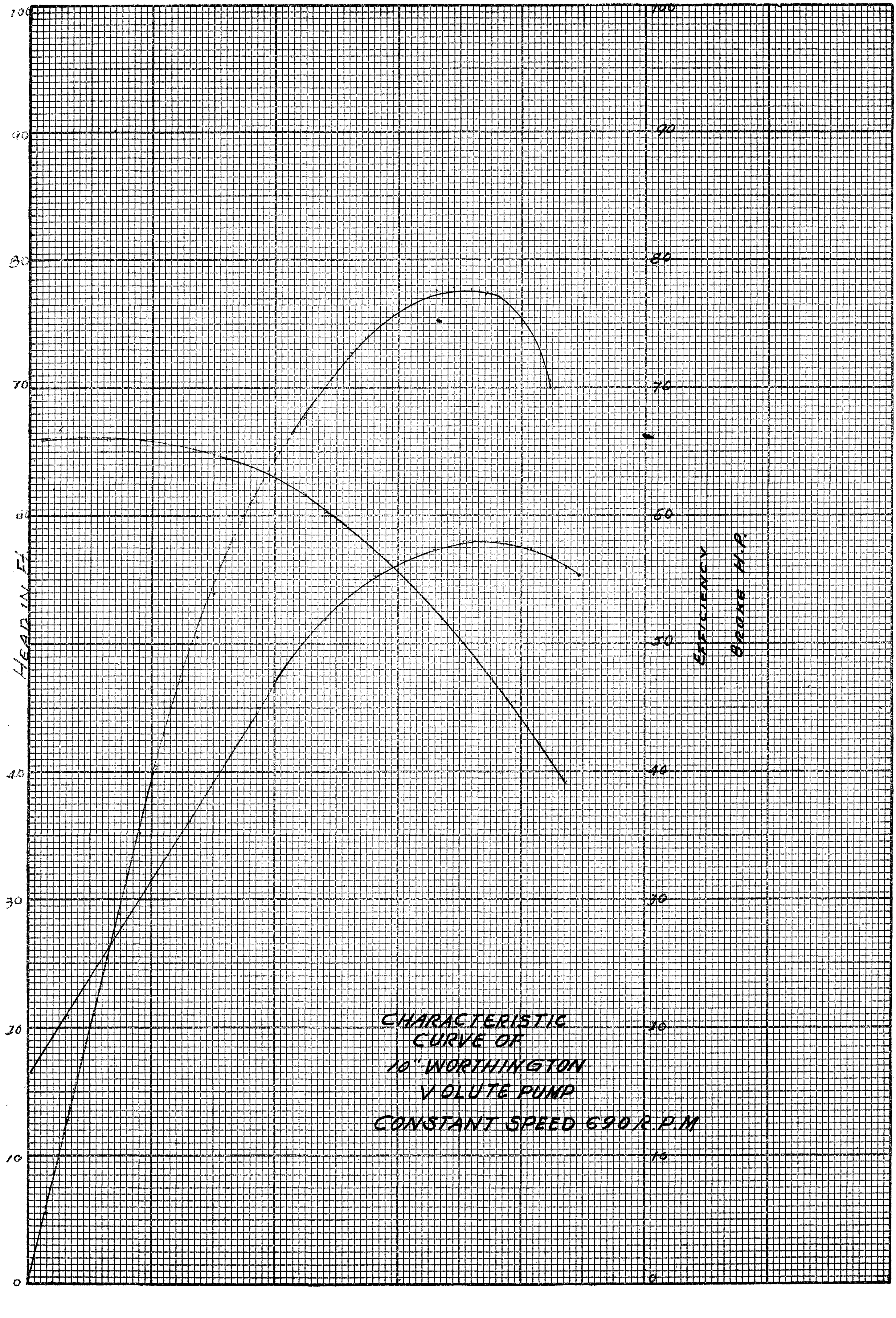
The impeller consists of a number of blades attached to a revolving shaft which may be enclosed between two round plates (a "closed impeller") or may not be so enclosed, but just clear the sides of the casing ("open impeller"). Open impellers are generally less efficient than closed especially after some months of use and are seldom employed for pumping clear water. In the development of discharge pressure, it may be inefficiency to develop the entire pressure by a single impeller, as either the diameter or the speed, or both, may be undesirably great. Since the discharge pressure from a centrifugal pump is the sum of the initial pressure at the inlet and the pressure energy added by the impeller, increased pressure can be secured by leading the discharges from one impeller into the suction of another. The discharge pressure is directly proportional to the number of stages, other things being equal.

The shaft which drives the impeller may be vertical or horizontal. The former permits placing the pump below water level, so that it is always primed and has no suction lift, while the motive power can be at any desired level; also the least area is required for housing a unit. The horizontal pump permits more effective construction of bearings and support and makes the entire unit more accessible; and with recent developments of self-priming methods is being generally adopted for most pumps except those of small capacity or where efficiency is of minor importance.

The increase in velocity given to the water in passing through a pump adds a certain pressure to that which it had on entering, and by passing the water through a series of pumps, the ultimate pressure is the sum of those contributed by the several units, less that lost by friction. Instead of using a series of pumps, a "multi-stage" pump is commonly used, in which a series of impellers are enclosed in a single casing, water from the circumference of each impeller being led to the center of the succeeding one. From two stages to six or more stages are common for pumping against high heads. The losses of energy in a centrifugal pump are due to friction in the bearings of the impeller shaft, friction of the water against casing and impeller, and internal friction of the water as it changes shape and velocity in passing through the pump. The first is a mechanical problem which is met by the usual methods of construction and lubrication of bearings. These are preferably placed outside the casing to insure that water will not reach them. The shaft enters the casing through a stuffing box, the main purpose of which is to prevent air being sucked into the casing where it is under negative pressure; this being insured in most pumps by forcing water into a water seal ring in the middle of the stuffing box.

CHARACTERISTICS:

The characteristics of centrifugal are the relation between head, capacity, speed, and horsepower required to drive the pump. It can be expressed by plotting the curve either from calculation or test data, and these curves represent the



100
90
80
70
60
50
40
30
20
10
0
HEAD IN FT.
EFFICIENCY
BRAKE H.P.
CHARACTERISTIC
CURVE OF
10" WORTHINGTON
VOLUTE PUMP
CONSTANT SPEED 690 R.P.M.

characteristics of the particular impeller chosen. In any one pump these are all dependent upon each other, so that for any given size of pump, capacity it may remain constant while head, speed and horsepower required are varied over a wide range. Theoretically the capacity produced by an impeller varies directly as the peripheral speed, while the head produced varies as the square of the speed, and the power required to drive it varies as cube of the speed.

Priming pumps: Centrifugal pump must be primed before start, in order to avoid injury to, or even the seizing of wearing rings and other parts by running dry. The simplest method of priming is to close the valve in the discharge and fill the system, when there is a foot valve on the suction pipe. In many cases, foot valves are not practicable nor desirable, and it is then necessary to close the discharge valve and prime with a vacuum pump or ejector. When foot valves are used, it is necessary to see that they are of the free-opening, clapper type with area through the valve sufficiently great to avoid unnecessary resistance. After vacuum priming, the pump may be brought to rated speed with the discharge valve closed, and then the pump put into service by opening the discharge valve. Air or other gases in the suction pipe or well will reduce the delivery and efficiency. Care should be taken to eliminate air before it enters the suction pipe by using a system of baffling.

The Chicago Pump Company furnishes a self-primer in which an air chamber is placed on the pipe line between the pump and the vacuum pump as this water falls or rises. In the De Laval automatic priming system the general principle is the same, there being in addition a vacuum tank so that the vacuum pump will need to be operated only intermittently being stopped and started by means of a vacuum switch. The "Hazleton" suction line primer combines a primer, check valve and strainer: it contains an air chamber which receives air from the suction pipe when the pump starts, stops the pump by means of a mercoid switch when full of air refills with water and then starts the pump again, and repeats this until all air has been exhausted from the suction. Crispin turbine valves, which permit air to pass through but no water, are furnished for use with automatic priming systems.

Driving Engines: There are several kinds of engines for driving centrifugal pumps, such as steam turbines, electric motors, and internal combustion engines. Since the modern motors were introduced to water pumping works, it takes other engines' places. But using of steam turbines to drive centrifugal pumps still keeps its advantages. Steam turbines may be obtained in all sizes for all commercial steam pressures and temperatures. These may be geared or direct connected to the driven unit, and may be of the single or multi-stage impulse, impulse-reaction or reaction type. The impulse blading mounted in one or two rows on the circumference of a wheel is curved so as to be driven forward by the energy in high velocity steam jets directed against the blades by suitable steam nozzles.

Internal combustion engines operate by means of the combustion gas cylinders, the gas being received as such or being converted in the engine from gasoline or fuel oils. Gasoline engines used for pumping generally have 4 to 8 cylinders, 900 to 1,800 r.p.m., and are used up to 600 or 800 h.p. Gasoline generally is cheaper gas, and is more reliable since it is not dependent on pipes which may be broken or otherwise put out of service. For starting, an electric starter and generator and storage battery are common equipment. For service operation of pumps, Diesel type engines are coming rapidly into favor as economical of fuel dollars. They can be had of 5 to 6,000 h.p. and for 200 to 2,000 r.p.m. 250 to 1,000 r.p.m. are the ordinary. For starting a diesel engine, the common method is by compressed air from an air cylinder kept filled by the engine itself or by an auxiliary engine and motor.

Motors for driving pumps are the most modern motive power and most efficient engines. There are various types of motors used, synchronous motors are commonly used in sizes of 100 h.p. and over. They are very efficient and power companies give the lowest rates for their operation because they operate at or near the unit power factor. They must be designed exactly to fit the service, and this can be varied but little as they run at constant speed under all conditions of load, but they are especially suitable for continuous uniform pumping as into a reservoir. The synchronous motor gives good efficiency at low speeds, which the induction motors do not. For smaller plants the squirrel cage induction type of motor is ordinarily recommended as suitable for centrigufal pump service, because of its simplicity of construction and adaptability to widely varying duties. Induction motors are available in any desired rating and are so constructed that they have high strength and rigidity, yet low weight per horse power. There are many possible mechanical variations, such as totally enclosed, splash proof, flange or vertical mounting, and ball or sleeve-bearings. In addition, squirrel-cage motors with special electrical characteristics, such as high starting torque with low starting current and normal starting torque with low starting current, are available in standard ratings. The wound rotor type has a lower starting current and so is sometimes more acceptable to the power companies, especially in the larger sizes, but they cost a little more. Squirrel-cage motors below 40 h.p. are usually 220 or

400 volt; for the larger sizes, 2200 volt are obtainable.

The temperature limits for electric motors are reached sooner at high altitudes; altitudes above 2000 feet should be given special attention.

Settling and Operating: In settling of centrifugal pumps, the foundation should be of sufficient depth to support the pump base rigidly, and should be located in accordance with the foundation plans of the pump, and sufficient allowance should be made for lateral adjustment of the bolts. The simplest and most efficient arrangement is the use of an electric motor and a pump mounted on the same shaft. If a centrifugal pump and a motor are to be operated on the same shaft, both the pump and the motor should be attached to the same rigid foundation so that the alignment of the shaft will remain true. Because of the difficulty of securing permanent, true alignment, flexible couplings are used on the shaft to allow some variation. However, after the bed plate has been bolted in position, and after the pump and motor have been placed in their final positions, the unit should be carefully tested for alignment by inserting a machinists thickness gage between the coupling flanges and by making sure that the whole shaft revolves freely when coupled together. The bed plate should then be rigidly grouted in place and the pump and motor dowelled to the bed plate. Suction and discharge piping may then be connected, but should be carefully exercised that these pipes come to the pump flange evenly and without strain. After pipe connections are made, should be again checked the alignment, and care should be taken to check that no air pockets are in suction line. The pump should be placed close to the water, and the suction pipe should have few or no bends. Wherever possible, suction line should not exceed 15 feet from level in well to center of shaft of pump, for cold water, hot water should come to the pump with little or no lift. Whatever the method of connecting the motor and the pump, it is highly desirable to provide for variable speed of operation as to obtain the greatest possible efficiency.

Operating: In order to maintain the speed of delivering the rated capacity against the rated head, of operating the centrifugal pump, great care should be given the shaft stuffing boxes, especially those on the suction end, to check that no air enters. When water seal lanterns are used in stuffing boxes, the gland bolts should be drawn up tight at first, then released so that they will be finger tight and allow a small leck of water through the gland. This method secures long life for packing and reduces liability of cutting the shaft. A gate valve and a check valve should be placed in the discharge close to the pump. The latter is especially necessary in long lines, because if the pump is suddenly stopped, the momentum of long water column will cause a water-hammer that will split the pump casing. It is necessary often to clean out the bearing thoroughly, including the thrust bearing, by pouring in kerosene and allowing it to run out at the bottom, as dirt is liable to get in during shipness or idleness. The bearings should be filled as full as possible with first-class lubricating oil similar to turbine oil. In order to increase the working efficiency and the life of the pump, we should be carefully protected and often check every part of equipment in connections of the pump. Pumps should be opened from time to time to make sure that no other matter is lodged in the impeller or passages and no undue corrosion is taking place.

STEAM TURBINES

The development of steam turbines and the introduction of modern centrifugal pumps were almost simultaneous, and the possibility of combining the two in a single and efficient, simple and inexpensive pumping unit. Owing to the fact that the economical speed of steam turbines is higher relatively than that of centrifugal pumps, the combination of two was delayed materially. In the early attempts at driving centrifugal pumps by steam turbines were not successful because of inability to get perfectly manufactured reduction gears. All these difficulties have been overcome and efficient gears can be obtained from some manufacturers, so that it is increased their usefulness and life.

"The action of the steam turbine depends upon the conversion of the heat energy of the steam into kinetic energy, and then in the transference of this kinetic energy from the steam to the rotating parts of the turbine. The latter part of the action is thus in principle much the same as that of the water turbine; but the former part has no parallel in the hydraulic motor. In a water turbine the fluid is at constant volume and at constant temperature, and its kinetic energy is gained at the expense of potential energy due to pressure or position."

In general, there are four types of turbines which applied to water works. (1) Single-stage impulse, consisted of a single high-speed runner with a number of nozzles in which entire expansion of steam from full pressure volume to vacuum took place. On issuing from the nozzles, the steam impinged upon moving buckets, which checked and reversed the velocity of the current. The reluctance of the steam current to having its direction and velocity altered gives rise to a force against the buckets, which sets the rotor in motion.

(2) Compound impulse turbines are the same as the single-stage, except that steam expansion takes place only partially in the first stage and is continued in successive stages until

final vacuum volume is attained. In the reaction turbine, approximately one-half of the expansion in any stage takes place in the stationary buckets, imparting to the steam a velocity substantially equal to that of the moving buckets, so that it enters them without impact. Further expansion takes place in the moving buckets, the spaces between which gradually grow smaller from the inlet to the exit side, forming a ring of moving nozzles. Velocity imparted to the steam by expansion in the moving buckets produces a reactive effort on these buckets, which turns the rotor. This effect is similar to that produced by water issuing from a hose nozzle.

(3) Impulse-reaction: In which the steam is expanded in nozzles and discharged against a portion of the perphery of the impulse wheel. The intermediate and low-pressure stages are the same as in the ordinary reaction type. Substitution of the impulse element for the high-pressure section of reaction blading is made only in high-pressure stages of machines in which blades are short. The reason for this is that the clearance at the end of the unshrouded blading represents a relatively large ratio to the area through the blades, and it has been found impracticable to use shroud rings on buckets of small section. The unshrouded blades allow steam to spill over the ends, which, in the case of short buckets, may be an excessive waste.

(4) Multi-stage impulse type: This type of the steam turbine, the steam is received from the governor into an annular space. The casing is bolted to a nozzle plate which projects the issuing steam upon the rotor attached to the shaft. The steam is then in turn projected to other nozzles for lower pressure until the last section of the rotor is traversed and final vacuum volume attained. In the machine illustrated, each stage is a complete turbine within itself, sections being added or left out as conditions require. Each section is united to the adjacent one by means of a ground joint, and long bolts extending from end to end hold the entire casing together. Adjacent wheels are separated by a nozzle stage, having self-lubricating carbon packing which insure little friction and minimum leakage.

There are also different types of turbines which are produced by different companies in the United States. In the De Laval Steam Turbine Company, the steam is first allowed to expand in one or more divergent nozzles of special construction. This expansion imparts enormous velocity to the steam, its heat energy being thus transformed into kinetic energy. As the steam issues from the nozzles it impinges upon the vanes of the wheel, and in its passage through the vanes the direction of its flow is changed and its velocity greatly reduced. The kinetic energy thus absorbed is imparted to the wheel, causing the latter to rotate at high speed. The De Laval Company, in addition to its steam turbines directly connected to electric generators, manufactures a regular line of centrifugal pumps, to be driven either by electric motors or by De Laval Turbines. (This was described in the chapter of centrifugal pumps, and its operations also be found in the page of Chicago pumping station.)

In the Westinghouse-Parsons Turbine, the steam after passing through a ring of fixed guide blades, impinges on a ring of moving vanes; then passes through another ring of fixed guide blades on to a second ring of moving vanes, and continues through alternate rings of fixed blades and moving vanes until it reaches the exhaust. The annular space in which the vanes and blades are set increases gradually in size, and the vanes and blades increase correspondingly in length, from admission to exhaust, thus providing the expansion necessary for the conversion of the heat energy into kinetic energy; while at the same time very high rotative speeds are avoided by the gradual absorption of the velocity of the steam by the successive rings of moving vanes.

In Kerr turbines up to 500 h.p. it is customary to make nozzle diaphragms in one piece each; above that size they are customarily split in a horizontal plane so that all stationary parts above this plane can be lifted off, completely exposing the rotor.

In the Curtis Turbine is to some extent a combination of the two foregoing types. Steam is admitted through a number of nozzles to a set of alternate rings of moving vanes and fixed blades.

Passing out of the last ring of moving vanes in the first set, the steam, with its expansion only partly completed, passes into a second ring of divergent nozzles from which it is discharged into a second ring of alternate rings of moving vanes and fixed guide blades. Each set of rings of vanes and blades, with its nozzle, is called a "stage," and the complete Curtis turbine contains from two to four such stages. All Curtis Turbines of 500 K.W. and over are now made vertical, and the weight of the moving parts is floated by pumping oil or water under a step bearing at the bottom of the shaft. Oil was formerly used, but water is now preferred.

Now, the modern steam turbines may be regarded as an accomplished fact. Each type, as at present developed and manufactured for sale, is the product of the best work of some of the very best designing engineers in this country or abroad. Neither of the above several types were put on the market in this country until it had been carefully tested for years under all sorts of conditions, by a company so strong financially that it could afford to spend all the money necessary to make its product a success, and of standing so important that it could not afford to do anything else.

The attitude of aloof expectancy with which the general public has watched for failures in certain structural details of each of these types may now well give place to a confidence that, in so far as the steam ends of these turbines are concerned, their design and construction are admirable for the purposes, and within the limitation, for which they are built and sold.

The advantage of steam turbines as a motor may be cited the following: High efficiency; low first cost; small floor space and head room; small expense for building and foundations; small expense for care and attendance; low depreciation and maintenance; freedom from vibration; simplicity of packing; small number of bearings, and of moving parts; and readiness with which repairs can be made and parts renewed; comparatively small size of all parts, insuring more perfect material; no oil in condensed steam, thus practically solving the serious problem of feed water.

Thrust Bearing: In steam turbines pumps the bearings consist of light shells, babbitt lined, as a rule divided in half so they can be readily taken out and replaced in duplicate. In the case of some very high-speed machines the shells are encased in cylinders, between which there are films of oil to give sufficient movement to nullify the effect of vibration of the shaft. Some bearings are supported in self-alining boxes while others are not. All bearings should be so made that their removal can be accomplished by dismantling as little of the machine as possible.

In some machines theoretical balance of thrust is obtained, but in order to space the rotating members properly and keep them from rubbing, a babbitt-lined thrust is used. Because of contact between the slippers and thrust collar is impossible with bringing the machine to rest, as the action of the face of the slipper is such as to entrap a perceptibly thick body of oil and maintain it at sufficiently high hydrostatic pressure to keep the two surfaces apart. Other manufacturers use the marine, multiple-collar thrusts. Satisfactory service is obtainable from any of them.

Method of Lubrication: There are two methods for lubricating the steam turbines. By oil rings and by forced feed accompanied with ring oiling. In the case of the oil relay governors this pump is directly attached to the governor spindle, and oil not required in the governor is relieved through reducing valves and then conducted to the bearings, in some cases at different pressures for different parts of the system. Each bearing is made with an oil well of large capacity, the overflow of which is free and such as not to disturb the main body of oil and prevent sedimentation. Oil overflow is returned to the pump through a water-cooling system and a screen to separate injurious solids. The principle of simple oil ring lubrication is identical, except that oil is not circulated. Reduction gears are lubricated in two ways, by submersion in oil so that the gears themselves act as gear pumps forcing oil between the teeth, and by means of spray nozzles projecting oil on the pitch line of the teeth at about 5-pound pressure. Bearings of reduction gears are lubricated by the two methods described and sometimes by the pressure incidental to revolving the gears in oil, which may be as high as 40 pounds per square inch. If introduced properly to the bearings, the oil insures satisfactory lubrication. Oil should meet the following specifications. It should be pure mineral hydro-carbon oil free from (1) tarry, slimy or saponifiable matters, (2) acid, soaps or thickeners, (3) water, (4) dirt, grit or other suspended matter. The specific gravity should be between 0.86 and 0.88 at 60°F. Flashing point, with open cup tester, should not be below 334°F. Viscosity as determined by the Saybolt 40°C. Viscosimeter should be not greater than 228 sec.

Couplings are used to prevent accidents, both rigid and flexible, are used between turbines and reduction gearing and between reduction gearing and pump. Often the pump has only one bearing, the inboard bearing being that of the gearing. These couplings consist essentially of steel flanges, machined all over, either bolted and keyed on taper portions of the shaft or else solidly forged on the shaft. They should in all cases be smooth on the exterior and free from projections. Flexible couplings furnished by most makers are essentially the same. The driving portion carries pins projecting into metal bushings imbedded in some flexible material in the driven flange. Another form of flexible coupling uses driving pins made up of thin plates pinned together at the ends and fastened into pockets.

Steam Pressure: Steam pressure using in steam turbines for general waterworks practice 175 pounds pressure, 100^{o} superheat and $28\frac{1}{2}$ to 29 inch vacuum are recognized as ideal. Higher pressures and superheat are obtainable only by sacrificing life of boiler plant. Lower pressures result in decreased efficiency as pressure decreases. Many turbines for low pressure, of mixed-flow type, have been installed and have been generally recognized as a source of economy. This point is disputed by some manufacturers, who claim it is usually cheaper to discard the steam engine, exhaust from which is used in the turbine, and purchase a turbine using full boiler pressure. This is, however, a point requiring investigation for each case. Foundations, condensing apparatus and other items, exclusive of maintenance of steam engines, often bring the cost to as much as or more than the cost of high-pressure turbines. The objection to mixed-flow turbines is the inefficiency resulting from the attempt to make a machine for two pressures, with the result that during a large part of the time one portion is running idle. Economy for given conditions is essentially the same by all manufacturers.

Consumption of steam per Brake h.p.-hr. by Steam Turbine

Brake h.p.	150 lbs. dry steam, 28" vac., lb./hr.	100 lbs. dry steam 28" vac., lb./hr.
800	13.2	14.0
700	13.4	14.2
600	13.5	14.4
500	14.0	14.8
400	14.6	15.5
300	15.1	16.2
200	15.7	16.9
100	16.5	17.6

For 27 inch vacuum instead of 28 inch, above steam consumptions would be increased 5 per cent. At ¾ load, steam consumptions would be increased 4 per cent; at ½ load, 15 per cent. Another prominent manufacturer gives the following rates and corrections for 125 pounds pressure, dry steam, and 28½ inch vacuum.

Brake h.p.	Steam consumption; lb./Brake h.p.-hr.
1500	12.1
1000	12.5
750	13.0
500	13.5
250	15.0

Correction for steam pressure is 1½ per cent for each 10 pounds between 100 and 125 pounds; correction for vacuum is 5 per cent per inch between 26 and 29 inches; superheat 1 per cent for each 10 up to 100° F; for pressures above 125 pounds correction will be 1 per cent for each 10 pounds pressure, for vacuum and superheated steam as above stated.

Economy: Mr.Dabney H. Maury was giving a very good conclusion in one of discussion meeting about the economy of using steam turbine pumps: "The question of the steam economy of the turbine engine seems to be identified with rim, or circumferential speed; which means that if a small and so a machine of low first cost is produced, and this seems to be one of the vital points in steam turbines, then a very high rate of revolution is needed for high steam efficiency. But these extremely high revolutionary speeds are entirely too high for even turbine pumps, the fact that water so umcompromising seeming to demand a certain speed of revolution in the pump to match any certain head of water. Therefore, the pump must first be made to run at a speed suited to the water column, and then the turbine steam engine directly coupled to this pump must be made of a diameter which will give the proper rim speed of the steam turbine. And when this is done in a manner which will give as high an efficiency as the very fast revolving steam turbine, it will be found that the first cost is not so low as is so generally talked about.

And, even after the large steam turbine is put to work, speeded to suit the pump and giving a proper rim velocity for its own steam economy, it will be found that its capital account is not so favorable as now represented and expected, nor will its net efficiency result in the pumping of water so cheaply as its reciprocating rival. In a pumping station the coal account is a constant drain upon resources, no matter how cheaply the coal may be bought, and it is not at all difficult to show the balancing point between coal duty and capital invested in the pumping machinery. With equal durability, a cheap machine can not hold its own in the pumping of water unless its steam economy justifies its use. And the more expensive machine, if its steam economy warrants its use, will drive out its rival. As to complication, there are very many more actual parts manufactured and placed in a turbine engine than in a reciprocating engine. But we need not worry; each type of machine will find and take its proper place in the natural fitness and economy of things." When we are going to design the station of applying steam turbine pump, have to consider all points as above, it was given a very satisfactory consideration and judgment.

RECIPROCATING PUMPS

Reciprocating pumps were considered the only pumps as the displacement pumps commonly used before in water works. Since the development of deep-well centrifugal pumps and steam turbine pumps, the reciprocating pump is seldom used. They may be classed as to operation as either single or double acting. Single-acting pump takes water on one stroke and discharges it on the other; double-acting pump takes and discharges during both strokes. As to construction they are divided into inside-packed and outside-packed pumps. Sometimes may be classed as single-stroke single-acting, and two-stroke and single-stroke double-acting.

In the first, a bucket raises the water in the well on the up stroke, it is held there by a check valve while the bucket descends and is filled through a bottom check valve, and again rises and lifts the column of water. Thus there is an intermittent discharge of water. With the double-acting pump water is delivered on the down as well as the up stroke, thus delivering about 90 per cent more than a single-acting. The two-stroke pump, the most efficient of the bucket or plunger pumps, has two buckets and two pump rods, one rod solid and moving in one direction while an enclosing tabular rod moves in the opposite direction. The plunger moves inside a brass cylinder, and is provided with several leather packing rings, usually cup-shaped concave to the water being moved; in double-acting the leather on the bottom half of the plunger is concave downward, and those on the top half upward. There are usually 4 leather. The leathers have to be renewed from time to time, the plungers are hollow with a ball, rubber disc, bronze conical or other valve at the top. The plungers are placed at such depth as always to be submerged, but ordinarily the suction chamber is provided with an extension 15' to 30' long to insure that air will not be sucked in. For double-acting pumps, most companies recommend limiting the submergence to 15' or 20' to minimize the difference between the loads on the up and down stroke.

The advantages of this kind of pump are: ability to operate against high heads, practically uniform flow of water, high efficiency, moderately quiet running, possibility of operating with slow speed power, not materially affected by variations in head, not complicated or difficult to repair. The disadvantages are relatively high first cost, capacity not easily indreased or decreased, great weight requires heavy foundations, must operate at slow speed and so cannot be direct-connected to motor, noisier than turbines, don't handle sandy water very successfully, limited capacity.

LONG SUCTION: If the suction of a reciprocating pump is long, even though the lift is low, on account of the variable velocity, a considerable portion of the suction head is absorbed in accelerating the water at the beginning of the stroke. A part of this force is recovered at the end of the stroke as pressure forcing the piston ahead, but unless the head is available at the beginning of the stroke the pump will not lift. If the speed of the piston is such that it moves more rapidly than the inertia of the water can be overcome, the water separates from the piston and may ultimately overtake it, as the latter is retarded in the second half of its stroke, causing severe shock or hammer.

The head at inlet of the suction for a maximum is equal to the depth of the suction opening below the water surface in the suction well plus the height of the water barometer, and the head at outlet is that corresponding to a perfect vacuum less the effective lift of the pump. When, as is usually the case, the pump is located above the level of water in the suction well the head available for producing flow is reduced.

The suction lift of a pump is dependent upon the pressure at which the entrained air in the water separates. The head at which the air separates is usually taken at about 26 feet below atmospheric pressure. Separation of air also may occur on the discharge side of the piston during the second half of the stroke when the piston is being retarded due to the velocity previously imparted to the water being so great as to carry it away from the piston.

AIR CHAMBERS: To prevent separation, an air chamber may be installed on either the suction or the discharge pipe and should be located as near as possible to the pump. The value of the air chamber increases with its size, cross-section being more effective than height. It should be so located that the water is drawn as low as possible without actually emptying the chamber at each stroke.

The settling and operating conditions were mentioned in the topic of interior design.

MISCELLANEOUS PUMPS

AIR-LIFT: The air-lift pumps were designed by rule of thumb methods, consists of an air pipe, footpiece, and eduction pipe. Compressed air from the air pipe enters the eduction pipe at its lower end through the footpiece, and the combined air-water mixture in the vertical eduction pipe rises to surface because the long column of mixed air and water is lighter than the shorter column of water in the well surrounding the eduction pipe. Evidently the greater the length of the pipe below the surface the greater the difference between the weight of the columns within and without the tube and the higher the water can be lifted. Generally the depth of submersion is made 1.5 to 2 times the lift.

The chief advantage of an air-lift pump is its dependability. All moving parts are on the surface, and should a breakdown occur the trouble can be located at once and repaired without removing heavy pipe and equipment from the well. There is nothing to wear except the air compressor, and its operation is the only cost. It can be used in a crooked well or one where there is considerable sand in the water. It will generally raise more water, from a small well than any other type of pump. Its chief disadvantage is its low efficiency. The highest overall efficiency, wire to water, which C. N. Ward has observed, is about 40 per cent. The air mixed with the water must be released at the surface, and the water repumped if it is to be raised above the surface. The air may be an advantage as when aeration is desirable for iron removal.

THE HYDRAULIC AIR COMPRESSOR: This apparatus is practically the reverse of the air lift. Water is caused to pass vertically downward through a tube or shaft at a moderately high velocity and by means of small pipes or an open surface at the top opportunity is given for the water to absorb as much air as possible. At the bottom the water is discharged against a considerable head and is made to pass underneath a collecting hood which is connected with a chamber for storing air. The reduction of velocity at outlet causes the water to release a portion of the entrained air, which rises through the collecting hood and passes to the air chamber under a pressure equal to the head of water above the free surface underneath the hood.

JET PUMPS: Jet pumps operate on the ejector principle, a small jet of water at high velocity is discharged through a throat, the upstream end of which connects to a suction pipe and the downstream end to the discharge. The velocity of the jet reduces its pressure below that of the atmospheric pressure and thus creates a partial vacuum at the throat into which water from the pump well rises and is then mingled with the jet and carried along at reducing velocity by it. The efficiency of this apparatus is greatest with a high suction lift and low pressure on the discharge, when it may reach 25 per cent or 30 per cent. When a steam jet replaces the water jet, the ordinary steam injector is obtained in which the vacuum is formed not only by the velocity of the jet but by the condensation of the steam.

The water-jet pump may be advantageously used to produce a large discharge through a nozzle at a low pressure for a fountain, and for fire fighting.

ROTARY PUMPS: Rotary pumps are positive displacement pumps with rotating elements turning inside a casing with inlet and outlet ports. This kind of pump is intermediate between the centrifugal and the reciprocating piston type.

The chief objection to this pump is the difficulty of keeping the revolving pistons tight. In the water works field the principal use of rotary pumps is for portable fire pumps. Recently a rotary deep-well pump has been put on the market. This pump, based on the Moineau patents, consists of a double-pitch single-helix thread rotor turning within a stator with single-pitch double-helix thread. Positive displacement results. These pumps are being manufactured in three sizes to discharge 8 to 55 g.p.m. from a well 4 inches or larger in diameter. Horizontal pumps of similar design are also manufactured.

In designing of a pump station, most of the engineers would have the same question in mind. What kind of pump should be used for their station? In the article on pump selection, there were already mentioned the advantages and disadvantages of different kinds of pumps, but the most important point is the local condition, such as water consumption demand, economic condition, transportation, and public etc. When we select pumps, we also should have the following idea: for water works service, reliability of the pumping equipment is conceded to be the most important consideration. The very nature of a waterworks demands this, not only from the standpoint of furnishing the city with its normal water supply, but also from the standpoint of being prepared, at all times, to furnish adequate fire protection to the city.

SELECTION OF PUMPS

There are some general principles of selecting pumps for a given installation one as followed: "First and foremost the integrity of the pump manufacturer must be assured. The financial status of the manufacturer must be investigated. The length of time the pump has been on the market, its performance for other purchasers must be known and weighed carefully before a decision is made. It does not pay to purchase a pump from a concern whose business is run on a shoe string basis regardless of how well the mechanical features of the particular pump may appear at the time." From the above principles in selecting pumps for a given installation pumping station, it is quite advisable and reasonable to judge what kind of pump is suitable for this station to fit service conditions, because we have given further understanding of working history of that particular pump which we want to select. There are several principal factors to be considered in the design of a pumping station in the following sequence: (1) "reliability: the most satisfactory method of determining the reliability of pumping equipment is to ascertain its past performance from existing installations. When untried equipment is under consideration, the purchaser should proceed with a greater degree of caution, getting opinions from leading water works engineers and requiring the builders to submit definite guarantees.

(2) suitability: most pump manufacturers are in a position to offer equipment for water works service, but it is for the water works engineer to word his specification in such a way as to permit broad competition on equipment suitable to the particular conditions."

(3) Durability: durability is dependent upon the material of which the pump is constructed, its general design proportions, the type of pump, the kind of service to which it is subjected, and the care given it during its life. Here is the mechanical design the important factor and must be carefully investigated.

There are two enemies of the pump, of the operator, they will affect the life of pump, sand and air. Sand is found in most water pumped from wells and it must be kept out of certain types of pumps, otherwise their efficiency and useful life is materially reduced. Water which contains a great deal of air or gas is likewise difficult to pump, it would harm the pump in the same way. In general, a pump may be pumping at the end of twenty years at practically the same efficiency with which it functioned at the end of its first year of use. The rule then on durability is to inspect the pump to be purchased carefully to see that it is well designed, and take good care of it during operating period.

(4) "Economy: in considering economy, it is necessary to know the efficiency of the prime mover of the gear reduction,

if such is required, and of the pump in order to estimate intelligently the operating expenses of the complete unit. It is also important to know the change in economy over such ranges of capacity and head as the particular conditions may require.

(5) Simplicity in design is desirable. The simpler a machine is in general construction, the easier it is for the operator to give the proper care and attendance, maintenance and repairs."

There is a medium to be reached by properly proportioning and selecting the various equipment for each particular installation that will give adequate and reliable service at an economically satisfactory annual overall cost. Therefore in designing a pumping station, the several factors mentioned above should be carefully weighed in the determination of each piece of equipment that goes into the station.. In the meantime, the relative cost and availability of the various fuels, coal, oil, and gasoline, and of electric power will have a direct bearing upon the type of pumping unit to be purchased.

Efficiency: In considering pumps, the efficiency of any machine or combination machines should be carefully investigated; there are three kinds of efficiency should be considered in selecting a pump. First, the mechanical pump efficiency is the ratio of the output of the pump itself to the input to the pump. This is a simple straightforward engineering relationship any good engineer with the proper means at his disposal may measure quite accurately the mechanical efficiency of a pump, which for various types of pumps now in use varies from 25 to 95 per cent.

Second, the plant efficiency or overall, is the ratio of power output of the pump to the power input to the plant. The efficiency takes into consideration the losses in transmission of power from the prime mover to the delivered water. In case the power purchased is electric, the efficiency is figured from wire to water, in case the power is generated in a steam plant, the efficiency is computed from fuel to water. This is generally the determining factor in selection of a pumping plant, because this efficiency may usually be obtained quite readily and it may be reduced to cost.

Third, commercial efficiency: This is the efficiency which should govern the selection of the pumping plant. It is the total cost per unit volume of water pumped during the entire life of the pump. The commercial efficiency takes into consideration the first cost, the cost of installation, taxes, insurance depreciation, operation, upkeep, repairs, replacements and all losses between the power received and the water delivered. This is very difficult to measure, because it will never be exactly the same between two pumping installations. If investigated it carefully, it will be obtained the approximated cost.

Capacity: Capacity refers to the quantity in gallons per minute which a pump will deliver. The important thing is that almost any capacity may be had in almost any type of pump if the money is available. Generally, however, centrifugal and deep well turbine pumps and their like are quantity pumps, that is, they are used where the head is low or moderate and when the quantity desire is large. Piston and rotary pumps and their like are used when the quantity desired is small or moderate and the total head great. Rod pumps and air lifts, only used in special cases, are employed where the quantity is moderate and the lift great or the well small.

Total head, suction and depth of pumping: In selecting pumps, the total water head and suction and depth of pumping, are also the important factors must be put in consideration. The total height through which water may be forced is limited only by the power available and the strength of pump and pipe connections. The total head of the air lift system is quite limited on account of its cost of operation and the fact that to secure the best efficiency, it should have a submergence of about 50 per cent, because it is not used to any extent where the lifts exceed 250 feet. The centrifugal pump has bee used where the total head exceeds 2,000 feet, however for heads over 750 feet on account of the first cost of the pump and the fact that the stages increase the efficiency of the pumps is materially lowered. Where the head is high, the pump which is generally most efficient, mechanically and commercially, is the piston or plunger pump. In fact it will generally be found to be most efficient for heads of over 300 feet.

Suction: Suction is the reading of a vacuum gage in feet of water when connected to the side of the pump. Most of difficulties with pumps are caused by suction. It is dependent upon the atmospheric pressure, which is governed largely by the altitude and the temperature.

The lift must always be less than the suction, (lift is the vertical distance from the pump proper to the free surface of the water), because the latter includes pipe friction, friction due to strainers, foot values, elbows, velocity head, as well as lift. When pumping water the lift is also materially affected by temperature, as the following table shows:

	Temperature of water at sea level				
	$60^\circ F$	100°	140°	180°	212°
Max. theoretical lift in ft.	33	31.4	27.7	16.7	0

Because of this limiting factors the lift generally should not exceed 15 feet and never over 20 feet. The rule regarding lift should be to eliminate it if possible by having the water flow to the pump under the positive pressure. If this is not practicable, then the suction should be made as large as possible and all friction reduced to a minimum. The greater the lift, the greater the amount of trouble and the less efficient the pump will be.

The table below shows the variation of suction with the altitude.

Altitude above the sea level (feet)	Theoretical suction possible in feet of water
0	33.9
2,000	31.4
4,000	29.1
6,000	27.1
8,000	25.2
10,000	23.2

Depth of pumping: Depth of pumping is the distance from the ground surface to the free surface of water to be pumped. The cost of excavation, the size of pumping unit, the theoretical suction possible, and the manner in which the power is transmitted to the pumping unit. Time does not permit a detailed discussion of how each of the factors limits the depth of pumping. In small eater work is now done from wells when depth is such that the cost of excavation prohibits the use of centrifugal or triplex plunger pumps, and when the rod pumps are used, the quantity is small, when the air lift is used the cost of operation is high and when the deep well turbine pump is used the cost of installation and upkeep is great. In those of all factors which presented as the general consideration in selecting pumps. Each pump selection is an individual problem and must be treated as such.

SUMMARY OF ADVANTAGES AND DISADVANTAGES OF THE VARIOUS TYPES OF PUMPS

A. Advantages of the reciprocating steam pump.

1. Low first cost
2. Great durability
3. Good flexibility
4. Operate against a high head
5. High efficiency
6. Well operation

Disadvantages.

1. Requires frequent adjustment
2. No good for pumping sandy water
3. Heavy and occupies a large floor space
4. Complicated
5. Priming is usually necessary

B. The advantages of piston or plunger pump.

1. Great durability
2. Operate against a high head
3. Has a uniform flow for multi-cylinders
4. High efficiency
5. Good suction

Disadvantages.

1. High first cost
2. Limited flexibility
3. Heavy and occupies large floor space
4. Must operate at a low speed
5. Priming is necessary
6. Not a good pump for sandy water

C. Advantages of rotary pumps.

1. Small and occupies little floor space
2. Fair flexibility
3. Easy to handle or operate
4. Starts quickly
5. Not necessary to prime
6. Has a uniform flow

Disadvantages

1. High first cost
2. Poor durability
3. Limited speed
4. Limited head

D. Advantages of air lift.

1. Good for pumping any kind of water
2. Not necessary to prime
3. Operating at the same time with varying depth in several wells
4. No moving parts below the surface of water
5. Occupies little space

Disadvantages.

1. High first cost
2. The discharge head is limited
3. Operating efficiency is very low
4. The flow is intermittent.

E. Advantages of centrifugal pump.

1. Low first cost
2. Excellent durability
3. Small weight and occupies small space
4. Easy and simple to operate
5. Starts quickly
6. The flow is steady
7. High speed of operation

Disadvantages.

1. Necessary of multistaging to produce high pressures
2. Lack of flexibility
3. The low suction possible
4. Necessary for priming

F. Advantages of turbine pump.

1. Moderate first cost
2. Small size, weight and space
3. Easy and simple to operate
4. Starts rapidly
5. Operated at a moderate speed
6. Constant and large flow
7. Not necessary to prime

Disadvantages.

1. Very low durability
2. Not very flexible
3. Operated against a limited pressure
4. Not high efficiency

In the selecting pumps for a pumping station, there has been a tendency to select a high efficiency pumping unit sometimes without regard to the adaptibility of the unit to the conditions under which it will operate and particularly without regard to economic considerations. At the same time, the boiler plant equipment and auxiliaries are selected with little thought. The pumping station should be considered as a unit and all equipment entering into its construction should be carefully selected with regard to adaptability and economy of the various parts with respect to each other and to the whole.

LIST OF REFERENCES

From American Water Works Association

1. Discipline and Regulations in Pumping Station, by C. B. Brush.

2. Growth of the Pumping Station, by C. A. Hague.

3. Water Work Pumping Stations, by C. B. Burdick

4. The Water Work Pumping Station, by R. W. Angus.

5. Notes on Pumping and Water Works Operation, by M'Kiean Maffitt.

6. Discussion of Manual of Water Work Practices.

7. Pumping Station Practice, by F. W. Dean.

8. Selection of Pumps to Fit Service Conditions, by F. G. Cunningham.

9. Selection of Pumping Station Equipment, by A. P. Pigman.

10. Modern Water Works Pumping Stations, by William Gore.

11. Efficiency in Water Plant Pumping Station Operation, by H. G. Coughlen.

12. The Value of Efficiency in the Purchase of Pumping Equipment, by A. M. Brenneke.

13. The Lubrication of Water Work Equipment, by W. B. Phillips.

14. Beautifying Water Works Properties, by C. S. Denman.

15. The Water Works from View-point of the Architect, by V. A. Matteson.

16. Making Water Works Structures Attractive.

17. Beautification of Water Work Properties, by W. W. Hurlbut.

18. Twenty Years' Progress in Centrifugal Water Work Pumps, by A. Peterson.

19. Centrifugal Pumps, by E. C. York.

20. Turbine Pumps for the Minneapolis City Water Works, by E. P. Burek.

21. The Selection and Operation of Centrifugal Pumps, by R. S. Hall and S. H. Smith.

22. Engines and Pumps, by J. G. Briggs.

23. Steam Turbines for Water Works, by D. H. Maury.

24. The Commercial Pumping Engine, by C. A. Hague.

25. Notes on Pumping Engines, by T. W. Yardly.

REFERENCE BOOKS

1. Water Supply Engineering, by Babbitt Doland.

2. Water Work Practice, by the American Water Works Association.

3. A Practical Hand-book of Water Supply, by F. Dixey.

4. Water Supply Engineering, by Fanning.

5. Sanitation Engineering, by Moore.

6. Public Water Supplies, by Turneaure and Russell.

7. Water Works Handbook, by Flinn Weston and Bogert.

8. Centrifugal Pumping Machinery, by C. G. De Laval.