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MODERN PUMPING ENGINES IN HOLLAND

BY

PROF. J. C. DIJXHOORN,
of the Technical University, Delft, Holland.

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18th March, 1924.

It is a well-known fact that the surface of a great part of the Netherlands is below sea-level. The *polders*, as these lower parts of the country are called, were originally lakes or marshes. These have been surrounded by dikes, and the water pumped out, and in this way valuable land has been reclaimed.

The machinery used for such drainage has to remain ready for use at any time, in order to keep, as nearly as possible, a constant level in the canals and ditches of the polders, by pumping out the quantity given by rainfall plus leakages of dikes minus evaporation.

For about three centuries, drainage of the polders was effected by scoop-wheels and open water screws driven by windmills. During the nineteenth century the greater number of these windmills were displaced by steam engines, and not many years will elapse before the picturesque old windmill will be entirely removed from the landscape in Holland.

Several of the steam pumping-engines deliver enormous quantities of water, but as a rule they work with a very low lift. To give an idea of their dimensions, the three steam pumping-engines that drained the Haarlem lake from 1848 to 1852 may be mentioned. These had a lift of 16 feet, and each discharged about 10,000 cubic feet of water per minute.

Only one of these original beam pumping-engines is left. It is in good working order, and it is intended to allow it to remain intact as a historical monument. The two other engines have been displaced by centrifugal pumping-engines. A lift of 16 feet is about the highest for any polder in the Netherlands, but, as a rule, lifts vary between 5 and 10 feet.

Nowadays many of the centrifugal pumping-engines for such drainage work are either driven by steam, Diesel engines, gas engines, or electricity, and they are distributed all over the country. The number and size of the pumps are increasing gradually with the demands of agriculturists to keep the water in the canals and ditches of the polders strictly at the most favourable level for the crops. The capacity of the pumps varies, according to circumstances, between 1,400 and 14,000 cubic feet per minute per pump.

The great majority of these pumps do not discharge the water of the polders directly into the open rivers or into the sea, but into a system of connected canals and small lakes forming a kind of intermediate reservoir called a *boezem.* There are a great number of these boezems in the Netherlands having an area of a county or province. Several of them discharge the superfluous water into the rivers or into the sea through sluices, only taking advantage of the lower tides on the outside. Others are provided with large pumping-engines for discharging the combined water of the polders at any time, independently of the tides of rivers and sea.

If the water level of a boezem should rise above a certain strictly fixed limit, there might be danger to the dikes of the polders, which must be avoided under all circumstances, as most of the polders carry a dense population. On the other hand, the level of the canals must not fall below a lower limit than is required for shipping, so it sometimes happens that in summer time water from the rivers has to be let into the canals.

To meet all requirements the Boards of several boezems have installed enormous pumping-engines, or have enlarged the existing ones, to enable the discharge of the combined water of the polders to be made, whenever necessary, by pumping it a second time. Thus it will be clear that the pumping engines must be of very great capacity but for a small lift.

The greatest boezem of the Netherlands is that of Friesland, a province of 1,280 square miles in the north of the kingdom, Fig. 1. Until a few years ago its superfluous water was discharged by sluices only, but in 1912 the Government of the province (the County Council) decided to lay down a pumping installation capable of discharging 140,000 cubic feet per minute into the Zuider Zee near Lemmer, a small fishing town on that sea, the lift to vary from 7 inches to 7 feet, a lift of 3 feet being considered as the standard.

It may be interesting to mention that this plant has no direct connection with the works to drain the greater part of the Zuider Zee itself. The completion of the latter works will take many, many years, as the State finances of Holland, just like those of other countries, demand the greatest economy. The less fertile grounds in the centre of that sea are not intended to be drained, but will form a lake with an outlet into the North Sea through a number of sluices. So in time to come the pumping engines near Lemmer will discharge into this central lake instead of into the open Zuider Zee. I was entrusted with the design of these pumping-engines, which were completed in 1920.

In the beginning of 1914, when a decision had to be made on the kind of driving power to be adopted, the price of crude oil had risen to such an extent that Diesel engines were practically excluded.

For electric driving the special circumstances were very unfavourable. In the first place, the number of working days in a year is very small. The number differs widely, of course, but 45 may be considered a fair average. A substantial exten-

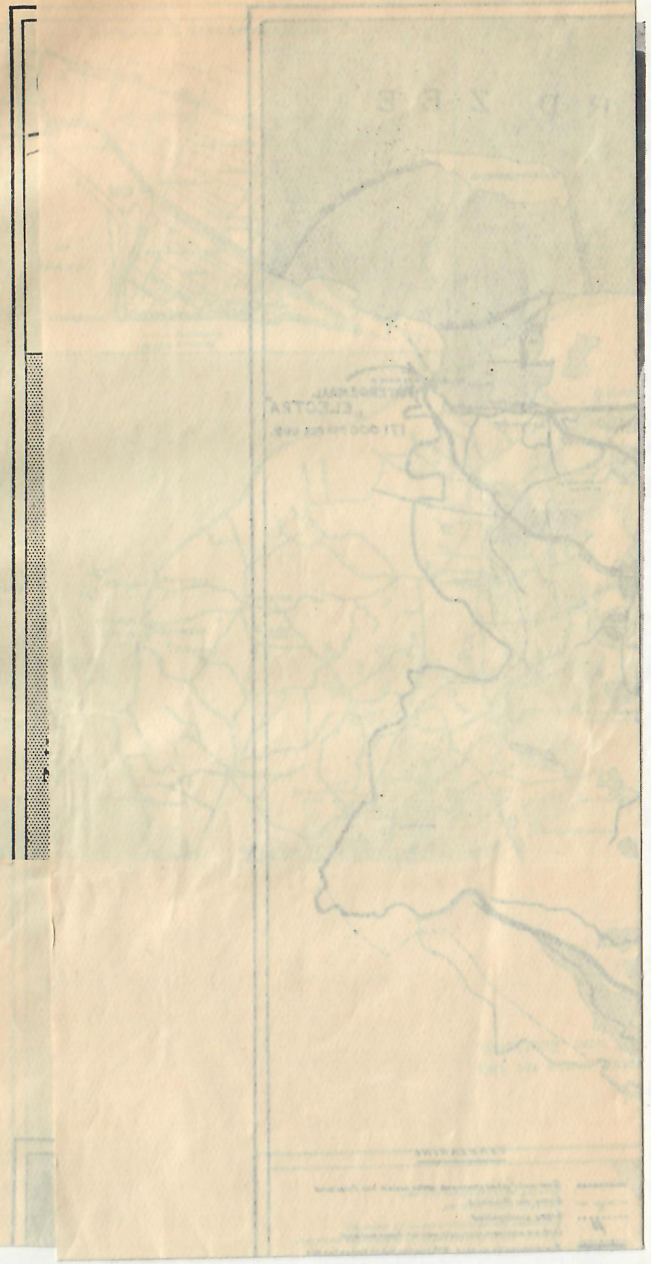

Fig. 2.—Friesland Pumping Works near Lemmer.

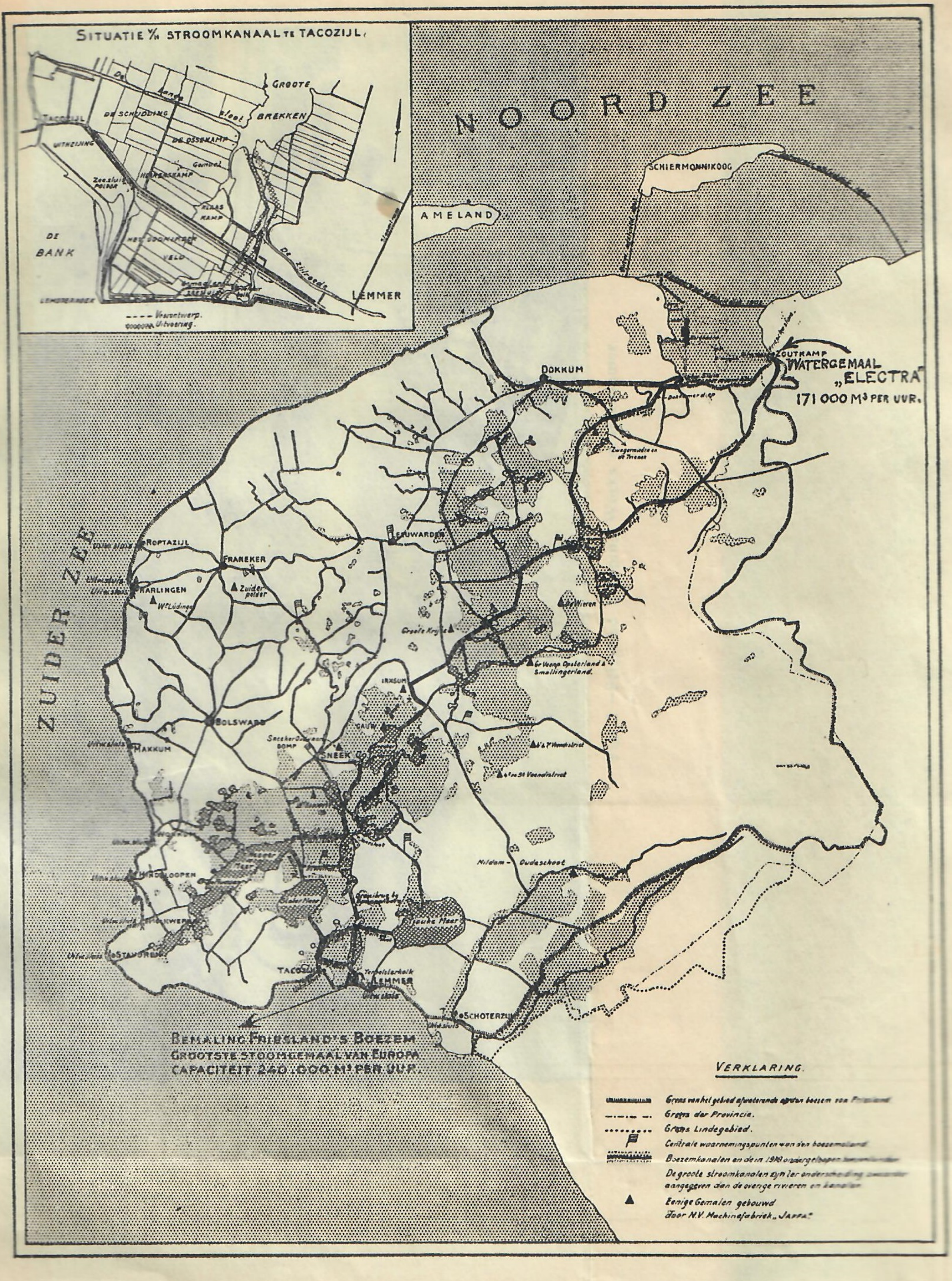

Fig. 1.—Province of Friesland.

The two arrows show the situation of the pumping works for this province near Lemmer, and those or "Electra" near Zoutkamp.

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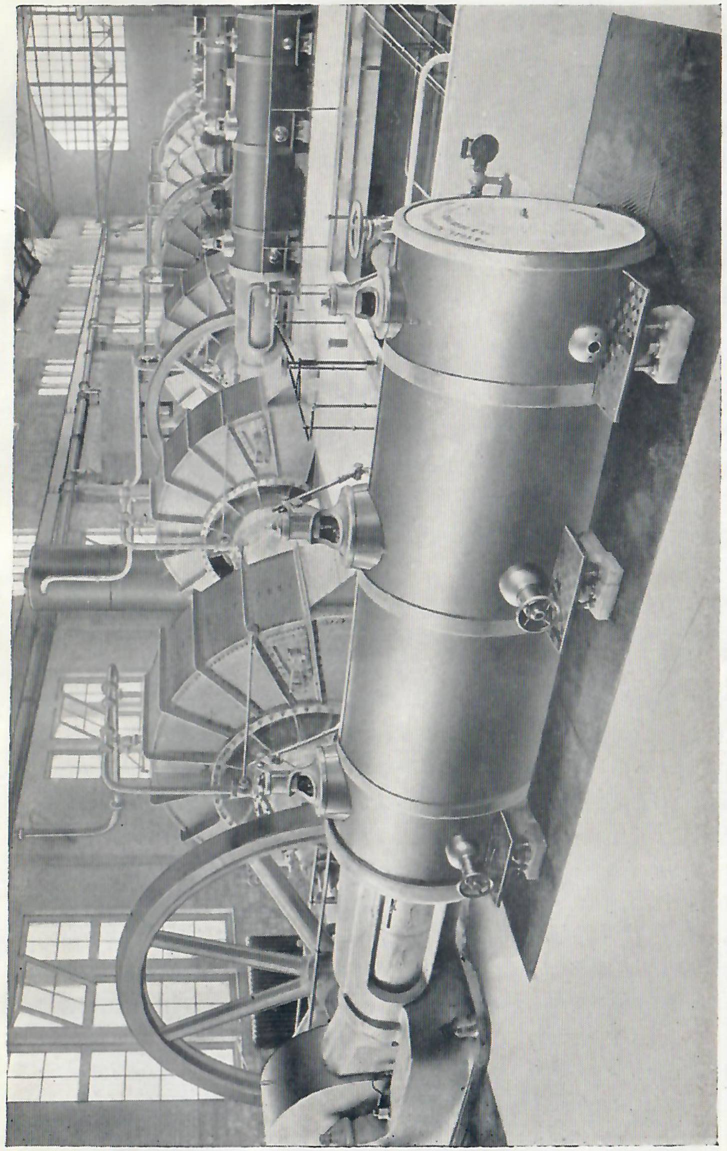


Fig. 2.—Friesland Pumping Works near Lemmer.

sion of the power house at Leeuwarden, the capital of Friesland, would have been necessary to provide the requisite power of from 1,400 to 1,500 kw., and also a cable of about 30 miles in length to serve exclusively the pumping machinery, as neither Lemmer nor the neighbouring cattle-breeding district requires electric power of any importance. Under these circumstances electric driving was also considered uneconomical, and steam power was chosen. The general arrangement is as follows:—

In an engine hall of 200 feet by 50 feet are four tandem compound-engines, each driving two centrifugal pumps of imposing dimensions, Fig. 2. As the water to be pumped may be brackish, surface condensation is adopted, every set of two steam-engines having one condenser, placed with its auxiliary pumps on the underground floor beneath the engine hall, Fig. 3.

The boiler house, 105 feet by 50 feet, contains six two-storey boilers, each consisting of a Lancashire boiler at the bottom with a multitubular boiler above it working at a pressure of 170 lbs. per square inch. Each boiler has 2,540 square feet of heating surface, and is provided with a superheater of 920 square feet, superheating to about 610 degrees F. Five boilers are amply sufficient for the total steam consumption under any circumstances.

The working time of, say, 45 days a year is too short to obtain the full benefit of mechanical stokers, so hand-firing was preferred. The short working time makes it impossible to have the best trained firemen, but with the boiler system and furnace arrangement adopted a reasonable economy is obtained even with firemen of average skill.

A steam-driven fan blows air into the closed ashpits. The regulation of the pressure in the ashpit is such that it is only a trifle more than what is required to overcome the resistance through the grate and the burning coal, and to prevent an inrush of air taking place when the fire-door is opened. By this system of "equilibrium draught" any important leakage of air through the brickwork of the boiler is prevented. The small engines for driving the fan and also the duplex feed-pumps are non-condensing, and the exhaust steam is blown through a closed feed-water heater having 65 square feet of heating surface. This complete set of auxiliaries is arranged in duplicate.

The main steam-engines have a single-acting H.P. cylinder and a double-acting L.P. cylinder, the latter being of the

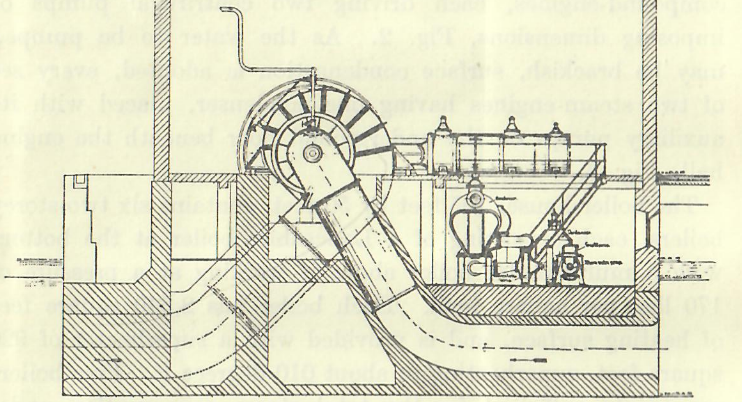
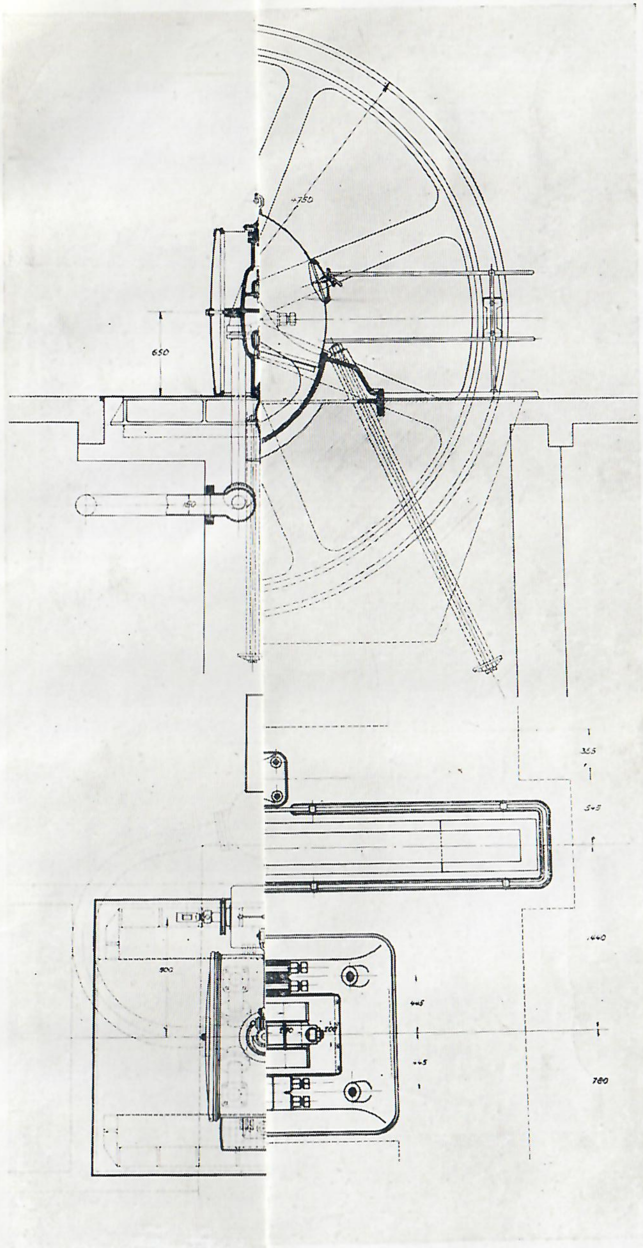


Fig. 3.—Section through the Suction Pipe of one of the Centrifugal Pumps.

uniflow type, Fig. 4. The diameter of the H.P. cylinder is $19\frac{3}{4}$ inches, that of the L.P. cylinder $32\frac{1}{2}$ inches, the stroke being $39\frac{3}{8}$ inches. There are two valves at the rear end of the H.P. cylinder, one for inlet at the top and one for outlet at the bottom. The L.P. cylinder has two inlet valves at the top only, the piston itself regulating the central exhaust. So that there are only four valves in all, each of the piston type, driven from the side shaft which runs along the cylinders and which is itself driven by bevel gearing in the usual way.

The front end of the H.P. cylinder is used as a receiver



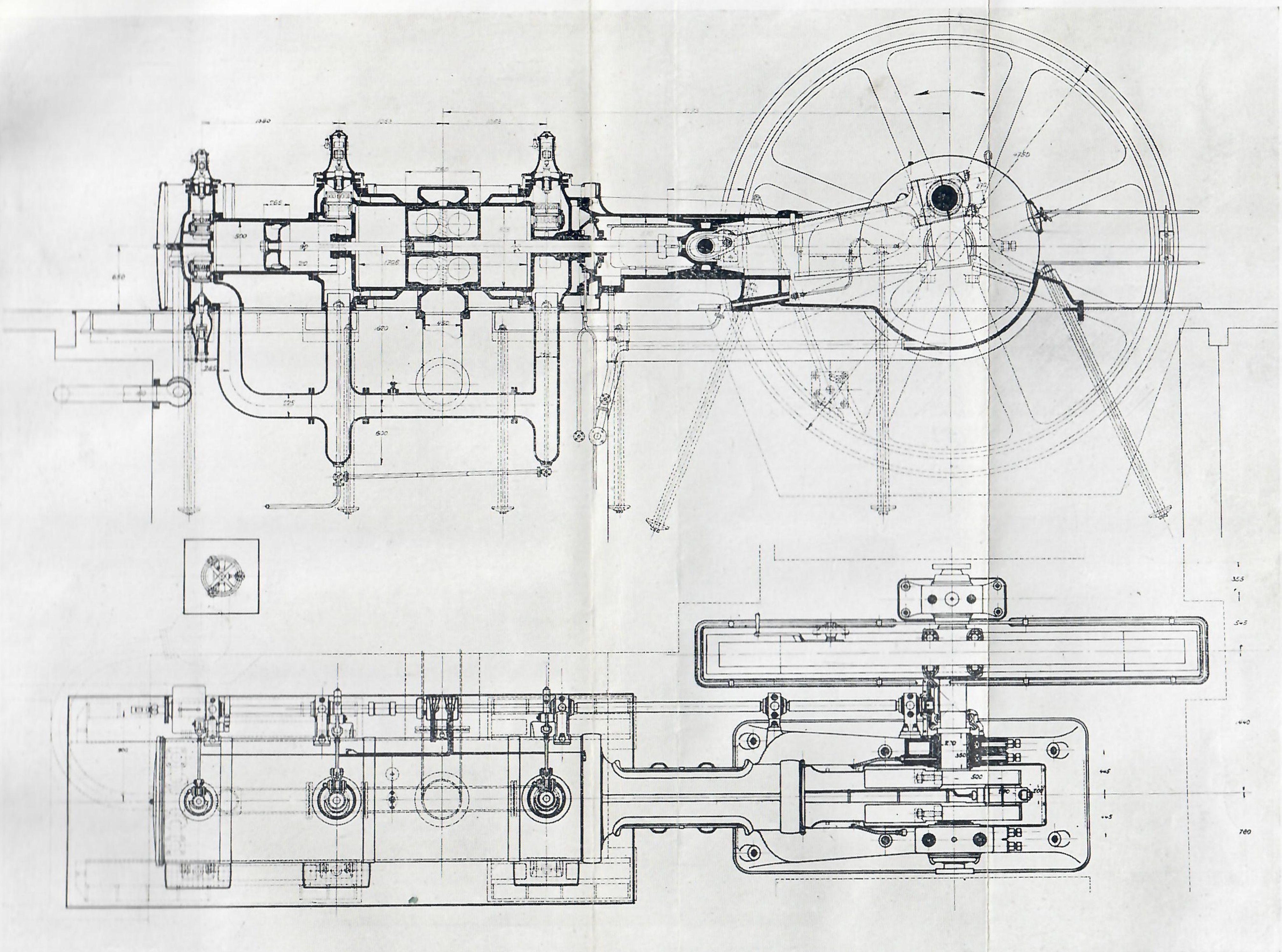


Fig. 4 —Main Steam-Engine Driving two Centrifugal Pumps.

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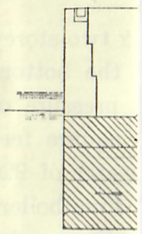

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between the cylinders. Thus the outlet valve of this cylinder is virtually an equilibrium valve, and the cylinder, in fact, works according to James Watt's well-known Cornish cycle. In my opinion, this combination of the excellent old Cornish cycle for the H.P. cylinder with the modern uniflow system for the L.P. cylinder forms a basis for economical working. The indicator cards prove that the front end of the H.P. cylinder practically does not perform any work on the piston at all.

The auxiliary pumps for the condenser are driven by a small horizontal tandem compound-engine running at 160 r.p.m., the crankshaft being directly coupled to the centrifugal pump for circulation water. The air pump is double-acting and driven from the crosshead.

A high condenser-vacuum is considered essential for steam economy, especially in this case where the L.P. cylinders of of the main engines are built on the uniflow principle. The vacuum varies between 28 inches in summer and 29 inches in winter. The exhaust pipes between the L.P. cylinders and the condenser are carefully lagged with non-conducting material in order that no steam condensation may take place in the pipes, but exclusively in the condenser. According to my experience, it is best to transport the exhaust steam at a mean density as low as possible to secure the smallest difference of absolute pressure between the L.P. cylinder and the condenser. Now to obtain a low value of this mean density it is necessary to prevent the formation of water drops in the connection-pipes by lagging them with felt or other non-conducting material. Another feature which gives the full benefit of high vacuum in the condenser to the L.P. cylinders is the conical widening of the central exhaust openings of the latter, giving them the form of short de Laval nozzles, Fig. 4. By this means the drop of absolute pressure between the L.P. cylinder and the condenser is only 1$\frac{1}{2}$ inch, the vacuum in the cylinder amounting virtually to 90 per cent. under average circumstances.

For simplicity's sake an ordinary wet-air pump, for water and air combined, Figs. 5, 6, and 7, was chosen, other constructions not being considered so suitable for standing idle and deteriorating during seven-eighths of the year. The design is simple, but some particulars may be worth mentioning. Water and air are led from the condenser to the air pump by separate pipes connected to the flanges *w i p* and *a i p*, Fig. 6, and the discharge of the pump has separate pipe connections too, the water flowing to the hot-well through the opening *w o p* at the bottom, while the air is being exhausted to the outside of the building through the pipe connection *a o p*.

From Figs. 5, 6, and 7, it will be seen that the water valves are at the bottom of the pump, the cross-section, Fig 6, showing a suction valve *w i v* opening upwards, and a discharge valve *w o v* opening downwards. For these water valves, light ring valves loaded by very light spiral springs were adopted. They work noiselessly at 160 r.p.m.

Of course, the air valves are situated at the top of the pump, Fig. 6 showing that the suction valves *a i v* open downwards and the discharge valves *a o v* open upwards. These air valves are ordinary flat India-rubber disc valves loaded by very light springs. The suction chambers for water and air have a vertical communication pipe *w a i* in the pump casting, Fig. 7. The mean water-level in this communication pipe varies according to the steam consumption of the engines under different circumstances.

In the same way the water chamber and the air chamber at the discharge side of the pump have a vertical communication pipe *w a o*. By this construction the air does not mix with the water in the air pump to such an extent as is the case with other constructions, and the vacuum-air has not to overcome any head of water whatever. The result is that a condenser vacuum of 28 inches in summer and 29 inches in winter is easily maintained.

The eight main centrifugal-pumps, Figs. 8 to 10, have each a

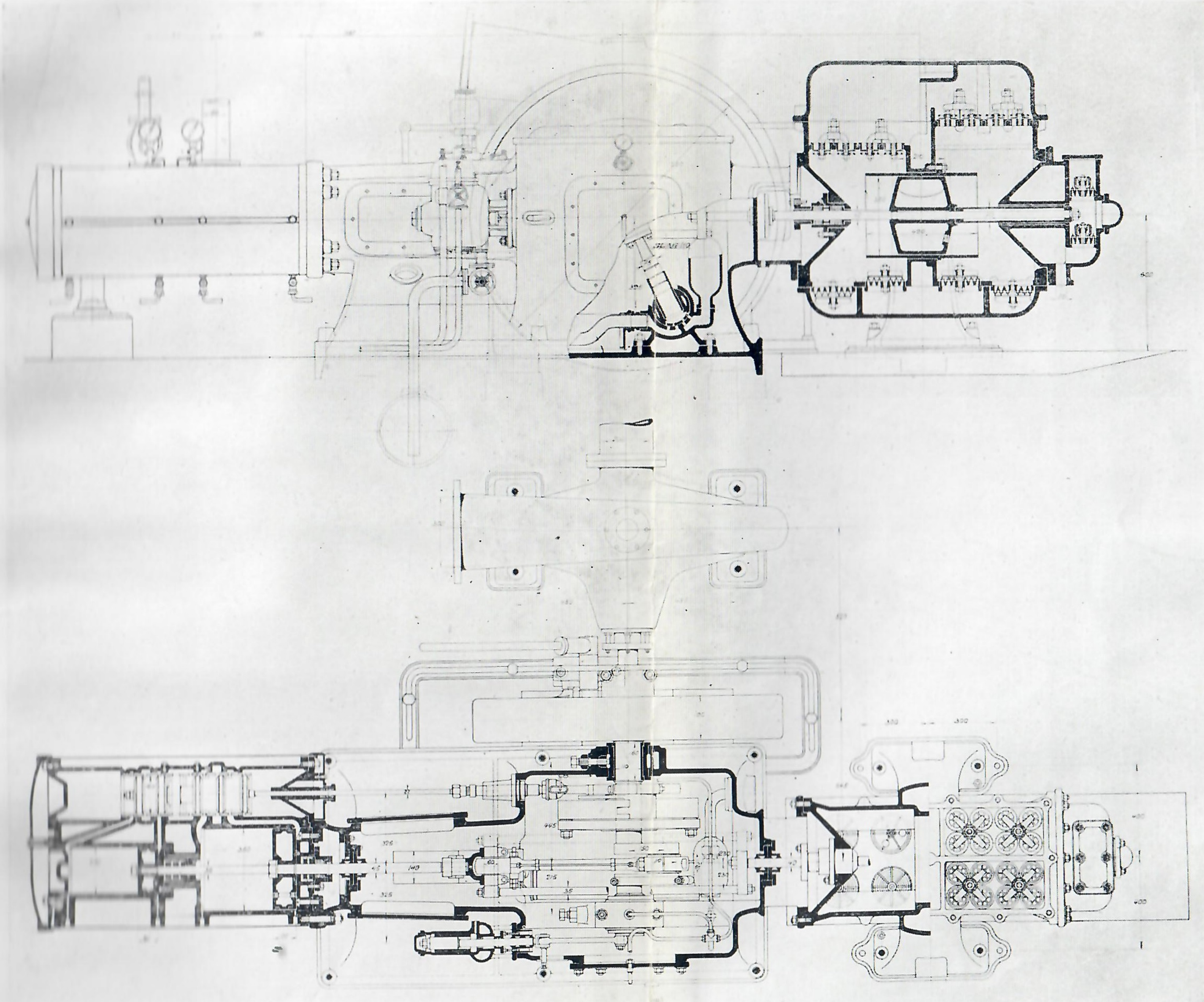

Fig. 5.—Auxiliary Engine for Driving Air Pump, Circulating Pump, etc.

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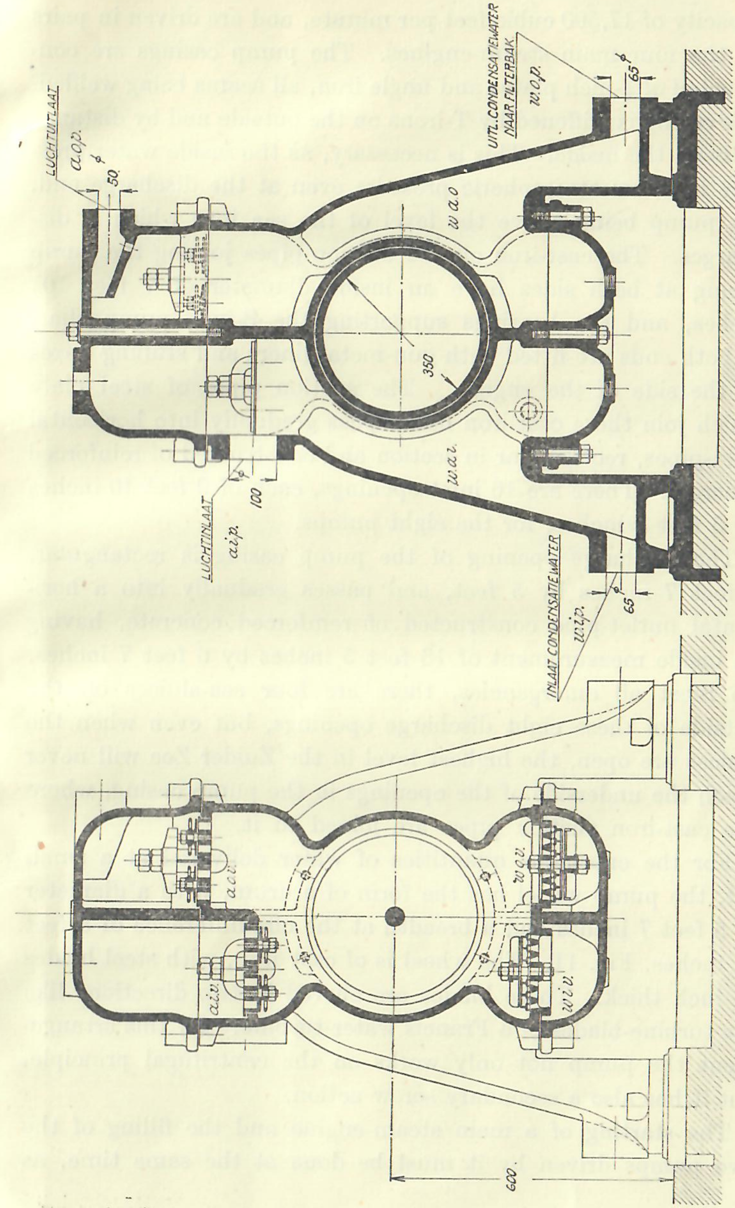


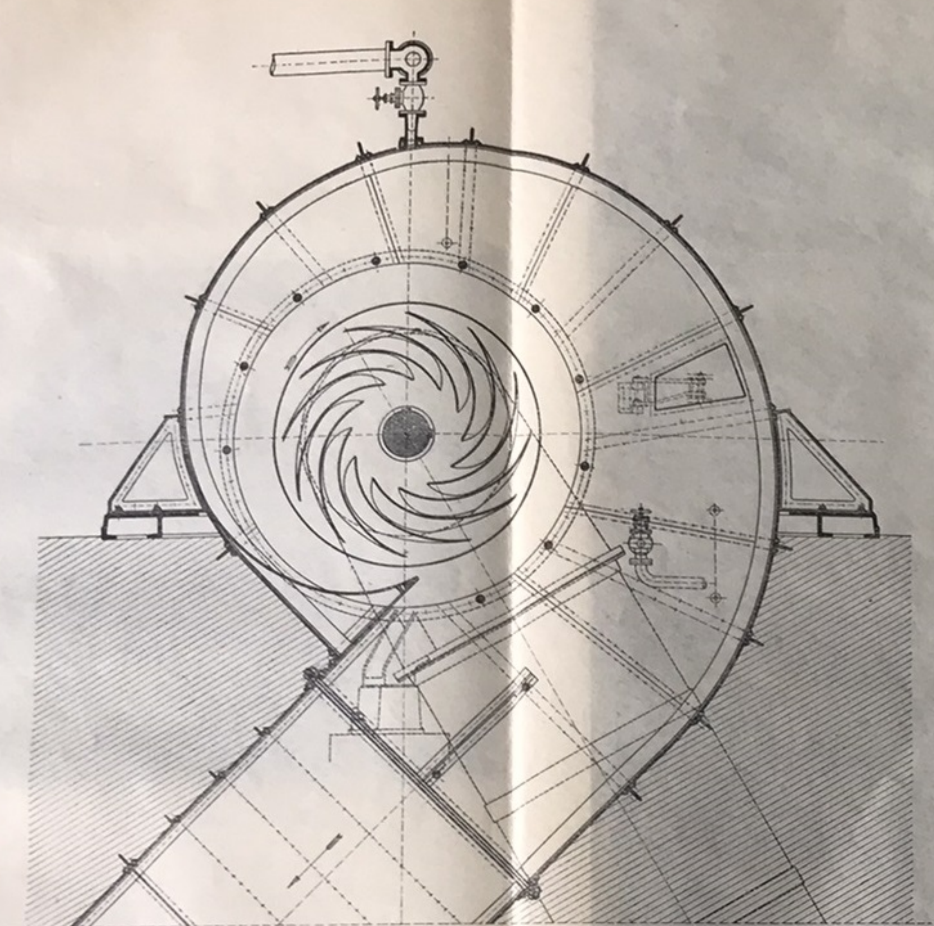
Figs. 6 and 7.—Cross-Sections through the Air Pump.

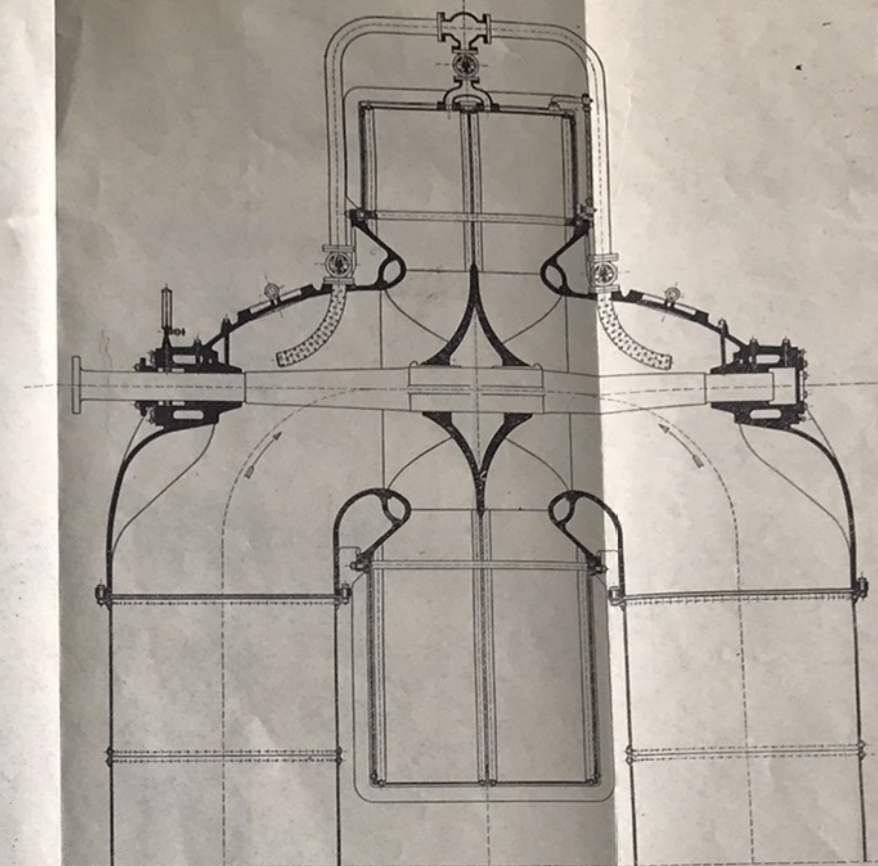
capacity of 17,500 cubic feet per minute, and are driven in pairs by the four main steam-engines. The pump casings are constructed of $\frac{1}{2}$-inch plates and angle iron, all seams being welded. The casing is stiffened by T-irons on the outside and by distance bolts on the inside. This is necessary, as the inside water pressure is below atmospheric pressure even at the discharge end, the pump being above the level of the sea into which it discharges. The cast-iron curved suction-pipes joining the pump casing at both sides have an inside diameter of 7 feet $10\frac{1}{2}$ inches, and the bearings supporting the 8-inch pump shaft at both ends are fitted with gun-metal liners and stuffing boxes at the side of the engine. The suction pipes of steel plate which join these cast-iron bends pass gradually into horizontal inlet-pipes, rectangular in section and constructed of reinforced concrete. There are 16 inlet openings, each of 9 feet 10 inches by 5 feet 3 inches, for the eight pumps.

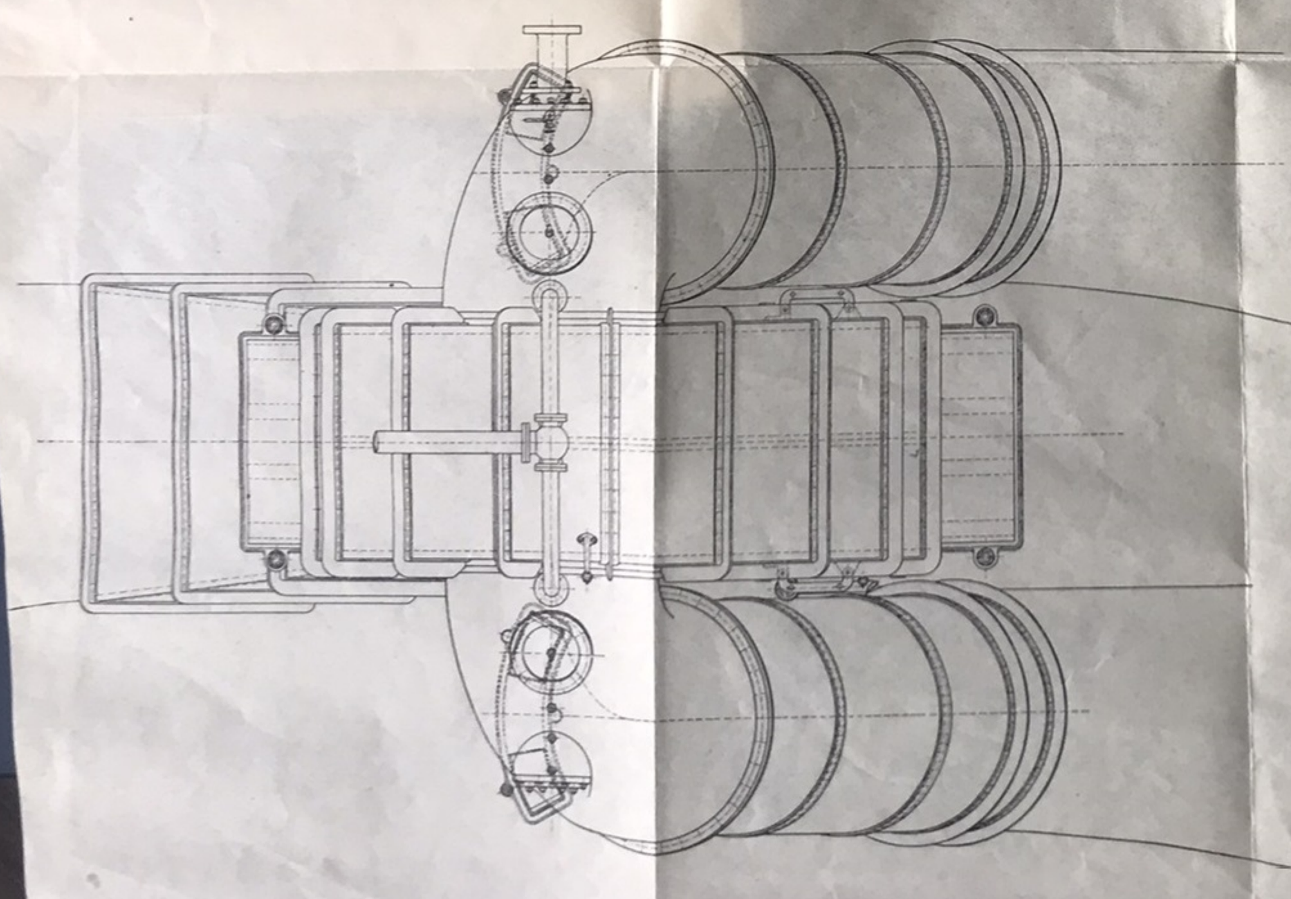
The discharge opening of the pump casing is rectangular, 6 feet 7 inches by 5 feet, and passes gradually into a horizontal outlet-pipe constructed of reinforced concrete, having an inside measurement of 16 feet 5 inches by 6 feet 7 inches. To meet all emergencies, there are four sea-sluices on the outside of these eight discharge openings, but even when the sluices are open, the highest level in the Zuider Zee will never reach the underside of the openings in the pump casing, where the cast-iron suction pipes are joined to it.

For the enormous quantities of water delivered at a small lift, the pump wheel has the form of a drum, with a diameter of 5 feet 7 inches and a breadth at the circumference of 3 feet $2\frac{5}{8}$ inches, Fig. 11. The wheel is of cast iron, with steel blades $\frac{5}{16}$ inch thick. These blades are curved in two directions like the turbine-blades of a Francis water-turbine. By this arrangement the pump not only works on the centrifugal principle, but it has also a secondary screw action.

The starting of a main steam-engine and the filling of the two pumps driven by it must be done at the same time, as







Figs. 8 to 10.—Main Centrifugal Pump.

Diameter of Pump Wheel, inches	67
Breadth at Circumference, inches	$38\frac{1}{2}$
Capacity of Pump, cubic feet per minute	17,500
R.P.M.	100
Mean Lift, inches	39

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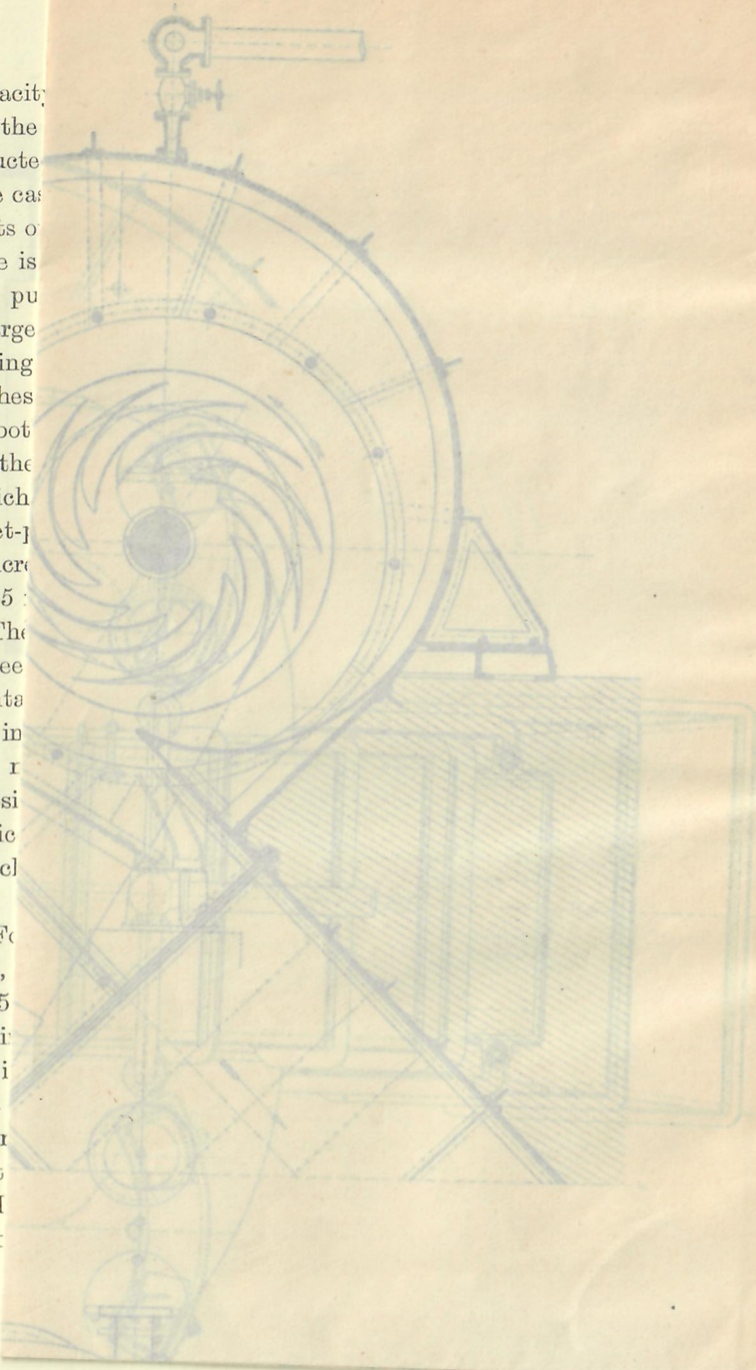


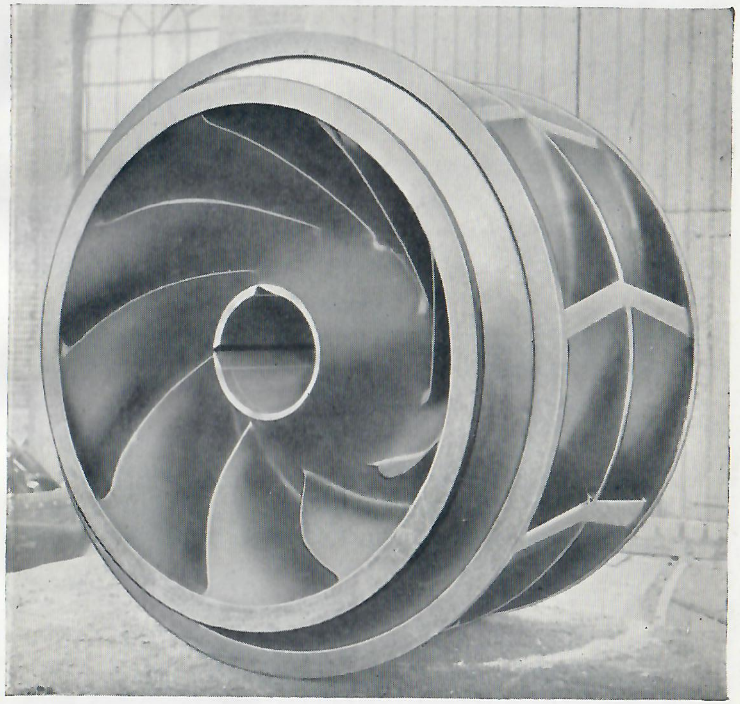


Fig. 11.—Pump Wheel.

there are no return valves to the pumps. The filling is accomplished in a very short time by means of a central vacuum vessel, in the form of a vertical cylinder 3 feet 3 inches in diameter and 20 feet high, erected in the engine room, Fig. 4, with pipe connections to each of the eight pumps. This vessel is evacuated beforehand either by the air pumps of the condensers, or by a powerful steam-exhauster, of which two are provided.

The connecting pipes to the pumps join the central vacuum vessel tangentially. As soon as the stop valves between these pipes and the pumps are opened, first air and afterwards a mixture of air and water passes through them. The vacuum vessel is then working as a water separator, and the water is discharged by a pipe at the bottom, the mouth of which is submerged in the sea, and at the same time the exhaustion of air is continued from the top.

By this arrangement the possibility of any water entering the air pumps or the steam exhausters is eliminated in starting the main pumps, and the filling of the big centrifugal pumps is completed within a few minutes.

An addition is being made to the steam pumping-plant for the purpose of securing absolutely pure feed-water, and a description of the arrangement may be of interest to members of the Institution. It is well known that there are several methods in use for purifying either the exhaust steam from the L.P. cylinder or the water from the hot-well with a view to obtaining oil-free feed-water, but none of them gives entire satisfaction. Therefore engineers in charge of surface-condensing engines are, as a rule, instructed to limit the use of cylinder oil to the utmost. If these instructions are followed the results may be fairly satisfactory when saturated steam is used; but with superheated steam this point demands the most careful consideration, as deficient cylinder lubrication may cause great trouble, especially with horizontal cylinders, where the weight of the pistons bears on the cylinder wall, The greater part of the oil may be separated by passing the feed-water, in the well-known manner, through a gravitation tank having a number of compartments, the water being taken from the bottom of a compartment and passed to the top of the next one, in which it again sinks slowly to the bottom; but it is not possible to free the water from the last particles of cylinder oil. A sample of the water taken from the last compartment and left standing for several weeks remains a trifle "milky." It does not make any material difference whether the compartments of the tank are filled with coke or with any other suitable material.

In the engineering laboratory of the Technical University at Delft, elaborate experiments were carried out to find a decisive solution of this problem. These experiments led to the following arrangement, which is now in regular use in the laboratory, with a 180 i.h.p. triple-expansion marine engine having well-lubricated cylinders.

The feed-water, slightly "milky" as delivered from the oil-settling tank, is pressed through an ordinary filter-press, as used in sugar factories, etc. To prepare a suitable filter-bed in the press a solution of alum is made, to which soda is added (3 lbs. of alum to 1 lb. of soda). The result is a flocky precipitate of alum hydroxide. Neglecting the water of crystallisation, the reaction is substantially represented thus:—

$$Al_2(SO_4)_3 + 3Na_2CO_3 + 3H_2O = 2Al(OH)_3 + 3Na_2SO_4 + 3CO_2,$$

the small quantity of CO_2 escaping. This flocky water is supplied gradually into the last compartment of the settling tank and pumped through the filter-press, the very thin flocks not causing the slightest trouble to the pump valves. The flocks adhere evenly to the cloth of the filter-press.

While the pump is working under normal conditions, the addition of water containing the filtering material, $Al(OH)_3$, is continued until the pressure in the filter-press has increased to about 20 lbs. per square inch. When the filter-press is ready

for its work, it will be found that the water delivered by it is absolutely clear, without any trace of oil. The total filtering area should be made ample in order to get a small filtering velocity. Experience has shown that excellent results are obtained with a velocity of from four to five feet per hour.

For the Lemmer pumping works, two filter-presses, each of 73 square feet capacity, are installed to be used alternately. The best results are obtained when the filter-press is kept continuously working. At any rate, it is necessary to prevent the layer of alum hydroxide on the filter-cloth from becoming dry when not in use. If this happens a new layer of filtering material must be added, there being no objection to increased pressure, as filter-presses for 100 lbs. per square inch and upwards can be easily obtained. The time during which a filter-press may be effectively used before it requires to be emptied depends upon various circumstances, and no data based on experience can yet be given regarding this point.

Of course, it is well understood that there is nothing new in filtering water generally by first adding alum to it. But I think that this method was not previously applied to the purification of feed-water, and hope that for clearing the feed-water from the last particles of oil it might prove to be of practical value to all users of surface-condensing piston engines, and especially to those users of engines working with superheated steam.

Careful trials were made at the Lemmer Pumping Works on January 25th and 26th, 1923, to ascertain the capacity of the pumps and the steam consumption of the engines. On the first day the engines were run at 95, 100, and 105 r.p.m. respectively, the lift of the pumps varying from 1 foot $10\frac{1}{8}$ inches to 2 feet $\frac{3}{8}$ inch.

A higher lift would have been more in accordance with the conditions for which the pumps were constructed, but the opportunity of making any trials at higher lifts did not present itself at the time.

Main Pumps.

Mean Lift, inches.	R.P.M.	Cubic Feet per Minute.
$22\frac{1}{8}$	95	17,830
$24\frac{5}{16}$	100	18,520
$24\frac{3}{8}$	105	20,550

The next day, when the steam consumption was measured, the lift of the pumps was still smaller, varying from 1 foot $5\frac{15}{16}$ inches to 1 foot $7\frac{13}{16}$ inches.

The mean results of two trials showing only little difference may be summarised as follows:—

R.P.M. - - - - - - - - - - -	100·15
Mean lift of pumps, inches - - - - - - -	$18\frac{7}{8}$
Water discharged per minute, cubic feet - - - - -	20,270
Water horse-power of four pumps, driven by two engines - -	240·9
Indicated horse-power of two engines driving four pumps - -	876·4
Total efficiency, $\frac{\text{W.H.P.}}{\text{I.H.P.}}$ - - - - - - - -	·275
Steam pressure at the engine stop-valve, lbs. per square inch -	149·6
Steam temperature " " " " " -	589° F.
Mean vacuum in condenser, inches - - - - - -	$28\frac{15}{16}$
Total steam consumption of two engines, including condensation in the steam pipe, and consumption of auxiliary pumps for condenser, etc., lbs. per hour - - - - - -	8,406
Steam consumption per I.H.P., lbs. per hour - - - -	9·59

The complete pumping engines were constructed at the Jaffa Engine Works, Utrecht, and the boilers by Deprez Brothers, Tilburg.

In 1915 the Government of Groningen, a province situated to the east of Friesland on the frontier of Germany, decided that three pumping engines, each capable of dealing with 33,333 cubic feet of water per minute, should be erected near the village of Zoutkamp on the Lauwer Zee, which is in open communication with the North Sea (in the north-east, Fig. 1). the water to be pumped into a lake of only one-quarter of a square mile in area, from which it would discharge into the open sea through sluices. The lift varies widely, but the

capacity of the three pumping engines together will be 100,000 cubic feet per minute when the lift does not exceed 4 feet 3 inches. The mean lift may be taken at 3 feet 9 inches. It is intended to install two more pumping engines of the same capacity in the same building.

The Board of the province possesses its own electrical power supply at Helpman, a suburb of the city of Groningen, situated at a distance of about 18 miles from the pumping works, and a considerable consumption of electricity might be expected in this prosperous part of the country. It is clear that under these circumstances electricity was selected for the driving power, and the new boezem received the name "Electra." The great difference of lift, ranging from zero to 5 feet 9 inches, presented some difficulty in choosing the best system of pumps. With a steam engine driving a centrifugal pump, it is possible to work at a higher number of revolutions at the greater lifts, and at a reduced number at the smaller lifts. But with an ordinary three-phase motor the number of revolutions is nearly constant, and a motor suitable for standard conditions might be heavily overloaded under different circumstances, the gearing between the motor- and pump-shafts being unchanged. A variable speed gear might have been used, but it seemed hardly commendable for about 600 effective horse-power. The conditions of the prescribed capacity at different lifts could hardly be fulfilled with ordinary centrifugal pumps working at a nearly constant number of revolutions, and with a reasonable efficiency.

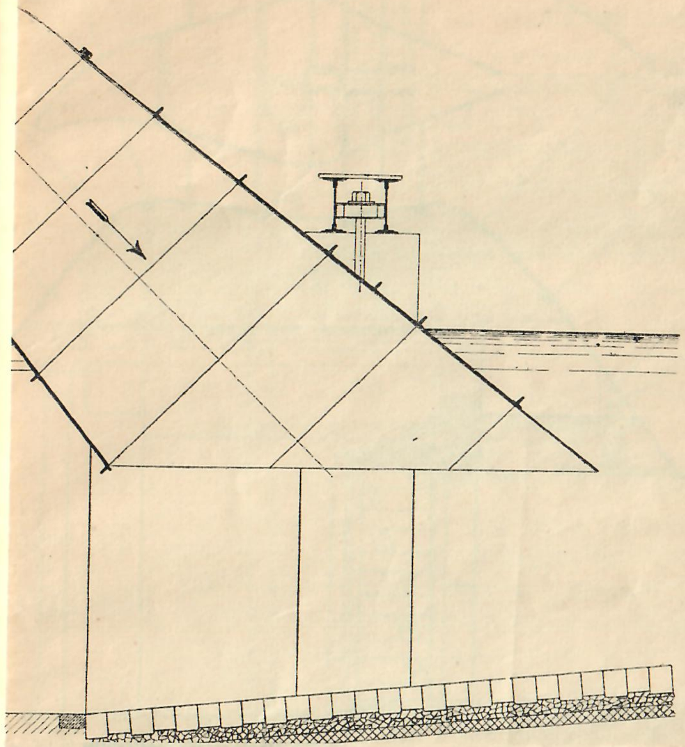
Entrusted with the project for these pumping engines, I was of opinion that these difficulties could be avoided principally by the adoption of screw pumps. Such pumps for small lifts are constructed on the siphon system so generally applied to centrifugal pumps working under similar circumstances. They have proved very successful, especially in the district of New Orleans, where this system was introduced by

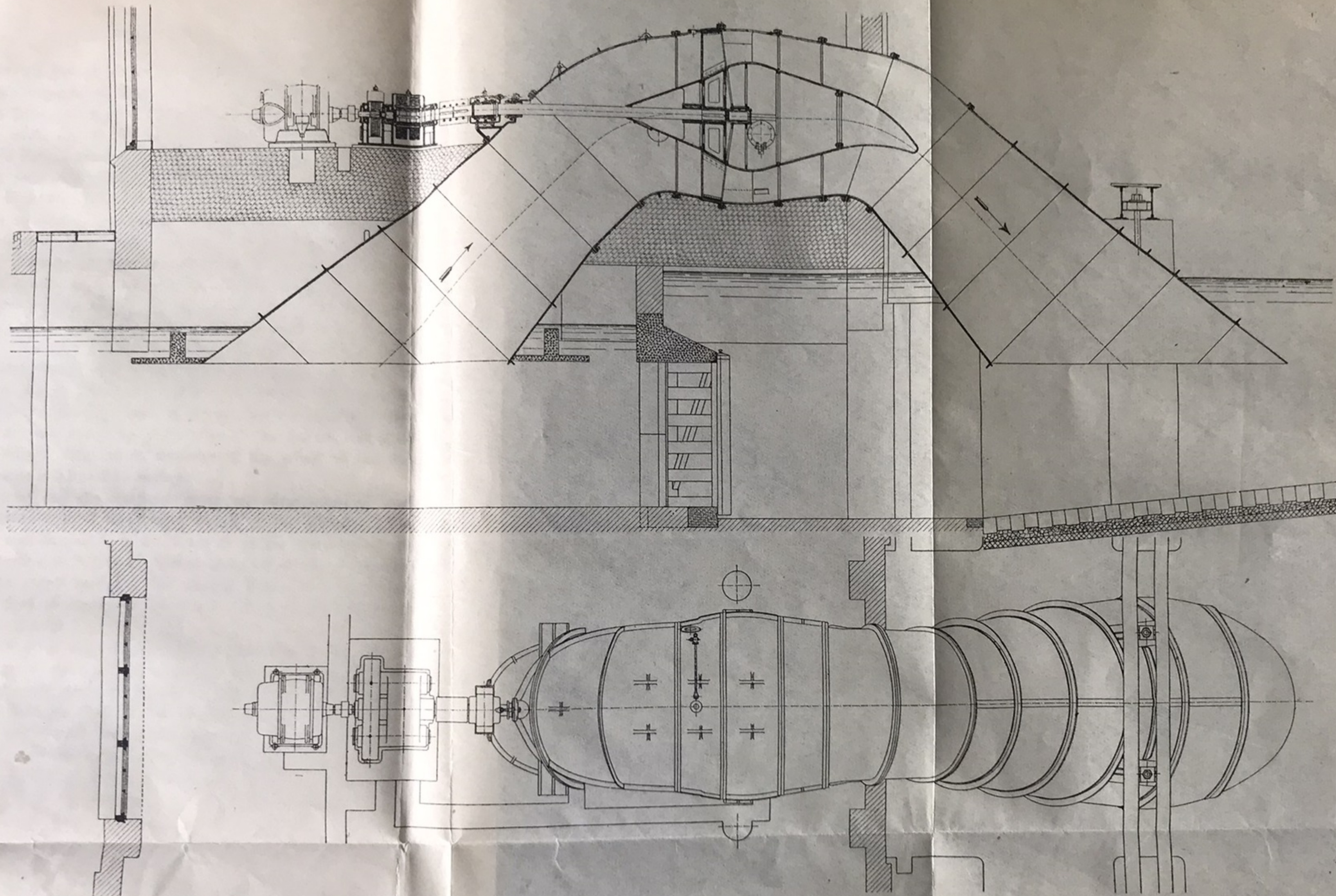
Mr. A. B. Wood, mechanical and electrical engineer of the Sewerage and Water Board of that district. For very large capacities, this system of screw pumps presented several advantages over centrifugal pumps when considering the circumstances of the Electra pumping engines, and so I had no hesitation in adopting it.

An advantage of fundamental importance already mentioned is that, when working at a constant speed but with widely different lifts, the power required for driving a screw pump varies less than that for driving a centrifugal pump of ordinary construction. On passing through a screw pump, the water is not liable to so many changes of direction as when passing through a centrifugal pump. The main flow in the latter enters the pump axially, passes the blade wheel radially, and is discharged tangentially. In the screw pump, Figs. 12 and 13, the main flow of the water is axial only. The result is that smaller losses of head, caused by friction, whirling, etc., might be expected with a well-constructed screw pump than with a centrifugal pump. For pumps working with very small lifts these losses represent a great percentage of the actual lift, and, consequently, a more favourable efficiency with screw pumps might be expected than with centrifugal pumps, especially at very small lifts.

The simpler form of the pump casing and of the adjoining pipes induces the designer to make all cross-sections of ample area, and there is no great difficulty in building units of much greater capacity than is possible with centrifugal pumps of reasonable dimensions. As a consequence, screw pumps, each for discharging 33,333 cubic feet of water per minute, were adopted for the Electra pumping works, and a notable economy in the dimensions and cost of the building was thereby secured.

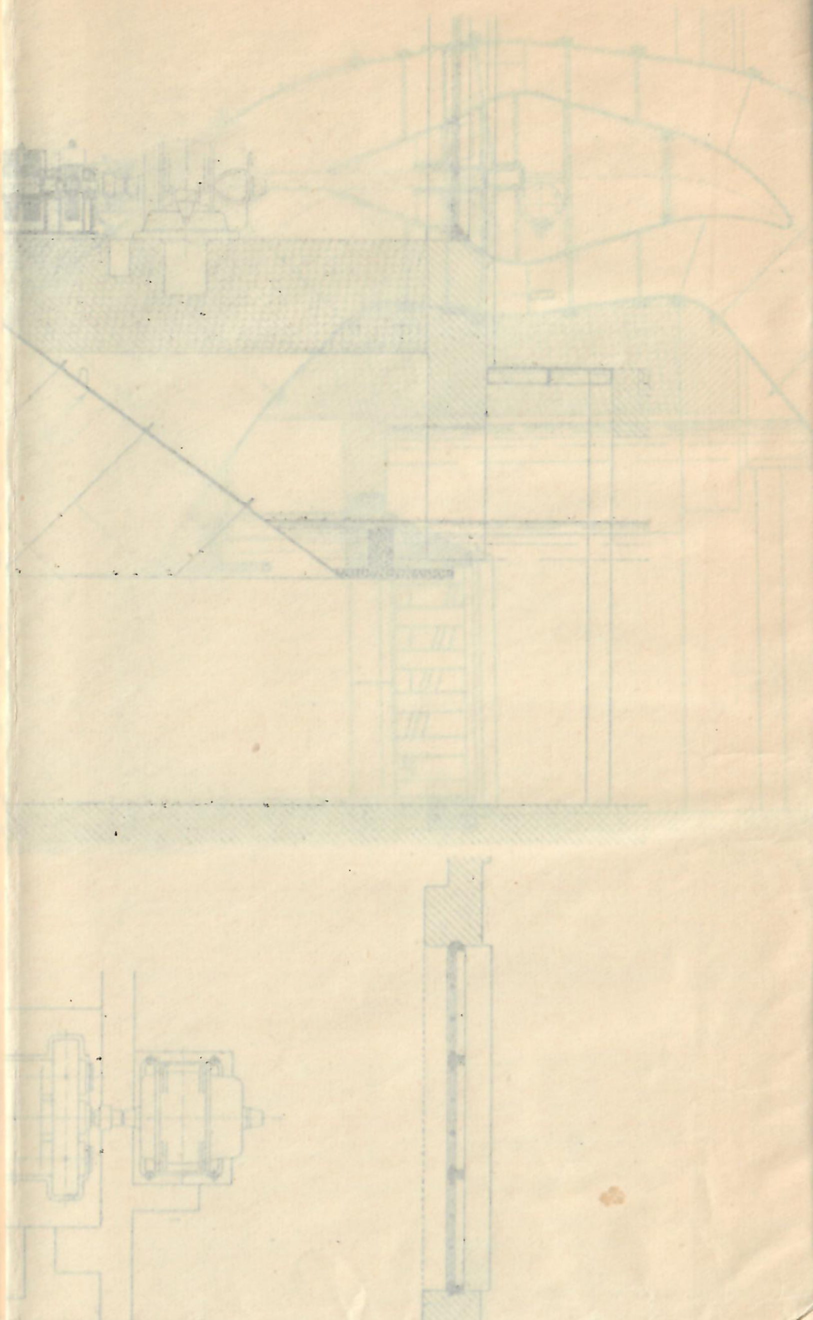
The general arrangement of one of the Electra pumps is shown in Figs. 12 and 13. The pump as a whole is a siphon pipe, and consists of a horizontal section containing





Figs. 12 and 13.—Screw Pump.

Diameter of Pump Wheel (outside), inches	141
Motor, r.p.m.	978
Pump Wheel, r.p.m.	53
Capacity of Pump, cubic feet per minute,	33,333
Mean Lift, inches	45



the working part of the screw pump, the adjoining inlet and discharge pipes being inclined at an angle of about 45 degrees. In the horizontal section the screw wheel is keyed to a horizontal shaft, and in the direction of the waterflow there is a circle of curved guide blades which lead the water again in an exactly axial direction. Only the outside ring section of the pump is active; the central part is hollow and double pear-shaped (*vide* the longitudinal section, Fig. 12). The centre piece of the pump wheel is conical, in accordance with the adjoining centre piece of the pump itself. The pump casing and its centre piece are made in cast-iron segments. There is a horizontal flange-joint at the centre line in order to make the pump wheel and the bearings of the shaft at both sides of the wheel readily accessible. These bearings are lubricated from the outside. The centre piece of the pump wheel is of cast-iron also. The screw blades are made of steel plate $\frac{3}{4}$ inch thick, strongly fixed to flanges on the conical centre piece, and are joined by angle iron to the conical rim-plate of the wheel. The inside diameter of the wheel at the discharge side is 11 feet $7\frac{3}{4}$ inches.

The inlet and the discharge pipes are constructed of steel plate stiffened by T-iron rings riveted at the outside. The conical suction-pipe is from 12 feet 9 inches diameter at the inlet opening to 9 feet 10 inches diameter at the connection with the pump casing. The conical discharge-pipe widens from 9 feet 10 inches to 13 feet 2 inches at the immersed discharge mouth.

Fig. 14 gives a good impression of the size of one of the pumps as it stood in the erecting shop of the engineering works of Stork Brothers, Hengelo. The mouth of the suction pipe as well as that of the discharge pipe is horizontal. Undoubtedly, inlet and outlet openings, like those of the Lemmer pumping works, where the direction of the inlet and the outlet flow of water is horizontal, are more favourable generally, but in the case of the Electra pumping works there was another consideration that led to the arrangement adopted. The five free openings for discharging the water of the boezem without pumping have each a width of 20 feet, and are under the pumping-engine building. Over each of these openings is a heavy block of reinforced concrete, and three of these blocks form the foundations for the pumps and the electric motors which have been erected so far. The position of the pump wheels is exactly above the sluices in the free outlet openings. To avoid any obstacle to the free flow of water through the sluice openings, it was judged best to make horizontal end openings to the inlet and discharge pipes of the pumps. The end thrust on the pump shaft is taken by a Michell block fixed to the pump casing.

At normal load the three-phase 3,000-volt electric motor runs at 978 r.p.m. The power is transmitted to the pump shaft working at 53 r.p.m. by a double gear. Forced lubrication for the bearings and the gearing is maintained by a pump driven by toothed gearing in the main gear casing. A point of interest is the starting of the main pumps. These are filled by evacuation of the casing while starting the motor, as is done with the steam-driven Lemmer centrifugal pumps, but with this difference, that the vacuum pumps are now electrically driven. But there is another difference with respect to the effect of evacuation on the main pump. When the water level is rising in a centrifugal pump which is running at a speed that approaches the regular number of revolutions, then at a certain moment the pump starts full delivery, the pump wheel working equally along its whole circumference.

When a screw pump of the construction described is evacuated in the same way, the pump is first working at a quarter of the blade-wheel diameter, then at a half of this diameter, and so on, the load on the motor increasing gradually, with increased evacuation. This is an advantage when using an electric drive, especially with a high voltage

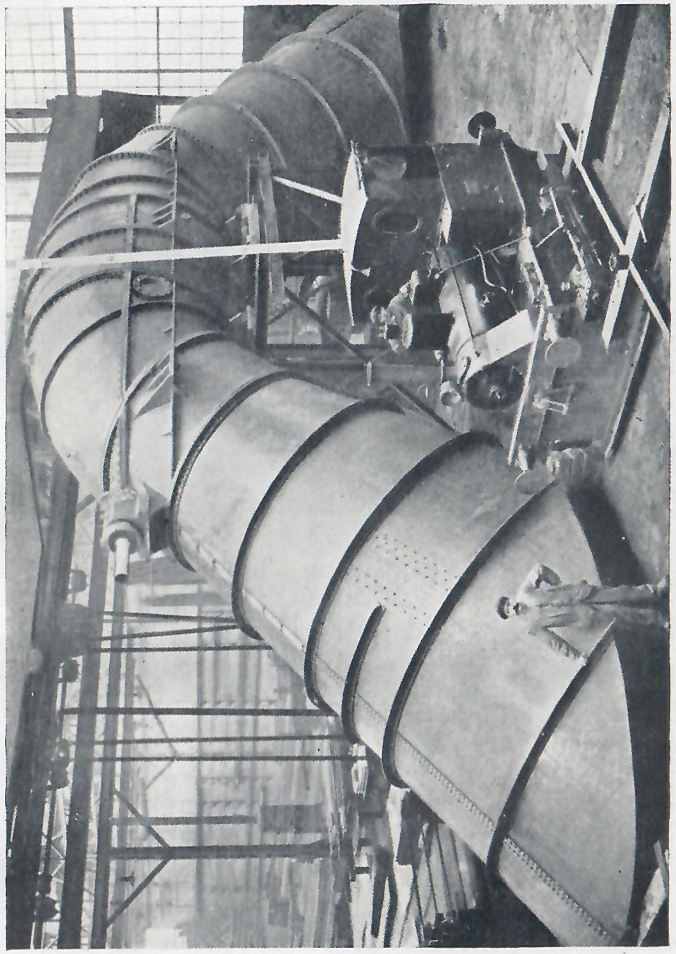


Fig. 14.—A Screw Pump for the "Electra" Pumping Works.

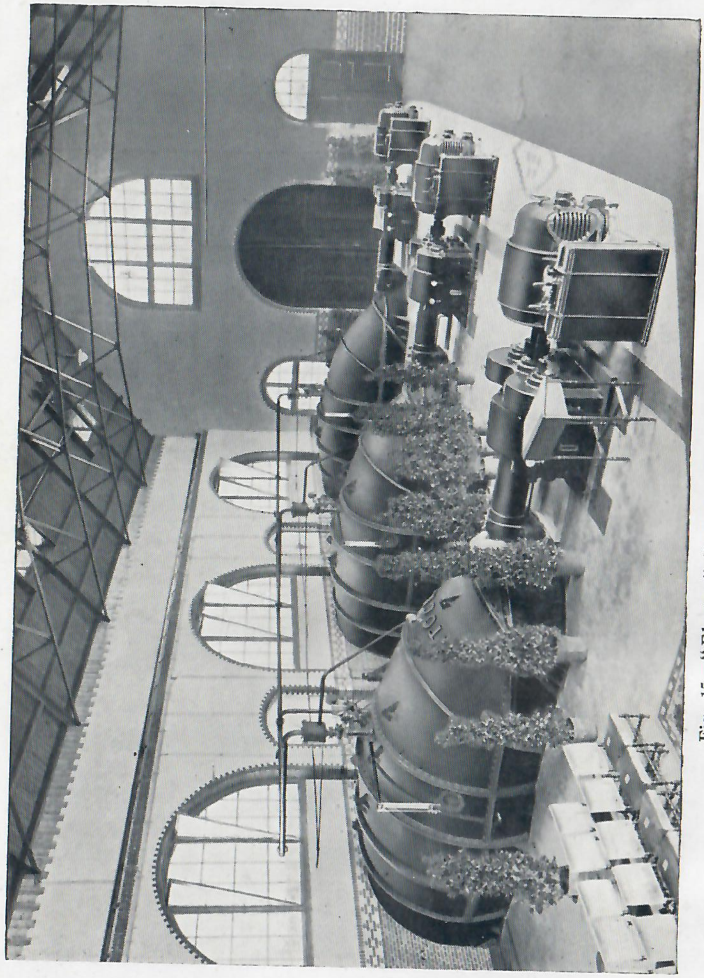


Fig. 15.—“Electra” Pumping Works near Zoutkamp.

and a long cable, a sudden overloading of which is to be avoided.

Each pump is provided with an emergency valve in order that air may be let in automatically, and, consequently, the pump will be emptied if the electric current should fail.

Under the conditions prevailing in 1918, the difficulties in completing an aerial line 18 miles in length from the power house to the pumping works, for driving three pumps at full power, were such that a cable of a smaller capacity was laid instead, and a provisional steam-plant was installed for generating the electric current for driving at full power. This provisional installation was built on the site of the fourth and fifth pumping engines, to be erected later.

The hall containing the three enormous pumping-engines gives an impression of extreme simplicity, considering that 100,000 cubic feet of water pass through it each minute. Fig. 15 shows the hall decorated with plants, etc., just before the arrival of the Queen of Holland and the Prince Consort on 5th November, 1920, for the official opening of the installation.

The results of the trials of the three pumping engines may be summarised as follows, the figures being the exact averages with lifts varying from 2 feet $1\frac{1}{8}$ inch to 4 feet $3\frac{3}{8}$ inches:—

R.P.M. - - - - - - - - - - -	53·2
Mean lift of pump, inches - - - - - - - -	44
Water discharged by each pump per minute, cubic feet - -	35,564
Water horse-power developed by each pump - - - - -	246·4
Mean kw. for 1 pump motor - - - - - - - -	341
Kw. per water horse-power - - - - - - - -	1·38

This result may be judged highly satisfactory, considering the small mean lift and the important change of this lift during the trials, amounting in fact to over 100 per cent.

Discussion.

Mr. W. B. Fulton (Associate Member): When stationed in Holland I had, on various occasions, to discuss engineering problems with Prof. Dijxhoorn, and benefited to a great extent by his advice. But it was on the question of pumps that he was pre-eminent. I think there are few men who have tested pumps, designed pumps, and discussed pumps more than he has. I have heard him referred to in Holland as "the pump doctor," because whenever there was any trouble he was invariably called in to diagnose and prescribe for the sick pump.

Engineers in this country certainly have some knowledge of ordinary centrifugal pumps, but they have, I believe, much to learn from Dutch engineers about these extraordinary centrifugal pumps which have been brought to a remarkably high degree of efficiency, and which have to deal with such immense volumes of water.

Mr. Robert Traill (Member of Council): Marine engineers and shipbuilders in this district are accustomed to centrifugal pumps of comparatively small dimensions as fitted on board steamships. I personally had no idea that centrifugal pumps were ever made of such large proportions as those which Prof. Dijxhoorn has designed and constructed for work in Holland. I particularly noted in connection with the first scheme dealt with in the paper the remarkably low steam-consumption obtained by the compound engine driving the pumps. I think it would be of great interest if Prof. Dijxhoorn could give some further details as to the construction of the engine itself, because a steam consumption of 9·59 lbs. per i.h.p. per hour shows a remarkably high efficiency. The electrically-driven pumps seem also to be very efficient. I have not worked it out—the figures given are in electrical units—but I imagine the economy is very high.

Fig. 16.

Fig. 17.

Fig. 18.

Prof. P. A. Hillhouse, D.Sc. (Member of Council): When speaking of the large undertakings in engineering and ship-building it is quite a common thing to make comparisons with the very earliest beginnings, and to compare, say, the "Aquitania" with a log of wood hollowed out and floating down a river. So I thought it might be of interest to compare these very efficient and up-to-date pumping installations, which Prof. Dijxhoorn has so well described, with a very primitive method of pumping which I saw in use in Japan, Figs. 16 and 17. This apparatus is used even in important engineering works where temporary pumping is required. It will be seen that it is a kind of treadmill, worked by one man or one woman. The person who is working the tread-mill holds on to two bamboo poles and walks steadily round the upper part of the wheel The lower part works in a circular chute, and the water is raised 12 or 15 inches by one wheel, an equal distance by another wheel, and so on until the desired total lift has been obtained. The wheel and its casing can be carried about by one person from place to place, Fig. 18.

Mr. W. Hamilton Martin (Member): Most of my life was spent in Holland, and I always marvelled at the clever and often very efficient means adopted by the Dutch to wrestle and reclaim their polderland from the seas. The island province of Zealand very appropriately has on its crest a lion rising out of the waves, beneath which are the words "Luctor et Emergo" (I wrestle and emerge).

I think it would be interesting if Prof. Dijxhoorn in his reply to the discussion would give an illustration and some more data concerning one of the first large pumping installations in Holland, an atmospheric steam-engine driving eight or ten pumping cylinders, to which he referred at the beginning of his paper. If I remember rightly, it was named "Leeghwater," after one of the most famous drainage engineers of that time. This engine was British made, and getting it into place was a wonderful feat in those days. Prof. Dijxhoorn is in a unique position to supply this information. He advocates the filtering of feed-water to clear it of the last particles of oil, and the method he proposes is of great practical value, and will no doubt be new to many engineers. He states that after the feed-water leaves the last filter-cloth it is absolutely clear, without any trace of oil. It may, of course, appear quite clear and yet contain a dangerous amount of oil. Is it to be understood that this method will extract the oil for an appreciable length of time without the filter-bed having to be renewed, and ensure that less than three grains of oil per gallon of water is left? Even this small amount of oil is sufficient to cause serious damage to the boilers.

By careful use of the oil in the engine, and by keeping the L.P. rod tightly packed, the oil should vary from 1½ to 1 grain to the gallon. As Prof. Dijxhoorn mentions, oil which floats can easily and should always be trapped in simple partitioned tanks, and prevented from reaching the pumps. Oil which forms an emulsion with the feed-water is, however, not so easily separated. A sample taken may remain milky for several days. To find out in a quick and sure manner what amount of oil is left in a sample of filtered feed-water, a simple oil gauge is an absolute necessity. In Holland many shipowners, the navy, and others make use of such a gauge, which in a few seconds permits accurate measurement to be made of the amount of oil mixed up in the feed-water in the finely-divided state that forms an emulsion. Apart from checking the working of the system, it enables the engineer to judge the result of any alteration, adjustment, or improvement which he may make in the working arrangement.

This feed-water oil gauge was invented by the late W. H. Martin (my father), while engineering manager of the Royal De Schelde Shipyard, at Flushing, Holland. Prof. Dijxhoorn is

no doubt acquainted with it. It consists of a glass tube with a closed bottom of white porcelain, in the centre of which is a conspicuous black spot. The outside of the tube has suitable graduations engraved (grains per gallon or milligrams per litre). The feed-water to be tested is slowly poured into this tube, while the black spot is observed through the liquid. As soon as this spot is on the point of becoming invisible, when held in a good light, the height of the column of liquid is read off on the scale, thus giving the number of grains per gallon, or milligrams per litre.

Mr. William Drysdale (Associate Member): It appears as if the engines illustrated in Fig. 3 run in the reverse direction of rotation from ordinary horizontal engines. Clearly the pressure will be on the top guide, and it would be interesting to know what technical reasons determined this arrangement. The main steam-engines are stated to have a single-acting H.P. cylinder and a double-acting L.P. cylinder. Is there any difficulty in starting this engine? It seems that the crank-effort diagram must suffer from this arrangement of cylinders. From the section of the engine, Fig. 4, it would appear to be rather a complicated job to withdraw the L.P. piston, and Prof. Dijxhoorn might be able to indicate how this is undertaken. He recommends lagging of the condenser exhaust pipe. Presumably data have been taken showing the increased condenser efficiency by this method, as it is rather a departure from standard practice. No doubt the advantages would show up with a long length of exhaust pipe between the engine and the condenser.

Dealing with the centrifugal pump, it is not clear from the section what means are provided for taking out the impeller or renewing the shaft. The casing appears to be built up solid, and presumably the impeller is drawn out by taking off one of the side covers, and I would like to know if this is so. The shaft is provided with a forged flanged-coupling, and no detail is shown regarding the method of taking out this shaft from the driving side. The above point is raised because in large pumps having a low lift, owing to the great weight of the working parts, the accessibility factor is often of very great importance. In pumps made with steel-plate casings, is there any difficulty experienced from corrosion with the water taken from the polders?

Figs. 8 to 10 show air-suction pipes to each suction eye, and presumably these have been arranged for in addition to the air connections on the top of the volute, so that the water may be completely deærated before entering the impeller. It is stated that the centrifugal pumps are started up before they are primed, and exhaustion is carried on until the pumps start discharging at full bore. No doubt the pipe connections on the pumps shown are made with the above object. Ordinary practice for centrifugal pumps, however, usually arranges for the pump to be completely primed and then started up, thus avoiding the sudden loading up referred to on page 18. Could not this practice also be adopted in this case? Has Prof. Dijxhoorn found any difficulty in priming these pumps?

In the impeller, Fig. 11, nine blades are shown. In Fig. 8 there appear to be 12 blades. It would be interesting to know if the number of blades in this particular class of pump has any direct bearing on the efficiency, and if the lift of the pumps means the total head developed by the pump, including losses in pipes and residual velocity head.

Mention is made of the difference in power characteristics between the centrifugal pump and the axial pump. Could Prof. Dijxhoorn show by curves on the same relative basis just where these differences begin to take effect? In connection with the arrangement of the suction and discharge pipes, Figs. 12 and 13, the immersion seems to be somewhat small on the suction side, and it would be interesting to know what Dutch practice determines as the minimum immersion

of the end of the suction pipe to prevent ingress of air due to eddy and vortex formations. The method of starting the Electra pumps is described, and no doubt suitable provision is made to prevent seizure taking place before the pumps are full of water. I presume that lignum vitæ is used for the internal bearings of these large pumps with some outside water supply.

Mr. W. H. Riddlesworth, M.Sc., M.Eng. (Member): Prof. Dijxhoorn is to be congratulated on having had the opportunity of designing and carrying out such complete and independent plants as those forming the subject of this paper.

It is obvious that capital charges must form a very large part of the cost of the work done, as the whole plant is standing idle for about seven-eighths of its time, and it must have been a matter for close and intensive study to determine exactly how much capital it was worth while spending in efforts to obtain fuel economy. It is probably the case that a cheap and relatively inefficient (mechanically speaking) plant would do the required 45 days' pumping per annum at a less total cost than one wherein elaborate efforts had been made to obtain the utmost efficiency as a machine. Fuel costs in Holland are probably high, and the rate of interest may be low, but Prof. Dijxhoorn would have the figures before him, and a statement showing the total annual expense, giving details of capital, labour, and fuel costs, would add considerably to the value of the paper, especially if there could be added some idea of the capital cost of obtaining, say, the last 10 per cent. of fuel economy.

The labour problem in such a plant as this is also a difficult one, as it is evident that it cannot be left unattended for 320 days in the year, nor can it be worked for 45 days per annum by casual labour; a trained staff of some size must be kept, but presumably not sufficiently large to man the plant in operation. Prof. Dijxhoorn's remarks on this subject, as also on the precautions taken during the long stand-by periods, would be appreciated.

The two pumps forming the subject of the paper are examples of reversed radial and axial-flow turbines, and the pump efficiency of the radial-flow type (centrifugal) is probably about

$$\cdot275 \div \cdot90 = \cdot306$$

(the first figure is quoted from the paper, the second is an assumed mechanical efficiency for the steam engine), whilst that for the axial-flow type (screw) is about

$$\frac{1}{1\cdot38 \div \cdot746} \div \cdot95 = \cdot568.$$

Water turbines of these dimensions and with similar difference of type are built, which have approximately the same efficiency irrespective of type, and it would be instructive to have Prof. Dijxhoorn's opinions on the reasons for this great loss of efficiency in the case of the centrifugal pump referred to in the paper.

It is especially well shown in the screw pump drawings that he is a keen student of the problem of stream-line flow of water, and akin to many problems in ship design is that of the form of the central fixture and middle portion of the wheel in the screw pump. This is analogous to the shaft support and boss of a propeller, and many ideas prevail as to the desirable length and shape. May I ask him to give us his idea of the length of tail necessary to avoid eddy-making and at the same time not unduly add to the skin friction by the additional surface exposed, and also of the advantage, if any, of a long coned fore-end (as fitted) as against the blunt rounded end generally adopted in shipwork?

The gradual tapering of the inlet and outlet passages is also of interest, and I should value a reasoned statement by Prof. Dijxhoorn of the best rate of growth of sectional area of stream per unit length. I should also like to ask him if any advantage would be gained by departing from the straight-line outline near the actual inlet and outlet openings and adopting a bell-mouthed form. This would, of course, involve a very rapid increase of sectional area in a short length which might produce more eddy-making than the removal of the sharp-edged entrance would avoid.

Mr. Robert Love (Member): Prof. Dijxhoorn deserves thanks for putting before the members of this Institution details of the large pumping plants which are installed in Holland. One point in particular which impresses the engineer accustomed to pumping plant, such as is fitted on board ship, is the enormous quantity of water delivered per hour by the various installations described in the paper.

I am surprised that no mention is made of the well-known Humphrey pump, as this type of machine appears to be eminently suited for conditions such as those under which the various plants described operate. Possibly Prof. Dijxhoorn may be disposed to give his views as to the suitability of this type of machine for use in Holland.

On page 4 mention is made of the Diesel engine having been practically excluded, due to the high price of fuel oil, and in this connection it would be interesting if comparative figures could be given as to the estimated cost of fuel over a fixed period for Diesel-driven and steam-driven installations respectively. The Diesel engine would appear to have certain advantages for intermittent work, as no stand-by losses would be incurred, such as exist with steam plant.

On page 7 reference is made to a condenser vacuum, of from 28 to 29 inches, being used in conjunction with the compound steam-engine, and in this connection it would be interesting to know if the gain in power of the engine, due to the high vacuum, was in excess of the additional power required by the water-circulating pump to maintain the vacuum.

Mr. Robert Love.

A most unusual feature is the use of lagging on the exhaust pipe between the engine and the condenser, in order, as stated in the paper, to prevent condensation of the steam in the pipe. General practice, at any rate in marine work, aims at condensing the steam as soon as possible after leaving the cylinder. It might be mentioned that about 15 years ago, in certain naval vessels with turbine installations, the exhaust pipes between the turbine and condenser were lagged, but this was to prevent as far as possible the temperature of the exhaust steam being raised by heat transmitted from the atmosphere of the engine room, the normal temperature of which under full-power conditions is usually above that of the exhaust steam.

Mr. N. G. Gwynne, C.B.E.: The plants described by Prof. Dijxhoorn and the results they give are of great interest to makers of pumping machinery for low lifts. The most striking thing is that, from a comparison of the results from these centrifugal pumps and screw pumps, the impression might be formed—I think wrongly—that the latter is a more efficient machine for small lifts. The efficiency, however, claimed for the centrifugal pump is extremely low. In support of this statement, authentic results obtained with some of the old pumping engines installed in Holland give an efficiency of $\frac{\text{w.h.p.}}{\text{i.h.p.}}$ of upwards of 60 per cent. The following results were obtained in 1894, on the trials of the Lynden pumping engines of the "Invincible" centrifugal type, the pumps which are used for the drainage of the polder Haarlemmermeer having 58-inch inlets:—

R.P.M.	90·9
Height of lift, feet	14·97
Water delivered per minute, tons	293
Water horse-power	298·3
Indicated horse-power	454
$\frac{\text{W.H.P.}}{\text{I.H.P.}}$	·657

Mr. N. G. Gwynne, C.B.E.

I think it will be agreed that these old plants are of historic interest. They are still doing excellent work, and if modern uniflow steam engines were substituted for the old engines, with increased boiler pressure, and also superheaters, I do not think much better pump efficiencies could be realised, even to-day.

Perhaps, however, the best comparison with the plants Prof. Dijxhoorn describes is the performance of the Fos and Galejon pumping engines installed in France, and tested under the supervision of a Dutch engineer, Mynheer A. C. J. Vreedenberg. During a three hours' trial of engine No. 2, which took place on 13th February, 1885, the following mean results were recorded:—

R.P.M.	111·2
Height of lift, feet	4·523
Water delivered per minute, tons	213·2
Water horse-power	20·181
Indicated horse-power	37·045
$\frac{\text{W.H.P.}}{\text{I.H.P.}}$	·5402

I think it is easy to see from these results, which were excellent at the time, that even if the lift had been as low as it is at Lemmer, the economy would have been much greater. It seems that the economical operation at Lemmer is entirely due to the high efficiency of the steam engines. I might say that I think the construction of centrifugal pumps for the conditions at Lemmer, to give an efficiency of $\frac{\text{w.h.p.}}{\text{i.h.p.}}$ of about 60 per cent., should present no difficulty, and I think this figure is quite conservative.

The Electra screw pump installation is very interesting. The efficiency claimed $\frac{\text{w.h.p.}}{\text{kw.}}$, namely, $72\frac{1}{2}$ per cent., which, I suppose, would mean a pump efficiency of over 80 per cent., is very high. It should be pointed out, however, that this result has been obtained by taking an average of the lifts and

Mr. N. G. Gwynne, C.B.E.
outputs measured at different times during the trial, which might be a source of error, and it would be preferable to know what the electrical inputs were corresponding to the different lifts and outputs.

I notice no information is given concerning the measurement of the discharges, which must always be a matter of considerable difficulty with such large volumes of water, and whatever method is adopted there is room for considerable discrepancies due to various factors, but perhaps Prof. Dijxhoorn will give particulars as to this and other points of interest, namely, the electrical measurements for the Electra pumps, etc.

I might say that I understand the lifts indicated are actual static lifts or vertical heights through which the water is lifted, and not the manometric lifts. The lifts given for the old plants are also static lifts, and, therefore, the manometric efficiencies would be higher in proportion to the pipe losses.

Mr. J. F. Breeze: When the conditions are suitable, centrifugal pumps can be designed to have the same characteristics as the screw pump, plus the advantages of the ordinary pump. Self-regulating pumps, for instance, will decrease the power consumed at constant speed if the head falls, but much better efficiencies are obtained for a considerable range of head if the speed can be varied, so that it is unnecessary for the designer to tie himself to the self-regulating design in every case.

The screw pump design in question does not appear to have any novel features; similar designs have been suggested, and machines actually built by various firms in the past, but they have been abandoned owing to the very limited application, which is an inherent feature of the design. An English firm installed a pump of similar type about 12 years ago, but it was removed and replaced by a machine of the ordinary

Mr. J. F. Breeze.
centrifugal type owing to the objection above stated. A similar design was put forward by a Continental firm, who made it the subject of a patent claim some eight years ago, but so far as I know it has never been used by this firm in actual practice.

The objections to the axial-flow pump are:—

1. It can only be used for relatively low peripheral speeds, and consequently, low heads. This is inherent in the design since, with high rotational speeds, the radial component of energy in the outer layers of water in the impeller is of considerable dimension, and cannot be wholly utilised in any form of axial-flow impeller. Consequently, with such an impeller the efficiency falls away rapidly as the speed of rotation increases, and so either high speeds or high heads are unattainable with such a design.

2. The design also has a very limited range of capacity, the head curve falling steeply as the quantity pumped increases. This is apparent by an investigation of the curves published by some pump makers, although the method of plotting is ingeniously chosen to obscure these defects. If, however, the curves are plotted in the usual manner of quantity horizontally, and head, power, and efficiency vertically, the limitations of the design are at once apparent. This has been done in Fig. 19, whereas the curves by some makers, already referred to, are compared with those of an ordinary centrifugal pump of the same capacity and maximum efficiency.

Fig. 19 shows that the falling horse-power curve, which is so frequently alluded to as an advantage of the pump in question, is really a defect brought about by the rapidly falling head curve. The rate of fall of the head curve is, however, so much greater than the rate of fall of the horse-power curve that the efficiency suffers seriously. It will be seen that for a fall of efficiency of from 80 to 70 per cent. the screw pump falls in head from 6·1 to 3·2 feet, while the

Mr. J. F. Breeze.

quantity pumped only rises from 25 to 27·5 cubic feet per second. With the centrifugal pump for the same drop in

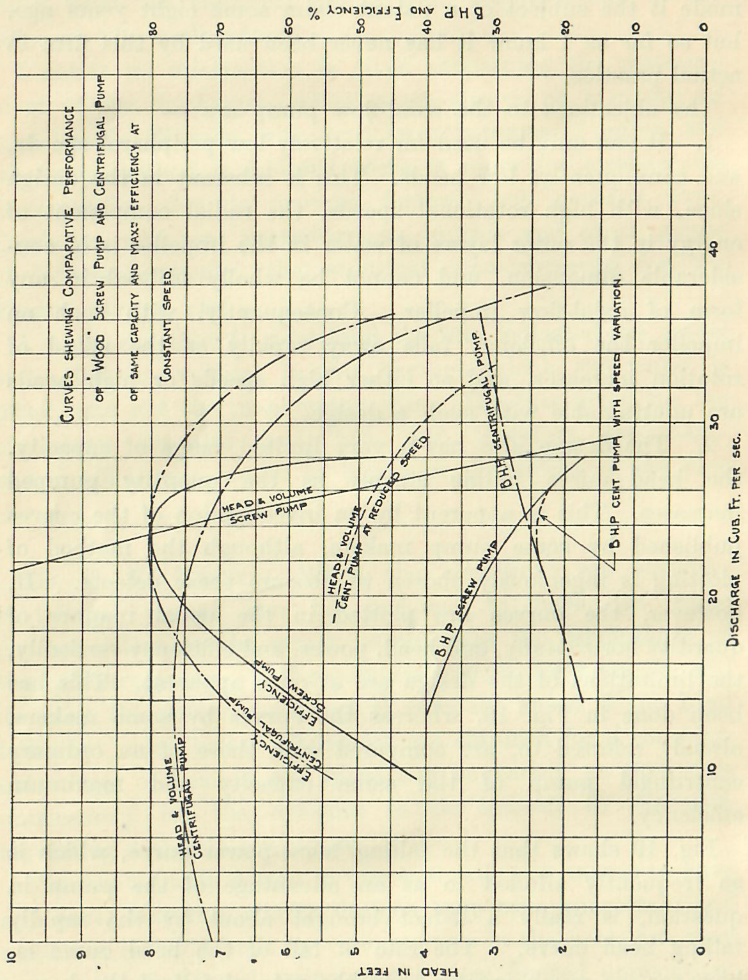


Fig. 19.

efficiency, the head only falls from 7·1 to 4·8 feet, while the quantity pumped rises from 25 to 34 cubic feet per second. It is true that with constant speed this is accompanied by a

Mr. J. F. Breeze.

rising power line, but this can be changed to a falling power line of precisely similar form to the screw pump by speed regulation, and this without such a serious drop in efficiency.

To show this a curve has been plotted for the centrifugal pump, assuming that the speed has been reduced so that when pumping 28 cubic feet per second the power absorbed is identical with that of the screw pump when operating at this capacity. It will be seen that under these conditions the screw pump will deliver 28 cubic feet against a head of 2·6 feet with 17 b.h.p., whereas the centrifugal pump will deliver this quantity against a head of 4·4 feet for the same expenditure of power. When it is necessary to have head-discharge characteristics which prevent a rise of power with a fixed speed and variable lift, even then the advantage lies with the centrifugal pump.

There is no serious difficulty in designing a centrifugal pump having axial suction and discharge flow, but there is no apparent advantage to render such a design advisable; the ordinary form of casing possesses all the advantages claimed for the screw pump, and has in addition a wider range and higher overall efficiency.

The advantages of the ordinary form of pump may be briefly stated as follows:—

1. Wider range of head and capacity.
2. Higher overall efficiency.
3. No greater floor space required.
4. No more foundations required.
5. Greater flexibility.

Centrifugal pumps are difficult to be improved upon by makers who possess the necessary experience to enable them to design according to the differing conditions of service

Mr. Kenneth Fraser: Referring to the method adopted for the purification of the feed water, it is possible that steam which is not oil free could cause irregular deposits of oil (and

Mr. Kenneth Fraser.

its subsequent modifications) on the outsides of the condenser tubes. It is also possible that local heating could take place elsewhere than at these oil deposits, and if the condenser is being run to its maximum capacity and is somewhat under-designed for its load, this local heating might, under certain conditions, especially with the use of sea-water, give rise to dezincification of the "plug" type. As a matter of fact, there would have to be so many coincident conditions occurring that I do not anticipate this trouble arising in practice. What is much more likely to occur is that the deposit of oil (and its subsequent modifications) would simply reduce the heat efficiency of the condenser.

Mr. Alan E. L. Chorlton, C.B.E.: Prof. Dijxhoorn's paper is extremely interesting, giving as it does the very latest practice in dealing with large quantities of water for low lifts. Whilst there is nothing in this country, not even in the Fen districts, quite so large as the installations described by Prof. Dijxhoorn, it may be that the experiences he has had will be of some use for special districts over here.

In the first example he gives, he has devised a special kind of engine in order to secure a high economy. Despite the fact that he combines the Cornish cycle with that of the central exhaust, the resultant steam consumption does not seem to be lower than has been obtained with the best forms of central exhaust engines alone. It would be interesting to know his own views on this point, and how much he thinks he has gained by adding the H.P. cylinder and the Cornish transfer. In passing I may say that one of the most ingenious Cornish cycle engines has entirely disappeared from use, namely, Willan's central valve. This engine gave remarkable economies, and, if built to-day with the further experiences gained and the high superheats used, there seems little doubt that economies could be obtained by it equal to the almost universally used central exhaust engine. It is, therefore, interesting to hear of the reviving of the Cornish cycle, and to consider whether it may not be adopted even further. Will Prof. Dijxhoorn, therefore, kindly state the advantages that he has obtained by its use?

Mr. Alan E. L. Chorlton, C.B.E.

With particular reference to the centrifugal pumps driven by these engines, in which an impeller of the Francis type is used, it is interesting to gather from the results of the tests how low the efficiency of these pumps is, the i.h.p. of the engine being given as 876·4, and the w.h.p. of the pumps as 240·9, *i.e.*, an efficiency of ·275. This very low efficiency is no doubt due to the low lifts, but if my reading of these figures is correct, it would have been better to use a combined hydraulic machine in which the pump side worked against, say, a head of 200 feet, discharged through a hydraulic turbine. A combined centrifugal pump and water turbine of such a large capacity should give an efficiency of 70 per cent. This seems so different from what has actually been obtained that it looks as if there were some snag in the proposition, and I would like Prof. Dijxhoorn's views on such a piece of apparatus.

The pumping of large quantities of water against low heads was considered a particularly suitable class of work for the Humphrey gas pump, in which the combustion of the mixture took place above the actual surface of the water itself. For lifts such as obtain in Holland, it is practically necessary to adopt the two cycle, and experiments are now being carried out with a view to applying this cycle to this class of work. The axial-flow pump, which is undoubtedly an extremely interesting design, bears some relation to the screw propeller used on board ship, except that guide vanes are used for controlling the flow of the water in the former, but it does not appear that, even with the use of these vanes, the efficiency of the pump is at all high. I understand that with the axial-flow pumps, as made by Messrs. Sulzer Bros., efficiencies up to nearly 80 per cent. have been obtained.

Prof. Dijxhoorn: In connection with Mr. Fulton's remarks, I may state that the triple-expansion marine engine which was used in my laboratory for the experiments on purifying the water from the surface condenser was constructed by Mr. Fulton.

Mr. Traill refers to the low steam-consumption of the pumping engines, namely, 9·95 lbs. per i.h.p. per hour. I think this good result may be attributed to the Cornish cycle and the L.P. cylinder with central exhaust. As already mentioned, the H.P. cylinder is single ended, and has only one inlet and one outlet valve, the latter discharging the steam to what is known as the receiver. Thus this outlet valve of the H.P. cylinder is, in fact, an equilibrium valve, and the cylinder works according to James Watt's well-known Cornish cycle, and that method of using steam has always given splendid results. It is well known that the results reached in 1834 with the Cornish type of steam engine were so good that it was not until about 1868 that similar results were obtained again. It was a long time before a real insight was gained as to why this old Cornish cycle was so excellent. Now in the H.P. cylinder, I adopted this same method of using the steam in a single-acting cylinder just as in the old Watt engine. But, on the other hand, in the L.P. cylinder I took advantage of the uniflow principle, which, in combination with the single-acting H.P. cylinder, forms, in my opinion, a basis for economical working. The valves used are piston valves, and are well suited for superheated steam.

Prof. Hillhouses's illustrations of the scoop wheels used in Japan are interesting, and I may say that they have also been used in Holland. During the last 300 years they were mainly driven by windmills, but in the 19th century steam engines were gradually adopted for driving them. Some of these scoop wheels driven by steam have enormous dimensions. For instance, at Katwyk, near Leyden, a pumping installation was built in 1880 comprising six scoop wheels, each of 30 feet diameter and 8 feet width, driven by two compound-engines, and they are working to a maximum lift of 7 feet. Of course, scoop wheels driven by wind had a far lower lift. In old times, when a higher lift was wanted, scoop wheels driven by windmills were built one behind the other. On this principle a project for draining the Haarlem Lake was worked out in the beginning of the 17th century, by the celebrated Dutch engineer Leeghwater. As the total lift in this case was to be 16 feet, the windmill he proposed consisted of 40 sets of four mills each, one behind the other, each windmill driving a scoop wheel having a lift of 4 feet. The drainage of this lake was accomplished two centuries afterwards by the pumping engines I mentioned, one of which still bears the name "Leeghwater."

Mr. Martin, the son of my friend the late Mr. W. H. Martin, of the Schelde Works, Flushing, mentions the pumping engine called "Leeghwater," but I regret to say that he is mistaken in calling this an atmospheric engine. As far as I know, only one single atmospheric engine has been used in Holland for drainage work, and it was erected at Rotterdam in 1776. The Leeghwater engine was built 70 years later. It was one of the three pumping engines used for draining the Haarlem Lake, which I mentioned in the paper. Of the Sims compound type, built by Messrs. Fox & Co. and Messrs. Harvey & Co., it had two vertical cylinders, one inside the other, the inside H.P. cylinder being 84½ inches in diameter and the outside L.P. cylinder 144¼ inches in diameter, with a piston stroke of 10 feet. This engine worked 11 vertical pumps, each 63 inches in diameter with a stroke of 10 feet, placed in a circle round the central engine house.

As to the method of purifying feed-water from oil, I may say that this method is such that the very last particles of oil are extracted. The result is absolutely as pure as drinking water. The late Mr. W. H. Martin's feed-water oil gauge is a most useful instrument which I have also used, but the new method for purifying the water gives results far beyond the most favourable point of the scale of Mr. Martin's gauge.

Mr. Drysdale rightly observes that the steam engines driving the Lemmer pumps run backwards, and I am glad to be able to state the reason. The condensers and pumps required underground space, and considering the strength of the building, which is exposed to the Zuider Zee when the sea sluices are open, the best disposition was to place the condensation plant on the land side and the main centrifugal pumps on the sea side. These pumps are what are generally called "underthrow" pumps, and they permit the breadth of the engine house to be somewhat less than if "overthrow" pumps had been adopted. The use of underthrow pumps occasioned the reverse direction of rotation for the steam engines, and there is no objection to this arrangement, as the engines are provided with forced lubrication throughout. The oscillating oil-pump is seen under the crankshaft of the auxiliary engine, Fig. 5.

The single-acting H.P. cylinder of the main engines does not give the least trouble in starting, and the fly-wheel is heavy enough to prevent any perceptible effect from the difference of the crank effort. The steam cylinders rest at both sides on heavy foundation plates with planed top faces, so arranged that the cylinders can easily be moved when necessary. Since 1892 I have invariably lagged the exhaust pipes of condensing engines. In many cases I found a gain of from two to three inches of vacuum in the L.P. cylinder, provided that the exhaust passages from cylinder to condenser were ample. The gain in cylinder vacuum is greater, of course, with a greater length of exhaust pipe than with a short one.

To Mr. Love I may remark that the gain of effective vacuum by the lagging is only to be expected when the temperature of the exhaust steam is essentially higher than that of the engine room, as is the case with most of the piston engines in our climate. As circumstances are so widely different, no

general rule can be given for the increase of cylinder vacuum by the lagging of the exhaust pipe. As to the construction of the main pumps, I may say that the impeller is drawn out with its shaft by taking off the outside side cover with the suction pipe bend. The main pumps are not provided with non-return valves, as these are quite unnecessary for pumps with such small lifts. Of course, the absence of non-return valves necessitates starting the engines while evacuating the pumps, but this does not cause the least difficulty. All the pumps are provided with air-suction pipes connected to the highest point of the pump casing and also to the suction bends. Only one of the pumps possesses inner air-suction pipes, shown in Fig. 9, and these were fitted in order to see if there would be any difference in the starting of this pump against that of the others. No difference was observed; all the pumps started equally well. The impeller, Fig. 11, is of the same construction as that of the Lemmer pumps, but has nine blades instead of twelve. It belongs to another similar pump, for the polder Noorder Kogge, and was chosen for reproduction as the photograph was better suited.

For the Lemmer works the measuring of the water pumped was done in two different ways simultaneously. In the straight canal leading the water to the pump works the water velocity was measured by means of a number of swimming sticks loaded at the lower end so as to remain in a nearly vertical position and free from the bottom, while the top reached just above the surface, and was provided with a small numbered flag. The exact time in seconds was noted when a swimming stick passed the subsequent lines across the canal that were fixed at equal distances apart. Of course several sticks were used at the same time, so that the exact water velocity (*i.e.*, the mean velocity from surface to bottom) was ascertained for every point of the breadth and plotted graphically for several canal-sections.

At the same time the water velocity in the cross-sections

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near the masonry walls just before the inlet openings of the 16 suction pipes of the pumps was measured by small turbine wheels (Woltmann wheels) giving an electrical signal for every 100 revolutions. In this way an exact graphical record was made of the velocity at every point of these rectangular cross-sections. When the complete installation was at work there was a most remarkable accordance between the swimmer trial and the Woltmann wheel trials.

In the case of the Electra works the water pumped could be measured directly, as it was discharged into an intermediate lake. The level of this lake was noted simultaneously on a number of scales around the lake, and the actual water surface was carefully measured at different heights. The loss of water per hour from this lake was ascertained just before and just after the trial and proved to be exceedingly small.

Mr. Riddlesworth rightly remarks that the efficiency calculated from the trials was, for the Lemmer centrifugal pumps with a lift of $18\frac{7}{8}$ inches, $\frac{\cdot 275}{\cdot 9} = \cdot 306$, and for the Electra screw pumps with a lift of 44 inches, $\frac{\cdot 746}{1\cdot 38 \times \cdot 95} = \cdot 568$. Of course, the lifts mentioned are actual static lifts, not manometric lifts. The losses from friction, whirling, shock, and velocity head at discharge amount to 69·4 per cent. in the first case, and 43·2 per cent. in the second, and represent an equivalent head of water for the Lemmer centrifugal pumps of $\cdot 694 \times 18\frac{7}{8} = 13\cdot 1$ inches, and for the Electra screw pumps of $\cdot 432 \times 44 = 19$ inches.

I quite agree with Mr. Gwynne that results of the trials of the pumping engines of Fos (Bouches du Rhône) tested under the supervision of my friend the late Mr. A. C. J. Vreedenberg, and those of the Lynden centrifugal pump—all Gwynne pumps which have a fame among pump builders for the excellent results obtained—might offer a fair comparison. Calculated in the same way with an assumed steam-engine efficiency of ·9, these tests show the following pump efficiency

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and losses from friction, whirling, etc.:—For the Fos pumps, with a lift of 54·28 inches, the efficiency is $\frac{\cdot 5402}{\cdot 9} = \cdot 602$, and the losses 39·8 per cent. For the Lynden pumps, with a lift of 179·64 inches, the efficiency is $\frac{\cdot 657}{\cdot 9} = \cdot 73$, and the losses 27 per cent. These losses are equivalent to a head of water amounting to, for the Fos pumps, $\cdot 398 \times 54\cdot 28 = 21\cdot 8$ inches, and for the Lynden pumps, $\cdot 27 \times 179\cdot 64 = 48\cdot 5$ inches. These figures show clearly how difficult it is to obtain a decent pump efficiency at very low lifts, and that the actual losses by friction, etc., for the Lemmer and the Electra pumps might be judged quite satisfactory as compared with those for the Fos and Lynden pumps. I do not pretend that the head lost by friction, etc., should be the only basis of comparison, but it should be kept in mind when considering the pump efficiency which might reasonably be expected.

As Mr. Breeze states, the screw pump is to be preferred to the centrifugal pump for very low lifts. The same pump efficiencies have been attained at Lemmer and at Electra as might be reached with water turbines working with similar heads, as Mr. Riddlesworth puts it, and this might be considered very satisfactory. For it is a well-known fact that it is far more difficult to obtain a reasonable efficiency when converting a velocity head into an actual head (the case of a centrifugal pump or a screw pump) than to convert an actual head into a velocity head (the case of the water turbine).

Mr. Love mentions the Humphrey pump, and I quite agree that it might have been well suited for pumping works in the low countries of Holland but for the deep foundations that are required for these pumps. In our marshy country the cost of these deep foundations is, in fact, prohibitive.

With the actual prices of crude oil as compared to those of coal, the Diesel-driven pumping engines are more economical than either steam or electrically-driven engines of great dimen-

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sions. But to obtain the necessary fuel for Diesel engines during war might be extremely difficult or even impossible. Now once a pumping installation of the dimensions of those described is built in a district, the possibility of inundation through want of fuel is to be absolutely excluded. Therefore, I feel compelled to recommend the installation of Diesel-driven drainage pumps only in such cases where there is a steam-driven or electrically-driven installation in reserve. It might be supposed that the Government coal mines in the province of Limburg would be able, under any circumstances, to supply sufficient coal to prevent inundation of the country by steam-driven drainage pumps, but experience has shown that the import of crude oil for Diesel engines might, under some circumstances, be stopped absolutely.

Mr. Chorlton is of opinion that the steam consumption of the Lemmer engines might also have been obtained with the best forms of central-exhaust engines alone, without compounding. Now I must confess that I was quite satisfied with the result of 9·59 lbs. of steam per i.h.p. per hour at the cost of the small complication of adding a single-acting H.P. cylinder to a uniflow L.P. cylinder, and I think Mr. Traill was quite right in calling this a remarkably low steam consumption. I doubt whether this consumption has been reached by any central-exhaust engine alone working at a piston speed of 657 feet per minute only. I quite agree with Mr. Chorlton's admiration for single-cylinder central-exhaust engines, but according to my experience the steam consumption of even the best of these engines notably increases after a few years' work, wear and tear being unavoidable. This increased consumption is less when steam is used in two pressure stages, *i.e.*, when the engine is compounded.