ENGINEERING OF A MUNICIPAL WATER WORKS SYSTEM

THESIS FOR DEGREE OF C.E.

RUSSELL ALGER MURDOCH

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Water - supply

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This topic may be divided into the following parts, viz., Water Supply, Pumping Equipment, Water Storage, and Distribution System.

WATER SUPPLY. The prime essential of a water works system is a sufficient supply of pure and wholesome water. Insufficient investigation into the source of water supply is the cause of obtaining improper supply either in quality or quantity leading to wasteful expenditure of money or to a complete failure of the water works system.

Water supply is obtained either from natural lakes or streams, artifical lakes fed by streams, springs or wells, or direct from wells. These wells are usually what is known as deep wells. In the case of springs, streams or lakes the problem is usually comparatively simple, in the case of deep wells a great deal depends upon the geological characteristics of the locality. In some localities water can be obtained within a comparatively small depth, in other regions it is necessary to go down several hundred feet before potable water is obtained in sufficient quantities.

The following will serve as an illustration of the uncertainty of obtaining a water supply from wells:-

In one Village where the writer was in charge of the water works installation a location for the pumping system was decided upon. After some investigation of the deepest of the drilled wells near by, in which water had been found at depths of from seventy five feet to one hundred and forty feet, an eight inch well was drilled between two of these wells with the following results:- On the surface was found twelve feet of sand which was followed up by seventy eight feet of blue clay, ninety feet of lime rock and twenty five feet of light shale, making a total depth of two hundred and five feet, all of which was so dry that water had to be poured into the hole so the drill could work up the rock. At two hundred and five feet a stratum of sand rock was struck, which ran ten feet deep and contained a small amount of water heavily saturated with salt, and some gas.

This water would flow out of the top of the casing at the rate of about one gallon in five minutes. Upon drilling deeper, sixty one feet of lime rock, one hundred twenty eight feet of light shale and eight feet of lime rock was encountered, all of which was practically dry.

This well was therefore abandoned and the drilling apparatus was moved about three thousand feet north west and a three inch test well drilled, with the result that after going through sixty five feet of clay and ten feet of hard pan, eight feet of gravel containing water was found. The water raised to a height of six feet below the surface and pumped twenty gallons per minute, which lowered the level to twenty five feet below the surface, the duration of the test being ten hours. The well was then reamed out to eight inches and again tested with the result that while it at first gave sixty gallons per minute,after six hours continuous pumping it was reduced to twenty gallons per minute.This capacity it would hold with continued pumping,showing that a small bed of gravel with a small inlet had been struck and that, although it would stand up under a pumping test of twenty gallons per minute for a considerable time, when pumped faster than that, the bed of gravel was soon pumped dry and the only source of supply was the small inlet of twenty gallons per minute.

It is evident that the testing well was an expense incurred which was of no value in showing the relative value of the large and small well, but only in showing that some water could be obtained in that locality.

In well number three a similar formation was encountered, sixty five feet of clay, fifteen feet of hard pan but only one foot of gravel, which was dry;then nine feet of hard pan and one hundred six feet of dark shale intermingled with a pebble formation producing water to the extent of forty gallons per minute under continued pumping. Below this was found four feet of light shale. In encountering the one foot of gravel in well number three evidently the edge of the gravel bed of the second well was struck.

In well number four the formation was as follows:- sixty five feet of clay, ten feet of hard pan, and eight feet of gravel which produced a very clear and good tasting water, but, when pumped would not stand up under more than ten gallons per minute pumping. This well was then drilled deeper through nine feet of hard pen, one hundred and seven feet of dark shale as in well number three,but with less pebble formation,which produced some water and gas. On drilling deeper, twelve feet of light shale was encountered, then a sand rock formation was struck as in well number one. This produced salt water. As the last twelve feet of this well was drilled with a six inch drill the two inch reduction formed a taper into which a pine plug, about four feet long, was driven and thus the salt was completely shut off allowing the use of the fresh water encountered above. This well was then tested and showed a capacity of about forty gallons per minute, without effecting well number three which was about fifty feet distant. It was thus found that wells could be spaced as near as fifty feet without effecting each other. Two other wells were drilled on the lot and similar amounts of water were encountered in the rock and pumping them did not effect the other wells.

These wells were all eight inch wells which was the economical size for the rock wells as there was ninety five feet of casing anda larger size would have cost more in proportion to the volume of water obtained, however in the case of well number two, a gravel well,it was evident that a four inch well would have produced all the water available from the gravel bed and would have cost mouh less money.

The records of the several wells above mentioned show the marked degree in which strata changes, as in the fifty feet from well number three to well number two the gravel changed from one foot of dry gravel to eight feet of gravel producing a small supply of very good water,and from well number one to well number three,which was three thousand feet distant, the rock formation was completely changed, the first showing ninety feet of lime rock and twenty five feet of light shale with no water and the latter showing one hundred and six feet of dark shale with a pebble formation and producing a fair supply of water, and below these formations as shown in wells one and four was a very similar form of sand rock and in both cases producing a very strong salt water, and gas.

Wells are generally used for the water supply in the Villages of Lower Michigan, except those bordering on the Great Lakes, however it is sometimes very difficult and expensive to obtain water in this manner and in some cases surface water supplies, by which is meant lakes, streams or springs, have been used.

In the case of surface water supplies where potable water is available it is only necessary to provide a proper intake pipe with suitable strainer on its end. There are two methods of connecting the strainers to the intake pipe, (1) If the water is not very deep dig a well in the bottom of the stream and turn the strainer down into it, (2) When the water is deep turn the strainer up toward the surface. In any case, the strainer should be well submerged so as not to get air. A foot valve in the pipe may be required depending on the suction of the pumps, if the water flows to the pumps a foot valve is unnecessary. The foot valve should be kept near the strainer so it can be easily reached in case of any trouble or repairs.

The source of water supply should be thoroughly gone over to see that there is no polution, and in case of doubt the water should be thoroughly analized, the latter is sometimes compelled by State laws.

Where potable water is not available a filtering system must be installed, this in all cases proves to be a very expensive system and usually the Village get their fire system installed on the first attempt and several years later installs the filtering plant. In this case, there are usually very few users of water for domestic and sprinkling purposes and the revenue therefore is very small and does not aid very much in paying for the fire system.

Where the river or body of water from which the supply is taken gets very low in dry weather a large reservoir must be constructed and an extra pump installed to fill this reservoir during the high water. This water becomes stagnant to a certain extent and becomes a breeding place for mosquitoes, and is also a very expensive arrangement, and should be avoided where it is possible to obtain artesian wells or potable surface water supplies.

The suction pipe should be made of ample size to keep down the friction to a reasonable amount. In the case of a small water works system the suction pipe would not be very large in any case and would probably be of no very great length. If this pipe is so small that appreciable work must be done by the pump to draw water through it to fill the cylinders, there is a constant expenditure of power delivered by the prime mover simply to overcome this pipe friction. It will readily be seen that this expense is continuous during the operation of the pump, whereas there would be little additional first cost in increasing the size of the suction line to save this expense, for the interest on the investment which would be almost negligable, would be largely, if not entirely, offset by the reduced power consumption. The first cost would then be practically the only additional expense.

It is safe to say under ordinary conditions that the cost for the additional power above mentioned would be far more than the interest on the additional investment due to the increase in the size of the suction line. It may also be pointed out that in some cases the pipe friction in the suction line would necessitate the use of a prime mover of larger size to drive the pump than would be required if this pipe friction could be decreased appreciably. This is especially true in the case of prime movers at determined speeds and rated horse powers, such as electric motors,gas engines,etc.,where we are limited in selection to certain standard commercial sizes.

In this connection the following points should also be considered, in general prime movers operating at less than full load are not so efficient as when operating near the point of its rated capacity, although in the case of electric motors a reasonable range at good efficiency may be obtained by the use of well designed motors. It is also necessary in the case of high suction liftsto run the pump at a slower speed than would otherwise be selected, thus requiring a larger pump at a given capacity than would be the case if the suction lift were less.

It is evident from the foregoing that high suction lifts, whether they be due to vertical lift or its equivalent in pipe friction, are likely to prove expensive features of design as they require larger pumps and more powerful prime movers without any corresponding advantage in increase, either, of discharge pressure, or of capacity. It is further true that the higher the total suction lift the more necessary and also the more difficult it is to make and maintain an absolutely tight suction line, on the whole then we may say that high suction lifts are to be avoided whenever possible. It is not usually practical to use suction pumps where the suction lift is more than twenty one or twenty two feet, except under such conditions as are outside the province of this paper.

If possible the water supply should be near the distributing and storage systems in order to reduce the cost of piping and pumping the water to the storage and distributing systems.

However this is not so essential where a very large storage capacity is near the business section of the Village and an auxiliary pumping plant installed to take the water from this storage and provide a pressure in case of fire, or where the storage tank is elevated high enough to produce a gravity pressure great enough to take care of the fire pressure in case some accident should occur between the supply system and the distributing system.

PUMPING EQUIPMENT. In dealing with this portion of the subject it will be necessary to pass over some features rather hastily as being of small importance to the Municipal Engineer and dwell more at length upon those portions of the matter which are of more significance in connection with the subject we are considering.

Pumps, in general, may be divided into three classes, broadly speaking; these are, (1) Steam Pumps, (2) Power Pumps, (3) Special Pumps.

Class (1) may again be subdivided into, (A) Direct Acting Pumps, (B) Pumping Engines.

Class (2) may be, in the same way, divided into, (A) Reciprocating Pumps, (B) Rotary Pumps, (C) Centrifugal Pumps.

Class (3) comprises those pumps which are in neither Class (1) nor Class (2), such as Hydrolic Rams, Air Lifts, Water Lifts, "Screw Pumps" etc.

We may define a steam pump as one which is actuated by steam and in which the driving mechanism (i.e. cylinders, valve motion, etc.) forms an integral and inseparable part of the design.

A steam pump is said to be direct acting when steam pressure is applied (in the steam cylinder) to a piston on one end of a rigid rod at the other end of which a similar piston acts against the water in the water cylinder. The axes of the steam and water cylinders, then coincide. Such a pump works by direct steam pressure, the steam being admitted to the cylinder during the full stroke, no advantage being taken of its expansive qualities. There is no "cut off" of steam at any intermediate point in the stroke.

A pumping engine is an integral combination of a steam engine and a pump, (i.e. steam and water cylinders have not coincident axes, and the steam is used expansively, (i.e. steam is admitted during only a portion of the stroke, cut off taking place at the proper point as determined by the setting of the valve).

A force pump is one in which the motive power is furnished by a source separate from the pump itself, such as a steam or gas engine, an electric motor, etc. The pump and the prime mover, in this case, may be– and often is– purchased from different manufacturers.

A reciprocating pump is, as the name implies, one in which the water is displaced by reciprocating pistons, or plungers. This necessitates the transformation of a rotary to a reciprocating motion, since the motion of power delivery of practically all prime movers is rotary.

A rotary pump is one which works by displacement produced by the rotation of two intermeshing cams, which, in the smaller sizes usually take the form of gears.

We may define a centrifugal pump as one in which the water is delivered due to the action of centrifugal force, which is developed by the action of a rotary part (the impeller) causing the water to rotate in the casing and, by the centrifugal force due to its rotary motion,to be thrown outward to the spaces provided in the casing, whence it is delivered through the proper passages to the discharge.

Of the spiral pumps more will be said hereafter.

Given a proper and sufficient water supply, the next step is the determination of the type of system to be used and, consequently, of the type of pump.

There are many points to be considered in the selection of the pump. Usually the first question which arises is whether a steam pump or a power pump shall be used.

The direct acting steam pump is one of the most uneconomical devices for pumping which is in common,- the writer almost said too common,- use.

Such points as are in favor are, (1) Low first cost, (2)Simplicity,(3) The fact that every competant operating engineer is familiar with it. Its low cost is what recommends it to most purchasers.

Where electric current is available, and economy is any object, it should never be used. In fact it is a very good plan to consider such a pump as the last type to be seriously thought of for a water works plant, and only to be used in the case of unanswerable objections to the use of other types.

The pumping engine is far more economical than the direct acting steam pump, and for very large water works systems and high suction lifts it is the type of pump to be prefered, especially for high duty cintinuous service.

Since the scope of this paper is limited more especially to the requirements of the water works of smaller municipalities, from the foregoing it is evident that it is about the power pumps that we shall have most to say.

Their advantages are, (1) Economy of operation, (2) Flexibility of operation, (3) Reliability, (4) Simplicity, (5) Adaptability. It is not difficult to show (See appendix) that the electric motor is, under ordinary conditions, the most economical and the most convenient prime mover to use for driving a power pump for use in the average small municipal water works plant, even if it be combined with the lighting plant, as is frequently the case. There is one possible exception to this, and that (steam turbine driven centrifugal) will be considered later.

We must now consider the different types of power pumps and their suitability for the various conditions of operation usually to be met with.

Briefly, we may outline the various types as follows:-

(I) Reciprocating pumps,

(1) Single Cylinder,

(A) Horizontal, (a) Single Acting, (b) Double Acting.

(B) Vertical, (a) Single Acting, (b) Double Acting.

(2) Duplex
(A) Horizontal, (a) Single Acting, (b) Double Acting.
(B) Vertical, (a) Single Acting, (b) Double Acting.
(3) Triplex
(A) Horizontal, (a) Single Acting, (b) Double Acting.
(B) Vertical, (a) Single Acting, (b) Double Acting.
(II) Rotary Pumps.
(a) Gear Cut Cams, (b) Special Cams.
(III) Centrifugal Pumps – "Turbine" / "Volute.
(1) Single Suction
(A) Open Impeller, (a) Single Stage – Horizontal / Vertical.
(B) Enclosed Impeller, (a) Single Stage – Horizontal / Vertical,
(b) Multi-Stage – Horizontal / Vertical.
(2) Double Suction
(A) Single Stage
(B) Multi Stage.
(IV) Special Pumps.
(1) Hydraulic Rams
(2) Air Lifts
(3) Water Lifts
(4) Sinking Pumps
(5) Helical or "Screw Pumps.
(V) Auxiliaries.
(1) Air Compressors
(2) Pressure Regulators
(3) Float Switches
(4) Relief Valves.

Taking the foregoing schedule in order, we may briefly make the following comments:-

Single cylinder, horizontal, single acting pumps are not in use except for very small domestic water supply systems such as residences, small farms, etc. They are usually made in small capacities only; they are low priced, and, as made, are not of very high efficiency.

Double acting pumps of the same type are made in larger capacities, and are used for domestic water supply, for farm use, and for commercial purposes, such as pumping water, chemicals, and oil or gasoline in factories. They are made in larger capacities than the single acting pumps of this type and usually run about sixty percent in efficiency. They, also, are low priced pumps.

The vertical single cylinder pump is rarely seen in a power pump, except as a small pump for pressure purposes (i.e. a force pump or small boiler feed pump.) In a modified form, however, this type of pump plays a very important in connection with Municipal Water Supply.

This modification consists of separating the cylinder from the pump mechanism and placing it at a distance from the remainder of the apparatus, (i.e. the cylinder is placed below the water (submerged) and the crank shaft, gears and frame are set above, the cylinder being actuated by a wood or metal rod, known as a "sucker rod" which is really a greatly lengthened piston rod. In this form the pump is known as a "Deep well working head", which term does not, in its strict sense, include the cylinder; the latter always being spoken of separately.

The particular advantage of this type of pump is that it will raise the water from a depth, below the surface, that would be impossible to consider were it necessary to set the entire pump above ground and depend upon suction.

Duplex pumps, both of the horizontal and vertical type, both single and double acting, are often used for municipal water works systems. They are lower priced than the triplex pumps, but have certain disadvantages and are not so generally useful as the triplex type.

Triplex pumps are, in general to be prefered for the class of service we are considering. They are made in both the vertical and horizontal types, and both single and double acting.

The smaller sizes are made in the vertical type and with single acting plungers. The larger sizes (say, four hundred and fifty gallons per minute, or more) may be had in the vertical type and either single or double acting, although the latter is much more expensive in first cost.

Very large sizes are made in the horizontal double acting type only, and are quite costly, but in many cases are better suited to the conditions than a steam pumping engine.

The advantages of a triplex over a duplex pump may briefly be summed up as follows:-

(1) The cranks are one hundred and twenty degrees apart, this gives a more continuous discharge than the duplex pump, in which the cranks are ninety degrees apart, and an evener and less fluctuating load on the prime mover. While the double acting duplex pump apparently gives a more even discharge curve than a single acting triplex pump, the load on the prime mover and the strains on the bearings are not so uniform. Needless to say the double acting triplex pump has a much more uniform discharge than any duplex pump could possibly have.

It is evident that while, in a horizontal double acting pump, the design may be of the outside packed type, in a vertical pump of the double acting type, a plunger cannot be used, but recourse must be had to a piston; hence all vertical double acting pumps are of the inside packed patern.

In general, triplex pumps are of higher first cost than duplex.

Typical performance curves of a triplex pump (vertical, plunger type,) are given in the appendix.

It is to be noted that being positive displacement mechanisms, all of the above pumps can be used on suction lifts, excepting certain types of cylinders used in connection with deep well working heads.

Regarding rotary pumps, little need be herein said, as they are used in large sizes only in certain localities – principally the New Englang States – save for factory purposes. Their efficiency is fairly good, about sixty percent, but they are noisy in operation and are subject to certain inherent traits which place them under bann in many cases. Their chief advantages are –

(1) Compactness
(2) Lack of reciprocating parts
(3) Positive displacement of water discharged
(4) Suction is good on moderate lifts
(5) Low first cost
(6) Simplicity.

The centrifugal pump is very well suited to certain classes of service. Designs have, within recent years, been worked out that would have been considered as utterly impossible, ten years ago.

Where, a few years ago, this type of pump was regarded as a rather interesting but impractical scientific toy, good only for large volumes against low heads, and it was even stated by good engineers that its efficiency could never be over twenty five or thirty percent, public openion has now rushed to the other extreme and many engineers and technical men (not to speak of laymen) demand a centrifugal pump for every installation regardless of its suitability for the conditions of operation.

It is hardly necessary to say that such people have not the slightest conception of the theory and design of centrifugal pumps and it is to be regretted that they are in such a large majority, as such a course of action is very likely to bring into disfavor one of the most useful types of pumping machinery we have.

It is also to be regretted that there is probably more misunderstanding regarding the centrifugal pump, today, than there is in connection with any other piece of apparatus which is in equally common use.

Within its limits, the centrifugal pump is extremely useful and has many advantages over any other type of pump. If its limitations are to be exceeded, however, it is far better not to use it at all, as nearly every advantage will be foregone and it is likely to prove a detriment to the installation.

Its principal advantages are -

(1) Simplicity
(2)Compactness
(3) Low first cost
(4) Lack of reciprocating parts
(5) Good efficiency.

Its principal disadvantages are -

(1) Lack of suction
(2) Sensitiveness to changes in speed and head
(3) General lack of knowledge of its characteristics, among both consulting and operating engineers.

It is not fair to charge up against the apparatus the misrepresentation on the part of careless or unscrupulous manufacturers or salesmen, which are the cause of considerable dissatisfaction on the part of the purchaser, when the installation is finally completed, due to the incompatibility between the pump characteristics and the operating conditions.

While it is not the intent of this paper to go into the details of pump design, nevertheless it is not out of place to say a few words regarding the action of centrifugals, as they are becoming a more and more important feature of water works engineering as time goes on.

Since a centrifugal has no suction, if it is desired to actuate it automatically, it is evident that it must be installed with "flooded suction"- i.e. so that the water flows through the suction piping to the pump.

It is preferable to keep the suction lift of all pumps as low as pssible - on centrifugals especially so, In the case of a plunger or reciprocating pump, high suction lift may be compensated for in a measure by selecting a large sized pump and running it at a slow speed, thus allowing the cylinders to fill more easily than would be the case if a smaller pump were run at a higher speed. With a centrifugal pump, however, this cannot be done, as the speed (with a given number of stages) has to be suited to the discharge pressure required.

Neither is it economical to use a large diameter of impeller at a slower speed, as the impeller is, from elementary considerations, a water brake, and, since the brake action varies as the fifth power of the diameter of the impeller, it is evident that doubling the diameter increases the brake action thirty two times, due to this increase. The brake action depends, of course, on the friction between the impeller and the surrounding water, and also upon the adhesion of the waterto the impeller (which may be considered, naturally, in connection with the friction). Since the friction between two moving bodies in contact is a function of their relative velocity, it follows that the brake action is a function of the velocity of the impeller - i.e. its speed. But since the linear velocity of any point on the impeller depends upon the semi diameter (radius) it follows that the brake action must be some function of the diameter. As a matter of fact, the brake action of the impeller varies only as the square of the speed. Inasmuch as the brake action of the impeller is one of the internal losses of a pump, it is very evident that a small diameter and high speed impeller will be more efficient than a large diameter impeller running at a slower speed, both delivering against the same pressure.

This explains why some manufacturers will bid upon a pump of more stages than others. They save the brake energy by using smaller impellers, the speed also being kept down by using more stages, and, consequently, obtaining less pressure per stage.

This fact explains why the efficiency of a centrifugal (or turbine pump) is not dependent entirely upon workmanship or design, as, by using a larger number of smaller impellers, the saving made by reducing the brake losses may offset careless or improper design. Such a piece of apparatus, of course, may be cheaper, but embodies more wearing parts and, while the material may be of the best, and the commercial efficiency high, nevertheless it would be a comprimise to obtain the desired result.

Briefly, the pump which will do a certain work with the fewest number of stages with equal or less horse power than another, is of better design - i.e. its design comes closer to fulfilling the requirements. It is important to remember that this brake energy is not indicated in any way by the so-called "characteristic curves" of a centrifugal.

The following facts may be briefly stated:-

For a given impeller, (1) the capacity varies directly as the speed, (2) the pressure($\frac{mv^2}{r}$) varies directly as the square of the speed. (3) The horse power ($\frac{\text{foot pounds per min.}}{33000}$

$$= \frac{\text{gallons per minute} \times 8\tfrac{1}{3} \times \text{head in pounds} \times 2.3}{33000}$$

$$= \frac{K_1 \cdot \text{capacity} \cdot \text{head in pounds} \cdot K_2}{K_3} = \frac{K \cdot K_1 \cdot K_2}{K_3} \cdot S \cdot S^2$$

$= K_4 \cdot S^3$) varies as the cube of the speed.

In the above, $K_1 = 8\frac{1}{3}$ is the factor for converting gallons to pounds (weight)

$K_2 = 2.3$ " " " " " pounds to feet (pressure)

K_3 is the number of foot pounds in a horse power (33000 per minute)

K_4 represents $\frac{K \cdot K_1 \cdot K_2}{K_3}$

Where K is the combined proportionality factor between the speed and the capacity and pressure.

These are the same formulae as are used for steel plate fan computations.

Hence, by doubling the speed of a certain impeller it will deliver twice the capacity against four times the pressure, but will take eight times the horse power to do it.

Since the maximum pressure developed by a centrifugal pump is independant of anything but the speed of the impeller, it follows –

(1) That it may be used to discharge into a closed system without fear of any excessive pressure developing.

(2) The discharge valve may be shut off without harming the pump (provided it is done so as to avoid water hammer).

(3) When the discharge valve is closed, since the pump is delivering no water, theoretically the horse power equals zero, because, in the above formula, capacity equals zero, hence, the numerator of the fraction being zero, its value is zero. Practically, however, we have the brake action of the impeller and also the friction of the bearings,etc. This explains why the horse power curve does not start from zero at zero capacity. (See appendix).

In the above items are covered the principal inherent differences in action between a centrifugal and a positive displacement pump.

In the latter, any pressure (up to the safe working limit of the pump) may be pumped against at any desired speed (and consequent capacity) provided the required horse power is available and provided the speed exceeds the R.P.M. slip (See appendix). The centrifugal on the other hand, is extremely sensitive to variations in –

(1) Speed

(2) External resistance – i.e. variations in the discharge pressure or "counter pressure", because –

(1) Any variation in speed changes the delivery (capacity) accordingly and <u>also the pressure against which the pump will operate</u>.

(2) Since, at a given speed, the maximum pressure is fixed, it is evident that, if the external resistance be increased beyond a certain point, the pump will no longer

deliver water, but will simply churn the water in the casing. In fact, such a condition may be demonstrated by gradually closing off a valve in the disgharge line. The discharge will gradually decrease as the resistance increases, until, at the point where the counter pressure equals the pressure developed, no water will be discharged.

Conversely, it is apparent that, if we have a pump delivering a certain capacity against a certain discharge head, and this head is <u>decreased</u> the delivery will be <u>increased</u>. As a matter of fact, the increase will be rapid – more rapid in proportion than the reductionof head to which it corresponds.

Refering to the general formula,

$$H.P. = \frac{8\frac{1}{3}\ G.P.M. \cdot 2.3 \cdot \text{pressure in pounds}}{33000}$$

if the G.P.M. increases more rapidly than the pressure decreases, it is evident that the H.P. will be decreased.

This brings us to the most important development in the design of the centrifugal pump – i.e. the "non overload" impeller.

By this term, we signify an impeller of such a form that, if the pump be designed to deliver a certain capacity against a certain head, and the head should, by accident or design, be reduced even to free discharge at the pump, the increase of capacity (the speed being constant) will be so regulated (automatically, by the design) that the load on the prime mover will not be increased beyond a certain point (usually about ten percent increase) and may, beyond a certain point, actually be decreased. In other words, the horse power curve should be convex upwards, with a well defined maximum (See characteristic curves in appendix). This feature is embodied, today, in the design of nearly all manufacturers.

From the foregoing considerations, and from the shape of the characteristic curves (See appendix) it is very evident that it is quite necessary to know as nearly as possible the exact condition under which a centrifugal pump is to operate in order to be able to select the proper pump for the service. This is to be born in mind when dealing with the manufacturer of such apparatus, as a conscientious and reputable manufacturer will hesitate to bind himself to assume any responsibility for the operation of a centrifugal pump unless he knows exactly the nature of the service for which it is intended.

If this detailed information is not forth coming, he will make certain assumptions upon which to base his guarantees and recommendations. If these assumptions do not happen to be correct, confusion will inevitably result – either in connection with the tabulation of the bids, or else, when it comes to the final test of the apparatus for acceptance.

In either case it will be plain to all concerned that the responsibility rests with the Engineer for his failure to supply the manufacturer with the proper data.

Prime movers for the small and medium sized Municipal water works are usually –

(1) Steam Engine
(2) Steam Turbine
(3) Internal Combustion Engine
(4) Electric Motor.

The steam engine is rarely used because it requires, in addition to its own rather high first cost (if of an economical type) the additional outlay for a boiler plant and certain auxiliaries.

The steam turbine, while in some cases cheaper than the steam engine, is also, in those types, less economical in operation than the high class engine. It has the advantage of lacking reciprocating parts.

Furthermore, the requirements of the Insurance Associations or Underwriters make it necessary to carry a certain steam pressure day and night and to comply with certain other necessary but exacting requirements which entail additional expense.

We must also remember that, in the small sizes which must be considered (i.e. the whole plant taken as a unit) the apparatus cannot be as economical in operation as that in a large central power house, nor, as will be later shown, is such an arrangement as convenient as others hereinafter considered.

The internal combustion engine (gas, gasoline or oil engine) will, in its better types, be found more economical than the steam engine, nor, considering the fact that it requires no boiler plant or auxiliaries, will it be so expensive as the steam plant.

It is necessary, where the internal combustion engine is to be used to drive a plunger pump by direct connection, to provide a clutch between the pump and the engine. Here, as in other places, such a clutch is a necessary evil and a possible source of trouble. This is one good reason why an internal combustion engine should be avoided if possible. The engines themselves are now reasonably reliable and have, by improvements in design, been freed from many of the more or less serious defects which appeared in their earlier forms.

As such engines are commonly rated, they have no overload capacity; hence a larger size of engine must be selected to provide for this deficiency.

By far the most convenient form of drive for a pump in a small or medium sized water works plant is an electric motor. The extension of the Central Station transmission lines has made electric current available in most towns at a very reasonable figure. This also is a point in its favor.

The following considerations also recommend it -
(1) No boilers required
(2) No storage of inflamable liquids to be provided for.
(3) Reliability
(4) Simplicity of operation
(5) Adaptability to automatic control
(6) Adaptability to direct drives
(7) Adaptability to variable speeds where required
(8) Overload capacity
(9) Compactness
(10) High efficiency
(11) Low first cost, all things considered.

The principal disadvantage in their use is the fact that a storm may brake the transmission line from the power house, which under the present conditions,may be many miles away. However,the up to date Central Station rarely suffers an interruption in its service of more than a few hours, and this may be easily provided against by standpipe capacity.

However, the distributing system of a large up to date Central Station is so complete that it is usually possible to reach the same point in at least two ways - one direct, and the other round about by feeding through cross connections from some other town which, though reasonably close, is on another direct line from the Station.

In some cases, where a system contains several generating plants, all tied together (electrically) it is possible to feed any town on the system two ways from each plant, thus reducing the chances for interruption of service to a minimum.

The small local plant is usually not so reliable as to service. but an interruption of service, on account of the simpler existing conditions is usually a simple matter to take care of - provided the management and operation is in capable hands.

The motor itself requires, really, less actual attention than the pump. It needs only to be kept clean and properly oiled.

It may be automatically started and stopped by a float switch, pressure regulator or other similar device, depending upon the type of the system.

On direct drives the electric motor is unequaled. The direct current motor gives flexibility of speed control which is desirable in many cases - especially for plunger pumps. If variable speed is desired in the case of alternating current motors, the slip ring (phase wound) type must be used.

On account of the torque necessary to start plunger pumps, for alternating current use, the high torque type of moter is required; where variable speeds are desired (polyphase circuits) the slip ring type, as has already been stated, must be used.

In the case of direct current motors, variable speeds may be obtained by the well known methods - i.e. shunt field control or armature control or a combination of both, using the armature control for speeds below rating and the field control for speeds above rating.

In the case of a plunger pump, there is no economy in armature control, as the power required (above friction horse power) varies, theoretically, directly as the speed, and, practically, very nearly so.

In the case of the centrifugal pump, however, the power required drops off much more rapidly than the corresponding speed; hence, less current is required to drive the pump at slower speed, and, consequently, less current passes through the rheostat - e.g. since the horse power varies as the cube of the speed, at half the speed, one eighth normal horse power would be required. Further, neglecting the lowering in virtual resistance of the armature, due to the slower speed, one eighth of the normal E.M.F. would be required at the terminals (actually, it would be less than one eighth). This would mean seven eighths of the E.M.F. would be applied to the resistance (rheostat), but, since, in a series circuit, the current is the same in all parts, one eighth of the normal current passes through it.

The loss in the resistance is - $W = I^2R$

Where W equals Watts power lost

I equals current in rheostat

R equals resistance of rheostat.

hence, only one sixty-fourth of the loss takes place that would take place if the whole current were passed through the rheostat and armature.

Now, since the applied E.M.F. is the same (across motor and rheostat combined) always (neglecting variable voltage due to "regulation"), there is a greater loss when the full current (eight times as much) passes through the armature, whose resistance is only one eighth of the combined resistance, for, the I^2R formula being true,

I^2 becomes one instead of one sixty-fourth and,

R is one eighth;

hence, the I^2R loss may <u>roughly</u> be compared as being as one times one-eighth, as apposed to ,one-sixtyfourth times one, or as one-eighth to one-sixtyfourth - i.e. eight times as much.

The above is only very rough and neglects electrical losses etc. in the motor; it also assumes that the current in the field of the motor remains constant while that of the armature changes. This is not true, as the shunt field and armature are in parallel across the line. It will serve, however, to show that armature control of centrifugal pumps is far from being as wasteful as might be supposed.

Attention may be called to the fact that some manufacturers rate their centrifugal pumps as requiring so much horse power per ten feet of head. This is not correct.

In the first place, the friction horse power must be considered. In the second place, the brake horse power curve is not a straight line, but a curve. The horse power per ten feet of head must, therefore, be only an approximate figure. The curves given show typical forms and it will be evident from them wherein the error lies.

A few words must be said in connection with automatic controll.

The Pressure Regulator should be used where the area of the water storage is small and the pipe is high making a large variation in pressure, or, when a float switch would be likely to get out of working order by freezing or some other cause.

The Float Switch is very good where the area of the storage reservoir is very large and the change of pressure very small.

WATER STORAGE. Under this heading we must consider, the Natural or Artificial Reservoir, the Elevated Tank, Stand Pipe and Direct Pumping system.

By Natural and Artificial Reservoirs is meant natural reservoirs formed by valleys, into which water flows or is pumped, lakes in the hills etc., reservoirs partly natural and partly artificial,such as, reservoirs formed by hills and dammed on the low side, rivers dammed up to hold a large body of water behind the dam or valleys fed by springs and dammed to hold a large body of water in reserve. Artificial reservoirs are generally large excavations in the ground banked up arround the sides with the excavated material, to increase the depth, thus forming a reservoir.

In some cases these reservoirs are covered with a cement bottom and sides, with or without rubble foundation (depending on the soil), or where the earth is in a large degree impervious to water the reservoir is only sodded from the water line up, the remainder being left earth,

These reservoirs are used mainly where a direct pressure system or a gravity system, is installed, and in localities where, during the dry seasons the water supply is very small, necessitating a large storage to be kept in reserve.

The pumps may, where the water flows into the reservoir, under low head, take their suction from the reservoir, which then becomes a settling basin as well as a water storage basin. Under proper conditions, i.e. in the case of automatic control, where the pump suction is"flooded", centrifugal pumps may be used. In this case, we would have the pumps pumping directly into the mains. Power economy neglected, with centrifugals running at constant speed, no relief valve is required provided that the piping system will stand the shut off head of the pumps, for the maximum pressure obtainable will depend solely upon the speed at which the pumps are run, and, other things being constant, cannot increase beyond this point unless the speed be increased. (See characteristic curves in appendix and section "Pumping Equipment").

Where the reservoir is elevated, as on top of a hill, the pumps may take from the source of supply and pump into the reservoir, the supply pipe feeding the distribution system being taken from a point near the bottom of the reservoir.

In this case,the reservoir furnishes a gravity head on the system, and the pumps discharge against a constant (or nearly so), the control being by float device operating the pumps according to predetermined water levels in the reservoir. Given an overflow of proper capacity, and, since the reservoir is an open basin, the discharge head on the pumps cannot increase beyond that corresponding to high water in the reservoir. Hence, except to guard against accidental or (emergency) closing of the valve in the inlet, no relief valve or by-pass is required in this case.

The Elevated Tank is probably the most generally used of the storage systems, where a constant supply of water is available. They are also sometimes used in connection with reservoirs, as a method of elevating water to a height great enough for domestic pressure and a light fire pressure. These elevated tanks are made of capacities varying from thirty thousand gallons to one hundred and fifty thousand gallons.and sometimes greater. However, tanks of less than fifty thousand gallons capacity are rarely used as, less than that would be a very small amount of storage in case of a fire.

Where the elevated tank is used the pumps are usually run at intervals controlled by automatic regulators so as, to keep about two thirds of the tank capacity available at any time in case of fire.

The Pneumatic Pressure Tank is frequently used in connection with small municipal systems and subdivision water systems. It is more generally used in connection with farm systems and residence water systems. In a water works system where a pneumatic pressure tank is usedfor the storage, and domestic and fire pressures, tanks of sufficient capacity to be of any use in case of fire are seldom installed on account of the great first cost and therefore duplicate pumping machinery and greater water supply is necessary than with the other systems. Also an auxiliary air compressor is necessary to keep up the pressure. When using a pneumatic pressure tank all machinery should be in duplicate so, at any time a sufficient water supply could be obtained in case of fire.

The Stand Pipe, although at one time almost universaly used as the storage tank for municipal water systems, is almost completely superceded by other devices, on account of the great cost and the large volume of water near the bottom of the stand pipe which is not available at any appreciable pressure. Its chief use at present is in cases where it can be set on a natural elevation thus eliminating to a large extent the above objections. It then really becomes a closed elevated reservoir."Pressure Regulators" or their equivalent are used in connection with it, and relief valves are usually installed.

It may be mentioned here, that a relief valve or air chamber may be used to advantage where pumps operate against very high heads, to absorb the shock of water hammer which may occur when the pump ceases to operate – i.e. when it is stopped. Water hammer may also be caused, especially in the case of centrifugals, either by the inertia of water in the discharge due to a high head or to a large volume of water under low head, as it depends both upon mass and pressure – i.e. the "force behind the mass" which produces velocity.

For this reason,a check valve should be installed in the discharge lines, near the pump. This check valve may in certain cases be omitted (e.g. when, in the case of a centrifugal, the suction head is low and there is no foot valve or equivalent. It must be borne in mind that whenever a foot or check valve is placed in the suction line leading to a centrifugal pump, a check valve must be installed in the discharge; otherwise the water hammer may burst the casing – a not uncommon occurance under such conditions.

The value of water hammer is uncertain. It is approximated by the use of various empyrical formulae, and a value of fourteen or fifteen times the working pressure is quite often assummed. This is, however, by no means certain. It depends upon the rapidity with which the force producing it is checked – the quicker the inertia of the moving water is overcome, the greater is the water hammer – i.e. closing a valve instantaneously to check a flow of water would produce a very excessive water hammer as a result, while closing the same valve very slowly might not produce any appreciable water hammer.

The direct pumping system will not be dealt with at any length in this paper as it is used mainly in large city systems.

This system consists of pumping directly into the mains, using no storage or pressure tanks, the pressure being furnished directly by the pump. There are usually several pumps used in this kind of a system, some pump working continuously, and the others being thrown into service as the water consumption demands.

DISTRIBUTING SYSTEM. Given the necessary water supply, the first problem that confronts an Engineer in the design of a water distribution system is to determine the proper size of pipes to use.

The water mains should be so designed thet the combined loss in head from friction in pipes, joints, bends,etc., under fire consumption will not be great enough to reduce the pressure below that necessary for fire use. Long stretches of small pipe should never be placed in a distributing system, neither should too many branches lead from a small main. In other words, the (reasonable) capacity of any main should not be exceeded.

The system should also be designed so extensions can be made without taking up pipe already in the system and replacing it with larger sizes of pipe. A large part of the cost of a distributing system is in digging the trenches and laying the pipe, and in the majority of cases the extra cost necessary to increase the size of the pipes enough to make an adequate system out of an inadequate one would be a great deal less than the extra expense of taking up a small pipe a few years later and replacing it with a larger one.

Fire hydrants should never be placed on less than a four inch pipe, as it is impossible to get the proper fire streams from the smaller sizes. Furthermore the fire insurance inspectors will not recognize smaller pipe as any fire protection whatever.

It si, in general, advisable to make all primary and secondary feeders, in small Municipal water systems, of six inch pipe or larger, and make short cross ties in the gridiron system of not less than four inch pipe. The system should be laid out in such a manner as to make complete circuits of all lines, thus doing away with all dead ends (barring very unusual cases) and eliminating to a large extent the water hammer which is a great strain on the pipe.

In spacing the hydrants in a water system the Engineer should always keep in mind that fire hydrants are cheaper and last much longer than fire hose; therefore the hydrants should be spaced close enough together so that a sufficient number of fire streams can be obtained at any point without using excessive lengths of hose. Another reason for the close spacing of hydrants is because the friction loss per hundred feet of fire hose is very great compared with the loss in pipes and hydrants and, consequently, if the hydrants are spaced too far apart, a greater pressure is necessary at the pumping station to overcome this extra friction. Insurance inspectors require that hydrants be placed not more than two hundred and fifty to three hundred feet in the business districts, and in the residence districts not more than double that distance, in order to get the maximum reduction in insurance rates.

In placing gate valves in a distributing system care should be taken to have them so situated that long stretches of pipe would not need to be cut out in case of a break in any part of the system, also, that in case of a break at any point, all fire hydrants could be gated in such a manner that they could be fed from another direction. A good plan to follow in placing valves and hydrants is to place valves at all pipe intersections on every pipe leading from that intersection, and place the hydrant on the largest of these pipes and between the valves. By so doing in a gridiron system no hydrant would be cut out of service unless all pipes leading to that hydrant were put out of service. In some cities and villages, gate valves are put in the lead from the main to the hydrant, so the hydrant may be cut out for repairs without in any way effecting the remainder of the system.

There are several kinds of pipe used in distributing systems, the chief of these are, cast iron bell and spigot pipe, cast iron pipe with patented "Universal Joint", and wood pipe. Cast iron flanged pipe are sometimes used, especially, in high pressure lines, and, wrought iron and steel pipe are also sometimes used. The latter three will not be taken up at any length in this paper as they are not in general use in this vicinity. They are, however, frequently used in the West, where exceptionally high heads are sometimes obtained. In this case, spiral riveted steel pipe is commonly selected.

Cast iron bell and spigot pipe, probably the most widely used in municipal systems, is made in four classes – A, B, C, and D, weights and thicknesses of which, depend upon the pressures which they are to withstand, class"A" being the lightest and class "D" the heaviest. The weights, dimentions etc., of these classes of pipe are given in a set of specifications adopted by the American Water Works Association, and are recognized by all foundrymen casting bell and spigot pipe.

The standard length of these pipe, is twelve feet. However, some foundries have recently started casting lengths up to sixteen feet in the smaller diameters, and claiming that there is a large saving in labor and joint material and also leaving less liability for joint leaks by reducing the number of joints. There has been a great amount of talk,

among those not casting the longer pipe, about the inability of casting pipe symetrical in the added length, and statements have been made that the pipes are liable to be crooked and uneven in wall thickness. The writer has used both twelve and sixteen foot pipe in the same job and has found upon cutting pipe of both lengths that the wall thickness is as even in one as the other, and that pipe that can be handled without the use of a derrick lays much faster in the longer lengths than in the twelve foot lengths.

The classes of pipe usually used in municipal systems are class "B" and class "C", class "C" being used chiefly where the village is not equipped with a fire engine but develops all the pressure at the pumping station and attaches the fire hose directly to the hydrants. It is also used to some extent in the larger of the village systems in the vicinity of the pumping station or, where an extra pressure is liable to occur.

In laying bell and spigot pipe great care should be exercised in making the joints, the bells and spigots should be thoroughly cleaned before making the joint, and sufficient lead should be put into the joint to allow calking it firmly to make it water tight. Care should be taken in calking the joint not to split the bell by driving the lead too hard,which is frequently the case.

It is well in putting in any kind of distributing pipe to have all pipe tested in the open trench, as often small leaks will show up that would not show for some time after the trench had been filled in, also, in sandy soil, the water leaking out would run away in the sand and the leak would have to be very large in order to show on the surface of a closed trench. When leaks are found in an open trench it is a very simple matter to repair them, while, in a closed trench the water may appear, if it appear on the surface at all, some distance from the leak and considerable dirt must be removed before the leak is found. The only indication of such a leak may be a more rapid settling of the back filling in the general vicinity of the trouble.

Some of the chief objections to bell and spigot pipe are, inexperienced calkers frequently split the bells in making the joints, or, make leaky joints which are hard to repair, (2) Liability of expansion and contraction making leaky joints, and,(3) the high cost of laying the pipe and making the joints.

Cast iron pipe with patented "Universal Joint", is cast in six foot lengths making it very easy to handle and with machined joints, one slipping inside of the other and forming a tight joint, metal to metal, the joint is painted with white lead before being made and is then drawn together by bolts through two lugs on each pipe, on the larger sizes three lugs are cast. These pipe are very easily put together, as all that is needed is a rachet wrench, and a pail of paint, eliminating the high cost of making joints and the liability of leaks on account of inexperienced calkers. The "Universal Joint" pipe is comparatively new pipe on the market and Engineers hesitate to recommend its use in municipal water systems, although some Engineers prefer it to bell and spigot pipe.

Some of the chief objections to this kind of pipe are –

(1) The liability of breaking the lugs at the joints by drawing the pipe together too tight.

(2) High cost of pipe on account of the machined joint.

(3) Liability of the wrought iron bolts rusting in two and loosing the joint, causing a leak.

(4) The machined surface of the joints,being exposed to the water on one side and the earth on the other, being subject to corrosion quicker than a coated pipe.

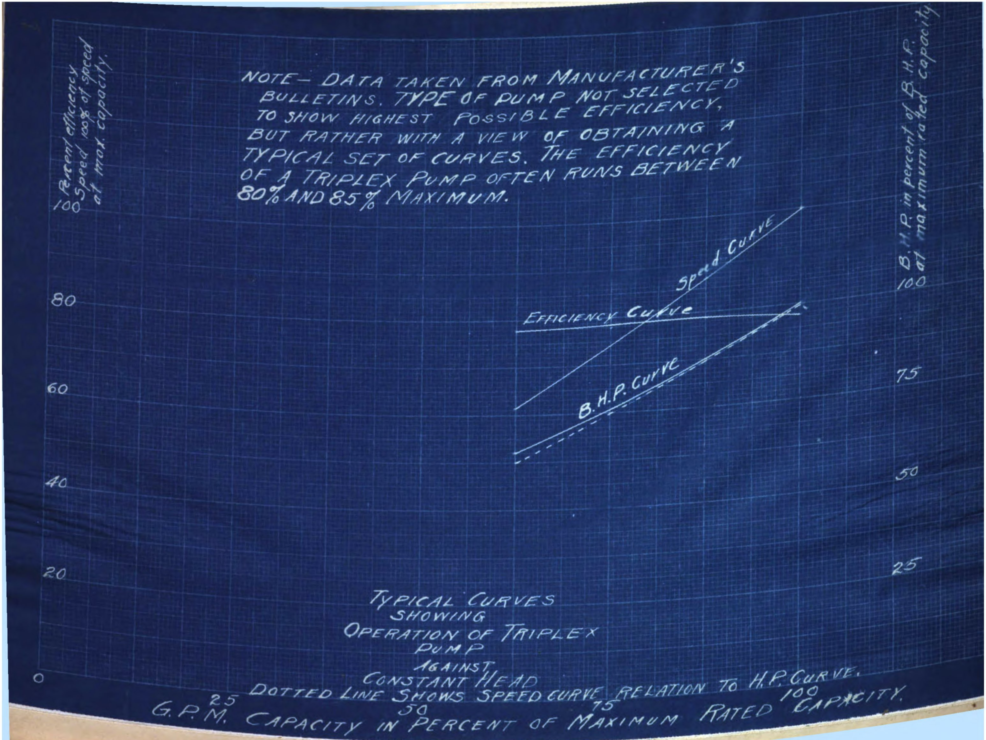
(5) A smaller weight and thickness of pipe of the same class. The makers claim the lack of weight is compensated by using a better grade of iron on account of the necessity of machining the joints.

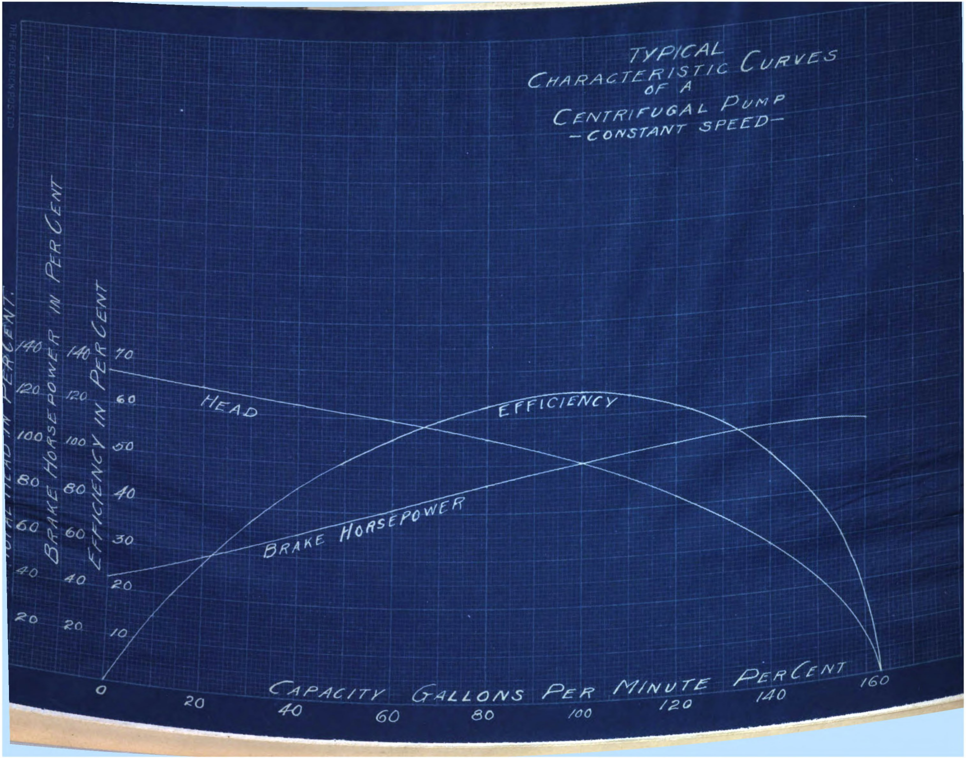
The wood pipes used in distributing systems at the present time are made of staves bound together by a spiral of strap steel and, rolled in a composition of pitch and sawdust, to preserve the wood from the soil. On account of the difficulty of obtaining good wood for staves, a good wood pipe is hard to get, and,,consequently, its use is not so general as in former years. Wood pipe, unless made of one or two kinds of wood especially adapted to use in water, is liable to impart a taste of wood to the water.

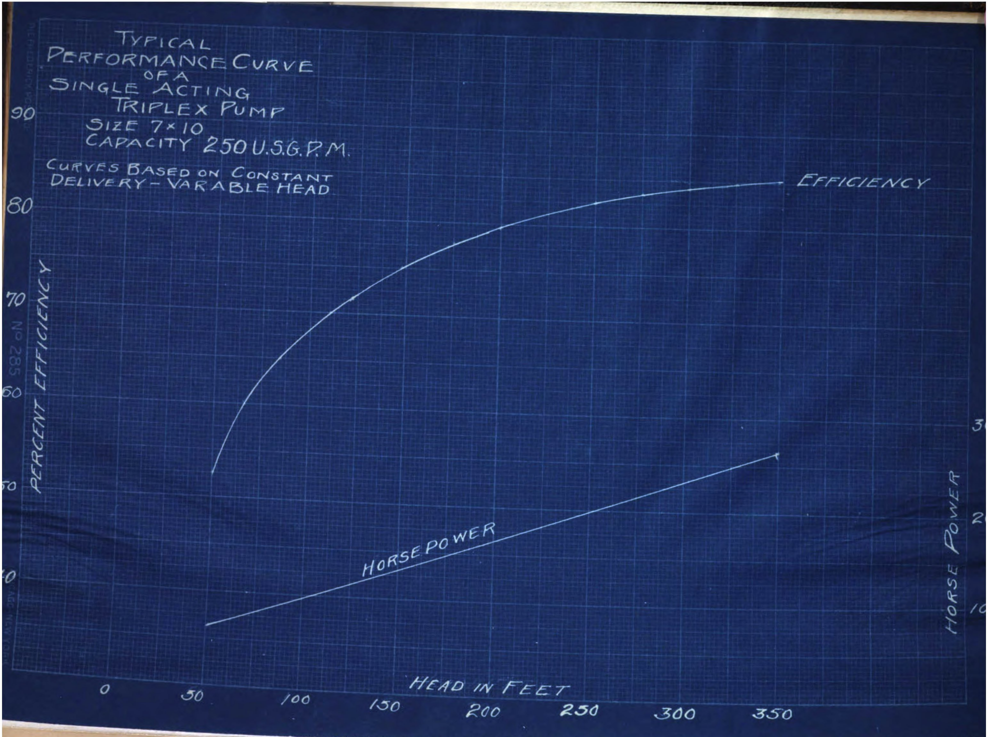
Under large pressures, wood pipe is very apt to leak and often burst causing great inconvenience to the people, on the lines bursting. Wood pipe is lower in cost than cast iron; however, this difference is getting smaller continually as wood becomes more expensive and cast iron pipe becomes cheaper, and it is probable that this is to a large extent the reason for the difficulty in obtaining good wood pipe in recent years.

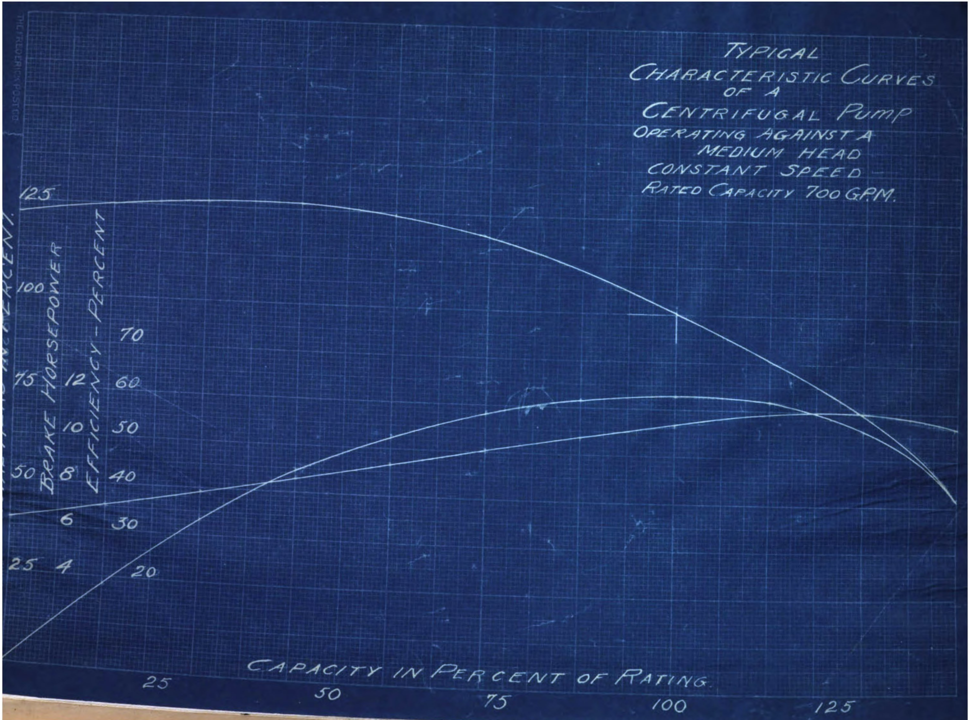
Wood pipe is light to handle and easy to lay, as the joints are made by a sleave on one pipe slipping over the end of the other, and swelling tight when soaked in water.

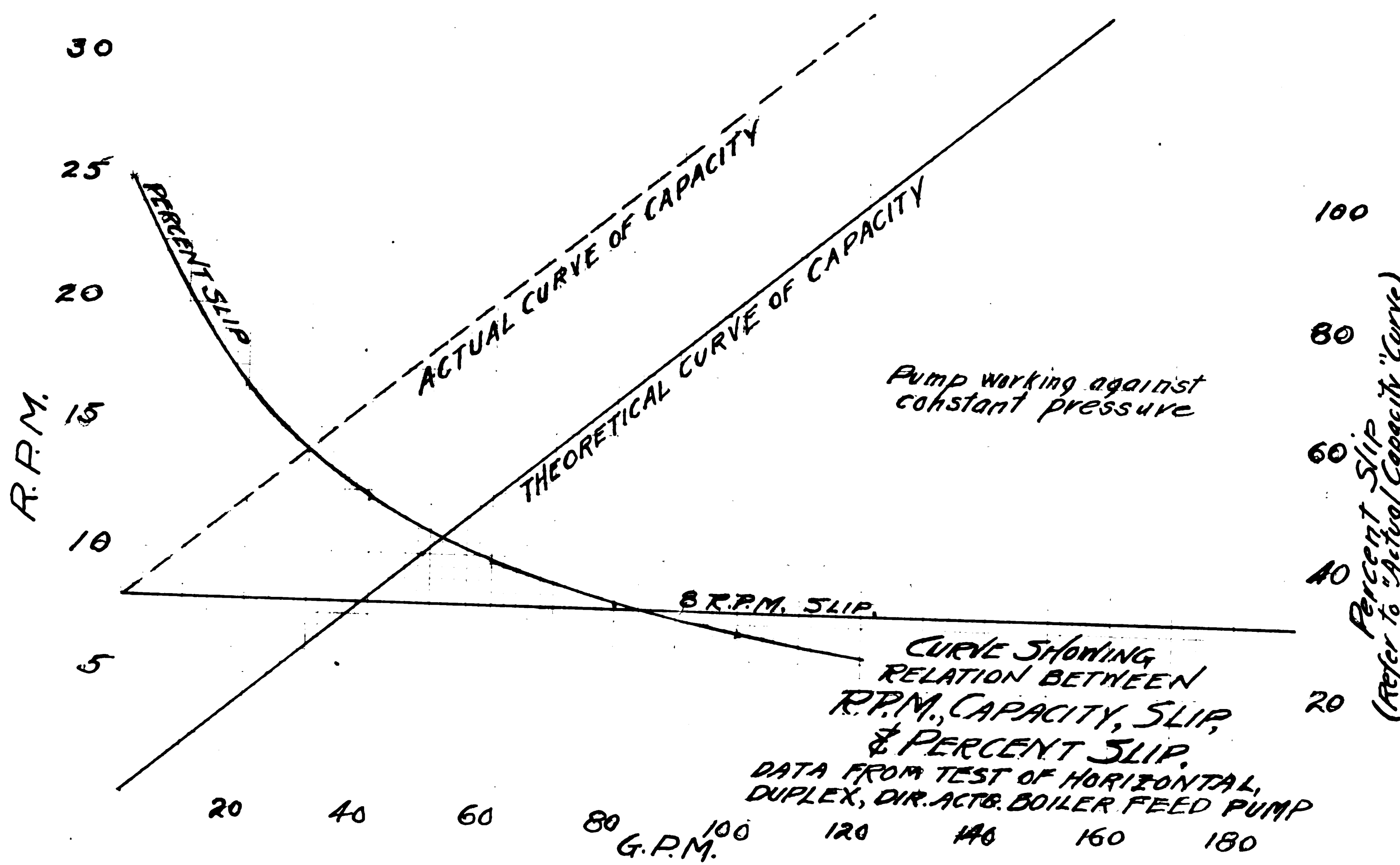
These pipe properly made last a great number of years under ground, and always being smooth inside so that the pipe friction is a minimum. One of the best woods to be used for making wood pipe is <u>number one</u> white pine.

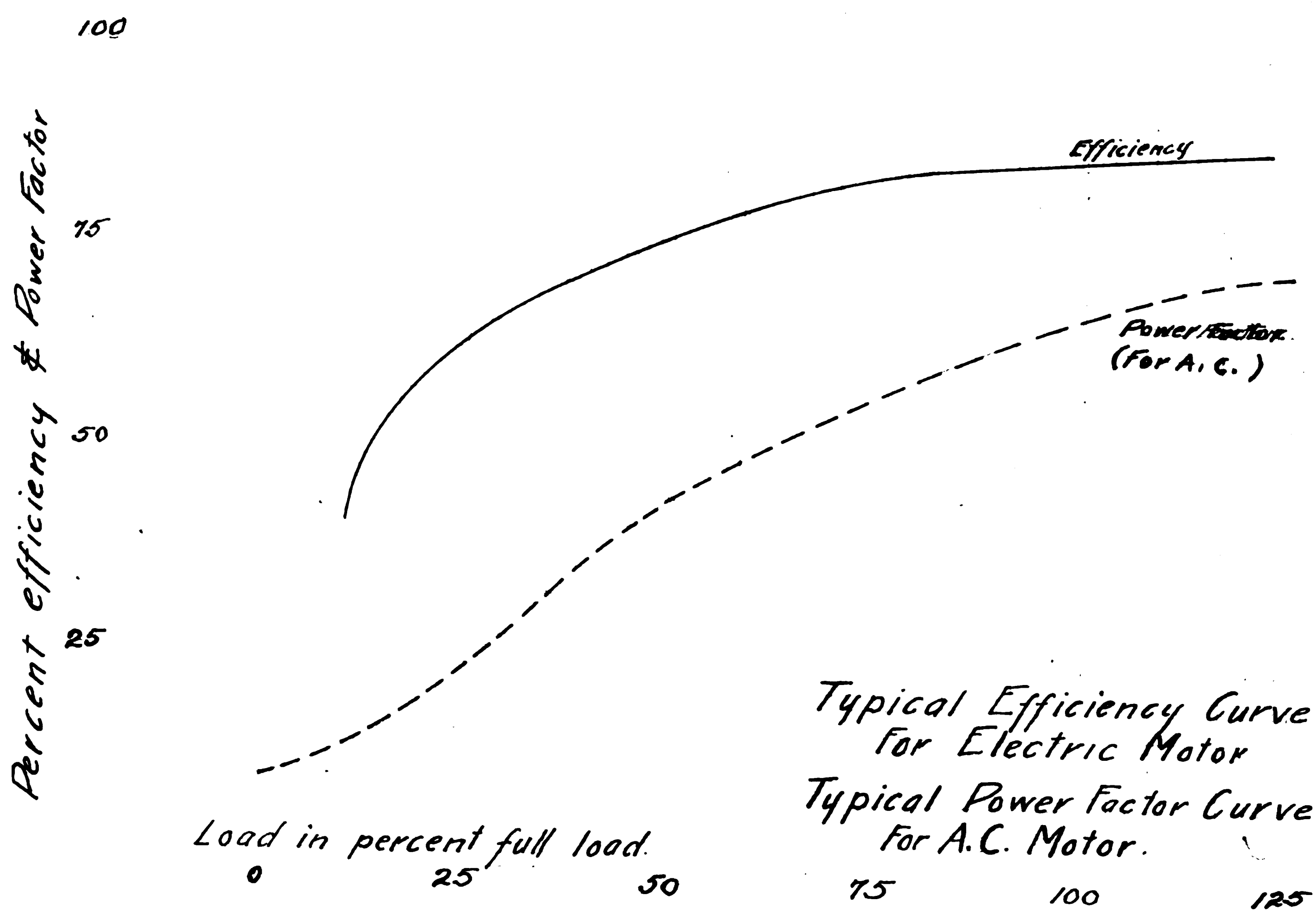

Percent efficiency
Speed 100% of speed
at max. capacity.
NOTE– DATA TAKEN FROM MANUFACTURER'S BULLETINS. TYPE OF PUMP NOT SELECTED TO SHOW HIGHEST POSSIBLE EFFICIENCY, BUT RATHER WITH A VIEW OF OBTAINING A TYPICAL SET OF CURVES. THE EFFICIENCY OF A TRIPLEX PUMP OFTEN RUNS BETWEEN 80% AND 85% MAXIMUM.
B.H.P. in percent of B.H.P.
at maximum rated capacity
Speed Curve
Efficiency Curve
B.H.P. Curve
100
80
60
40
20
0
100
75
50
25
TYPICAL CURVES
SHOWING
OPERATION OF TRIPLEX
PUMP
AGAINST
CONSTANT HEAD
DOTTED LINE SHOWS SPEED CURVE RELATION TO H.P. CURVE.
25
50
75
100
G.P.M. CAPACITY IN PERCENT OF MAXIMUM RATED CAPACITY.


TYPICAL
CHARACTERISTIC CURVES
OF A
CENTRIFUGAL PUMP
—CONSTANT SPEED—
TOTAL HEAD IN PER CENT.
BRAKE HORSEPOWER IN PER CENT
EFFICIENCY IN PER CENT
HEAD
EFFICIENCY
BRAKE HORSEPOWER
CAPACITY GALLONS PER MINUTE PER CENT
0 20 40 60 80 100 120 140 160
20 40 60 80 100 120 140
10 20 30 40 50 60 70


TYPICAL
PERFORMANCE CURVE
OF A
SINGLE ACTING
TRIPLEX PUMP
SIZE 7×10
CAPACITY 250 U.S.G.P.M.
CURVES BASED ON CONSTANT
DELIVERY - VARABLE HEAD
EFFICIENCY
HORSE POWER
PERCENT EFFICIENCY
HEAD IN FEET
HORSE POWER
90
80
70
60
0
50
100
150
200
250
300
350


TYPICAL
CHARACTERISTIC CURVES
OF A
CENTRIFUGAL PUMP
OPERATING AGAINST A
MEDIUM HEAD
CONSTANT SPEED
RATED CAPACITY 700 G.P.M.
BRAKE HORSEPOWER
EFFICIENCY - PERCENT
125
100
75
50
25
12
10
8
6
4
70
60
50
40
30
20
CAPACITY IN PERCENT OF RATING.
25
50
75
100
125


R.P.M.
30
25
20
15
10
5
G.P.M.
20
40
60
80
100
120
140
160
180
Percent Slip
(Refer to "Actual Capacity" Curve)
20
40
60
80
100
PERCENT SLIP
ACTUAL CURVE OF CAPACITY
THEORETICAL CURVE OF CAPACITY
8 R.P.M. SLIP.
Pump working against
constant pressure
CURVE SHOWING
RELATION BETWEEN
R.P.M., CAPACITY, SLIP,
& PERCENT SLIP.
DATA FROM TEST OF HORIZONTAL,
DUPLEX, DIR. ACTG. BOILER FEED PUMP



Typical Efficiency Curve
For Electric Motor
Typical Power Factor Curve
For A.C. Motor.