ON IRRIGATING MACHINERY ON THE PACIFIC COAST.

BY MR. JOHN RICHARDS, OF SAN FRANCISCO.

In offering the present paper to the Institution of Mechanical Engineers the author does so with a tolerably complete knowledge of the very advanced practice in England in this class of machinery; and his purpose is mainly to explain the differences that have been called for by local circumstances in California.

Character of the Country.—The western or Pacific slope of the Sierra Nevada or coast range of mountains in California is very abrupt, the crests of the range being so near that the snow is visible from the coast during the whole year. Hundreds of streams cross this narrow country, falling either direct into the Pacific ocean or into the great basin formed by the Sacramento and San Joaquin rivers. These two rivers, the largest in California, run in opposite directions, nearly parallel with the coast, and meet at the Bay of San Francisco, forming a continuous valley 400 miles long and from 50 to 100 miles wide. The small streams for the most part are fed by melting snow in the summer; and every gulch or cañon has its rivulet or brook. They increase in volume until they pass into or through the hills at the foot of the mountain range; and there, unless of considerable size, they may wholly disappear in summer by percolation through the silt or by evaporation. Streams exposed to the torrid air which in summer sweeps across the sand deserts of southern California are dried up with wonderful rapidity. The evaporation from Salt Lake, exposed to the same dry wind, is sometimes equal to half an inch per day, or 64 million tons of water. Notwithstanding this great loss by evaporation, the quantity of water falling into the ocean on the coast of California has been estimated at 100 million cubic feet or $2\frac{3}{4}$ million tons per

L

minute, enough if distributed properly to irrigate 25,000 square miles.

The Pacific coast in California may be said to consist of a mountain slope, fissured everywhere by water; and of alluvial plains formed by the sediment deposited from the water, which varies from coarse gravel and sand to fine silt, as the velocity and volume of the water courses have determined. Nearly the whole country is therefore underlaid with strata of sand and gravel, which afford water everywhere at various depths.

The need of irrigation arises from three causes:—the lack of rain, which in summer ceases wholly along the coast; the want of surface water; and the free percolation into the sand beneath. The area requiring irrigation comprises most of the land in the country, except the low-lying sedimentary plains near the mouths of the rivers, and around the Bay of San Francisco, where water reaches the surface by capillary saturation.

Water Training.—In the days of placer gold-mining, a large part of the running water in the mountains and foot hills was collected in extensive ditches, flumes, and iron pipes; the water was as important as the gold, which could not be washed out without it. Placer mining is gone; but the ditches remain, most of the water now being required for the more permanent business of fruit growing and other kinds of agriculture. Perhaps no part of the world equally rugged and difficult of access has been so thoroughly explored and mapped as this. From the tops of the mountain ridge to the depths of the cañons there is scarcely an acre that has escaped the search for gold and silver. The information thus acquired respecting the surface of the country was made use of as soon as agriculture began to receive attention; and the result is that nearly all land is now occupied upon which water can be led, not only by training small mountain streams, but also by leading long canals, or ditches as they are called, from the rivers; until at the present time, or when works now in hand are completed, the only remaining resource for getting water will be by lifting it from the rivers or the gravel strata by machinery.

Character of the Machinery required.—The standard methods of raising water for irrigation and drainage, commonly adopted in the Netherlands and elsewhere, would not apply on the Pacific coast. Permanent foundations are wanting; a number of small separate pumping stations, widely distributed, are required, instead of a few large establishments centrally situated; and a high efficiency is essential in the machinery employed, because of the high cost of fuel, coals of indifferent quality being worth from 30s. to 40s. a ton. For raising 420,000 gallons per hour from 6 to 10 feet high the cost of the machinery is from £500 to £600. For raising 1,000,000 gallons per hour from 10 to 14 feet high the cost is from £800 to £1,000, including engines, boilers, pipes, and framing. This must account for the light sections and other scant proportions that will be observed in the drawings; material enhanced in value 40 to 50 per cent. by tariff taxes is of course used sparingly. An efficiency of 65 to 70 per cent. is attained in most cases when the head or lift is between 8 and 16 feet. For pumping from deeper wells the machinery is much more expensive, in proportion to the quantity of water raised, both because of the greater length of the driving connections to the pumps, which are placed in the bottom of pits in order to be within suction distance of the water, and also because of the greater strength required in all parts to stand the speed and pressure.

Fruit farms, on account of the labour and attention they require, are limited in size; and irrigating machinery must come within moderate limits of cost. Where the water is drawn from the gravel, concentration of pumping is out of the question. Percolation is not free enough to admit of large quantities being raised at one point and distributed; and even if this were possible, adjacent wells would be robbed, and litigation might ensue. In some experiments at San José, California, during the year 1885, it was found that, in drawing 15,000 gallons per hour from two artesian wells of 10 inches diameter and 200 feet depth, neighbouring wells at distances of from 200 to 600 yards were lowered. In this instance the water rose naturally to $2\frac{1}{2}$ feet above the surface of the ground at the wells, and was lowered only 6 feet by drawing 15,000 gallons

per hour. The wells here referred to, and indeed nearly all wells in irrigated districts, are tubes of sheet iron from 6 to 14 inches diameter, sunk by forcing, the earth being removed through the interior of the tubes.

In the broad alluvial plains along the Sacramento river, and especially in places near to its banks, percolation is so rapid that some attempt has been made at concentration of pumping plants. One well of 40 feet diameter and 16 feet depth, having an infiltrating surface of 1,000 to 1,200 square feet, yields 180,000 gallons an hour; and others of smaller infiltrating area yield a proportionate quantity. But these are in places where the water-bearing strata are much thicker than usual, the gravel coarse, and the saturation greater than in most other parts of the country.

Early Irrigating Machinery.—One of the earliest appliances for raising water in California was the Chinese pump, illustrated in Fig. 1, Plate 1, which consists of an endless band travelling round pulleys at top and bottom of a moderate slope, and carrying a series of wooden floats or crossbars fixed on its outer face; the under span ascending through an open trough carries up water from a ditch or pit and delivers it into a launder or flume at top. The endless bands are sometimes made of india-rubber or cotton canvas; but more commonly consist of a pair of ropes, upon which the crossbars, having their ends split, are clamped at regular intervals by means of screws. It is a very cheap contrivance, and for low lifts is still employed to a considerable extent by the Chinese and Italians; it was doubtless introduced into California by the Chinese in imitation of similar pumps extensively used in China for raising water from the canals, where the lift is only a few feet. For slopes not steeper than 20 degrees, and lifts of only from 3 to 6 feet it is found to be very economical in cost of working; and is said to be capable of high duty when the wooden floats or crossbars are so arranged and proportioned as to render the rising span nearly buoyant in the water, and especially when the inside of the trough is lined with metal to diminish the friction. For irrigation these pumps are commonly driven by horses, and for other purposes are employed only

temporarily: and so far as the writer knows no experiments have been made to determine their real efficiency. For lifts exceeding 10 feet and slopes steeper than 30 degrees, the friction and leakage render them unsuitable; and their use is being abandoned as better methods are introduced.

Tube-Well Pumps.—These pumps, or the method of constructing them, grew out of the oil-well experience in the Atlantic States. In Fig. 2, Plate 1, is shown a common method of working such pumps by means of a beam and engine. The tubes or barrels T, which constitute both well and uptake, are made of galvanised iron, from No. 18 to No. 14 B.W.G., or 0.050 to 0.085 inch thick, with the longitudinal seams riveted and soldered together throughout. They are made from 6 to 14 inches in diameter; and are sunk to depths varying from 100 to 200 feet, sometimes more when pure water is wanted. The water rises in the wells to heights varying with different seasons; and in some cases overflows at the surface, as in the well at San José already mentioned. The pumps are placed at different depths accordingly. For irrigation the wells are generally arranged in a quadrangle when there are four; or as shown in Fig. 2, when there are two, the distance between them being from 10 to 20 feet. The distance apart does not seem to be a matter of much importance; in pits such as that shown in Fig. 3 the same kind of tubes are put down within a few feet of each other.

These crude looking pumps are much more effective and economical in their working than would be supposed. The pump rods are of wood, their section being equal to half the area of the working barrel; consequently in both the up and the down stroke the delivery is equal to half the capacity of the barrel. In effect therefore the pumps are double-acting, with only one set of valves, and the load is in a measure equalised between the up and down strokes; they correspond with the ordinary bucket-and-plunger arrangement common in mining districts. The working barrel is either a brass casting bored out, or made of drawn brass tube. The foot-valve at bottom is inserted from the top, and can be drawn out and replaced

without trouble, after the pump-rod and bucket-valve have been removed.

The two tube-wells of 10 inches diameter at San José, already mentioned, were put down by contract for 5s. per foot for the first 100 feet, including everything. For a second 100 feet the cost per foot would be something more, not exceeding 50 per cent. extra and generally less, according to the nature of the ground to be sunk through. Wells from 7 to 8 inches diameter, and not exceeding 150 feet deep, cost from 4s. to 6s. per foot, including galvanised tubing inserted ready for use. Much depends of course on the nature of the ground; and if boulders are met with, the whole work may be lost. It is not easy to withdraw the tubes, and in case of obstruction they are generally abandoned.

A serious impediment to the use of these pumps is the wear of their valves or leathers, which are soon destroyed by sand and gravel. To renew them, the pump-rods of 50 to 100 feet length have first to be removed by drawing them up and disconnecting the sections one at a time. As the rods are long, heavy, and inconvenient to handle, half a day's time of two men may be required to replace a leather which will not last twenty-four hours after it is inserted. Accordingly for pumping from the sand and gravel strata the author is of opinion that no machinery which involves close-fitting pistons or sliding joints of any kind exposed to the water can ever succeed in California.

Centrifugal Pumps.—The destruction of pistons by the sand and gravel has led to the adoption of centrifugal pumps. In these, with their constant and rapid flow, the sound of the gravel striking against the elbows and sides of the pipes can be heard distinctly. A pile of gravel and coarse sand soon accumulates wherever the speed of the discharged water is slow enough to allow of precipitation; and the wonder is what supplies the displacement thus caused at the bottom of the wells. Elsewhere it has not been common to recommend centrifugal pumps for high lifts, and they have been considered less economical than piston pumps; but the opinions hitherto entertained regarding them have been much modified by the experience of their working in California. A head of 100 feet

however, for a centrifugal pump to work against, is a very different thing from a head of only 10 feet; the impact or mechanical push of the vanes, which is a very important factor, diminishes as the head increases, and as the speed of the tips of the vanes exceeds that of the water in the volute casing. When the head exceeds 40 feet, efficiency declines rapidly, but not to such an extent as to outweigh the great economic advantages of centrifugal pumps for heads up to 100 feet or even more.

For lifting water from the gravel strata in California, four kinds of centrifugal pumps have been employed, namely:—firstly, the common make with open vanes revolving in a plain volute casing; secondly, wheels with shielded or encased vanes, the water being drawn in at the centre and discharged from the circumference; thirdly, compound pumps with two or more wheels acting in succession upon the water during its passage through the pump; and fourthly, balanced pumps receiving the water at one side, whence it is deflected in an easy curve to the circumference by a conical disc on which are formed the vanes. These various forms of the centrifugal pump may be regarded as phases of development, adapted in some cases for particular objects, but generally reverting from encased vanes, compound or double wheels, and other features, back to the original simple form of the first pumps in use prior to 1820. The wheels with encased vanes, for example, have been a feature of the earlier practice with most prominent makers. These wheels were made in America as early as 1831, mainly with the object of partly avoiding side thrust when a single inlet was employed.

Centrifugal Pumps with Open Vanes.—These were at first employed for lifts up to 30 feet, and were usually arranged as shown in Fig. 3, Plate 1, at the bottom of rectangular pits sunk to the depth required for bringing the pumps within suction distance of the water. The pits have often to be sunk 50 feet or more below the surface, and are usually 10 to 12 feet long and 4 to 6 feet wide. The sides are lined with planks of redwood (*sequoia*), which is very durable under exposure in such situations. Two or more tube-wells are sunk from 50 to 150 feet below the bottom of the pit; and in them are placed

suction pipes S, connected by bends at top to the upper side of the horizontal pump casing, as shown in the drawing. This mode of connection is adopted simply for convenience in the present case, in which there is no upward thrust; but in some cases for a different purpose, as will be further described presently. The pump P is driven by a vertical shaft, which is mounted in pivoted bearings B of the peculiar kind shown in Figs. 4 and 5, Plate 2, each having a supporting collar for carrying the weight of the shaft and pump wheel. The compression couplings C, shown in Figs. 6 and 7, for connecting the several lengths of which the shaft is made up, are so constructed as to be almost instantly loosened or removed. These couplings were introduced in England a short time ago by the writer, and have given evidence of superiority over the more intricate modifications that have preceded them.

The uptake or rising main U from the pump, Fig. 3, Plate 1, is of galvanised iron, and preferably two to three times as large in area as the delivery nozzle on the pump. The pumps are charged in several ways, always from the top of the pit. In Fig. 3 is shown a steam ejector at E, with a small pipe running down to the pump. Air pumps are sometimes used. Charging with water is out of the question, because foot-valves are no longer employed; it was found that the rapidly entering water, loaded with sand and gravel, cut away the valves like the sand-blast process; and there is no room in the well, as there is above, for making flap-valves that swing clear of the current.

For some of the earliest pumps horizontal driving shafts were employed, with bands extending down the pit from a shaft at top to the pump at bottom; but the weight of the bands, the danger to any one descending the pit, and the delay caused by breaking, rendered that plan undesirable, and it has given way to vertical driving shafts. One of the first experiments in deep pumping with a centrifugal pump was made in a case where the water stood at 70 feet below the surface; and when it had become lowered by pumping, the lift was 74 feet. The pump was a compound one, driven at 900 revolutions a minute, raising 10,000 gallons an hour. The pit was only $3\frac{1}{2}$ feet square, and the pump was fixed at 60 feet below the surface. A band

passing down the pit was employed for driving ; but the difficulties attending its use were such as to direct attention to other and safer methods of transmitting power in deep pits.

Centrifugal Pumps with Shrouded or Encased Vanes.—Nearly all makers of centrifugal pumps in California and elsewhere have at first followed Sir Henry Bessemer's plan of more than thirty years ago (Proceedings 1852, Plate 69, Figs. 9 and 10), employing a shrouded wheel, in which the sides of the vanes V are attached to two enclosing discs that revolve with them, as shown in Fig. 10, Plate 3, and in the plan of the wheel, Fig. 12. The difference is very great between a wheel or runner constructed in this manner with closed sides, and an open wheel without enclosing discs attached to the vanes. With the shrouded wheel a water-tight joint must be maintained all round the inlet orifice: otherwise the water would only circulate through the pump, passing from the circumference back to the inlet. Such leakage is increased by the pressure, which at all points on the sides of the wheels is the same as in the discharge pipe or at the discharge orifices of the wheels. The skin friction of the water is no less with a shrouded wheel; the water, instead of being driven round in contact with the sides of the stationary casing, flows through the wheels as it does through the pipes, without any greater skin friction in passing through the wheel than for an equal distance in the pipes; but on the other hand there is an equal skin friction of the outside of the wheel itself. The latter has been found to be diminished by having a considerable thickness of water intervening between the outside of the revolving wheel and the inside of the stationary casing. In the pump shown in Plate 3 there is only a very narrow clearance space at the sides of the wheel; but here unusual care has been taken in construction, the wheel being turned and made perfectly true after being keyed on the spindle. The resistance greatly increases if the wheels are not perfectly true; but up to the present time the data respecting friction in such cases are meagre. Experiments now being made in the University of California it is hoped will before long afford useful facts respecting the friction of submerged bodies revolving at high speed.

As the water enters through one side only of the wheel, it causes a thrust in that direction, which is equivalent not to the force of suction only, as is generally supposed, but to the area of the inlet multiplied by the maximum pressure of the discharge. The pump being inverted, with the suction inlet at the top, the entering water flows downwards, and the reactive force is consequently upwards. The upward thrust, which in most cases would be objectionable, is here turned to practical account for supporting the weight of the vertical driving shaft and the pump-wheel. The plan of inverting the pump so that the suction enters at the top was introduced in California by the writer in the latter part of 1883; and was then believed to be of great importance, because of the difficulty of supporting the vertical driving shafts by other means in the deeper pits. In the case of one pump, completed in 1886, the weight of the shaft and its attachments was nearly 2,000 lbs. The shaft was of steel, $2\frac{1}{4}$ inches diameter, and ran at 600 revolutions a minute. The upward thrust was sufficient to carry this shaft, together with some additional weight which was found necessary. The lift was 90 feet, inlet of pump 10 inches diameter, throat of discharge 5 inches diameter, uptake pipe 10 inches diameter. This problem of thrust upon enclosed wheels taking water at one side is an intricate one. If the rear side of the wheel is exposed, as is common, to a pressure equal to the discharge, the thrust, as already stated, is equal to the inlet area multiplied by the discharge pressure. If the wheel is shrouded on one side only, the thrust will be equal to the whole area of the wheel multiplied by the discharge pressure.

At starting there is of course no upward thrust until the pump is charged. Provision is therefore made at C, Fig. 10, Plate 3, for carrying the shaft on collars, which are already required for steadying the revolving wheel laterally in the pump casing, and are so arranged as to support the shaft vertically for a short time, unassisted by the water thrust. The collars are screwed upon the shaft, and several thin washers of steel are inserted between them and the seat which carries them. They run in a pool of oil; or rather oil and water, because there is generally a small pipe leading a little water back from the discharge pipe D to the thrust box C. The joint thus

formed seals the pump, taking the place of a packing gland. The suction pipes SS in Fig. 10 are shown as they are commonly arranged, for branches leading in from right and left; their large area is intended to be equal to that of a number of branch pipes, and to keep the flow in all at a uniform rate as nearly as possible.

Compound Centrifugal Pumps.—Two of the main problems to be dealt with in applying centrifugal pumps to high lifts are how far the impact or mechanical push of the vanes may be disregarded as a factor in the pump's duty, and how the bearings and driving gearing may be maintained in proper order at the high speed required. Practically the speed at which the pump should be driven increases as the square of the height of lift. For example, the circumferential speed of the revolving wheel for a lift of 60 feet will be at least six times as fast as the discharge column should flow; while for a head of 80 feet the circumferential speed for the same flow would have to be more than ten times that of the discharge current. It is therefore seen in how rapidly increasing a degree the revolving wheel must overrun the flow as the lift increases; and how rapidly the effect due to impact or mechanical push of the vanes falls off, as the velocity of the wheel increases. For lower lifts the extent of overrunning diminishes in the same degree, and the gain by impact is increased accordingly. It is easy to attain high efficiency in centrifugal pumps working against a low head; but it is a difficult matter to arrange such pumps suitable for working in the deep pits in California, against a pressure of 43 lbs. per square inch or 100 feet total lift, and to secure results that are satisfactory. Thus far it has not been possible to make experiments for determining definitely the efficiency attained in these high lifts. From such observations as have been made it would seem that from 35 to 45 per cent. of the indicated power has been realised in water raised.

Some of the pits at first made were too narrow to admit pumps with volute casing and with a single wheel large enough to attain the required speed. In such cases the pumps have been compounded, as shown in Plate 4, so as to reduce the speed of rotation and diminish the size of the wheels and casing. In the compound

pump here shown with two revolving wheels R, the main casing is made in five parts, consisting of three hoops or rings and two intervening diaphragm plates, all secured together by external bolts. The driving shaft from the top of the pit is coupled to the pump spindle at C. A charging pipe P is carried down from the top of the pit, as in the case of Fig. 3 previously described. The foot of the delivery main M is surrounded by an annular air-vessel A. The water is drawn by suction into the top chamber T, whence it passes downwards through the two wheels or runners R, and out through the discharge chamber D, the delivery valve V, and the rising main M.

The two shrouded wheels have each five curved vanes, as shown in the plan, Fig. 16, Plate 4. The exact shape of the curves is believed by the writer to be a matter of very little importance in practice; and the number of the vanes, whether two or six, does not make much difference in a high-speed pump. Curved throat-pieces and tangential tips to the vanes are found in such cases to be of practical value so far only as they tend to obviate friction and consequent slight loss of power. The diaphragm above the upper runner is a plain flat plate; but the intermediate diaphragm between the two runners is made with fixed guide-blades on its upper side, for leading the water back from the circumference of the upper wheel to the central inlet into the lower. Besides the double inlet at SS, two more inlet orifices are provided in the top cover at I I, Fig. 15, for convenience of attaching additional suction pipes in different cases; but it is not often that all four inlets are required. The delivery valve V is arranged to swing clear of the ascending column of water; the area of passage is here contracted, and determines the pump's capacity. In all other parts the area of passage is made much larger. Except for avoiding concussion from the water in stopping the pump, the air-vessel A may seem superfluous in a continuously acting pump; but it is not so, and air-vessels are now applied by the writer in all cases for deep pumping. The seat of the delivery valve V is raised so as to leave an annular space all round it, for catching any gravel deposited in the valve chamber; this space is commonly made much larger than shown in the drawing.

The bottom bearing of the pump spindle at B, Fig. 13, is simply a hole bored in the base plate. There is no strain upon it when the wheels are carefully balanced. It is of course exposed to sand and gravel, but these do not seem to have much effect upon bearings of steel running in cast iron; either the sand is at once pulverised and washed out, or in some other way attrition is prevented. Similarly the throats of the inlet orifices in the revolving wheels do not seem to wear after they have worn themselves out of contact.

Triple Compound Centrifugal Pump.—In Fig. 17, Plate 5, is shown a vertical section of a proposed triple compound pump, which however was not carried out because of the low efficiency that such an arrangement must entail. The suction pipe S is here connected with the bottom of the pump casing, and the water entering at A ascends through an inlet orifice in the underside of the bottom runner, from which it is delivered to the top of the pump, and thence passes downwards through the two upper runners, and from the lower of them to the delivery pipe D. Two of the three wheels balance each other in vertical thrust; and the upward thrust of the third would be sufficient to support the steel driving shaft of $2\frac{1}{2}$ inches diameter, together with all its mountings, the whole weighing 1,800 to 2,000 lbs.

In one instance the working of a centrifugal pump has been interfered with by the liberation of carbonic acid gas in the suction pipe, owing to the vacuum of 6 or 8 lbs. per square inch below the atmosphere. The presence of such gas in artesian water had previously been suspected, because of a constant accumulation of air, as it was supposed to be by those in charge of the pumps. The difficulty is easily overcome by avoiding pockets or catchment places on the suction side.

Balanced Pump with single lateral inlet.—In Plate 6 is shown the construction now adopted by the author for pumps with a single inlet at one side, a form most suitable for the requirements of the Pacific Coast, and essential in many cases. The drawing shows a

pump of 12 inches bore arranged for a head of 30 feet. The wheel consists of a curved disc D, shaped so as to deflect the water gradually from the centre to the circumference. On the face of the disc are formed the vanes U and V of unequal area. On the back of the disc are also vanes N. Holes C are made through the disc, so that any water passing over the circumference may circulate in this way. An equal or nearly equal centrifugal action is thus set up on each side of the disc, and there is no axial thrust, the pump being balanced in the same way as though there were double inlets, one at each side. In this arrangement the suction pipe is easily removed, and can be hoisted vertically clear of the pump. The water passages are also more free, and of large area until the disc is reached. In order to guard the spindle bearing from sand and grit, the packing is placed at P inside the main bearing B, which acts also as a gland for compressing the packing. This arrangement is now employed in all the various modifications of centrifugal pumps from the author's designs, and in working permits no leak of either air or water; and the packing seldom needs renewal. The pumps are characterised by great steadiness of running, and an absence of the pulsation or jar common with free or open vanes or with shrouded wheels. Such jar is often caused by an obtuse or imperfectly formed throat-piece at T, especially with shrouded wheels, the radial flow being interrupted at that point.

A matter perhaps of some interest is the method employed of giving the proportions for different sizes of pumps of this class; it is applicable also to various other kinds of mechanical engineering work. The dimensions of all the various parts are arranged in a table, which includes one class of pumps from 2 inches to 10 inches; and this table takes the place of drawings for each size, especially in constructing patterns. In the present instance the table gives eighty dimensions for each of nine different sizes of pump. The several dimensions cannot be assumed from graduated scales, but must be the result of accurate drawings for nearly all sizes. This plan has been applied to various kinds of work in the author's practice, and is believed to be of great value in any case where system and uniformity are possible. The dimensions can be easily changed for special

machines, and determined by approximation, without the usual difficulty of working out a wholly new design.

Improved Pit Pumps.—In Fig. 21, Plate 7, is shown the common arrangement of what are called pit pumps in California. When the water rises in the wells within suction distance of the surface, horizontal pumps similar to that shown in Plate 6 are employed; but when this distance exceeds 20 feet, rectangular pits are sunk, from 10 to 60 feet deep, as previously described and as shown in Fig. 21. Two or more tube-wells T are sunk from 50 to 150 feet below the bottom of the pit; and in these are inserted the suction pipes S, leading to the suction box A on which the pump P is mounted. The driving shaft D is supported in thrust boxes BB, and when of several lengths is connected by clamp couplings, as shown in Figs. 8 and 9, Plate 2, the bolts L passing through the ends of the shaft D, so that the couplings may not drop down if they should come loose. The pump being balanced, there is no thrust except that caused by the weight of the spindle and wheel. This is taken up in the thrust box E, which has an annular oil-chamber, and collars that perform the double office of supporting the spindle and sealing the joint to prevent the entrance of air, thus taking the place of the common packing gland. The air-vessel H and check-valve V are shown in enlarged section in Fig. 22. The valve V is so arranged that when open it stands clear of the water-current, as indicated by the dotted lines; otherwise the facing is soon cut away by the sand and gravel, which act like the sand-blast. Foot-valves cannot be employed in the suction pipes, because in most cases there is no room in wells for a case large enough to allow of the valve opening fully. The valve seat at K is raised to avoid the valve being fouled with gravel. The external case H is made rectangular in plan, with the two-fold object of giving it elasticity, so that it shall not be broken by water-shock in stopping, if the air cushion should fail, and also of allowing the valve to open fully. The uptake pipe U is usually made of sheet-iron coated with zinc and soldered at all joints. The area of these pipes is an important matter, and does not seem to conform with the usual rules and computations respecting resistance.

It is found expedient to have their area at least four times that of the pump discharge, when the head exceeds 50 feet. A charging pipe N is carried up to the surface, where an air-pump or steam-ejector is employed to exhaust the air and fill the pump P.

Among the principal objects aimed at in the present pumps are—the greatest possible simplicity; easy separation into parts, so that the machinery can be raised out of the pits or lowered into them without tackle; access to all interior parts; and the highest efficiency possible under the circumstances. The circumferential speed of the pump-wheels in feet per minute being approximately 500 times the square root of the head in feet, wheels of 24 to 30 inches diameter can be used for heads up to 100 feet without the speed of the shafts exceeding the rules of safe practice.

In 1884 the author designed compound or double-wheel pumps for use in pits, two wheels being employed as proposed many years ago by Mr. Gwynne and also by continental makers; but with the difference that the water was drawn into the top of the pump and discharged from the bottom, as shown in Plate 4. The wheels being unbalanced, and subject to a thrust equal to the area of their inlet multiplied by the head, by inverting the pump this force was employed to support the weight of the revolving parts. This seemed a good method of evading the thrust; but the least change of speed destroyed the equilibrium, so that the thrust was first up and then down; moreover the upward thrust did not begin until the pump was acting, and consequently in starting, or in case of the pump drawing gas so that the water failed, the whole weight of the running parts was thrown on the pump bearings. A number of these pumps have been made, and have performed very well, with the exception of the above difficulties and a low efficiency. The efficiency was reduced by the discharge from the wheels being radial and the impact being of course lost. The effect of the mechanical push of the vanes is no doubt greatest when the relative speed of the tips of the vanes and of the water at the same point is approximately as two to one; and it diminishes as this ratio is departed from in either direction. This indicates for high heads the expediency of a contracted volute or casing, so as to give the water as great a

velocity as possible there until the discharge is reached. Some recent experiments confirm this view.

In Plate 3 is shown a horizontal pump for shallow pits, designed by the author in 1884, and applied in a number of cases for lifts from 30 to 50 feet. It is also an example of balancing the weight of the driving shaft by the upward thrust of the wheel, the water being taken in at the top. The wheel is of the shrouded or encased kind with six vanes, discharging into a volute casing. These pumps were at first arranged without a packing gland for the spindle; but the irregularity of the upward thrust and the consequent lifting of the shaft prevented effective sealing by the thrust collars at C. A difficulty sometimes experienced with these pumps receiving the water at the top is the accumulation of carbonic acid gas given off by the artesian well water, especially from deep wells. In the pumps arranged as in Fig. 21, Plate 7, this does not occur, because the gas is free to ascend and pass out with the discharge water.

Low-lift Centrifugal Pumps for land reclamation and irrigation.—As the Sacramento and San Joaquin rivers approach the ocean, the sedimentary plains bordering upon them sink below the level of the winter and spring floods, and hundreds of square miles become covered with water from one to ten feet deep. These plains are called tule lands, from a kind of soft reed of that name which covers the whole surface where water stands. When drained of water and cleared of the tule growth, the soil is a bed of vegetable compost of such surprising fertility and strength that crop after crop can be grown in the same year. It is mainly on these tule lands that are produced those prodigious crops of wheat, barley, potatoes, &c., which have rendered California famous in agriculture. These fertile lands, lying near San Francisco, and reached by water, rail, and roads, are of great value, and their reclamation has been the object of costly and extensive efforts. The work has been attended with great difficulty, and the larger part of the area once drained has subsequently been lost again, in consequence of the fluctuations of the rivers being so uncertain, and the period of exact observation having not yet been long enough for determining the levels of high

M

floods. Moreover placer mining has sent down silt enough to change nearly all the levels during the past twenty years. The embankments when made of peat have not weight enough to resist the pressure of the water; and being buoyant are sometimes floated away bodily. They are so porous that the percolation is enough to require pumping machinery in most cases; besides which, the rainfall in winter and spring has to be pumped out when the rivers are higher than the lands. The uncertainty as to the quantity of water to be raised, the absence of permanent foundations, and the speculative nature of the attempts to reclaim the land, require machinery not merely of a cheaper kind than elsewhere, but also of quite a different character from that employed in other parts of the world, where land drainage is mostly performed at central pumping stations constructed for a definite and permanent duty. The tule lands are divided into districts, for each of which there is an engineer by whom all plans and estimates for pumping machinery are closely examined; and a guarantee of efficiency is required.

Besides the reclamation of the tule lands, there is also the nearly analogous duty of pumping from rivers to irrigate what are called the bench lands, lying from 15 to 30 feet above the water level. The limit of the height to which water can profitably be raised by machinery for ordinary crops at the present price of fuel and cost of machinery may be set down at 25 to 35 feet. Most of the pumps now in use are of small size, such as may be driven by threshing engines of 25 to 35 I.H.P., and are of the types already described.

In Fig. 23, Plate 8, is shown a reclamation pump of the usual construction, which is mounted on a framing made of Oregon pine. This is a hard stiff kind of timber, almost as strong as ash, straight grained and without knots, of which beams can readily be obtained 50 feet long and 24×12 inches section. For the smaller pumps, iron bed-plates are employed; and also for the larger, wherever the extra cost is not objected to; but the timber frames answer very well, provided the machinery is so arranged that its working shall not be interfered with by such flexure as the timber framing is liable to. The centrifugal pump is arranged with its spindle horizontal; and in order to avoid end thrust the wheel is made with open vanes. The

interior of the casing is turned smooth; and the wheel is also carefully turned after having been fixed on its spindle. The engine E has two single-acting cylinders, of which the diameter is usually equal to two-thirds that of the discharge pipe D from the pump, when the total lift is not to exceed 20 feet. The driving shaft is of steel, and is connected with the engine by a compression coupling C, Figs. 6 and 7, Plate 2, the same as previously described. The bearing B next the pump is mounted on a planed iron seating, so that it can be slid back when the pump gland requires packing. By thus supporting the driving shaft close up to the pump, no bearing is required on the suction side of the pump, which would be objectionable on account of the obstruction it would offer to tule roots, weeds, straw, and other rubbish that finds its way into the pump.

All the parts have to be arranged for allowing of ready access to the interior of the pump and pipes. The suction pipe S is slung by a chain N, so that it can be lifted away from the pump in case of the foot-valve at F becoming choked. The inlet nozzle of the pump casing can be cleared from ordinary obstructions by removing the hand-plate at H. The two side-plates of the pump casing are easily removed. Whenever the wheel becomes clogged with tule roots, the suction pipe S and the plate on the same side are loosened and swung aside; the coupling C is also loosened, and the wheel can then be drawn out at the suction side to be cleared. The time of the whole operation need not exceed ten minutes.

The pump here shown, Fig. 23, Plate 8, is of a semi-portable character, and adapted to most cases, but not to all. When the head varies on the delivery side, as it does sometimes from 1 foot to 14 feet, it is evident that a pump arranged in this manner would not answer. The pump and engine must of course stand above the water-level, which varies both inside and outside the embankment. There is no means of working economically against a low head, except by submerging the pump wheels. The height of the suction lift must be more than the variation of the water inside the embankment. Consequently when the water is low on both sides of the embankment, as much as two-thirds of the work may be lost, unless the syphon

action of the discharge pipe can be relied upon. A bottom discharge for the pump would remedy this difficulty in a measure; but it would involve the addition of an air-tight sluice-valve in the discharge for starting the pump, and also a pneumatic or steam charging apparatus. The syphon action of the discharge pipe soon ceases, especially when the pipe is large, unless there is some means of continuously exhausting the air given off by the agitation of the water in the pump. To connect the discharge pipe with a condenser, or to employ other means of exhausting the liberated air, introduces complication not compatible with the attendance commonly received by such pumps on the Pacific Coast.

Submerged Pumps.—In Fig. 18, Plate 5, is shown a vertical pump of the Whitelaw type, of which several have been constructed on the Pacific Coast from the writer's designs; it is one of the cheapest arrangements, and places the machinery well above the water, excepting only the pump-wheel which is submerged. The engine and boiler are placed on the top of the embankment M, and are generally raised one to two feet above the ground; the embankment itself is in most cases wide enough for a roadway on the top, whereby fuel can be hauled or access obtained to the works when the whole country is flooded. The pump casing P is a vertical cylinder, having a suction nozzle at the bottom, and a flange at the top by which it can be suspended from the bottom of the trough T. The pump spindle is supported in three bearings as shown, and is driven by a band from the engine E. A pair of bevil wheels are sometimes employed at the top of the spindle, so as to avoid twisting the band. The wheel or runner R is curved upwards, so that the tips of the vanes terminate parallel with the sides of the pump casing. Inside the casing is inserted a central sheet-iron cone C; and the current of discharge water, ascending through the widening annular space between the cone and the cylindrical casing, loses its velocity gradually as the area of passage enlarges; while at the same time the whirling motion with which it quitted the wheel is checked by means of curved blades B fixed on the outside of the cone, whereby the current is deflected upwards.

Since centrifugal force acts at right-angles to the axis of rotation, it is evident that the water has to undergo deflection through one more right-angle in a pump of this kind, with curved runner discharging parallel to the axis, than when the discharge is at right-angles to the axis. But although the efficiency may thereby be impaired to the extent of as much as 10 per cent., this is often of less importance than the countervailing advantages gained with submerged pumps. There is no charging to be done, no valves, and no pipes. Tule roots and other obstructions pass freely through the runner, and are thrown out against the pump casing, where they are soon worn away. The pump shown in Fig. 18 is for raising 400,000 gallons an hour, the cylindrical casing being 40 inches diameter, and the engine capable of developing 35 H.P. Similar pumps have been erected on the San Joaquin and the Colorado river, and have raised 660,000 gallons an hour.

Nearly forty years ago Mr. Whitelaw's experiments at Johnstone, near Glasgow, demonstrated that a high efficiency could be attained with pumps arranged in this manner. The only impediment is in utilising the energy of the water after it leaves the wheel R. If the velocity is destroyed by impinging against the body of water in the uptake P, the efficiency for low heads will not exceed 40 per cent. The pump shown was much improved by inserting above the wheel R the cone C having curved deflecting blades B, which change the motion of the water from a horizontal to a vertical direction. With careful attention to the various conditions accompanying the action of centrifugal pumps, this arrangement has much to recommend it, especially in economy of first cost. In the Louisiana district about the mouth of the Mississippi river, pumps of this kind are extensively employed for low lifts, the action being analogous to that of a turbine water-wheel inverted, and centrifugal effect being almost disregarded.

Bulkhead Pumps.—In Fig. 25, Plate 9, is shown a plan of a pair of centrifugal pumps arranged for driving the water through a bulkhead against a head varying from nothing to 10 feet. The

pumps are submerged to a sufficient depth to require no charging, and consequently no valves are necessary. The area of the two discharge nozzles is 150 square inches each, and the quantity of water delivered is 500,000 to 800,000 gallons an hour. This arrangement is the least expensive that can be adopted for land drainage or irrigation; it was suggested by a Dutch engineer who had erected similar works in Java, and has been found in every way satisfactory. The embankment is cut through, and a strong timber bulkhead A is erected across the gap. The pumps P P are placed immediately behind the bulkhead, with their discharge nozzles projecting through it. Flap valves opening outwards are hung over the discharge nozzles at D, to prevent back flow through the pumps when not working; in dry seasons they are sometimes opened for letting water flow through for irrigation. The vertical pump-spindles are driven by bevil gearing from a horizontal shaft. The engine E is single-acting, with two cylinders of 10 inches diameter, and its speed is 300 revolutions per minute. The machinery shown in Fig. 25 was erected during 1885, on the Sacramento river, 75 miles from San Francisco, for draining tule lands.

The average head in this case being only from 3 to 5 feet, it was considered that the water could be driven more by direct push than by centrifugal force. The pumps were constructed accordingly with smooth iron vanes, bolted to a square extension on the pump spindle, as shown in Fig. 26, Plate 9. The throats of the suction inlets were made very sharp, and brought in as close as possible to the inner tips of the vanes. In the writer's opinion the effect would have been much the same, or perhaps even better, if the volute casing had been replaced by the ordinary concentric casing. When a good turbine water-wheel will realise a duty of 70 to 80 per cent. by the direct pressure of the water, there seems no reason why a centrifugal pump, considered as a turbine-wheel acting in the reverse manner, should not utilise in some near proportion the power applied to it for moving and raising water. The writer is not aware whether any investigations have been made in this direction; but there appears to him to be a close analogy between the two cases, at least for low heads.

Pumps driven by Bands.—In Fig. 27, Plate 9, is shown an arrangement for raising 900,000 gallons an hour by means of two centrifugal pumps driven by bands. The two discharge nozzles from the pumps are each 115 square inches area. The pumps have open wheels, and double suction-pipes S, one on each side, not joined; each pipe has a foot-valve of 100 square inches area. The suction-pipes themselves serve as the supports for the pumps, being made strong and with large flanges to rest on the timber framing. The sump U is 6 feet deep, and the suction-pipes dip into it to different depths, so that when the water supply falls short the higher pump will run empty or be disconnected, leaving the lower only to continue working.

The discharge pipe D carried through the embankment is 30 inches bore, and is set with slope enough to let the water run down it from the pumps when the head at the discharge outlet O is not too high. The engine E is placed level with the top of the embankment, 15 feet above the pump floor. The whole of the machinery is mounted on wooden framing, being on treacherous ground; it was erected during the winter, when no other foundation was possible, for the purpose of draining the leakage and rainfall from 8000 acres of land, surrounded by embankments 15 miles long; the estate is on the Sacramento river, and is one of the best maintained in the valley. The embankments are of a superior character, being for the most part made of clay or loaded with clay; they sink however, and have continually to be raised and strengthened. This plant has since been increased to a capacity of 2,400,000 gallons an hour, by the addition of pumps of 30 inches bore, driven by a directly connected engine.

Single-acting Engines.—For pumps directly geared to engines, the practice differs somewhat from that of English makers; but is much in advance of the methods employed in the Eastern States, unless it be in the case of one firm there, who have copied Messrs. Gwynne's pumps and drive them with pairs of single-acting engines. The author at first employed single-acting engines, as shown in

Fig. 28, Plate 10. These are in some respects well suited for driving centrifugal pumps where permanent foundations are wanting, inasmuch as they are wholly self-contained, work at high speed with reasonable economy, and occupy but little space. As the thrust on the connections and bearings is in one direction only, there is no compensation to look after. There are no glands to pack, except that of the valve-spindle, and scarcely any oiling to do. In Fig. 28 is shown a longitudinal section through one of these engines, and in Fig. 29 an end elevation. The valves are of the oscillating cylindrical kind, the steam entering at S round the outside of the valve V, and exhausting through its interior. The connecting-rods are of brass, made as light as possible. The crank shaft is of steel, with cranks opposite, and with counterbalances bolted on at C. The valve-gear G is of the simplest construction, consisting merely of an overhung crank and connecting link; the eccentricity of the crank can be readily adjusted for regulating the lead of the valve, or reversed for running the other way. Automatic gear for controlling the speed by the cut-off is sometimes applied; but for regular duty, like pumping, the throttle-valve adjusted by hand is quite as good, and is better understood by attendants. The crank chamber M is partially filled with a bath of water and oil, which is splashed by the cranks into all the bearings and also into the cylinders; no other oiling is required, except of the valve-link, which is made hollow so as to be oiled at both ends while in motion. The cylinders are surrounded by a rectangular casing which serves as an air-jacket, so that but little heat is lost by radiation.

The objections to this class of engines are their dimensions in the direction of the crank-shaft, a want of steam economy, and the low duty consequent upon the compression at the top of the upstroke, required to keep the bearings in contact and to avoid knocking. The difficulties that have been met with during the past ten or twelve years in maturing these single-acting engines are considered by the writer to lie, not in the principle or mode of working, but in providing a suitable connection for transmitting the power from the pistons to the cranks on the driving shaft.

Differential or Compound Engines.—In the author's later practice the engines adopted are of the differential or compound type, as shown in Fig. 30, Plate 10, embodying nearly all the advantages enumerated in favour of the single-acting engine, but in smaller space and more simple. The steam is admitted first into the annular space A surrounding the trunk T, and after acting in the upstroke underneath the piston P is expanded upon the top in the downstroke, acting then on the difference of area between the two sides of the piston, and expanding three times or more. The engines are made without stuffing-boxes except for the valve-stems; and oiling is performed by enclosing the parts, as in the single-acting engines. In this way a good expansion is attained with a single and simple slide-valve; and the engine is reduced to the fewest and simplest parts possible. In Fig. 24, Plate 8, is shown one of these engines connected with a pump for low heads not exceeding 15 feet.

Hydraulic Rams.—Owing to the extensive use of small hydraulic rams on the Pacific Coast, some experiments were commenced at the beginning of last year 1887 by the author in conjunction with Messrs. W. T. Garratt and Co., engineers of San Francisco, in order to see whether larger machines of the kind could be constructed for meeting the requirements of raising water from the mountain streams. As yet these experiments are by no means completed; but the author believes some of the constructive features are of sufficient interest to warrant their being appended to the present paper. The various phenomena that arise in employing the impact of water in hydraulic rams are such as to render the matter one of experiment, unless in cases where the intermissions or valve-movements are controlled by independent machinery, that is by some power independent of the flow or issue of the water passing through the ram. The latter is unquestionably the correct method, if the supplemental mechanism can be made durable and reliable, as no doubt it can.

The first experiments made were with small rams having inlet pipes from 2 to 3 inches diameter, as shown in Fig. 31, Plate 11, in which I is the inlet pipe and D the discharge pipe; C is the check or

foot-valve, and A the air vessel; and V and E are the escape valves fixed on the same stem. A plan of the top of the lower valve E is shown in Fig. 32. The two valves V and E being nearly balanced, the difference of their areas constitutes the measure of the upward or closing force, which is of course much less than in the case of a single valve. The valves fall by their weight in the usual manner; and are raised partly by the stream rushing out round the upper valve V, but mainly by the upward pressure of the issuing current against the curved shield S fixed on the valve stem.

In working it was found that accurate adjustment was required to suit the head or fall of the driving water; and also that the shock was too great for the safety of large rams. The method was therefore changed to that shown in Fig. 33, Plate 11, in which the two escape valves V and E are arranged to pass up freely through their seats, and are stopped by an air cushion at the top. The waste water nearly all escapes at the upper valve V, small outlets only being provided in the lower valve E for permitting sand to escape if any should be carried into the machine. The closing is effected, as before, mainly by the upward pressure of the issuing stream against the curved shield S. When the valves are shot upward in closing, the shield enters the air chamber above it, in which it fits as a piston, and the momentum is thereby checked without the least shock. An air cock is inserted in the top of the air chamber at L, for regulating the amount of resistance offered by the air cushion. Additional weight if required for opening the valves is added on the top of the valve-stem at K; it is found however that, the higher the delivery head, the less is the weight required, because of the reflux. Snifting valves were at first applied, but seemed unnecessary. Rams arranged in this manner work without noise or jar, and give a high efficiency for forcing four to five times the height of the propelling head, and are suitable in most cases for irrigating purposes; but when the resistance is increased, the elastic blow or percussive impulse of the current is not enough to raise the check-valve C against the increased area caused by its lap.

In Plate 12 is shown another arrangement of hydraulic ram, in which the escape valve is opened by independent mechanism. The

water enters at I, and the waste escapes at the bottom through four holes shown in the sectional plan, Fig. 37. These holes are alternately covered and uncovered by the four wings of the oscillating valve V, which is mounted on a spindle S. The valve is opened by means of the water-wheel W and the tappet motion shown in Figs. 34 and 36. The two tappets coming in contact at each revolution of the water-wheel open the valve to such an extent as may be determined by the adjusting set-screw in the slot at A. As soon as the tappets disengage, the valve is closed by the reaction of the issuing stream against its curved ribs or vanes, as shown in Fig. 37, the motion being arrested by the tail T of the tappet arm, Fig. 36. In this manner the motions of the waste valve V can be controlled at will, and a greater efficiency attained than with the ordinary method of employing the force of the issuing stream for closing the valve by lifting it. Experiments have not yet been made to determine the most effective motion of the valve with respect to the time of closing; but the indications point to variable requirements in this respect, depending on the resistance offered or the height to which the water is being raised. The action of the machines is smooth and regular when the closing motion is not too abrupt.

While unable at present to furnish a more complete description of this class of machines, the author hopes the subject is wide enough to permit of its being again brought before the Institution on a future occasion in a more complete form.

Discussion, 30 September 1887.

Professor W. CAWTHORNE UNWIN considered the paper was extremely interesting, because it gave a kind of record of the slow evolution of a particular class of machinery, extending over a long course of years, and no doubt embodied results due to extensive experience: so that the conclusions at which the author had arrived ought to be received with a very considerable amount of respect.

What would most attract the notice of English engineers was the account given of centrifugal pumps, especially of compound centrifugal pumps. These had been proposed a very long time ago, having been described in Morin's book on pumps; but for some reason or other they had never found favour in this country, and comparatively few had been constructed in Europe. But obviously in California they had succeeded; and looking at them from any theoretical point of view, they certainly ought to succeed. He could not conceive why, in many cases where centrifugal pumps were used in this country with moderately high lifts, the pumps had not been made compound. It appeared to him that the whole of the difficulty which arose in adapting the centrifugal pump to a moderately high lift was cleared when the pump was made compound. Perhaps some of the Members might have seen in Manchester the triple compound centrifugal pump designed by Professor Osborne Reynolds, which was working with great success, and he believed with considerable efficiency.

In page 39 of the paper it was stated that after the head reached 40 feet the efficiency of centrifugal pumps fell off rapidly; but he knew of some practical results which would contradict that; and especially from the theoretical point of view he could not conceive why at 40 feet head the efficiency should in any way diminish. The centrifugal pump was simply a reversed turbine; and turbines were being put up on falls not of 40 feet but of 400 feet, and showed the same efficiency at the higher head as at the lower. He did not know of any instrument used by engineers, in the design of which there was sometimes more recklessness of scientific considerations than was seen in the design of centrifugal pumps. Either a

centrifugal pump was put up to work on lifts varying from 0 to 30 or 40 feet; or if the lift were constant, the pump was expected to pump sometimes 1000 gallons an hour and sometimes 10,000. No single machine like a centrifugal pump could possibly be adapted to such great variations of condition, without working for a great part of the time at a low efficiency.

The low efficiency of the centrifugal pump had arisen chiefly from two causes. The first was that the pump was expected to adapt itself to the motor, instead of the motor being adapted to the pump. It was convenient to run an engine at a certain speed suited to the engine itself; and therefore the pump was wanted to run at the speed which suited the engine. The efficiency of the centrifugal pump, like that of the turbine, was very closely connected with the diameter of the pump; and if good efficiency was wanted in centrifugal pumps, they must be made of a diameter which suited the lift. The friction of the pump increased something like as the fifth power of the diameter: whence it was easy to see that the waste of work, which was almost entirely friction in the pump, increased very fast if the pump was made of too large a diameter. The second cause of low efficiency in centrifugal pumps was the absence of proper arrangements for utilising the kinetic energy of the water leaving the pump disc.

A statement made in page 41 of the paper appeared to him to be an error, which, though not very serious, affected the choice of the type of pump. The author there spoke of pumps with encased or shrouded vanes as having been largely used and in many cases abandoned; and the only argument he used against the efficiency of such pumps was that they were liable to have considerable leakage at the joint between the pump and the casing all round the inlet orifice, Fig. 10, Plate 3, because the pressure at that joint was the full pressure due to the head in the discharge pipe. That however was not the fact; for the water between the stationary casing and the pump-wheel was put in rotation by the friction of the outside surface of the revolving pump-wheel. As the consequence of this water being in rotation, the ordinary proportion of pressure or head at the joint round the inlet orifice was only one-fourth what it

(Professor Unwin.)

was at the outer circumference of the wheel; and therefore, although there might be a slight gap at the joint, any leakage at that point he thought was not really a very serious matter.

In regard to the unbalanced axial thrust of the centrifugal pump which received the water on one side (page 42), the way in which that thrust acted was perhaps not at first sight quite intelligible. Within the last week he had received from California an account of some experiments on the amount of this thrust, suggested no doubt by precisely the experience described in the paper; and they so far explained the action of the thrust that he would point out the results to which they led. In some of these pumps, as mentioned in the paper, the whole weight of the pump and gearing was supported by the upward thrust due to fluid pressure in the pump. It had occurred to Professor Hesse to see whether a good footstep might not be made by utilising this thrust; and the attempt had been made in the way shown in Fig. 38, Plate 13. The foot of the vertical shaft S was immersed in a cylindrical casing of water; on the shaft was fixed a perfectly flat circular disc with radial vanes V on its upper face only; while in the bottom of the casing were fixed similar stationary radial vanes B. There was only a little clearance left between these stationary vanes and the plain underside of the revolving disc; and only a little clearance also between the circumference of the disc and the sides of the casing. In the revolution of the shaft the disc with its vanes V acted like a centrifugal pump, producing on the top side of the disc a distribution of downward pressure corresponding with the parabolic surface shown by the area ACWCA, Fig. 39; there was thus a low head or pressure at the centre and a high head or pressure at the circumference. On the underside of the disc the water was kept practically still by the fixed vanes B; and therefore the pressure all over the underside of the disc was practically uniform. This uniform upward pressure on the underside of the disc was that due to the higher head at its circumference on the upper side, and was represented by the rectangle ACCA; and consequently the area contained within the interior of the parabolic curve CWC represented the effective upward thrust which supported the weight of the shaft. At first sight it might be said that this was pretty enough

in theory, but that the friction would be much greater than that of an ordinary footstep. From some singularly careful experiments however, which had been made in California and appeared to be entirely trustworthy, the result arrived at was that for a shaft carrying a weight of 2 or $2\frac{1}{2}$ tons it was possible to design a footstep of this kind of quite moderate dimensions, with a casing of about 18 inches diameter, and with a friction only about half that of an ordinary footstep.

The PRESIDENT then adjourned the discussion to the next meeting. In the meanwhile he would ask Mr. George Richards, who was present, to express the thanks of the Institution to his father for this interesting paper; and to request that, if he had any more information to give, he would kindly send it in time for the continuation of the discussion at the next meeting.

Adjourned Discussion, 2 February 1888.

Mr. RICHARDS sent the following reply to the observations made in the discussion at the previous meeting:—

On reflection perhaps Professor Unwin will modify his statement that a centrifugal pump is simply a reversed turbine. Conversant as he is with the laws governing the operation of these two machines, it appears to the author that he must have some other meaning than that they are identical; for centrifugal action, which is the principal factor in the duty of a pump, holds a secondary rank in a turbine, and is often wholly disregarded. His remarks concerning the adaptation of centrifugal pumps to their work are fully confirmed by the author's own observations and experience.

In respect to the objection to wheels with encased vanes, the intention in the paper was to point out that in the case of a single-

(Mr. Richards.)

inlet pump such wheels cause an axial thrust equal to the area of the inlet multiplied by the discharge pressure. While Professor Unwin is unquestionably correct in assuming a rotation of the water on the smooth sides of an ordinary shrouded wheel, yet when two or more such wheels are compounded this rotation of the water is not permissible, and has to be prevented by baffling vanes or fixed guide-blades, in order to destroy centrifugal effect and so to permit the water to return to the centre of the second wheel.

The axial thrust of the pump discs is an obscure matter or at least not well understood. A wheel of 24 inches diameter constructed as in Plate 6, but without the vanes on the back, would when working against a head of 40 feet sustain an axial pressure on the back of more than 7,000 lbs. This is opposed by less than one half as much pressure on the front face, leaving what may be called a destructive force pulling the wheel and spindle towards the front or inlet face. The pressure resulting from the impact of the entering water on the front or receiving face, and the gradually increasing pressure on this face from the central inlet to the circumference, are subjects well deserving attention from a scientific point of view: as is also the pressure at different points of the pump casing from the central axis to the circumference, which so far as the author knows is a matter not yet treated upon in any literature on the subject.

Mr. HENRY DAVEY remarked that the triple compound centrifugal pump, illustrated in Fig. 17, Plate 5, appeared to him at first sight to be a very peculiar construction, and one which he did not believe could give a high efficiency. Having had some little experience with centrifugal pumps, though not with compound centrifugal pumps, he imagined from the drawing shown that a compound pump of that construction must possess some radical defects. Such a pump he considered should have a freer vortex or delivery channel round the circumference of the wheel; the casing of the pump was here so near the circumference of the wheel, that there was a very small vortex indeed, and by no means a free one. Moreover the water was baffled, as the author had explained, with the object

of destroying its centrifugal force in leaving the topmost wheel, and of permitting it to go to the centre of the next below. This baffling must detract largely from the efficiency of the pump. Taking the case of an ordinary single centrifugal pump on a vertical spindle, as shown in Fig. 41, Plate 14, the delivery from the pump should be something of the form indicated at D, with a large free vortex in front of the mouth of the pump. Guide vanes had been put into pumps of that construction, with the object of utilising the energy in the vortex for causing the water to ascend; but unless the guide vanes had been very cleverly arranged he believed they had been proved to do more harm than good. This had certainly been the case in two or three pumps of that kind which he had himself put up. Guide vanes were useful in a large centrifugal pump if they were above the free vortex, and if there were not too many of them, say not more than three. In the pump shown in Fig. 17, Plate 5, there appeared to be vanes immediately under the topmost wheel, so that the water which was rotating in front of the mouth of that wheel was at once baffled by the vanes underneath it, and was thereby compelled to take an inward direction towards the suction of the next pump. In this baffling there must be a considerable waste of energy. In the first place there would be a loss of energy from want of a free vortex in front of the mouth of the wheel; and then there would be a further loss of energy from the baffling caused by the fixed vanes.

The collar bearing shown in Fig. 4, Plate 2, did not appear to him to be a good kind of bearing for carrying a heavy weight, such as the heavy vertical spindle of a heavy centrifugal pump. In Fig. 40, Plate 13, was shown a bearing which he believed had been first introduced for centrifugal pumps by Messrs. Easton and Anderson, and which he had used himself when bearings of the kind shown in Fig. 4 had failed. On account of its shape it was called an "onion" bearing; and it consisted of a steel forging, turned to the bulb shape B, with a steel shank passing up through an overhead girder and held by nuts on the top. The spindle S was steadied laterally by the usual bearings to keep it central; but the weight was entirely taken by the gun-metal collar C, which was coupled to the top of the spindle by a flange joint

N

(Mr. Henry Davey.)

with bolts. It would be seen that the upstanding rim upon the top of the collar formed an oil cup above the onion, while the top of the spindle formed an oil cup below : so that the onion ran completely submerged in the oil, which could not possibly get away. This bearing was highly successful, as he could say from experience in several instances where he had applied it, and where an ordinary collar bearing had entirely failed, and a thrust block had also failed. Why this kind of bearing was so successful was not simply because it was submerged in oil, or because the surfaces were larger or of a better shape, but also because it was entirely free, and did not bind the spindle in any way whatever ; the spindle was steadied in its own guides, while this suspending bearing was free to take an even bearing. It was not so with the ordinary collar bearing, which had to perform the two functions of supporting the load and also of centering the spindle. There was a freedom in the onion bearing which there was not in the ordinary collar bearing or thrust block ; and it was partly due to this freedom he thought that the bearing was so successful. In one case he had taken out a thrust block which had about three times the area of bearing surface that there was in the onion bearing which he had substituted for it ; and with the latter he had never had the slightest trouble, whereas the thrust block had always been failing before.

Mr. JOHN G. MAIR pointed out that Fig. 17, Plate 5, was stated in the paper to represent merely a proposed triple compound pump, which however had not been made because of the low efficiency that such an arrangement must entail. He desired to thank the author for so generously giving the results of so extensive an experience in low-lift or irrigating pumping machinery. Some of the arrangements of centrifugal pumps described in the paper were undoubtedly good ; but a pump arranged so that the water leaving the disc could continue its rotation in a whirlpool chamber would give the best efficiency. Good examples of this had been given in the paper by the late Mr. David Thomson,* describing the centrifugal pumps of his

* Proceedings of the Institution of Civil Engineers, 1871, vol. xxxii, page 28 and Plate 9.

design which had been made by Messrs. Simpson and Co. for Leith and West Hartlepool docks.

In designing low-lift pumps a question often cropping up was at what height of lift was it better to adopt a centrifugal pump rather than a reciprocating pump. In Fig. 44, Plate 16, where the abscissae represented the height of lift in feet and the ordinates denoted the percentage of efficiency, it was seen from the curve RR that the efficiency of a reciprocating pump fell off very fast indeed as the lift decreased; and it became an important question for engineers what type of pump was most suitable for low lifts. From the experiments made with the centrifugal pumps at Leith and West Hartlepool docks their efficiencies were 70 per cent. on a 20-foot lift and 49 per cent. on a 12-foot lift, as shown by the line C in Fig. 44; but it must be borne in mind that, although a centrifugal pump, if running at a uniform speed, had the advantage of increasing its discharge when the lift was decreased, still its efficiency was at a maximum for that speed only for which it was designed. From the diagram, Fig. 44, it would appear that for pumping water to a less height than about 30 or 35 feet centrifugal pumps had an advantage over reciprocating pumps. An efficiency of over 60 per cent. on 15-foot lifts had generally been obtained by Messrs. J. and H. Gwynne, and of 58 per cent. on a 5 ft. 6 ins. lift, as shown by the line G. But when the lift fell to so low as 5 or 6 feet, it was a question whether scoop wheels, preferably of the Sagebien type, or screw pumps, were not more efficient. Some very large Sagebien wheels put up in Egypt gave an efficiency of 70 per cent., while the large Archimedean screws made on Mr. Wilfrid Airy's system, and also put up in Egypt, gave an efficiency of 80 per cent.; but these had been partly replaced by centrifugal pumps made by Messrs. Farcot of Paris, having vertical spindles driven direct from the crank-shafts, which were reported to give an efficiency of 65 per cent. The scoop wheels used in the Fen districts generally had flat floats, and therefore lifted the water higher than the discharge level; while the Sagebien wheels had curved floats, and were more economical. In a series of notes on scoop wheels by Mr. Wilfrid Airy in "Engineering," vol. ix, 1870, a description was given of

(Mr. John G. Mair.)

the Fen wheels, and it was stated (page 274) that if scoop wheels were thoroughly well designed and made they should have an efficiency of 75 per cent., exclusive of the engine. Wheels and screws were very much heavier than centrifugal pumps of equal pumping capacity, and they ran at very slow speeds and required the discharge level to be constant; so that, taking all points into consideration, he believed that for lifts below 30 or 35 feet centrifugal pumps were the best to adopt for general purposes. He preferred to use a larger diameter of disc than was usual, so as to run at a moderate speed and thereby avoid excessive wear and tear; and this saving more than compensated for the loss of efficiency due to the extra disc friction.

For pumping out graving docks, where the height of lift was a varying one, centrifugal pumps were undoubtedly the best to use. In Fig. 45, Plate 16, were shown the results of experiments with two of the large centrifugal pumps made by his firm for the Tilbury docks; from which it would be seen how the discharge decreased as the lift increased, the speed of the discs not varying much during the trials, except at the very end when it was increased in order to run the steam down in the boilers. The blades of the fans were made flatter curves than they would have been, had the lift been a constant one.

Mr. HENRY DAVEY asked whether the reason could be given for the lower efficiencies of the reciprocating pump that were shown in Fig. 44 for lower lifts.

Mr. MAIR replied that the efficiencies he had given in Fig. 44, Plate 16, were simply the results of actual experiments.

Mr. H. D. PEARSALL, referring to the subject of hydraulic rams, which was dealt with in the concluding portion of the paper, considered the use of hydraulic rams on a larger scale than hitherto was no doubt a very desirable object if it could be attained. The author's experiments with rams were undoubtedly a valuable contribution to the subject; but they had not, as he had candidly

admitted, solved all the problems presented. The reason of the difficulties encountered, and the means for their removal, he would endeavour to show. Until the air cushion or dash-pot was added, it was stated on page 58 that the shock of the closing valve was too great for the safety of large rams; and this had indeed always been found by other experimenters. And when the air cushion was added, it would further appear (page 58) that the ram had not power enough to raise any water to more than five times the height of the propelling head. Moreover the cushioning action was not carried very far, and seemed still quite imperfect; for on page 59 it was stated that the action was smooth and regular "when the closing motion is not too abrupt." Those facts were valuable and interesting; but the author had not pointed out, and did not seem to be aware, that the loss of power observed was the natural consequence of adding the air cushion, which evidently acted by checking the motion of the waste valve and causing it to move slowly towards the end of its stroke. That was the moment when the water which was seeking to escape through the valve was flowing at its greatest velocity, while the smallness of the orifice was tending to check the flow of the water. If the motion of the valve was made slow, that action lasted for a longer time, and the flow of the water was checked very considerably. Such a check was so much absolute waste of energy, and fully accounted for the want of power in the ram. How much energy was thus lost was not difficult to estimate. If the resistance had the effect of reducing the velocity of the water by only one quarter, the energy of the column of water was reduced one half: that is to say, one half of the whole available energy of the machine was consumed in overcoming this useless resistance. As a matter of experience, great loss of effect had invariably resulted from all attempts to soften the blow of the waste valve, whether by dash-pots or balance weights, or by any other of the devices which had been tried from time to time; and the above explanation showed why. About three years ago, when in want of some very large rams, he had studied their construction and had come to the above conclusion, which at first sight seemed to indicate that it was impossible to make large rams at all; for it was evidently impossible to bring large valves

(Mr. H. D. Pearsall.)

to their seats with the very great quickness which was absolutely necessary in order to avoid great loss of efficiency. Ultimately however he had succeeded in evading the difficulty by adding an ante-chamber, into which some of the water could flow while the waste valve was closing: so that the act of closing did not check the flow of water, and therefore the motion of the valve in closing might be made slow without detriment. In Figs. 42 and 43, Plates 14 and 15, which were vertical sections of a machine lately made on his design, the ante-chamber added for this purpose was shown at A. When the waste valve W was opened, the water-level fell in the ante-chamber, and thus admitted air through the passage G: so that, while the waste valve W was again closing, the water could rise in the ante-chamber without meeting with any resistance from the air, which escaped freely through the passage G. The consequence was that the closing of the waste valve W did not tend in the slightest degree to check the flow of the water; and hence there was no need to close the valve with great rapidity. This device therefore removed the chief difficulty in making large hydraulic rams. The waste valve was an annular balanced sliding valve, actuated by a motor M which was driven by the small quantity of air that was forced into the air-vessel V together with the water at each stroke. The motor both opened and closed the waste valve, at the exact times found most suitable. In order still further to avoid any shock of the waste valve W on its seat in closing, the new form of valve shown in Figs. 42 and 43 had been devised, the principle of which was that the valve was not brought hard home to its seat at all, but was only brought close up to its seat without actually touching it. The seat consisted of a loose hanging flap F of india-rubber; and when the pressure rose inside the flow pipe P, it pressed the flap against the edge of the valve, and so completed the closing.

The true theory of hydraulic rams appeared to be so little understood that he should like to make one observation on it, especially as the author appeared to sanction an erroneous theory by speaking in page 58 of the "percussive impulse of the current." There need not necessarily be any percussive action at all in the ram. If a mass of 2 tons was in motion with a velocity of 4 feet per second,

it possessed a stored up energy of 1 foot-ton, and would overcome a resistance of 1 foot-ton whether that resistance acted gradually through a long time or suddenly through a very short time. This he considered was the true theory of the ram; while the theory which represented it as necessary that a blow should be struck by the momentum of the water was not correct. The action of the machine he had made was entirely successful; it was as smooth as the best reciprocating pump, and gave the very high efficiency of about 70 per cent. In this way he believed that the problem of applying the hydraulic ram to large quantities of water had now been solved; for in the first machine made, 4 tons of water moving at a high velocity were brought to rest at each stroke with perfect ease and gentleness, and without sacrificing any efficiency in obtaining that gentle action. The flow through the flow pipe was $1\frac{1}{2}$ million gallons of water per day. Moreover the form of the machine was such that it was equally adapted for very much larger sizes. From thus performing in one simple machine and at one operation what had hitherto required the combination of two or more complex machines, it seemed obvious that a great economy both of construction and of power must result. One of these hydraulic rams was now being erected at St. Mary Cray, near London, where it could be seen at work.

Mr. GEORGE RICHARDS had hoped to hear some remarks upon the principle of balancing the vertical shaft in such cases as those described in his father's paper. Though not himself acquainted with the subject of hydraulics, he fully appreciated the difficulty of running heavy upright shafts and lubricating them, which appeared to him to be one of the principal points in the paper: whether novel or not he did not know. In discussing a better form of thrust bearing, it seemed to him to have been overlooked by Mr. Davey that the great point was to avoid thrust bearings of every kind; and if they were avoided, it appeared to him that a very great difficulty had been overcome. For his father's information he should be glad to hear whether the principle described in the paper was entirely new, or whether any of the members had seen in use that method of

(Mr. George Richards.)

overcoming the heavy weight and friction, and the consequent trouble in working pumps of that class, especially when they were obstructed by sand and dirt.

Mr. HENRY DAVEY explained that the onion bearing which he had described was not meant to carry the weight of the pump and shaft altogether, but only part of the weight. The pump to which he had applied that bearing was constructed on the principle described in the paper, but with a separate shield S immediately over it, Fig. 41, Plate 14, which was carried by three suspending bolts B from the girders overhead; and the clearance round the pump rim formed a small opening from the space beneath the shield into the delivery of the pump, so that by making the shield of large enough diameter the pump could be altogether supported, and its whole weight taken off the bearings. It was not usual however to take the weight entirely off, but to leave a little weight on the spindle; and it was this small remainder that was carried by the onion bearing.

Mr. WILLIAM SCHÖNHEYDER mentioned, in reference to Mr. George Richards' enquiry, that the balancing of vertical centrifugal pumps had been effected many years ago by the late Mr. David Thomson, who had constructed a large number of such pumps, and had done a great deal to improve centrifugal pumps. His centrifugal pump at Leith, made in 1862, which had been referred to by Mr. Mair, was constructed in the way already described by Mr. Davey; and the joint between the lips of the fixed shield above and the revolving pump had to be carefully attended to, otherwise there would be a certain leakage of water into the space under the shield, whereby the balance would be destroyed. Not only had Mr. Thomson balanced a portion of the weight of the shaft, but in one or two instances he had overbalanced it: so that, instead of a downward pressure on the collar bearing provided at the top of the pump, there was actually an upward pressure. The arrangement adopted by the author in the balanced pump shown in Plate 6, with vanes on the back of the pump wheel for circulating the water in the balance

chamber, appeared to him to be a very good step in the right direction. Probably in order to get the axial thrust properly balanced in this way, some experimenting would be required; but the arrangement seemed a capital one for ensuring a very perfect balancing of the pump.

The increased friction of the pump if made of a large diameter had been spoken of in the paper and by Professor Unwin. Increased friction was also occasioned if the pump was driven at too high a speed; and it was to a large extent owing to the way in which as a rule the vanes were made that pumps were obliged to be driven at high speed. The present shape of the vanes was due he thought to some experiments made by the late Mr. Appold on what were then the best centrifugal pumps; but those experiments he believed had included only three shapes: the curved form shown in Fig. 26, Plate 9, the radial form with perfectly straight vanes, and straight vanes inclined backwards. None of these three however was the best form. A study of the turbine, in connection with Professor Unwin's remark that a centrifugal pump was simply a reversed turbine, would lead to a better shape for the vanes, something like that adopted by Mr. Thornycroft in some of his turbine propellers for propelling boats by a stream of water issuing from the stern; and also like that adopted in the centrifugal pump recently erected in Egypt, of which Mr. Mair had spoken. That was the only way in which higher efficiency could be obtained, and the speed of the pump kept down to a minimum of less than the velocity due to the head against which the pump was working. When pumps were constructed in that manner he believed efficiencies as high as 70 per cent. were to be obtained.

He had had an opportunity of seeing at work at Wolverhampton the hydraulic ram described by Mr. Pearsall. It had a 12-inch driving pipe, and he believed it was the biggest hydraulic ram ever worked successfully and quietly; it worked as quietly as any good pumping engine.

The PRESIDENT was sure that every one who had read the paper would feel much indebted to the author for having taken the trouble

(The President.)

out in California to send the information which he had furnished to the Institution. They would therefore ask his son, Mr. George Richards, to convey to him their warmest thanks for the paper, and their best wishes to him for success with his machinery in California.

Mr. E. B. ELLINGTON wrote that he could confirm Mr. Mair's remarks as to the reduced efficiency of reciprocating pumps working against low heads of water, from his own experience of what might be called reversed pumps, namely hydraulic lifts. The efficiency of these machines fell very rapidly as the pressure of water decreased below 70 feet head; and he had never succeeded in producing an efficient hydraulic lift with less than 65 feet head. The friction of water in hydraulic machines was probably constant for all pressures, and the friction of rams passing through glands was also almost independent of pressure; this was no doubt the explanation of the phenomena referred to.

Mr. RICHARDS wrote, in respect to Mr. Davey's remarks (page 65) upon the collar bearing, that it seemed to have been overlooked that these bearings had no duty to perform except at starting and until the pump wheels attained their full velocity, and that under these circumstances the form of bearing was not of much consequence. Had the thrust been continuous, a Schiele bearing would have been employed. The onion bearing described by Mr. Davey undoubtedly owed the excellence of its performance to its approximation to the "curve of equal tangents," in which the angle of the faces corresponded with the velocity of the surfaces. From the baffling vanes used in the compound or double-wheel pumps, there was obviously and unavoidably a loss of energy. The water had to be compelled to return from the circumference to the centre, and within a small space. To enable it to do this, its energy must be destroyed; and the baffling vanes tended to relieve the wheel vanes from drag or friction, and only destroyed energy that would at any

rate be lost. It must also be considered that the energy of the water, so important a factor at low heads, was to a great extent lost at high heads, because of the difference between the velocity of the wheels and that of the water in the discharge casing, even when a volute form was employed; and in the case referred to the energy of the water was so inconsiderable that baffling in any way caused but little loss in the pump's duty when the head exceeded 60 feet.

In the case of the hydraulic rams with an air cushion to stop the escape valves, Fig. 33, Plate 11, it was to be observed that the escape valves were closed before the air cushion began to act, and that the air acted as a yielding resistance to the energy of the driving column, the same as if the air was contained in a separate or auxiliary chamber. If this resistance began before the escape valve was closed, there would evidently result the loss of energy pointed out by Mr. Pearsall (page 69). There was no trouble and apparently a high efficiency in working rams in this manner with an air cushion under low pressure; when the discharge resistance was increased to 80 lbs. per square inch or upwards, a new set of conditions seemed to be called forth. The balanced oscillating or radial valves, Plate 12, worked almost without friction, closed themselves when released, and were in some respects at least preferable to sliding valves, especially when there was sand in the water.

IRRIGATING MACHINERY.

Fig. 1.

Chinese Pump.

Scale $1/60^{th}$

Fig. 2.

Tube-Well Pump.

Scale $1/100^{th}$

(Proceedings Inst. M. E. 1888.)

Fig. 3.

Pit Pump.

Scale $1/100^{th}$

IRRIGATING MACHINERY.

Plate 2.

Pivoted Bearing.

Compression or Clamp Couplings.

Fig. 5. *Plan of Fig. 4.*

Fig. 7. *Elevation.*

Fig. 8. *Plan.*

Fig. 9. *Vertical Section.*

IRRIGATING MACHINERY.

Centrifugal Pump

with Shrouded Wheel.

Fig. 10.

Vertical Section.

Fig. 12.

Plan of Wheel.

Fig. 11.

Side Elevation.

Scale 1/16th

Plate 3.

Plate 3.

(Proceedings Inst. M. E. 1888.)

Ins. 12

6 0 1 2 3 4 5 6 Feet.

IRRIGATING MACHINERY. Compound Centrifugal Pump.

Plate 4.
Fig. 16.
Plan of Wheel.

Fig. 15. Plan.
Scale $1/32^{nd}$

Plate 4.

Scale $1/16^{th}$ Inches 12 6 0 1 2 3 Feet.

Proposed Triple Compound Centrifugal Pump.

Fig. 17.

Vertical Section.

Fig. 18. *Submerged Vertical Pump*

IRRIGATING MACHINERY.

Plate 6.

Fig. 19.
Side Elevation
with suction pipe
removed.

Balanced Centrifugal Pump with single lateral inlet.

Fig. 20.

Vertical
Section.

(Proceedings Inst. M. E. 1888.)

12 Ins. 6 0 1 2 3 4 5 Feet 6

Plate 6.

Improved Pit Pump.

Fig. 21.
Elevation
Scale $\frac{1}{24}^{th}$

Fig. 22.
Section of Air-vessel.
Scale $\frac{1}{8}^{th}$

(Proceedings Inst. M. E. 1888.)
12 Ins. 0 1 2 3 4 5 6 Feet 7

Scale $\frac{1}{24}^{th}$

Fig. 23. *Reclamation Pump.*

Fig. 24. *Centrifugal Pump*
worked by Differential Engine.

Fig: 26.

Plan of Vanes.

Scale $\frac{1}{10}^{th}$

Fig. 25.

Plan of Pumps.

Scale $\frac{1}{60}^{th}$

Fig. 27.

Centrifugal Pumps

driven by Bands.

Scale $\frac{1}{120}^{th}$

(Proceedings
Inst. M. E. 1888.)

Scale $\frac{1}{120}^{th}$

0 10 20 30 Feet 40

IRRIGATING MACHINERY.

Plate 10.

Single - acting Engine.

Differential Engine.

Fig 30.
*Vertical
Section.*
Scale $\frac{1}{16}^{th}$

(Proceedings Inst. M. E. 1888.) *Scale $\frac{1}{16}^{th}$*

Ins. 12 6 0 1 2 3 4 Feet.

Plate 10.

Hydraulic Rams with automatic escape valves.

IRRIGATING MACHINERY.

Hydraulic Ram with valve worked independently.

Fig. 35. Vertical Section

(Proceedings Inst. M. E. 1888.)

Ins. 12

6

0

1

2

3 Feet.

Scale $\frac{1}{12}$ th

Plate 12.

Fig. 36.
Plan of
Tuppel Gear.

Fig. 37.
Sectional Plan at XX.

Plate 12.

IRRIGATING MACHINERY.

Plate 13.

Hydraulic Footstep.

Fig. 38.

Vertical Section.

Fig. 39. *Diagram of Pressures.*

(Proceedings Inst. M. E. 1888.)

Onion Bearing.

Fig. 40. *Vertical Section.*

Fig. 41. Centrifugal Pump

with shield suspended above.

Hydraulic Ram.

Fig. 42. Ante-chamber and Waste-Valve.

(Proceedings
Inst. M. E. 1888.)

Fig 44. Efficiencies of Centrifugal and Reciprocating Pumps.