THE HYDRO-PNEUMATIC AND HYDRAULIC SYSTEMS OF SEWERAGE.

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The following paper on the hydro-pneumatic and hydraulic systems of sewerage has been compiled chiefly from particulars supplied to the author by Mr. W. C. Bennett, M. Inst. C.E., Commissioner and Engineer-in-Chief for roads, bridges, and sewers, etc. These particulars were collected by Mr. J. W. Macdonald, M. I. M. E., A. M. Inst. C. E., while on a visit to England, during which time he visited the works at Henley on Thames, described in Mr. Henson's paper, also those at Eastbourne.

THE WORKS AT EASTBOURNE.

The works at Eastbourne furnish a good illustration of what can be done by Shone's hydro-pneumatic system in raising sewage from the low-lying districts, which must always necessarily be excluded from any purely gravitation scheme. Such low-lying districts have usually been provided for by pumping the sewage on to the level of the gravitating sewers by means of pumping engines. At Eastbourne, which is a sea-side health resort, the sewage of the low-lying districts is elevated by means of ejectors, similar to those described in Mr. Henson's paper. These ejectors are located at three stations, and these are supplied with compressed air from an air compressor which is situated outside the town itself. The air compressors and engines are of the horizontal type, working tandem, and in pairs, so that one engine and compressor can be idle, when there is no flood water to deal with. The air compressors are Sturgeon's patent, the engines are each 12 h-p., nominal, and the compressed air is delivered into the air mains at a pressure of 13 lb. per square inch. The average lift for the ejectors is about 25 feet, and the maximum quantity lifted in

24 hours, four million gallons, equivalent to 21 effective horse-power. At the ejector stations there are either two or three ejectors, respectively, thereby keeping up a constant flow of sewage. The air mains are of cast-iron, about nine inches internal diameter, and are laid in the roads to the different ejector stations. The ejector stations take the place of pumping stations, and raise the sewage to the out-fall sewer along which it flows to the out-fall by gravitation.

The pressure under which the ejectors discharge their contents into the outfall sewer gives an additional velocity to that due to gravitation, by which the outfall is made to discharge a very much larger quantity of sewage than under ordinary gravitation principles; and is rendered sufficient to meet the greatest demands upon it due to increased population, thus saving the town a very great outlay, which would have been necessary in duplicating the outfall sewer, the cost of which was about £40,000. It is necessary to state that these works have been thoroughly successful.

The three stations, including ejectors, inspecting chambers man-holes, air and sewage mains, compressors and boilers in duplicate, engine house, boiler and receiver house, two cottages for the engineer and stoker, including land, law, and other expenses amounted in the aggregate to £85,000.

The annual cost for running the plant, including engineer, stoker, fuel, water, oil, tallow, &c., &c., is about £600.

These works were carried out by Mr. C. Jones, Borough Surveyor.

The Shone system as an adjunct to the gravitation system is well illustrated by the works at Eastbourne; but the complete system is to be more clearly seen in Mr. Shone's proposals in dealing with the sewage of Southport.

The author has visited this town on several occasions, and can testify to the utter failure of the purely gravitating system as constructed there, in spite of its enormous cost. The sewers laid on the gravitation scheme with gradients of 1 in 3,000 and in 5,000 were much too large for the quantity of fluid discharged.

The velocity in the existing sewers, even when running ⅔ full is insufficient to make them self-cleansing. It is proposed to establish eight ejector stations into which the sewage flows by gravitation down gradients of 1 in 200, and from which it is ejected into stoneware pipes. The sewage is finally ejected out to sea along an iron pipe 15 inches in diameter. These data speak of themselves, and prove conclusively the enormous advantages of the Shone system over that of the purely gravitation system for such places as Southport.

THE ECONOMY OF USING COMPRESSED AIR TO ELEVATE THE SEWAGE FROM THE EJECTORS.

Although compressed air is not generally an economical medium for conveying power, there are certain cases in which it is both economical and convenient. The following extract from the *Engineer* shows the work done in compressing air for various lifts both adiabatically and isothermally, as applied to Shone's system :—

"To provide uniformity of working receivers are required, the air being compressed to a slightly greater pressure than is necessary to raise the sewage ; but in some instances the mains themselves afforded quite enough storage capacity. When the full pressure is attained, a self-acting arrangement stops the air-pumps, so preventing useless expenditure of power. As soon as the ejector is filled an automatic valve admits the compressed air, which forces the fresh sewage either into a rising main under pressure or into a gravitating sewer, and so on to the places where it is to be treated or utilised, the conveyance being so rapid that there is no possibility of the generation of foul gases by decomposition. In using compressed air in this manner, it is obvious that the whole of the work done by the compressing engines is sacrificed, and for isothermal compression this is represented by the expression $AV. \log._e R$, where A is the atmospheric pressure on a unit of area, V the number of units of volumes of free air compressed and discharged into the receiver by one stroke, and R the ratio of compression. The total work done both by engine and by the external air during one complete stroke is $AV. (1 + \log._e R)$, the work done by the air being in all cases equal to that required to discharge the compressed air out of the cylinder. It is evident, therefore, that there must be a limiting value of the height to which liquids can be raised on the Shone system as economically as by direct pumping, and the following table, showing the work done in compressing the air to different absolute pressures in six cases, has been calculated with a view to ascertain this limit:—

Lift in Feet.	Isothermal Compression.			Adiabatic Compression.			Mean Value of Columns 3.	Mean Value increased by 25 p. cent.
	1	2	3	1	2	3		
6½	859	706	1·22	900	802	1·12	1·17	1·46
3	1467	1058	1·39	1500	1300	1·15	1·27	1·59
49½	1940	1270	1·53	2150	1657	1·30	1·42	1·77
66	2328	1411	1·65	2700	1970	1·37	1·51	1·89
82½	2650	1512	1·75	3200	2166	1·44	1·59	1·99
99	2938	1587	1·84	3620	2376	1·52	1·66	2·08

"Columns 1 give the value of the work done by the engine in compressing the air isothermally and adiabatically respectively; columns 2, the nett work done in raising the liquid; and columns 3, the ratio between the two values. As the actual compression is probably somewhere midway between isothermal and adiabatic, the mean ratio is given in column 4, while these increased by 25 per cent., to allow for friction and leakage, are given in column 5. No allowance has been made for slip past the ejector valves, as it is stated to be extremely small in proportion to the volume of each discharge."

Besides this, Sir Frederick Bramwell, in the case of the Mekarsky air compressors at Chantenay, found the value of this factor to be 18 per cent., so that there would be more than sufficient margin to cover the loss from slip. In the case of engines used for sewage pumping, the indicated horse-power of the steam cylinder is not unfrequently equal to double the power estimated in nett weight of water raised, and only under exceptional circumstances is the former less than one and a-half times the latter. Up to lifts therefore of about sixty feet it would seem that forcing by compressed air is more economical than by direct pumping, while if the pumping machinery is of small capacity, the economy is likely to extend even above this height.

Besides being able, upon Shone's plan, to eject sewage up to a lift, say of sixty feet, at *one* pumping station as economically as if the most economical pump was employed to do the same amount of work, sewage can also be ejected at ever so many different pumping points, however far or distant they may be from one another. This is very important in view of the necessity there is, from a purely sanitary point, for erecting numerous sewage stations in flat or low-lying habitable areas, where it is impossible for the sanitary engineer to design gravitation sewers pure and simple, which shall carry away the sewage that is discharged into them freely and innocuously to one outfall, whether that outfall be at a pumping station or elsewhere.

Shone's system may also be conveniently employed in distributing the sewage over a sewage farm. The quantity delivered to every carrier is under perfect control, and any portion of the farm may be isolated from the remainder.

In applying Shone's system to such places as Southport, it is necessary to divide it into as many sections as are necessary to ensure, as per the laws of hydraulics, the sewers laid within them acting properly. This can be readily done by sinking in a central or some other convenient position within the various sections pneumatic ejector stations.

To these, as to a steam pumping station, the sewage would flow quickly through properly inclined gravitation sewers, of small bore; and all being comparatively short in length, the sewage from the house furthest away from the pneumatic ejector station could not fail to reach that station in a fresh and undecomposed condition.

To insure the small main sewers, supplying the pneumatic ejectors with sewage, being swept clean, as it were, twice a day, flush tanks, supplied with clean water are to be placed where necessary, at the heads of the small, properly laid, main sewers converging at the ejector stations. These flush tanks are so designed that they can be filled and emptied automatically once, twice, or any desired number of times during the day.

The works which have been carried out by Mr. W. C. Bennett, for the sewage of Sydney, are so well known to the members of this Association that it will not be necessary for the author to describe them. These works are designed to dispose of the sewage of Sydney by gravitation, either out to sea at Ben Buckler's Point, or on to the sewage farm at Cook's River. There are, however, certain low-lying districts, situated round the harbour, which could not be provided for in this gravitation scheme.

There are five outfall sewers which at present discharge their contents into the harbour, one at Blackwattle Bay, two at Darling Harbour, one at King-street, and one at Woolloomooloo Bay. It is proposed in Mr. Shone's scheme to erect ejector stations at these outfalls and to elevate the sewage to the level of the intercepting sewers, in order that it may be disposed of in the manner referred to.

In the case of Shone's ejectors, as applied to Sydney, the main advantage is that whereas skilled labour would have to be employed night and day at each pumping station, if Cornish pumping machinery is used, with Shone's system skilled labour would be employed only at one station.

The loss of pressure in conveying the compressed air to the different stations is small, as the pressure is low, and frictional losses of machinery at the station are avoided by passing the air directly into the sewage itself.

The solid matter is always ejected first, and the valves are flushed by the water following. The ejectors are arranged to discharge and fill once in every minute, at an air pressure of 16 pounds per square inch, but the rate of discharge can at any time be increased by increasing the pressure.

The difference in prime cost between Shone's system and the pumping system is considerable. The total prime cost of the pumping scheme, with five Cornish pumping stations, according to Mr. Appleby's estimate, would be £29,740; the total prime cost of 5 ejector pumping stations would be £39,000, or £10,000 in favour of pumping stations.

The working expenses, however, reverse the order in favour of Shone's system.

Taking the interest on prime cost at 4 per cent., coal at 4 lb. per I.H.P. per hour, at 18s. per ton, labour, etc., etc., the annual cost of Shone's system would be about £4,000; while the total annual cost of five pumping stations would be about £8,000, or £4,000 more than Shone's system.

With either system, if desired, the pumping might be stopped at night, for several hours at least, and the small amount of sewage that would come down might be discharged into the harbour from a Penstock chamber, or collected in an underground tank.

The exhaust air from the ejectors may give some trouble in the case of sewers with flat gradients, although with proper gradients no nuisance need be apprehended. At Eastbourne a chimney was provided, but Mr. Appleby, who has made experiments on sewer gases in the London sewers, states that a fine spray of water round the exhaust pipe is sufficient to thoroughly purify the air, which can then be admitted into the atmosphere.

A system has been patented in this colony by Mr. Appleby which the author thinks will prove a dangerous rival to the Shone system. It proposes to eject the sewage from ejector or hydraulic pumping stations, as in the Shone system, substituting, however, water for compressed air. The drawing on Plate I. has been prepared to illustrate this system, as proposed by Mr. Appleby for Sydney, which consists of a hydraulic pumping plant and accumulators for storing power.

Hydraulic pressure mains are laid from the central station to the subsidiary stations to convey water at 700 lb. per square inch to the special hydraulic pumps, which consist of a hydraulic ram with a simple apparatus which will put on the pressure automatically whenever there is a charge of sewage to be lifted to the intercepting sewer, and will open the exhaust ready for the next stroke.

The solid matter is first ejected, and the liquid follows, thereby cleansing the pump chambers and valves. Each pump holds 34 cubic feet of sewage, and, when working at full speed, discharges four times in one minute, equivalent to 136 cubic feet per minute. Each hydraulic pump when working at full speed uses 3 cubic feet of water per minute at a pressure of 700 lb. per square inch. The total quantity of water used per minute by the hydraulic pumps, when working at full speed is 24 cubic feet, or 150 gallons, equal to 200,000 gallons per day of 24 hours.

The areas of the pumps are in the proportion of 50 to 1, which, with 700 lb. hydraulic pressure, gives neglecting friction about one atmosphere on the sewage, or 34 feet head, or actually about 25 feet head.

A considerable quantity of water is used in this scheme.

In Mr. Appleby's proposals for Sydney, a central pumping station would be built at Blackwattle Bay, and four subsidiary stations at the same positions as those proposed in the Shone scheme. The useful effect in transmission by hydraulic pressure in Appleby's system will be at least ninety per cent.

The author does not propose to compare, in this paper, the relative advantages and disadvantages in pneumatic and hydraulic transmission of power, as it would exceed the scope of this paper. The prime cost of Mr. Appleby's system, as applied to Sydney, would be £27,800. This includes duplicate pumps at each station.

The working expenses would be slightly greater than in Shone's system. The author considers that either system would work efficiently, as proposed for Sydney, and that the question of cost is so nearly the same that they must be considered to be of equal merit.

In conclusion, the author desires to thank Mr. J. A. MacDonald, for much of the valuable information placed at his disposal on the subject of this paper.