

THE LITTLE HAY PUMPING STATION
OF THE
SOUTH STAFFORDSHIRE WATERWORKS COMPANY.

MR. FRED. J. DIXON, M.Inst.C.E., M.I.Mech.E.,
ENGINEER-IN-CHIEF.

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It needs little consideration to perceive that the water supply of this thickly-populated country continually presents fresh problems as the urban populations in differently situated districts increase, and that, in consequence, no standardised method of ensuring it can be adopted. Some districts, for example have no large catchment areas within reasonable distance and have, therefore, to adopt the deep borehole method of supply. This method presents distinct points of engineering interest, both civil and mechanical and we accordingly here give an account of a plant in which it is employed, our description being illustrated by Figs. 1 to 7, on pages 4 to 9. The plant is that comprised in the Little Hay Pumping Station of the South Staffordshire Waterworks, in which the water is raised from two deep boreholes by multiple-impeller centrifugal pumps low down in the boreholes, and is then transferred by similar pumps, mounted on the same vertical shafts and situated at the tops of the boreholes, to a service reservoir. The pumps are driven by vertical four-stroke cycle air-injection heavy-oil engines, and the whole plant forms a good example of an independent self-contained station.

Before describing the station itself, however, some consideration must be given to the source of supply and to the methods of reaching it. It may be mentioned at the outset that the working of the Little Hay Pumping Station is subject to certain conditions imposed by Act of Parliament for the protection of wells and other sources of water supply within a radius of 2 miles of the station. In the Company's Act of 1922, which sanctioned the Little Hay Pumping Station, a condition was also imposed that the boreholes must be lined to a depth of 50 ft. from the surface to keep out all surface waters. The station is situated half-way between Sutton Coldfield and Lichfield about one mile off the main road, and near the village of Little Hay. The Little Hay brook runs through the grounds of the station. The geological position of the site is on the Bunter Pebble Beds. The Keele Beds which here underlie the Bunter, crop out above $1\frac{1}{2}$ miles to the south and $1\frac{1}{4}$ miles to the east; 5 miles to the west is the eastern boundary fault of the South Staffordshire Coalfield. In choosing the site it was anticipated that the Bunter formation would here be about 150 ft. thick, and the site is placed centrally to tap the underground waters of this area. The site is $1\frac{1}{2}$ miles from the company's well and pumping station at Shenstone; a sufficient distance as proved by experience, to prevent any interference.

The geological formation, a section of which is given in Fig. 1, page 4, was first proved by a trial boring, 6 in. and 5 in. in diameter, to a depth of 309 ft. 6 in., penetrating the Bunter formation and the upper Keele beds. When this trial boring reached a depth of 56 ft., it became artesian, and the discharge gradually increased as the boring proceeded until it reached a rate of 2,500 gallons per hour, at which rate it remained fairly constant until the station commenced to pump. A short pumping test was carried out on this trial boring, a yield of 7,500 gallons per hour being obtained, the water falling to 5 ft. below ground level. When the main boreholes were being sunk slightly south of the trial boring, the strata were found to correspond very closely with those proved in the trial boring. A series of main borehole cores, with the depths from which they were taken, is shown in Fig. 2, page 5.

A commencement was made with borehole No. 1, in February, 1927. A shaft, 8 ft. square, was sunk to a depth of 10 ft., and a timber framework built inside to hold a 48-in. internal diameter guide tube 15 ft. long. This guide tube was then sunk by excavating from the inside until its upper edge was 1 ft. 6 in. below ground level. On account of the soft nature of the strata it was then decided to proceed by percussion boring. A pilot hole $26\frac{1}{2}$ in. in diameter was driven in advance. Boring of the pilot hole was suspended at intervals while the main boring was trimmed down to the full diameter of 47 in. When the 47-in. diameter boring had reached a depth of 50 ft., steel lining tubes of 44 in. internal diameter by $\frac{5}{8}$ -in. thick, and totalling a length of 50 ft., were lowered in. The tubes arrived on the site in four lengths of 12 ft. 6 in., the first length having a steel shoe welded on. The first length of tube was lowered into the top of the borehole and held firm with clamps. The second tube with one end chamfered was placed on top of the first tube and wedged into correct alignment. The joint between the two tubes was then electrically welded. The method used in welding and the handling rig employed is seen in Fig. 3, page 6, in which are shown two lengths of 40-in. perforated lining tube in process of being welded together.

When the weld had cooled it was carefully inspected and coated inside and outside with bituminous solution. When the bitumen had set, the tubes were lowered as far as necessary and another length of tube welded on. When the lining tubes had all been welded they were carefully set vertical,

Fig. 1.

298-89 C.L. 299-08

38' 0" No. 1. REST LEVEL 298-13 O.D. FEB. 1ST 1929.

38' 0" No. 2. C.L. 298-61 O.D. 298-89 O.D.

15' 0" GUIDE TUBE 45' I.D. 5/8" METAL (SOLID)

50' 8 FT. SQ. DIA. SHAFT BORING

4-12' 6" TUBES 44' I.D. 5/8" METAL (SOLID)

45' 5" 50' 3"

TRIAL BOREHOLE

LITTLE HAY BROOK

No. 2.

No. 1.

KEY PLAN.

AVERAGE WATER LEVEL WHEN PUMPING 58,000 G.P.H. DURING PUMPING TEST MARCH 19TH. - APRIL 2ND. 1928.

101' 0"

118' 0"

123' 0"

126' 0"

153' 6"

164' 0"

174' 0"

208' 6"

220' 4"

220' 4"

4-12' 3/4" 1-12' 0 1/4" PERFORATED TUBES 40' I.D. 5/8" METAL

8-12' 3/4" 1-12' 0 1/4" PERFORATED TUBES 40' I.D. 5/8" METAL

4-11' 3/4" SLOTTED LOWERING PIECE 40' I.D. 5/8" METAL

160' 6"

155' 4"

4-16' 3" PERFORATED TUBES 21' 3/8" I.D. 5/8" METAL

23" DIA. BORING

44" DIA. BORING

44" DIA. BORING

4-15' 6" 4-15' 6 1/8" 6-15' 6 1/4" PERFORATED TUBES 40' I.D. 5/8" METAL

1-15' 6" 4-15' 6 1/8" 6-15' 6 1/4" PERFORATED TUBES 40' I.D. 5/8" METAL

4-6' 1/2" SLOTTED LOWERING PIECE 40' I.D. 5/8" METAL

44' 7 1/2"

49' 9"

39' 0"

26' 6"

25' 6"

21' 0"

11' 6"

4' 6"

1' 0"

GRAVEL

RED SAND & SOME MARL

RED SANDSTONE

RED SANDSTONE & PEBBLES

LAYERS OF MARL & SANDSTONE

RED SANDSTONE & PEBBLES

LOOSE CONGLOMERATE

DARK RED SANDSTONE WITH MARL PARTINGS

CONGLOMERATE

CONGLOMERATE

HARD CONGLOMERATE

RED MARLY SANDSTONE

RED MARL WITH GREY PATCHES

RED MARLY SANDSTONE

RED MARL WITH GREY PATCHES

220' 0"

209' 0"

220' 4"

29' 9"

SHAFT COMMENCED FEB. 7TH. 1927. SHAFT COMMENCED APRIL 19TH. 1928.
BORING COMPLETED DEC. 6TH. 1927. BORING COMPLETED NOV. 6TH. 1928.

(3522.F.)

"ENGINEERING"

and a quantity of cement and sand was put down the centre to seal the bottom of the tubes. The annular space between the lining tube and the borehole was then filled by pumping down a grout composed of 2 parts sand to one part cement (Ferrocrete). The operation of grouting the 44-in. lining tube is shown in Fig. 4, page 7, the lining tube being shown projecting above the top of the guide tube. This operation was carried on continuously until the annular space, and any cavities that may have existed in the strata, were completely filled. The grout was allowed to set for 14 days before boring re-commenced. An attempt to bore by the rotary method with chilled shot was abandoned as it was found that the strata was too loose to make reasonable progress. Boring therefore, continued by the percussion method, a 25-in. diameter pilot hole

temporary foundation of rolled steel joists and baulks. This test plant is shown in Fig. 5, page 7, the delivery pipe running to the right. The pump discharged into a large weir box fitted with baffles and an 18-in. wide rectangular weir plate, the rate of flow being gauged and recorded by an integrating Lea recorder. The weir box is shown in Fig. 6, page 8, with $7\frac{1}{2}$ in. of water passing over the weir, at which depth the delivery was approximately 55,000 gallons per hour. During the pumping test, the daily quantity of water raised averaged 1,390,000 gallons. The depth of the water level in the borehole below the ground surface was measured prior to the commencement of the pumping test and at regular intervals thereafter by an electrical apparatus. Prior to the test the depth of the water level was 6 in. below ground level and



FIG. 2. MAIN BOREHOLE CORES FROM HARD CONGLOMERATE.

being driven in advance and trimmed down at intervals to $43\frac{1}{2}$ in. diameter. When the $43\frac{1}{2}$ in. diameter boring reached a depth of 160 ft., perforated steel lining tubes 40-in. in internal diameter and $\frac{5}{8}$ -in. thick and totalling 114 ft. in length, were lowered in on a special tool and released when firmly bedded on the bottom of the borehole. These tubes were jointed by the electric welding process. The borehole was continued 23 in. in diameter, boring by the rotary method with chilled shot. After the pumping test this portion of the borehole was lined with $21\frac{1}{2}$ in. diameter perforated steel lining tubes.

The pumping test for yield was carried out over a period of 14 days continuous pumping. The pumping plant consisted of a 12-cylinder Crossley petrol engine coupled through a gearbox to a Sulzer vertical spindle borehole pump, and the whole secured on a

the average depth recorded during the test was 115 ft. below ground level.

Since the sinking of the second borehole the yield of the first borehole has increased, and with the permanent pumping plant at work the water level now only falls to 63 ft. below original ground level for the same rate of pumping. When the pumping test ceased the water rose quickly in the borehole and after half an hour was 25 ft. below ground level. During the progress of the test the water pumped from the borehole was regularly sampled and analysed, the water being sterile, of good taste and colour and having a total hardness of 16.4 parts per 100,000. A number of wells in the vicinity were kept under observation during the test, and it is interesting to note the steepness of the cone of depletion of the water table. At the trial boring (53 yards distant from the main borehole) the water

level fell from overflowing to 34 ft. below ground level. At another well, 225 yards distant, the water level was only lowered slightly. More distant wells were not affected by the pumping. This fact amply proves that the borehole is a sufficient distance from the company's well at Shenstone.

During the pumping, test experiments were

in the trial boring and then broken, thus releasing the dye. The dye appeared at the pump delivery in $7\frac{1}{4}$ minutes. Experiments showed that the dye took 45 seconds to travel from the pump suction in the borehole to the delivery. The time taken for the dye to travel 160 ft. through the strata was therefore $6\frac{1}{2}$ minutes equivalent to a speed of



FIG. 3. WELDING LENGTHS OF 40-IN. PERFORATED LINING TUBE.

conducted to determine the rate of flow of the underground water to the borehole. A quantity of green dye (fluorescein) was placed in the trial boring 160 ft. distant from the main boring. The dye travelled down the trial boring, passed through the strata and appeared at the pump delivery in 8 minutes. In a further experiment a glass bulb containing dye was lowered to a depth of 150 ft.

24.6 ft. per minute. On completion of the pumping test, the second borehole was immediately commenced. It is situated between the first borehole and the trial boring and at 38 ft. centres from the first boring. Boring proceeded in a similar manner to that described except that the 44-in. boring and 40-in. perforated lining tubes were carried to the full depth of the borehole, 220 ft. The borehole



FIG. 4. GROUTING 44-IN. LINING TUBE.



FIG. 5. TEMPORARY PUMPING PLANT FOR YIELD TEST.

was completed without difficulties in December, 1928. It was not considered necessary to carry out a pumping test on the second borehole.

The buildings comprise the pumping station, shown in Fig. 7, page 9, with two cottages for workmen adjacent. The latter, not seen in the figure, are erected in a quiet domestic style with warm red brick facings and rich brown tile roofs. The accommodation in each cottage provides three good-sized bedrooms, bath-room, parlour, kitchen, scullery and larder, with usual outbuildings. They are substantially built to give minimum maintenance and are fitted with steel casement windows having leaded lights. The cottages are supplied with electric light from the pumping station. As

The floor of the engine house is laid with 6 in. by 2 in. red Ruabon quarries, and is constructed entirely independent of the engine foundations, being carried on 3-in. steel columns resting on the main concrete raft carrying the buildings. Particular attention was given to the construction of the engine beds of the Diesel engines. To avoid vibration to the buildings these were built in mass concrete taken down to a rock foundation, and isolated from the remainder of the building, with an elastic joint formed with 3-in. tarred slag between the engine foundation and the concrete raft under the main building. The low projecting building in front of the engine house and on either side of the front steps, houses the settling tanks into which



FIG. 6. TEMPORARY WEIR BOX FOR YIELD TEST.

will be seen from Fig. 7, the pumping station has been designed in a free Renaissance style with multi-coloured brick facings and red Hollington stone dressings. The engine house is a fine hall 88 ft. 8 in. by 32 ft. 4 in., having a glazed brick dado 5 ft. 6 in. high, with buff brick facing above—finished with an elliptical vaulted reinforced concrete roof covered with asphalte and surmounted by a concrete-framed lantern light roofed with patent glazing. The roof is constructed with reinforced concrete panels 3 in. thick, resting on 9 in. by 4½ in. reinforced-concrete secondary beams, 3 ft. 6 in. apart, carried on pre-erected elliptical shaped steel roof principals, cased with concrete and fixed at 12 ft. 8 in. centres. This roof was designed to produce a light, clean, and pleasing effect, and being covered in asphalte gives easy access to the lantern light for cleaning and maintenance.

the water is pumped from the boreholes and whence it passes to the force pumps. The basement below the engine house contains the borehole pumps and the various piping, &c., in connection with the pumping plant, and at the rear are the heating chamber, 2 silencer chambers, fuel pump room and two steel tanks for holding 160 tons of Diesel fuel oil, sufficient supply to keep the station going for 26 to 28 weeks under present conditions.

At the back of the engine house on the ground floor are the office, workshop and store room, and sanitary conveniences, and above these are the service fuel oil tank rooms. All opening lights in windows and lantern light of the engine house are operated with screw gearing and the building is heated with hot water and lighted with electricity generated on the premises. The main idea in the design and construction of the engine house and

auxiliary buildings has been to give liberal lighting and fresh air to all parts, also easy access and straight runs to pipe and cable lines. Every care has been exercised to prevent any possibility of pollution to the boreholes by oil leaking from the oil storage tanks and these were formed of riveted steel plates caulked on the inside, tested, and afterwards grouted solid in neat cement.

The pumping plant consists of two vertical six-cylinder 4-stroke cycle heavy oil engines driving through a double helical bevel speed increasing gear, a vertical spindle multi-stage turbine-type borehole pump and a multi-stage turbine-type force pump, both pumps being mounted on one line of shafting. The auxiliaries consist of a vertical

borehole pump lifts the water from any depth in the borehole down to 150 ft. below basement level, 300 A.O.D., and delivers it into the settling tank placed in front of the engine house. The force pump takes its suction from the weir chamber in the settling tank and delivers the water into the company's Barr Beacon reservoir at a static head of 441 ft. above basement level at the station, through 2,970 lineal yards of new 18-in. diameter steel pipe main and 7,700 lineal yards of existing 24-in. diameter cast iron pipe main. At the same time the engine is capable of driving the 15-kw. generator providing the necessary lighting and power supply for operating all the auxiliaries with the exception of the overhead crane. Under these condi-

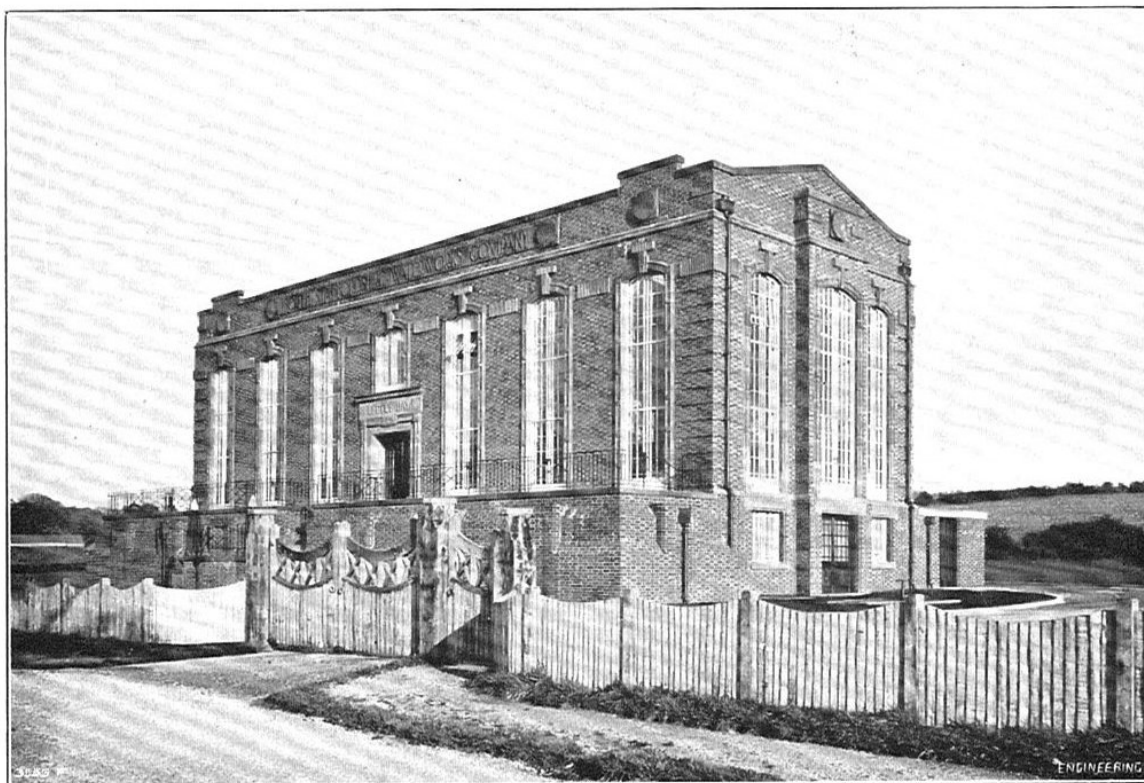


FIG. 7. EXTERIOR OF ENGINE HOUSE.

two-cylinder airless injection two stroke cycle engine driving a 25-kw. direct current generator, 15-ton overhead travelling crane, auxiliary petrol/paraffin engine-driven air compressor, electrically-driven fuel pump for filling the overhead tanks from the main storage tanks, electrically-driven drainage pump, two electrically-driven cooling water pumps, two electrically-driven crank chamber vapour extraction fans, two 15-kw. direct-current generators driven from a pulley on the engine crankshaft extension, two main fuel oil storage tanks, two overhead fuel oil tanks, two overhead water service tanks and a venturi meter and pressure recorder.

Each engine, with its borehole and force pump forming one unit, are of such size and power as to ensure easily, in continuous working, the delivery of 50,000 to 55,000 gallons of water per hour. The

tions, the total head, including friction in the main, is 626 ft. Each engine is capable of driving its borehole pump, force pump and generator, under similar conditions as regards continuous working and quantities delivered, when the borehole pump is lowered to a depth of 200 ft. below basement level, making a total head, including friction in the mains, of 676 ft.

Towards the end of the first portion of our account of the Little Hay Pumping Station of the South Staffordshire Waterworks Company, we gave an outline description of the machinery installed. This we now deal with in greater detail. The general layout of the plant is shown in Figs. 8 to 11, on Plate, in which all the units previously enumerated can be identified, while they are separately described below.

The main engines are of the vertical totally-enclosed single-acting four-stroke cycle type. A

view from the air compressor end is shown in Fig. 12, below. There are six cylinders, each of 325 mm. ($12\frac{13}{16}$ in.) bore by 440 mm. ($17\frac{5}{16}$ in.) stroke. Each engine is capable of developing 338 brake horsepower continuously when running at a normal speed of 300 revolutions per minute. Cylinders Nos. 4, 5, and 6 are fitted with compressed air starting valves. All the fuel, air and exhaust valves are placed in the cylinder covers and are operated from the horizontal camshaft by means of cams and split levers to facilitate dismantling of the valves. The governor, which is totally enclosed, and is of the spring-loaded type, is driven by chain from the

pump delivery passes before discharging into the settling tank, and a receiving tank placed in the basement adjacent to the cooling-water pump. After starting up the main engine, the belt-driven 15-kw. generator is brought in and the cooling-water pump started. This pump sets up a pressure which automatically cuts out the overhead tank and the set then operates on a closed circuit. The pump takes its supplies from the receiving tank and delivers the water through the cooler to the main engine from which, after passing through the water jackets, it is returned to the receiving tank. This system utilises the same water over and over again,

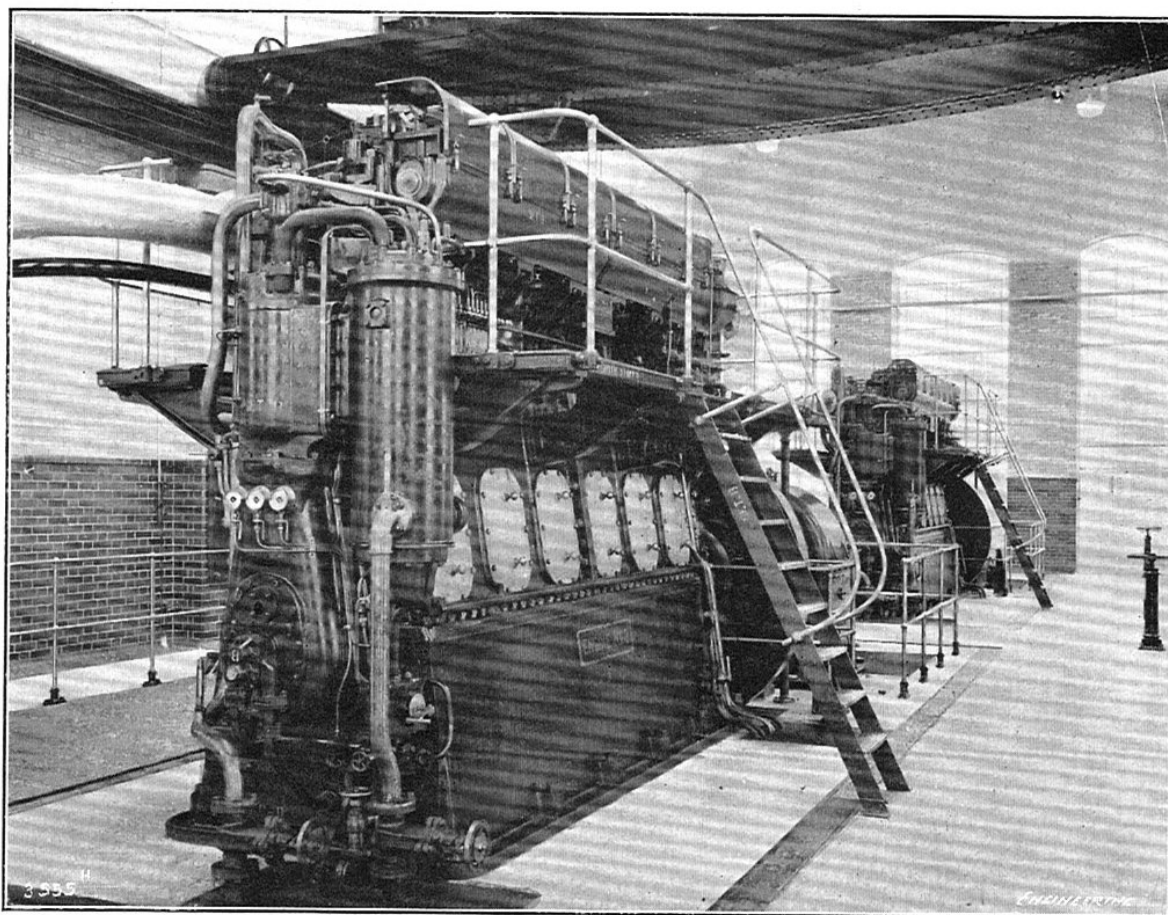


FIG. 12. HEAVY-OIL ENGINES FOR PUMP DRIVING.

crankshaft. A jockey sprocket wheel provides chain adjustment, and the camshaft is gear-driven from the governor. The exhausts from the six cylinders are connected to water-jacketed manifolds leading into a common exhaust pipe which is carried under the engine-room floor to two silencers in series, the latter being placed in a chamber at the rear of the building. The outlet is carried up a brickwork shaft and the exhaust can be readily observed. The cylinder liners, covers and exhaust collectors are water-jacketed.

The cooling-water system, for each engine, consists of an overhead tank under ball-valve control for use when starting up, an electrically-driven cooling-water pump, a tubular cooler placed in the settling tank through which the borehole

and so reduces scale formation to a minimum. The receiving tank is provided with a make-up connection under ball valve control, and overflow and drain connections, the quantity of make-up water being measured through a meter.

The lubrication of the pistons and cylinders is effected by a mechanically-operated pump driven by a ratchet off the camshaft. A separate sight feed is provided for each of the six cylinders and the three stages of the compressor. Each engine is fitted with forced lubrication, the pump being provided with hand gear for flushing the bearings before starting. The oil is drawn from the sump and pumped through a dual filter provided with change-over valve to allow for cleaning one filter while the other is in operation. The oil is then

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[illegible]

This detailed plan of the engine room for the H.M.S. Fish Hawk shows a symmetrical layout around a central corridor. At the top, there are fuel oil storage tanks (No. 1 and No. 2) and pumps, along with an office and workshop. The central section features two large 15 kW belt-driven generators, each with its own No. 1 and No. 2 engines. Below these are force pump suction tanks and settling tanks for both No. 1 and No. 2 engines. The bottom section includes auxiliary engine fuel service tanks, air reservoirs, and various discharge and overflow drains. The right side of the plan shows a heating chamber, oil receiver, and auxiliary compressor. The entire room is equipped with extensive piping, valves, and monitoring instruments like water level indicators and vacuum meters.

Fig. 1
Borehole Pump Discharge

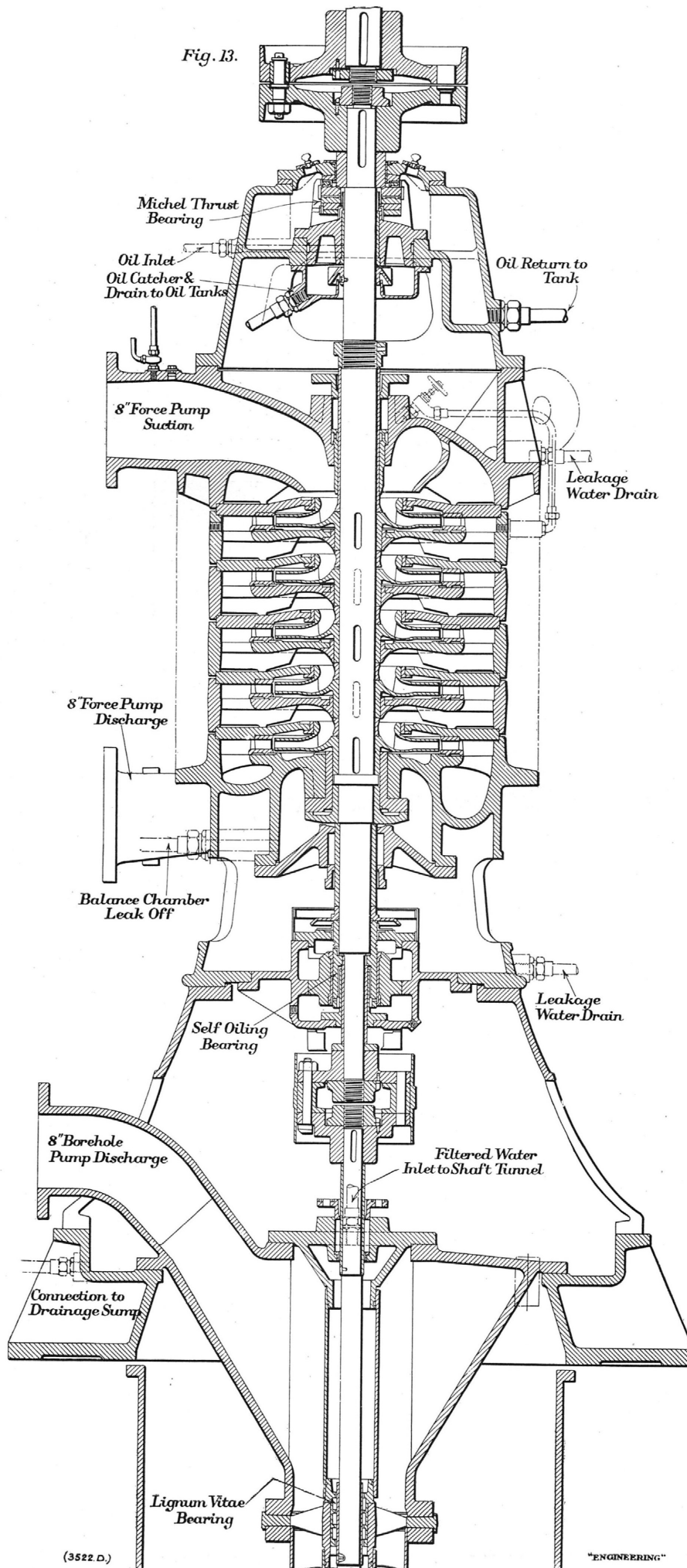
Discharge Pipe

Borehole Pump

Strainer

220-112 Below Top of Lithology

Fig. 13.



passed through a cooler before circulating through the bearings.

The governor is fitted with hand adjustment for varying the speed. It controls the position of an eccentric shaft through a system of levers, the shaft carrying a horizontal lever underneath each of the six fuel pumps. A small plunger attached to the lever controls the suction valve of the fuel pump, and so regulates the amount of oil delivered to the power cylinders, the suction valve being held off its seat for a portion of the delivery stroke. At heavy loads, when the engine speed tends to fall, the suction valve is closed early, whereas at light

of the fan. The flywheel is carried on the crankshaft extension, which is supported by an outer bearing. The 15-kw. generator is driven by a pulley next to the flywheel. A flexible coupling of the pin-and-link type is fitted between the crankshaft and the gear shaft. A ball thrust locating bearing is also fitted between the flexible coupling and the gearbox to take any engine thrust off the gears.

The bore-hole pump is designed to lift from a depth of 150 ft. below basement level. It is of the vertical-spindle, multi-stage, centrifugal type, with seven single inlet impellers working in series, as shown in Fig. 15, page 13. The impellers and guide

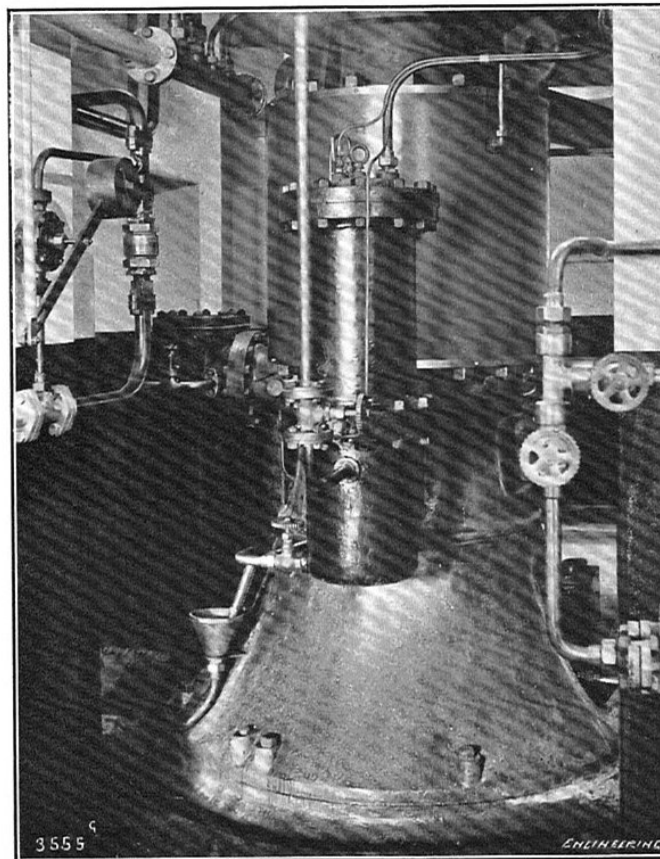


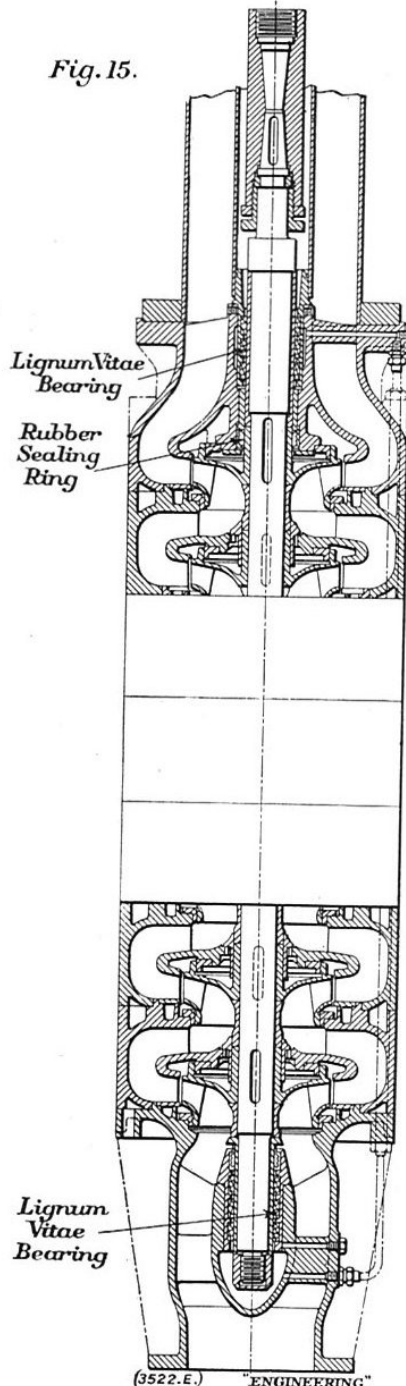
FIG. 14. FORCE PUMP AND LUBRICATING WATER FILTER.

loads, when the speed tends to rise, the suction valve is held open over a longer portion of the stroke and so reduces the quantity of oil delivered to the power cylinders.

The air compressor is of the vertical three-stage type. The cylinders have cooling jackets and there is also a set of cooling tubes between each stage. The last stage of the compressor delivers to the blast-air bottle, and from this the two starting-air bottles are charged. Pressure gauges mounted near the air bottles indicate the pressure in the L.P. and intermediate stages of the compressor, and the starting and blast-air bottle pressures. A vapour extraction fan draws the vapour out of the crank chamber and discharges it into the engine exhaust shaft. An oil separator is fitted on the suction side

passages are of bronze; the body segments, containing guide passages for directing the flow of water to the various stages, are of cast-iron. The steel impeller shaft of the pump is entirely cased in gunmetal and the two pump bearings are water-lubricated by the enclosed shaft-bearing lubricating system, rubber sealing rings preventing the pump water from entering these bearings. A suction pipe, foot valve, and strainer are fitted. The sections of the bore-hole delivery pipes, from which the pump is suspended, and the rods forming the driving shaft are all made to one standard length. The pipes are flanged and a shaft guide bearing is inserted at each joint. This guide is spigoted into both flanges to secure accurate alignment. The actual bearing consists of *lignum-vitæ* segments carried in a

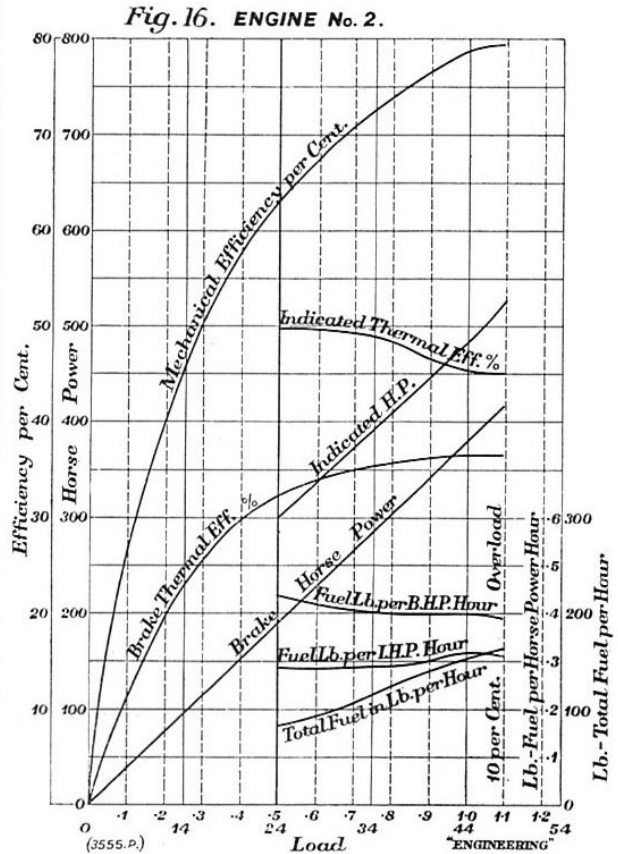
gun-metal sleeve. The space between the segments allows the lubricating water to pass through, and the gunmetal sleeve is secured to the centre boss of the guide casting, with radial ribs joining this portion to the outer spigoted rim, which is secured by the flanges. The coupling boxes connecting the several lengths of shafting are made of steel. Each



rod end is coned and the drive is transmitted by sunk keys. The boxes are secured to the rods by split collars and screwed gun-metal nuts provided with lock nuts.

The whole of the pump work is suspended from a head-box carried in a circular stool casting, and the delivery branch of the bore-hole pump is

embodied in the head-box casting. This arrangement will be clear from Fig. 11. The bore-hole pump delivery is taken to the water cooler in the settling tank, where it passes round the outside of the cooling tubes and out through a bell-mouth pipe. The water traverses the full length of the settling tank to allow any sand in suspension to



settle and then flows over a weir into a suction chamber from which the force pump takes its suction. Attached to the settling tank is a water-level indicator with an alarm bell, which rings if the water falls to weir level or rises to overflow level. A compressed-air recording depth gauge is connected to the bore-hole, and this registers on a weekly chart the level of the water below the engine-house floor. As previously stated, the engine is capable of driving the bore-hole pump, force pump and generator, when the bore-hole pump is lowered to a depth of 200 ft. below basement level. Should this be necessary, other stages will be added to the bore-hole pump.

The force pump is of the vertical-spindle, multi-stage, centrifugal type, placed directly on a stool carried on the bore-hole pump head-box and driven by the vertical shaft, which also drives the bore-hole pump. As will be seen from Fig. 13, the pump has five single-inlet impellers working in series. The impellers and guide passages are in bronze. At the delivery end of the pump a hydraulic balancing device of the disc type is fitted. A rigid coupling is fitted between the bore-hole pump shaft and the bottom of the force-pump spindle. On the top of the force-pump body is fitted a Michell

thrust bearing, which supports the whole of the rotating elements and, at the same time, accurately locates the pump impellers in relation to the guide passages. This thrust bearing is of the single-collar type with upper pads to prevent lifting if the

carried on two steel girders. The gearing is of the double-helical bevel type, having a gear-increasing ratio of 22/76 teeth. The gears are lubricated by a pressure spray, which is directed into the teeth where they mesh. The lubricating pump is mounted on

Fig. 17. No. 2. BOREHOLE PUMP.

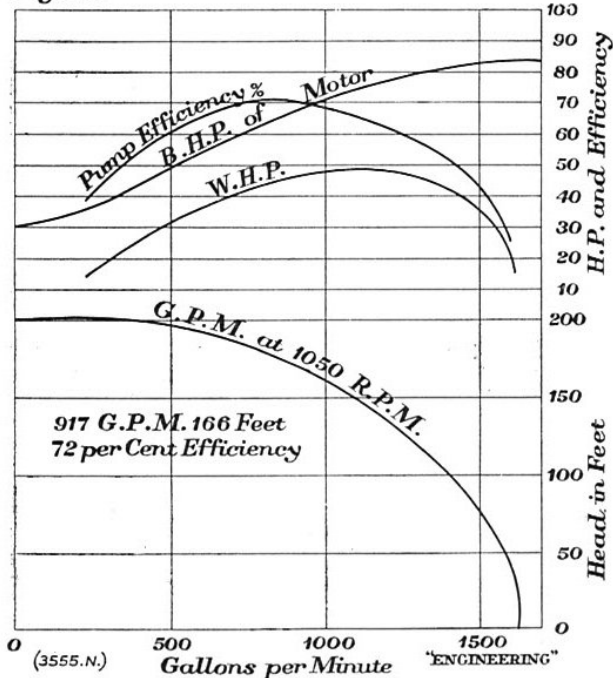


Fig. 18. No. 2. FORCE PUMP.

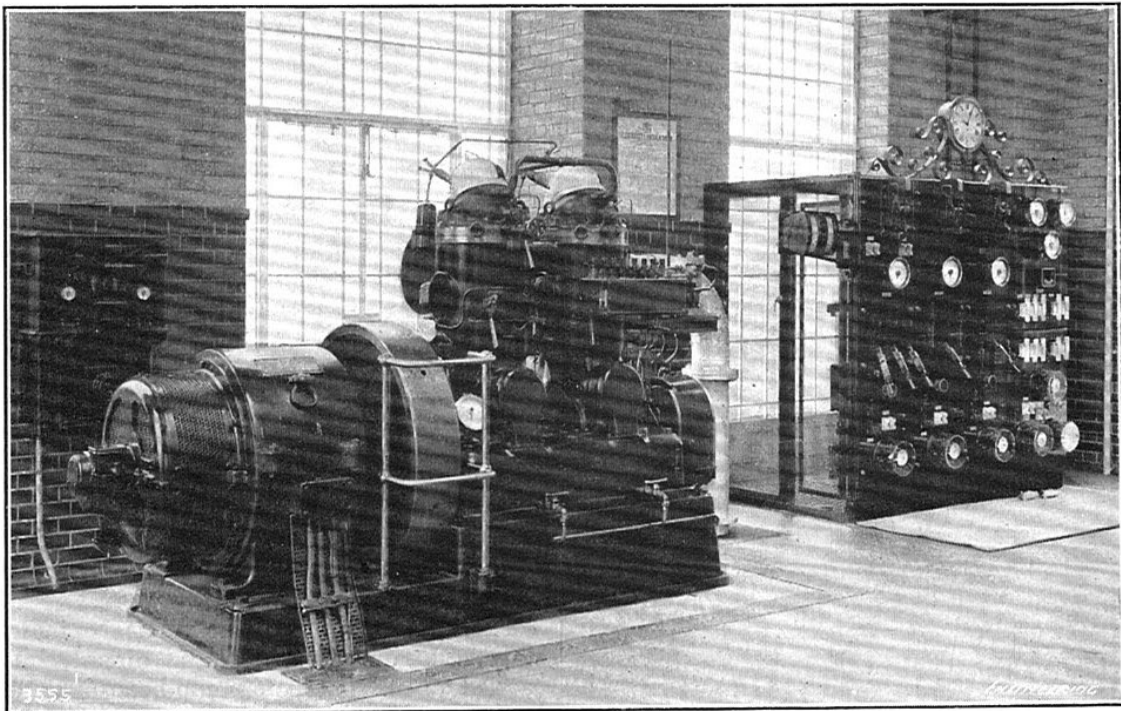
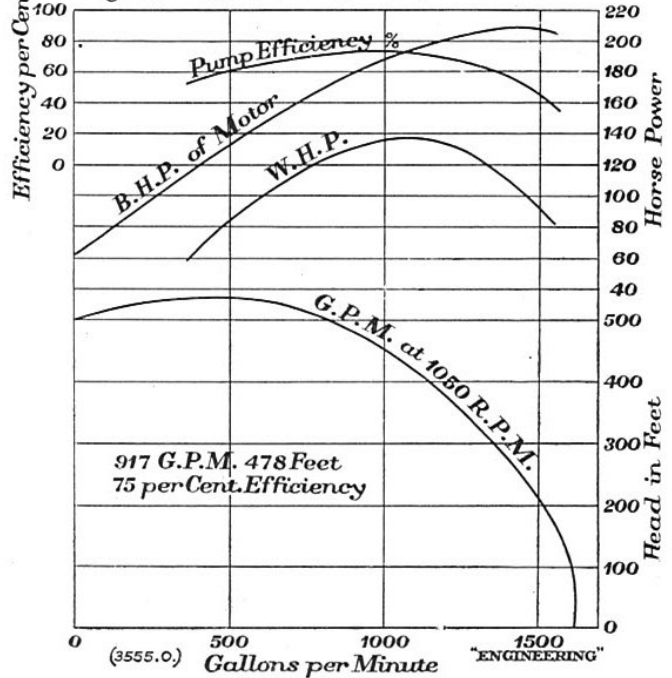


FIG. 19. 25-Kw. GENERATING SET AND SWITCHBOARD.

hydraulic balance fails. It has a forced-lubrication system which is water-cooled. Immediately above the thrust bearing is the flexible coupling which transmits the drive from the gear-box. The gear-box is mounted on a box-section bedplate

the side of the gear-box and is driven by spur gearing off the main gear-shaft. The pump takes its suction from a water-cooled return oil tank. A hand pump is fitted for priming before starting up. It is shown at the left hand of Fig. 14, page 12.

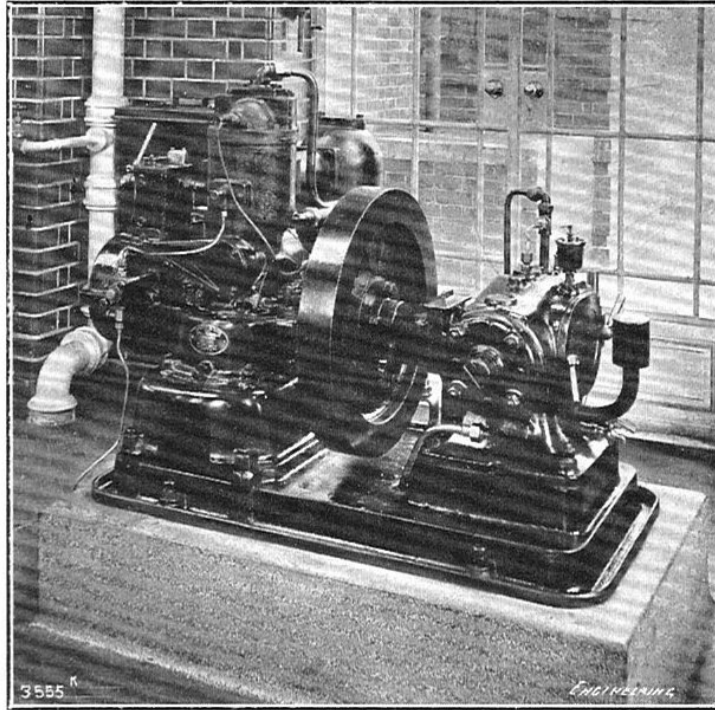


FIG. 20. AUXILIARY AIR-COMPRESSOR SET.

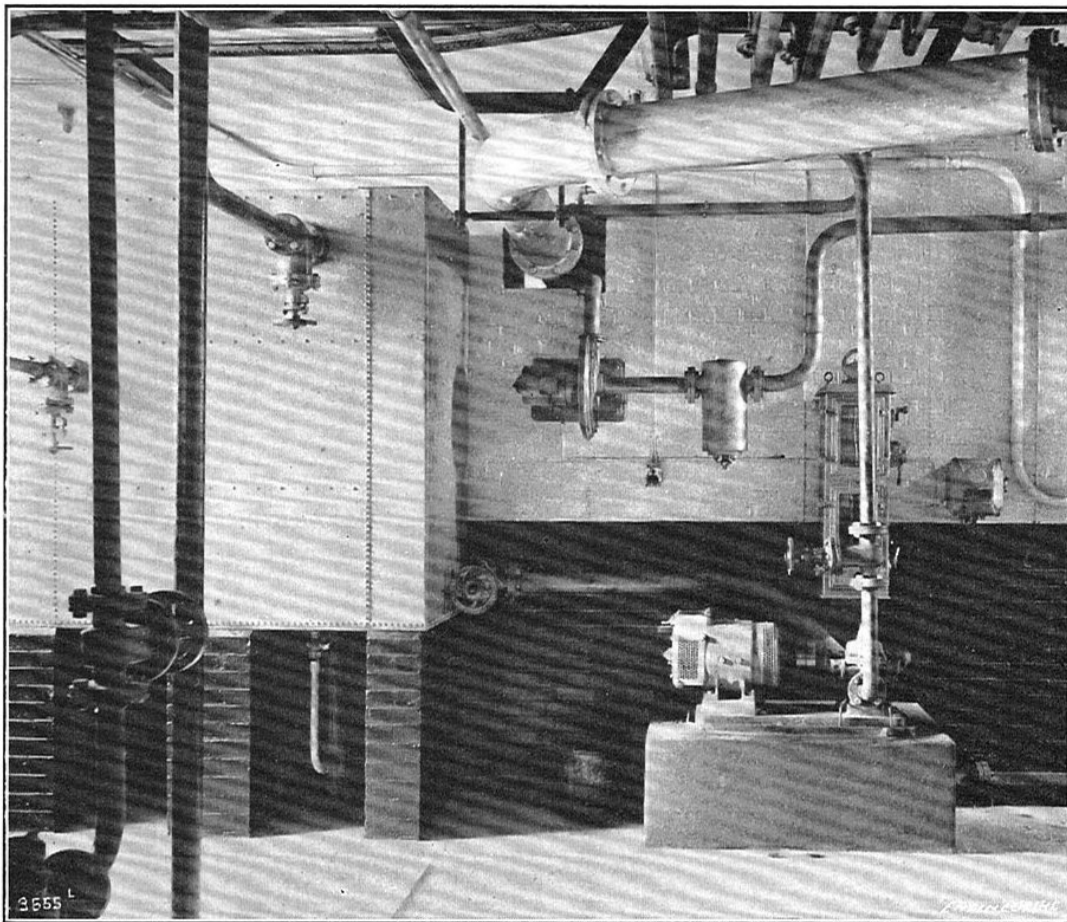


FIG. 21. COOLING-WATER PUMP AND TANK.

The force-pump delivery branch is fitted with a non-return valve and a sluice valve between the pump and the main, and both valves are fitted with by-passes for priming. A water filter is mounted on the side of the force-pump casting, through which all the water for lubricating the bearings of the borehole pump transmission-shafting passes. The water is taken from the delivery main and is passed through a meter before reaching the filter. Inlet and outlet pressure gauges are fitted. The water enters at the bottom of the filter and passes through a layer of coke, and then through a brass perforated filter covered with moleskin cloth to the outlet in the

and provided with a strainer to clean the fuel oil on delivery. Both storage tanks are provided with vent pipes which are led outside the building. The storage tanks are fitted with floats and gauge boards which are graduated in feet, inches, and tons. The fuel pump lifts the oil from either storage tank into two overhead supply tanks, each having a capacity of 600 gallons. The overhead tanks are provided with overflows, which are led back to the storage tanks, in case the attendant does not stop the pump when the tank is full. Compressed-air recording gauges indicate the level of oil in these tanks in the engine-room. The overhead tanks supply a service

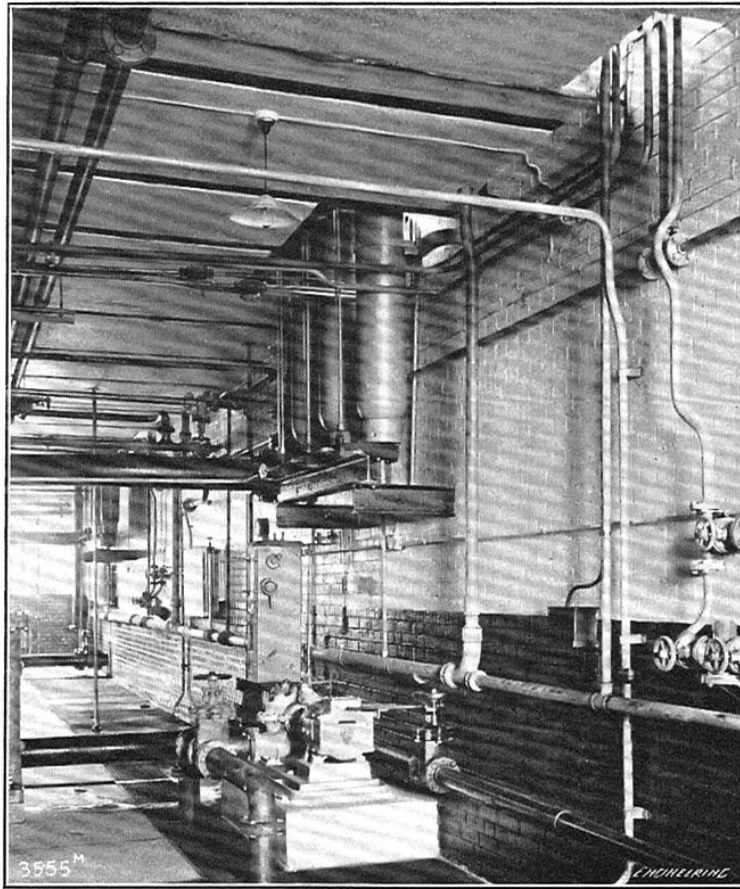


FIG. 22. DRAINAGE PUMP AND AIR BOTTLES.

top cover. This filter is clearly shown in Fig. 14. A Venturi meter and pressure recorder are fixed in the engine-house, and the Venturi tube is placed in the 18-in. main adjacent to the engine-house. Pressure gauges are mounted on a board in the engine-house giving the borehole-pump discharge, force-pump discharge, and delivery main pressure. The borehole water-level indicator is mounted on the same board.

Two main mild-steel sectional oil storage tanks are built in the basement at the rear of the engine-house, having capacities of 67 tons and 97 tons, respectively, and connected by a levelling pipe. Either tank can be filled from a road wagon through a receiving chamber situated outside the building

tank to each engine, which is placed in the engine-room at a height which gives the required head on the engine fuel pumps. These tanks are provided with ball valves which maintain the oil at a constant level. The paraffin tanks for starting up are alongside the fuel service tanks. These are filled by hand as required. A change-over valve is provided on the fuel line to the engine fuel pump.

The engine room is served by an overhead crane having a lifting capacity of 15 tons and capable of lifting the whole borehole pump or the heaviest portions of the engine. The longitudinal and cross traversing motions are operated from the engine house floor by means of endless chains. The lifting motion is driven by an electric motor and has two

speeds. The full load can be lifted at a speed of 10 ft. per minute and light loads up to 5 tons can be raised at 30 ft. per minute.

The 15-kw. direct current generator is driven by a belt from a pulley on the engine crankshaft extension. Belt-tightening gear of the Lenix type is fitted, also a Benn clutch to disengage the generator if desired. This generator is of ample power to light the station and the two cottages, and also provides power for the auxiliary plant. The current is led to a main switchboard and distributed from there. A three panel switchboard is installed, there being a separate panel for each of the 15-kw. generators and for the 25-kw. generator. The panels are provided with single-pole circuit-breakers with no-volt and overload releases, paralleling and isolating knife switches, field rheostats, ammeters, voltmeters, wattmeters for the various power and lighting circuits and a leakage indicator. A vertical two-cylinder semi-Diesel engine drives the 25-kw. direct-current generator. It is run entirely independent of the main engines, and has its own fuel service tank and air bottles. A unit of this size is necessary for working the crane, whilst it also supplies the power for lighting and running any auxiliary motors when the main engines are shut down. The current from this generator is led to the main switchboard and distributed from there. A view of this set and of the switchboard is given in Fig. 19, page 14.

The cooling water pumps are of the centrifugal type and are each driven by a $3\frac{1}{4}$ brake horse-power motor. Each pump delivers 40 gallons of water per minute against a head of 60 ft. at from 1,800 to 1,850 r.p.m. These pumps are situated in the basement as shown in Fig. 21, page 15. Above the pump seen in this figure is one of the motor-driven vapour extraction fans previously referred to. Above this again is one of the main engine exhaust pipes to the silencing chamber. The tank on the left is the cooling water receiving tank. The fuel oil pump is also electrically driven. It has a 2 brake horse-power motor and delivers 25 gallons of fuel oil per minute against a head of 30 feet at 1,400 r.p.m. The motor control panels of these pumps are situated in the basement close to the pumps.

The air bottles of the main engines and the auxiliary generating set are interconnected so that one set can be charged from the other. In addition, an auxiliary air compressor is provided to charge all the bottles if required. This consists of a single cylinder petrol/paraffin engine 4.8 h.p., with a direct-driven two-stage compressor mounted on a common base-plate, as shown in Fig. 20, page 15. This unit is capable of giving a maximum compression of 1,000 lb. per square inch when running at 480 revolutions per minute and can draw a maximum of 312 cubic ft. of free air per hour. The air bottles are arranged to project through the engine-room floor as shown in Fig. 22, page 16. Below them is seen the electrically-driven drainage pump, a sump being provided in the basement for drainage purposes. A pipe leading to the brook takes away the normal drainage by gravity, but should there be any excess water it is emptied by means of the single-stage centrifugal pump shown, which is driven by a

$2\frac{1}{2}$ brake horse-power motor and delivers 150 gallons of water per minute against a head of 25 ft. at 1,250 r.p.m. An electrically driven oil Streamline renovator is installed in the basement. When necessary the lubricating oil from either engine crank

Data Recorded on Official Trials.

	Set No. 1.	Set. No. 2.
<i>Engine Particulars:—</i>		
Average I.H.P. from two sets of cards	427.79	389.55
Corresponding B.H.P. from curves	304.0	283.0
Revolutions per minute	302	302
Average mean pressure in cylinders, lb. per square inch	83.8	76.3
Average exhaust gas temperature, deg. F.	622.5	591.2
Temperature of cooling water to engine, deg. F.	62.3	65.8
Average cylinder jacket outlet temperature, deg. F.	147.9	123.2
Temperature of cooling water from engine, deg. F.	165.5	135.4
Cooling water pressure at engine, lb. per square inch	16.0	15.16
Injection bottle blast pressure, lb. per square inch	900.4	900.5
Forced lubrication. Pressure leaving filter, lb. per square inch	21.1	20.0
Forced lubrication. Temperature leaving cooler, deg. F.	112.3	104.4
Gearbox lubricating oil pressure, lb. per square inch	5.0	5.0
Output of belt-driven generator, kilowatts per hour	1.66	1.66
<i>Pump Particulars:—</i>		
Revolutions per minute	1,043.2	1,043.2
Total head on borehole pump, ft.	157.42	163.7
Total head on force pump, ft.	483.55	476.1
Total head on pumps	640.97	639.8
Water pumped, gallons per minute	916.66	918.61
Water horse-power	178.0	178.1
Mechanical efficiency of engine, per cent., B.H.P./I.H.P.	71.06	72.64
Combined efficiency of pumps and gears, per cent., W.H.P./B.H.P.	58.55	62.93
Overall efficiency of plant, per cent., W.H.P./I.H.P.	41.6	45.71
<i>Test Results:—</i>		
Actual fuel oil used per hour, lb.	110.5	109.22
Actual fuel oil used per I.H.P.-hour, lb.	0.258	0.28
Actual fuel oil used per B.H.P.-hour, lb.	0.363	0.386
Actual fuel oil used per W.H.P.-hour, lb.	0.62	0.613
Actual fuel oil used per 1,000 galls., lifted 100 ft., lb.	0.313	0.309
Cost of fuel oil per 1,000 galls., lifted 100 ft., at 3/4 15s. per ton, pence	0.1257	0.1241
Gross calorific value of fuel oil, B.Th.U.	19,810	19,670
Net calorific value of fuel oil, B.Th.U.	18,575	18,435
Thermal efficiency on I.H.P., gross value, per cent.	49.8	46.2
Thermal efficiency on I.H.P., net value, per cent.	53.1	49.3
Thermal efficiency on B.H.P., gross value, per cent.	35.4	33.53
Thermal efficiency on B.H.P., net value, per cent.	37.7	35.77

chamber is drained into an adjoining dirty oil tank from which the renovator is fed. The temperature of the oil is increased by an electric heating element before it passes through the filter into a clean oil receiver which has a capacity of 50 gallons. This clean oil when required is returned to the crank

chamber by means of a semi-rotary hand pump. The building is heated throughout by means of radiators and hot water pipes. A coke-fired boiler is installed for the purpose in a heating chamber at the rear of the building.

Some particulars of the results of the official trials of the plant and of the conditions obtaining at the tests are given on page 17. Both engines were tested, on consecutive days, for 6 hours.

It is of interest to note that the guaranteed fuel consumption given by the machinery contractors was 111 lb. per hour, with oil of a net calorific value of 18,300 B.Th.U. and a water horse-power of 173·95. After correction of the appropriate figures for the higher calorific value of the oil actually used in the tests, and for the difference in water horse-power, it was found that the actual performance had improved on the guaranteed consumption figure by 1·27 per cent. for Set No. 1, and by 3·2 per

cent. for Set No. 2, a condition illustrating very well the degree of precision now arrived at in the design of Diesel-oil engines and centrifugal pumps. The plotted test results for Set No. 2, are shown in Figs. 16, 17 and 18, pages 13 and 14. The engine curves, Fig. 16, were obtained on the brake trials at Messrs. Allen's works, and the pump curves, Figs. 17 and 18, were plotted from the data recorded at the pump tests in the same works.

The whole of the scheme was designed and carried out by the company's engineer-in-chief, Mr. Fred. J. Dixon, M.Inst.C.E., M.I.Mech.E., to whom we are indebted for permission to publish this article. The main engines, pumping plant and auxiliaries were supplied by Messrs. W. H. Allen, Sons and Company, Limited, of Bedford. Messrs. T. Lowe and Sons, Limited, Burton-upon-Trent, erected the buildings, and Messrs. C. Isler and Company, of London, sunk the boreholes.

