greatly exaggerated; but, on the other hand, there undoubtedly are certain waste products, which, if present in sufficient proportion, add most seriously to the difficulties of sewage purification. This matter forms the principal subject of the third Report of the Sewage Disposal Commissioners. It is a many-sided topic, and may be most appropriately elucidated by the collection of information from those who have had practical experience as to the conditions under which difficulties do and do not arise in the treatment of trade effluents of various kinds.

7. *Bacterial Sewage-Works at present in operation.*—It is frequently asserted that bacterial methods of sewage-purification are still in a merely experimental stage. It would be well therefore if advantage could be taken of the present opportunity for placing on record the number and magnitude of such works as are now in actual operation, and of those which are under construction.

The following speakers took part in the discussion of the subject:—Messrs. C. Hawksley and B. Latham; Dr. S. Rideal; Messrs. J. Lemon, W. J. Dibdin, and G. Chatterton; Lieut.-Col. Jones; and Mr. A. J. Martin.

“Steam-Turbine Driven Centrifugal Pumps for High Lifts.”¹

By CECIL WEST DARLEY, M. Inst. C.E.

DURING the recent prolonged drought in New South Wales—now happily at an end—Prospect Reservoir, having when full a capacity of 12,000 million gallons, upon which Sydney depends for its water-supply storage, became almost emptied; and a scheme had to be devised for supplementing the supply by bringing water from the Nepean River, some 14 miles away, which necessitated a lift of 240 feet, including friction-head. The Department of Public Works cabled to England for two sets of pumps to raise $7\frac{1}{2}$ million gallons a day as a temporary measure, both sets to be suitable for removing subsequently to permanent work elsewhere when the temporary call ceased. The requirements were as follows:—the first set to be capable of raising $4\frac{1}{2}$ million gallons per day 240 feet on temporary work, and eventually $1\frac{1}{2}$ million gallons per day 700 feet on permanent work; the second set

¹ *The Engineer*, vol. xcvi. p. 29. *Engineering*, vol. lxxvi. pp. 9 and 32.

to raise $3\frac{1}{2}$ million gallons per day 240 feet on temporary work, and eventually 10 million gallons per day 80 feet on permanent work. As no ordinary form of reciprocating pumps would be equal to such a range of duty, it was decided to adopt centrifugal pumps in sets of three, capable of running in series or in parallel, since the quantities and heights in each requirement adapted themselves to this arrangement. Three well-known firms were invited to tender; and eventually the offer submitted by Messrs. C. A. Parsons and Company, of Newcastle-on-Tyne, was accepted. It will be sufficient to describe the first and larger set, and to give the tests made thereon.

The set consists of a Parsons compound steam-turbine, direct coupled to three high-lift centrifugal pumps. The steam-turbine is of Messrs. Parsons' standard 250-kilowatt pattern, bladed to suit the conditions of condensing. Below it are placed a surface-condenser and air-pumps. The latter are driven by vertical spear-rods, connected with the turbine shaft by cranks and worm-wheel gearing, which is proportioned so as to drive the air-pumps at one-thirty-fifth of the speed of the main shaft. There are two air-pumps of the Parsons compound pattern. Circulating-water for the condenser is obtained from the main suction-pipe, in which a simple throttle-valve is placed between the branches to and from the condenser; the main can thus be throttled so as to divert the required quantity of water through the condenser. An oil-pump, driven by a small rocker-lever from the air-pump motion, draws oil from a collecting-tank, and forces it through pipes to the various bearings under a pressure of 5 to 6 lbs. per square inch. The exhaust-end foot of the turbine rests on the end of the steel-girder bed-plate which carries the three pumps. The steam-turbine shaft and the three pump-shafts are all independent, each mounted on its own pair of bearings, and provided with claw-shaped flexible couplings.

The centrifugal pumps are probably the most interesting feature of the set. Each is designed to deliver $1\frac{1}{2}$ million gallons of water per 24 hours against the head of 240 feet, when running at a speed of 3,300 revolutions per minute. The pump consists of a central double-sided runner or impeller, 12 inches in diameter, revolving in a closely-fitting bushed casing. The water, entering the pump at the bottom, is divided into two streams, which pass up the two sides and enter the runner through bell-mouthed passages. At each side of the runner there is a pair of small propellers, which assist the flow into the central runner. The horizontal shaft which carries the runner is $3\frac{1}{4}$ inches in diameter,

and is provided with ring-and-groove glands, which serve in suction-pumps to keep the air out, and in pressure-pumps to keep the water in. The play of the shaft endwise is limited by a thrust-bearing. The water, in leaking out, has to force its way through a series of minute annular spaces, and in doing so it loses most of its pressure and its ability to leak. Any water which gets past the first series of grooves is tapped off into a pocket, and returned to the pump. When used as suction-pumps the outer pocket of each gland is connected by a small pipe to a low-pressure water service, so that water may leak into the pump, instead of air. No packing material is used in the glands; and, as the shaft is not in running contact with them, they are not liable to the slightest wear. Small $\frac{1}{2}$ -inch valves are provided for regulating to the right amount the supply of water to the suction-glands. During the official trials there was not the slightest trace of water to be seen at the glands.

The inlet-pipe to each pump is 11 inches in diameter, and the outlet from the volute is 10 inches in diameter. A short radial diffuser-chamber is provided at the circumference of the runner; and the volute is proportioned in the usual way.

Access to the pump-shafts and runners is easily obtained by simply lifting the top half of the pump body, when the shaft couplings can be freed, and the shaft lifted out by two men. It is thus an easy matter, in the event of any accident to the runner, to take it out, shaft and all, and replace it by a spare one. All the shafts are interchangeable; and a shaft can be changed, and the engine re-started, easily within about half-an-hour. The pump runners and propellers are constructed of a bronze alloy of Messrs. Parsons' own make, which has been found especially suitable for use with water having a high velocity.

All the bearings in the engine are of the tubular oil-cushioning kind, similar to those employed in steam-turbines. They consist of a central bush, which forms the bearing, surrounded by three concentric perforated tubes having just a suspicion of play between them. The oil finds its way between the tubes, forming an elastic cushion and ensuring the steady running of the shaft, while at the same time allowing it sufficient lateral play for enabling it to rotate about its own centre of gravity. The claw flexible couplings between each pump-shaft and the turbine-shaft are also sufficiently slack to allow each pump-shaft to rotate freely on its own centre without disturbing or setting up vibration in the other two.

Tests.—The Author considered it desirable to call in an inde-

pendent engineer to conduct the tests; and accordingly Mr. John Goodman, M. Inst. C.E., Professor of Engineering, Yorkshire College, was asked to undertake this duty. The following is an abridgement of his report.

Method of Testing.—Before commencing to take any measurements, the turbine was allowed to run for about an hour, in order to get it thoroughly warmed and under steady working conditions.

"The steam, after passing through the turbine, was condensed and measured in the makers' standard measuring-tanks, two in number, each of which held 2,590 lbs. This was checked and found to be perfectly correct.

"The head against which the pumps were severally delivering was measured by pressure-gauges on the delivery-pipes; and for measuring the final head, the accuracy of which was of great importance for determining the work done by the pump, two pressure-gauges were used, namely, an Elliott Brothers new calibrated gauge and one belonging to the makers.

"The water on leaving the pumps was throttled by passing it through a 6-inch sluice-valve until the desired head was obtained. The quantity pumped was measured by (1) a 14-inch Kent 'Venturi' water-meter; (2) a circular orifice in a thin plate on the end of the discharge-pipe. The head of water in the pipe at the back of the orifice was measured both by an ordinary pressure-gauge and by a mercury-gauge. These were subsequently tested, the former on a mercury column; and the necessary correction was applied when working out the results, which agreed closely with the simultaneous measurements made on the mercury-gauge. In all the trials the Venturi meter gave lower results than the orifice by 0.93 per cent. to 3.35 per cent.

Notes on the Trials.—The first 'contract' trial was made with dry saturated steam on the morning of 27 January, when everything ran perfectly. The head and the quantity of water delivered were remarkably steady throughout, and the steam-consumption was well under, and the power above, the makers' guarantee.

"It was intended in the afternoon to make an 'overload' test at about 1,000 feet head and about 2,000,000 gallons per day; the pump actually performed this duty, but before the preliminary hour's run was completed one of the bearings ran hot, and the test had to be abandoned for that day. On careful examination it was found that the temporary horizontal suction-pipe caused the water to enter the pump runner obliquely, and thus to produce a greater pressure on one side of the runner than on the other. The unequal pressure produced an undue thrust on the collar-bearing,

and thus caused heating. When the pump was erected however, the suction-pipe would be vertical, and the possibility of this again occurring would be remote. For the purpose of equalizing the side pressure when carrying out the overload trials, small holes were drilled in the runner disks, which had the desired effect; but unfortunately the efficiency of the pump was reduced. Comparing the results of trials 1 and 2, the speed in No. 2 was 0.9 per cent. higher than in No. 1, but the head was 2.3 per cent. less, and the quantity of water delivered 5.0 per cent. less, and the water horse-power 6.8 per cent. less, while the steam used per water horse-power was 9.8 per cent. more, partly owing probably to the steam being wetter in trial No. 2 than in No. 1. With the higher speed in trial No. 2, both the quantity and the head would have been expected to be greater than in No. 1. I am of opinion that the above-mentioned holes in the runners were the cause of the diminished efficiency in trials Nos. 2, 3, and 4; but Messrs. Parsons consider the pump to be much more reliable with the holes in the runner than without them. They have other methods in view, which would be equally effective without lowering the efficiency; but the time at their disposal would not allow of any further alteration being made.

"The results however of even the last-mentioned trials are very good indeed. I do not know of any authentic results of centrifugal-pump tests that can compare favourably with them; and when it is borne in mind that the steam-pressure was only 57 lbs. per square inch in three of the trials, the results must, I think, be regarded as exceptionally good. Taking trial No. 1, in which the consumption of steam was 27.93 lbs. per water horse-power hour, the makers inform me that a turbine of this size working under similar conditions uses 22 lbs. of steam per kilowatt-hour, or 16.4 lbs. per electrical horse-power hour. Taking 95 per cent. of this as the brake horse-power of the turbine, it gives 15.6 lbs. of steam per brake horse-power hour, thus making the combined efficiency of the pumps to be 56 per cent. This estimate has no pretence to great accuracy, but I think it cannot be far from the truth.

"Readings of all quantities were taken every 5 minutes. The ratio given in the last line of the Table annexed is the same as the 'efficiency ratio' recommended by the Thermal Efficiency Committee of the Institution of Civil Engineers."

No. 2 set of pumps is similar in general design to No. 1 set; but the central double-sided impeller is replaced by a simple

curved director, with four sets of propellers on each side. This form of design was rendered necessary, in consequence of No. 2 set having to deal with a much larger volume at a lower head.

The discharge from turbine-driven centrifugal pumps, when working under any constant head, is uniform, and absolutely free from the pulsation or shock, so often encountered with reciprocating engines. This renders air-vessels unnecessary, and makes such centrifugal pumps highly suitable for pumping direct into a long rising-main.

RESULTS OF THE TESTS.

Results guaranteed by the Makers.

Quantity of water delivered per day of 24 hours } in millions of gallons.	1·5
Total lift or head in feet	700
Speed, revolutions per minute	2,000 to 2,400
Steam pressure, lbs. per square inch	150
Steam consumption per water HP-hour, lbs.	37

Results of Professor Goodman's Tests.

No. of test	1	2	3	4
Date	27 Jan., 1903	3 Feb., 1903	..	..
Title of test	Contract	Contract	Overload	Superheat
Duration of test in hours	2	1·54	1·2	1·55
Steam-pressure in lbs. per square inch	57	57	84	55
Vacuum in condenser in inches of mercury	27·46	27·82	27·62	27·80
Barometer, inches of mercury	29·65	29·89	29·89	29·89
Condition of steam	Dry and saturated	Saturated	Saturated	95° F. Superheat
Weight of steam used per hour in lbs.	7,039	7,208	9,398	6,667
Weight of steam per water HP-hour in lbs.	27·93	30·67	28·83	27·89
Speed, revolutions per minute	3,300	3,330	3,710	3,340
Mean delivery pressure-gauge read-ings in lbs. per square inch	97 206 326	102 208 318	130 263 393	103 210 323
Height of suction in feet	11	11	11	11
Total lift in feet	762	744	917	756
Millions of gallons of water pumped per day.	1·573	1·499	1·689	1·503
Water HP.	1·623	1·513	1·723	1·555
Gross HP. that would be obtained from a perfect steam engine working on the Rankine cycle between the given limits of temperature	252	235	326	239
Water HP. × 100	720	759	1,019	733
Gross HP.	35·0	31·0	31·1	32·6

The following speakers took part in the discussion of the subject:—Messrs. W. Hunter, D. Halpin, G. G. Stoney, W. Carnegie, and H. A. Hill.

“Raising Water by Compressed Air.”¹

By PERCY GRIFFITH, M. Inst. C.E.

AMONG the many mechanical expedients known to engineers at the present time, few have come into common use more rapidly than the application of compressed air to the raising of water from wells and borings. In this instance however, as in many others, practical application has far preceded appreciation of the natural laws by which it is governed: with the inevitable result that, on the one hand, where success has been achieved, the advantages have been exaggerated; and on the other hand, failures have provoked unwarranted condemnation. No doubt the cause which is mainly responsible for this state of affairs is the simplicity of the apparatus involved. An air-compressor, driven by steam or electricity, with an air-pipe and a water-pipe having no moving parts, are the only requirements for lifting large quantities of water to considerable heights, under conditions which, in some instances, would be fatal to the ordinary form of pump. At this point however the simplicity of the plan, and especially of the laws by which it is governed, absolutely ceases; and the more carefully it is investigated, the more complex and indefinable become the problems presented by it. It is therefore desirable that, instead of blindly experimenting with applications where failure may involve loss of public money and detriment to the water-supply of large or small communities, a careful investigation should be made, both of the natural laws which govern the method, and of the details of construction which are essential to its successful realization.

In respect of a few points, on which experience hitherto has produced something of an approach to certain knowledge, the Author has collected data relative to a number of different applications; but, owing to the totally dissimilar forms in which the results have been recorded, and to the absence of any factors common to any

¹ *The Engineer*, vol. xevi. p. 31. *Engineering*, vol. lxxvi. pp. 10 and 33.