# TUBE WELLS.

By T. A. MILLER BROWNLIE,
Municipal Engineer, Amritsar.

During the past few years considerable development has
n place in water supplies from tube wells, and the largely im-
of these now working, afford a considerable relatively
igating and observing the effectiveness of this system of water
though many types of tube wells have been more or less
America for over ten years comparatively few principles.
regarding their working, and some twenty tube
supply appears to have been of these with a
haphazard manner, the ordinary wells. In
I have had opportunities of observing the behaviour of
subsoils merges into the horizontal plane
below normal spring level, at a distance of
approximately fifty feet from the well. In a specially small tube
well designed to deliver 2,000 gallons per hour under a head of
x feet, and sunk in the same subsoil as the masonry well, it was
observed that the cone of depletion is flatter, *i.e.* that it merges into
he horizontal plane six inches below spring level, at a considerably
reater distance from the tube than fifty feet. The experiments
ave not been numerous enough, nor have they been conducted in
fficient varieties of subsoil, to establish an equation for the relation-
ip between the two curves, but it is apparent that a fixed relation-
ip does exist. There is no apparent reason why a tube well
ould affect a greater superficial area at spring level than an ordi-
ry well, when both are worked under the same head and same
scharge, but the fact remains ; and I offer the following explana-
n as a probable solution.

Many of you have no doubt spent a few minutes watching
ys at some continental port dive after shillings thrown into the
a, and without considering the reason, have wondered at the
se with which the coin is secured before it reaches the bottom.

A coin when thrown into water does not sink in the direction its least resistance, but in the direction of its greatest resistanc Even when the coin is dropped, "edge on" into water it ve quickly turns over, and with an oscillating motion planes dow the oscillating motion becoming less and less until the coin sir steadily with one surface horizontal. Similarly, irregular shap plates sink with their surface horizontal, and rods sink with th long axes horizontal, stones and all irregularly shaped boc including silt and sand particles sink in the position of th greatest resistance. This peculiarity of all particles settling in t position doubtless accounts for the cleavage planes in m sedimentary rocks. An examination of a vertical face of sa at a sand quarry or elsewhere, reveals the same structure, an doubtless similar conditions exist in the water-bearing tracts where tube wells have been tried, and mean that the subsoil is of higher porosity in a horizontal direction than in a vertical direction. The tube well taps a considerable depth of these minute successive layers of "stratified sand," and on a head being created in the tube, there is more horizontal flow produced with the tube well than with the ordinary well, which taps only a few of the horizontal layers; consequently the larger proportional horizontal flow with the tube well, produces a flatter and therefore more extended cone of depletion.

The yield from tube wells within certain limits, like ordinary wells, varies directly as the head, and thus, if we know the yield of any tube well under any head, the yield for each foot of head can be calculated. Suppose that the yield of a 3½ inch tube well under a head of three feet is 2,160 gallons per hour, then we know that the yield under a head of one foot is one-third of this or 720 gallons per hour, the yield under a head of four feet $720 \times 4 = 2{,}880$ gallons, and at seven feet the yield is 5,040 gallons per hour. It seems reasonable, therefore, to assume that this 3½ inch tube well, under a head of ten feet, would yield 7,200 gallons per hour, and under a head of twenty feet 14,400 gallons per hour, and so on; or, in other words, that there is no limit to the head under which any tube well can be worked, and by increasing the head sufficiently, any desired discharge may be obtained. We know, however, that there is a limit to the head under which ordinary masonry wells may be worked, and what the amount of this head actually is, depends on the subsoil in which the well is sunk. Wells sunk in moderately fine sand can with safety be worked only to a head of approximately seven feet; if pumped to a greater head, sand begins to blow on the well floor, and at this and greater heads the yield ceases to increase directly

1168

as the head, becomes unsteady, and for a time may be considerably higher than the head justifies; in short, at seven feet head we have reached the critical velocity for this particular subsoil.

With a tube well having a certain water way area of straining material sunk in similar soil the disturbance of the subsoil commences as soon as a head is created, and, if excessive head is created, the sand, being practically in full suspension, is carried into the tube, provided the straining material is sufficiently coarse to permit it to pass, and the tube well becomes choked. If the tube well is provided with straining material fine enough to exclude all sand, then the particles pack round the strainer and have been known to become extremely dense, forming a practically impervious screen round the straining material, and thereby reducing the discharge to such an extent that the tube well is useless. In coarse subsoils of high porosity a greater velocity is required for packing to take place, and consequently a greater head is necessary to produce the increased velocity. The packing does not become so dense as in the finer subsoils, but the effect is the same as the resistance of the sand increases, and therefore the head in the tube has to be increased for a given discharge.

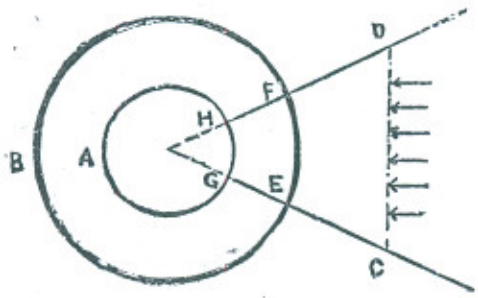
If in coarse sand the discharge from, say, a $3\frac{1}{2}$ inch diameter tube well is 857 gallons per hour under a head of one foot, then the discharge at two feet should be $857 \times 2 = 1{,}714$ and at $3\frac{1}{2}$ feet the discharge is approximately 3,000. At this latter discharge of 3,000 gallons per hour under a head of $3\frac{1}{2}$ feet, the head consumed in friction is roughly six inches; at a head of seven feet the discharge should be 6,000 gallons per hour, or exactly double the discharge at $3\frac{1}{2}$ feet, but a slight difference is noticeable at this discharge, and the head has to be increased two or three inches to obtain the 6,000 gallons per hour. This is due to the fact that a tube well of $3\frac{1}{2}$ inches diameter, which absorbs six inches in friction when discharging 3,000 gallons per hour, will absorb $24\frac{1}{2}$ inches in friction when discharging 6,000 gallons per hour. If the discharge is increased to 7,500 gallons per hour, this supply would be expected at a head of 8·8 feet, but the friction absorbed in the tube well is now $48\frac{1}{2}$ inches, or an increase of two feet friction for an increased discharge of 1,500 gallons per hour, and consequently a considerable increase in head is necessary to compensate for this highly increased friction. Similarly with

a large discharge of, say, 18,000 gallons per hour as an extreme example; the head at which this discharge might be expected would be $\frac{18000}{857} = 21$ feet, but we find that tube friction alone is over 23 feet for this discharge, the actual head being approximately 40 feet.

When one considers that 18,000 gallons of water per hour can easily be obtained from one tube well under a head of six to seven feet, or 50,000 gallons per hour per tube well from the same head, there is nothing to be gained by pumping to unlimited heads, and, as has been shown, any attempt to obtain an excessive quantity of water from a tube well will be at considerable sacrifice in economical working.

The "stepping point" of tube wells, or the maximum yield at which one size of tube should be worked, depends, to some extent, on the design of the tube well, and also on the porosity of the subsoil in which the tube is to be used. From enquiries made regarding the working of some of the more recent American tube wells, I find that for railway work, where these tubes are largely adopted, the "stepping point" in subsoils of medium sand is six feet head in tubes up to four inches diameter, and eight feet in sizes up to eight inches diameter; this corresponds closely to the working heads of convoluted tube wells in this country.

In two tube wells, one of small diameter, and one of large diameter, each having the same rate of infiltration, *i.e.*, straining velocity, and the same velocity of discharge; a slightly greater head is required in the large diameter tube well, and the reason for this is probably best explained by a reference to the attached diagram.



Let A represent in cross-section a tube of, say, four inches, and B a tube of eight inches diameter. For convenience the tubes are shown concentric. In a unit length of A, and two units length of B, under a head H feet, the smaller tube A discharges $g$ gallons per hour, and tube B discharges $4g$ gallons per hour, because the straining area of B is four times the straining area of A, and the infiltration velocity is equal for both tubes.* This arrangement makes the tube friction head equal in both cases. Now, referring to the cross-section, in any segment C D of unit length for both tubes, the quantity of water which has to pass any given section such as C D on that segment, is $g\,t$ for tube A, and $2\,gt$ for tube B, because tube B in unit length is obtaining twice the water that tube A is obtaining in unit length. The infiltration velocity is the same in both tubes, because section strainer E F is twice section strainer G H. The section C D multiplied by unit length gives the area C D, which is common to both tubes, and as $gt$ water is passing this area for tube A, and $2\,gt$ water is passing for tube B, the mean velocity for tube B is double the mean volocity for tube A. This doubling of velocity represents a corresponding increase of sand friction, which, if the discharge of the tube is to be maintained, must be overcome by an increase in head. This head can be calculated when the quality and compactness of the sand is known, therefore, for any velocity, the sand friction is known.

At the present time there are over a dozen types of tube wells in use, mostly of American design, in fact America is considerably ahead of most countries in this method of water supply, as tube wells have been in use there to a very large extent for over twelve years. The wells may be divided into two classes, single and double tube wells, the single being those which combine the tube body and straining material in one, the double type having the straining material applied to a tube body or frame of some kind. In the single form the tubes are made from perforated or slotted plates, a well known example of this type being Cook's tube, having a series of short circumferential slots, which are triangular in cross-section, thus permitting of a fine slot for the percolation of water, while, in the event of sand passing into the slot, it does not readily become wedged there as in the case of tubes with parallel side slots, but passes into the tube, leaving

* Note.—This is correct when sand friction is neglected, and is introduced to show that the additional head ultimately required in tube B is entirely due to sand friction.

the slot free. These slots have to be a considerable distance apart to permit of the particles of water, which pass through one slot at a low velocity, freeing themselves from the interior of the tube before they are caught up in the high velocity current passing up the tube. If the slots are close to one another there is a blinding effect on the interior surface of the tube, which reduces the efficiency of the slots. Of double tubes, the best known form is probably the Abyssinian tube well, consisting of a perforated pipe covered with a fine gauze strainer. This form obviates to a certain extent the interior blinding action, but the straining area is extremely small, and, in order to obtain the full advantage of a large straining area, distance pieces are introduced between the perforated tube and the straining material. One form of this construction is the convoluted tube well, in which the distance pieces are rolled in the sheet from which the tube body is made. In the double tube wells many forms of straining material have been tried, that most frequently used being wire gauze. Various sizes of mesh are easily procurable to suit subsoil conditions, but in the nitrate fields of South America, where tube wells are largely used, the life of wire gauze is very short, and its use has been abandoned, partly on this account, and partly because of its liability to become choked, particularly in subsoils containing a small percentage of clay. The strainers in use for the last seven or eight years in the nitrate fields, and for railway work, are slotted plates somewhat similar to those used in Cook's tube, or else wire winding on a star shaped frame, the wire being slightly ragged at short intervals to maintain the necessary straining space between each wire. These forms of straining material are considerably heavier than gauze, yet, in the impure water in which they are used, their life is comparatively short, the practically knife edges of the slots being eaten away, and the wires corroded, thus gradually increasing the straining openings. All these forms of tube wells have one feature in common, and that is, that the water passes through the straining material in a direction perpendicular to the material, thereby causing eddies in the tube, and detracting from its efficiency. In the event of sand blocking the outside of a tube, washing is rendered somewhat difficult on account of the particles having to be washed from slots, or other straining openings, at right angles to the tube.

A recently invented tube well claims to have overcome the deficiencies in the many forms now in use, and is constructed from a specially shaped band of metal. This tube may be either of the double or single form. Where the double form, the

Research Laboratory

band is wound on the tube body in such a way that each turn overlaps the previous turn. When made as a single tube, no core or tube body is used, but the band is wound as before, very much in the same way as a pipe lighting spill is made from a strip of paper. In this tube water passes between each twist of the metal band, and is therefore deflected upwards in the straining material before passing into the tube proper ; and it is considered that obstruction from sand packing or silting on the outside of the tube will be greatly reduced, as gravity will assist in the removal of such silt, which will fall away each time that pumping from the tube is stopped. One feature of this form of construction, which I consider to be a distinct advantage over most of the present forms, is that it may be made tapered ; and by slightly reducing the curve of the band required for a tube having parallel sides, this shape can be obtained. That the tapered form is more correct than a parallel sided tube, is, I think, fairly obvious. In their present form, tube wells have the highest internal velocity at the top end of the strainer portion while the velocity at the bottom of the strainer is practically nil. By having a tapered form, the internal velocity may be made practically uniform throughout the length of the strainer. This form of tube well is, however, still in the experimental stages, and time will tell if it possesses all the qualifications ascribed to it. Its simplicity of construction would appear to indicate low manufacturing cost, and it is hoped that full particulars of these tubes may shortly be published.

A great deal has still to be learnt regarding tube wells, and many experiments must be carried out before we can hope to even approach the best results. Much help might be given by the various officers using tube wells, if geological sections of borings were carefully recorded, and sands graded, also levels of depletion cones taken at frequent intervals, and recuperative yields recorded for all tube wells and ordinary wells by one standard method. Instructions for supplying this information might be printed, together with tables prepared for filling in the required data, so that all reports would be on one basis, and the requirements simplified as much as possible, so that the officers in charge of circles would not find the collection of information a burden. Some of the laboratory experiments could be carried out in order to obtain reliable resistance co-efficients for different grades of sand at various densities ; and all this would help greatly in the case of the Mr. [illegible] was [illegible] nc system of water supply, which at present is more or less of an experimental.

## DISCUSSION.

MR. BROWNLIE, in introducing his subject, said he did not wish to add anything to his paper, but would be very glad if those engineers who had carried out tests and experiments with tube wells, would be good enough to state the results of their experience and investigations, particularly regarding the points mentioned in the paper. His own experiments had been made chiefly in Amritsar district, and deductions made from results obtained in that district might or might not be correct for districts where the subsoil conditions were very different. As stated, he had found the cone of depletion for tube wells to be considerably flatter than for ordinary wells, in the same subsoil, and under the same heads. This feature had been observed in several districts, and the explanation which he would offer for consideration was, that this was due to sandy subsoils being more highly porous in a horizontal direction, than in a vertical direction, on account of the laminated structure of the subsoil.

Some engineers thought that there was no limit to the head at which tube wells could or should be worked, but with this he entirely disagreed, for the reasons given in this paper. He had also stated that there was a limit to the discharge which should be taken from any one tube well, on account of water friction in the subsoil. In the Amritsar district, where conditions were extremely favourable for tube well experiments, he had found the economical maximum discharge to be just over two cusecs, and any attempt to obtain a larger supply was at a considerable sacrifice of head, and became less economical than working two tube wells, each with smaller discharges.

Although a considerable number of water supplies had been carried out in America with tube wells, comparatively little had been written on the subject, and in India the system is quite in its infancy. He would therefore strongly emphasise the necessity for further experiments and investigations being carried out.

MR. HARVEY asked how near to an existing tube well another could be sunk without interfering seriously with the discharge of either, the distance being given as a function of the depth of the existing well. He also asked whether there was any harm in working wells which had yet to be worked alternately.

MR. NICHOLSON said that in an air lift system the submersion had been an artesian superpassage, and would render the cost of such a well excessive as compared with ordinary masonry well.

tube wells had been put down to tap this artesian supply, but as a good layer of clay was seldom available in which to end the tube, they had not been a success. The water bearing strata being of very fine sand, it was doubtful if a strainer tube well would work satisfactorily, and it was therefore decided to put down Brownlie and Ashford strainer tube wells and compare them.

In order to give the respective tubes every opportunity, it was arranged that the maker in each case should put down his own tube. The Empire Engineering Company unfortunately after nine months had not turned up to sink their tube, so the author was unable to give any opinion on the Brownlie type. The Ashford type had been put down by the Central Workshops, and so far had been entirely satisfactory. The head of the artesian supply was 4·7 feet, and the discharge of the five inch well was ·15 cusec. The length of strainer was however only twenty feet. The strainer was sunk in the following strata :—

Top eight feet very fine sand, nearly all passing 80 per lineal inch, and about forty per cent. passing 180 m lineal inch mesh.

Middle seven feet coarse sand and shingle.

Bottom five feet coarse sand, of which twenty per ce ed through 80 meshes per lineal inch.

Although the material was so fine, especially in eight feet, when the well started it ran clear in a few m and at no time, by collecting the water in a glass, wa appreciable quantity of silt determinable, and after three mo running the condition of the well was as good as when it sta running.

Mr. Nicholson further said that he had seen the D Khan tube well water supply, worked by Gardner umps from two tube wells. The day before he had hea . Brownlie's well had given out, and had been pulle was found to have all its pores closed as thoroughly as dipped in sealing wax. He asked Mr. Brownlie if he caus[illegible] the failure in this particular case

said the paper had been written a ntroversial. He had not intended as the previous spea aker had e had designed the d and a Brownlie

yield from tube wells compensated for the wells, directly with t

* Page 50.

was one [illegible] be done.

ube were sunk side by side, but the local offic s were handi-apped in making their tests, as the conditions were not identical ; he Ashford tube being direct coupled to the pump, while the Brownlie was connected through a sump.

In the Ashford well there was no means of knowing what head was on the tube, and hence it was not easy to make any comparison. There was no water supply at Dera Ghazi Khan, and therefore what was done had to be rushed at the beginning of the hot weather. Mr. Ashford was able to send his tube down at once, but Mr. Brownlie has not the same facilities, and has to get his tubes made by the Empire Engineering Company, who could not give what was required, and were accordingly asked to send up the best they could. What arrived was very rough, and after a time ceased to give water. When pulled up it was found that the outer covering of galvanized iron wire had been altogether eaten away, and the gauze strainer wrecked.

As a result of the late Lieutenant-Governor's advocacy everyone was keen on tube wells. They were not however a panacea for every water ill. Two conditions were essential ; first the water must rise to a certain height, (he had been asked at Montgomery to design a tube well supply, though the water table was ninety feet down), secondly it was necessary that the subsoil should be of great thickness and coarse texture. Most of the experiments had been made at Amritsar where the soil could be squeezed like a sponge, and a y kind of tube let down would produce water. He asked advi e on ho w best to test the yield of water which any stratum t likely to give.

CAPT. BATTYE said tubes up to her hundred feet in length could be used on the air lift syste m, a se hen e lectric power was cheap it would always pay to ad opt ot r lift. In California there were tubes over 450 feet deep working sat isfactorily. In India the advantages of the air lift system were insufficiently known. In fact very little was known about the s bject generally, and most of the formulae adopted were empyrical, nd not based on any well-defined theory of the subject. V pipe, th of the knowledge on the subject was entirely experim ead in friction, hands of a very few individuals. The laws gove by no means yet understood, and the subject ner there was any harm a considerable amount of research had yet to ere worked alternately.

Cheap water pow nat in an an i tem the submersion had low efficiency of the air would render the cost of such a well exces- and tear on deep with an ordinary masonry well.

conditions extremely unsuitable for machinery. It was very much open to question whether the excessive expenditure, that had to be incurred in keeping such plant in repair, would not be fully compensated for by installing plant in a proper machine hall under ideal machinery conditions, which was possible with the air lift system, and this in spite of the low efficiency of the system. This argument applied with considerable force in India, and in such places where field machinery was always subjected to intolerable treatment.

MR. MONTGOMERY pointed out that an air lift system had been tried in Lahore, but had proved a failure, though worked exactly in accordance with the makers' suggestions. So much sand had been blown out that a large depression had been created round the tube and the experiments had to be abandoned.

CAPT. BATTYE thought that Mr. Montgomery's reference to the experience already obtained with air lifts was likely to be misleading. He understood that all the experiments made up-to-date had been carried out with ordinary tube wells, in which no attempt had been made to exclude sand. Such tube wells were known to be quite useless in the Punjab where the air lift was adopted, and some experiments should now be carried out with this system, adopting either the Brownlie or Ashford tube with their special arrangements for the exclusion of sand.

RAI BAHADUR GANGA RAM said that he had studied the working of air lifts very carefully, and had seen several of them working in London. He considered that they were unsuited to places like Lahore. He understood that for the successful working of air lifts two conditions were essential, first that the depth of submersion of the pipe must be at least double the height of the lift, and secondly that there should be coarse gravel and not sand at the bottom of the pipe, and even then the efficiency was only about thirty-three per cent.

Mr. Brownlie erred in saying that the yield of a well varied directly as the head, in other words that the curve of yield was a straight line. From experiments made by him during his service period, he found that the curve dipped, the curve was a parabola, and on such, the yield varied as the

EMANN remarked that Mr. Brownlie had as the within certain limits, the head of pressure; an Ashfo

that there was no limit to the head under which a tube well could be worked; but that there was a limit to the head under which ordinary masonry wells might be worked, the limit depending on the nature of the subsoil, say, seven feet head in moderately fine sand. The speaker thought that the essential difference between a tube well and an ordinary masonry well was, that in the former the subsoil water could enter the perforated sides of the tube at any level of the portion of the tube which was immersed below spring level; whereas in the case of a masonry well the water could enter only at the bottom. In the latter case, therefore, the hydraulic gradient would be a line drawn from spring level outside the well to the centre of the bottom of the well; giving pressures varying from *nil* at the centre of the well-bottom, to a maximum at the well-curb. Hence the bulk of the flow into the well, and the highest velocity of inflow, occurred round its curb, or bottom-rim; and for this reason cultivators found it necessary to pack brushwood or gravel under the well-curb in order to restrain the velocity and prevent sand-blowing. Mr. Brownlie had also remarked on the vagaries of discharge from tube-wells under different heads in different classes of sub-soil. An explanation might be found in the fact that in capillary tubes, and even in tubes of small diameter at very low velocities, the flow varied directly as the head of pressure; and that was the case in subsoils of fine material. When however the head of pressure was increased indefinitely, a point was reached at which the velocity ruptured the septa between the pores of the soil, enlarging those pores, and introducing the law of flow through pipes, in which the velocity varied with the square root of the head, instead of the head itself. In the case of a tube well it was necessary to impose such a limit on the velocity of percolation flow as would not rupture the septa of the sub-soil concerned; and thereafter any increase of discharge might be obtained by increasing the area of the surface of the tube. This latter might be arrived at just as well by increasing the length of the tube as by increasing its diameter: the only limit being the discharging capacity of the tube, or pipe, for a given power applied, bearing in mind the loss of head in friction, as mentioned by Mr. Brownlie.

SARDAR LEHNA SINGH asked whether there was any harm in placing tube wells close together if they were worked alternately. He thought the fact that in an air lift system the submersion had to be double the lift would render the cost of such a well excessive, as compared with an ordinary masonry well.

MR. MACFARLANE mentioned that Mr. Ashford had apparatus in Amritsar for testing the permeability of soils, and was always ready to give an opinion on any specimens sent to him.

MR. VARMA thought it would have been more interesting and instructive if the author had given details of his experiences with some of the twenty tube wells which he had under observation. The subject was of great importance to an agricultural country like India, and any improvement effected on scientific lines in the design of irrigation wells, would affect a very large tract of country ; as spring wells were possible all over the Indo-Gangetic plain from the river Sutlej to Bihar, except in certain submontane districts, and in the alluvial plains of Gujrat in the Bombay Presidency. Percolation wells were possible in the Punjab to the west of the Sutlej, as well as in the submontane districts along the Himalayas, in the alluvial fringe along the east coast of the peninsula, and in the sandy beds of most of the rivers.

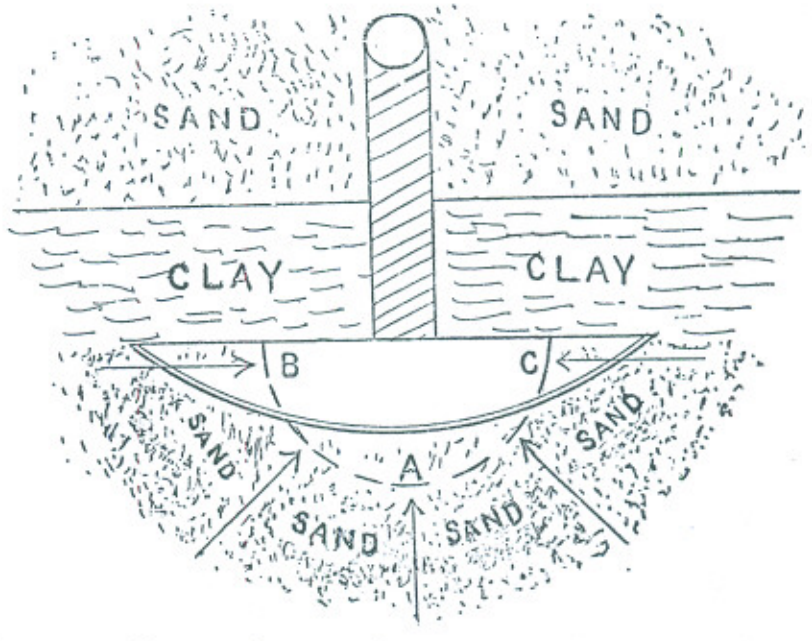
Tube wells with strainers were no doubt a great improvement over the old wells in the percolation tracts, but they had some disadvantages. The advantage of this system, compared with the old one in which sand was kept back by gravity alone, was that a very much smaller discharging surface was required, because the strainer would keep the sand in place even if the water was forced through it at a considerable velocity. A disadvantage was, that as the water was forced through the sand at a considerable velocity, a greater head would be required, and this would increase the lift out of the well, and the labour of lifting the water. Probably oil engines and the use of pumps would be necessary, and for sinking the wells technical knowledge and machinery would be required, which was not at the command of the ordinary cultivator or land-holder.

The author had noted the interesting fact that the cone of depletion for tube wells was flatter than that for ordinary wells, and it would have proved very interesting if he had detailed his experiments as to how he measured the extent of this cone, and what tests were applied to guage the accuracy of the results. One very simple test* would be the difference in depression of the water levels in the two wells, when they were worked. The depression of the water surface in a tube well having a flatter cone, would be less than that in an ordinary well.

* *Vide* Bulletin No. 22 U.P. Agricultural Series by E. A. Mc[illegible]ny, I.C.S.

The explanation offered for this phenomenon was not very convincing, as the two wells, having been sunk in the sub-soil, were working under exactly the same conditions of pressure and discharge, so that the velocity through the discharging surface of the sand was the same. The fact of the sub-soil being of higher porosity in a horizontal than in a vertical direction, was not required to establish the fact that there ought to be more horizontal flow. This could be established mathematically and otherwise, as would be shown later on. What the speaker could not understand was why, if two wells were sunk to the same depth, in the same sub-soil, the tube well should tap more horizontal layers than an ordinary well. By this he did not mean to imply that the depletion cone of a tube well was not flatter than that of an ordinary well, but that the explanation offered was not quite convincing, and that there ought to be something else in the nature of the sub-soil to explain it, or that the floor areas of the respective wells under comparison had something to do with it.

Take, for instance, a tube well as sketched, and suppose that




the first rush of water leaves the cone in the shape of a hemisphere. Water is flowing into it from all directions, as shown by arrows. The force tending to displace the sand was the friction acting in the direction of the arrows, while the force tending to keep it in place was the force of gravity acting downwards. It would also be noticed that at "A" the force of friction acted direct-

There is evidently a confusion of terms here between depletion cone and the cavity forming under a plain tube The speaker is obviously referring to the latter, and not to the strainer tubes dealt with by Mr. —EDITOR.

ly against the force of gravity, and was wholy or partly counteracted thereby, whereas at points B and C of the cavity just under the clay, the force of gravity acts in a direction at right angles to the force of friction, consequently the force of friction at the edges of the cavity was not in the least counteracted, and therefore the force disturbing the sand was most powerful at the edges of the cavity, where the slope was steepest, and least powerful at the centre, where the floor was level.

From this it would be seen that unrestricted horizontal flow must take place, and that the action of water flowing into the cavity would be to make the cone broader and shallower. The cavity would be deeper under the well orifice, and this depth would be six inches or more, just enough to pass the discharge required of the well. The extent to which the cavity could enlarge itself, depended on the velocity of the critical discharge of the sand. If the velocity of the water, due to any head of pressure, was greater than the critical discharge velocity of the sand, the sand would be displaced by the horizontal flow, and the cone would go on enlarging itself till the velocity was equal to that of the critical discharge of the sand, when no more sand would be displaced and the cone would not be enlarged any further. Again, if, by accident or otherwise more than the limiting discharge of the well was drawn when it was worked, the cone was enlarged, and once this enlargement took place, it was not possible for the cone or cavity to contract, in other words it was only capable of enlargement. Nothing could be deduced from Mr. Brownlie's paper as to whether the wells under his observation had or had not been overworked at any time, resulting in the enlargement of their cones.

From the description given above, it would be readily seen that the function of the cone was to provide, for the discharge of the water, an area of sand surface sufficiently large to reduce the velocity of the water to a point at which the critical discharge was not exceeded. Without further details of experiments however, it is difficult to discuss this point at greater length.

While pointing out the defects of tube wells with strainers, the author complained that particles of fine sand pack round the strainer, forming a practically impervious screen round the straining material, and thereby reducing the discharge to such an extent that the well became useless. So that, in coarse subsoils, though the packing did not become so dense, yet the effect was the same as the resistance of the sand increased, and there

fore the head in the tube had to be increased for a given discharge. In this connection a process patented by Mr. George Deacon, Consulting Engineer of Great George Street, Westminster, was brought to the notice of the Congress, whereby he had succeeded in removing from round an iron cylinder, all fine sand, till there was nothing against the strainers but coarse green sand, as big as fine gravel, through which the water flowed with ease. If this process were tried in the percolation well tracts in this country, it might suit many cases, and would do away with the complaint mentioned above. In any case a trial would show whether it was suited to the needs of the country or not. Mr. E. A. Molony had recommended it, but, being a patented process, full details were not known.

MR. BROWNLIE, in reply, said that :—

Mr. Harvey had asked how near one tube well might be made to another without interfering seriously with the discharge of either. Off-hand he was unable to reply to that question, but the results of his investigations on depletion cones, so far as they had been carried out, were given in his "Further notes on tube wells" which had just been published. When tubes were made close enough for the depletion cone of one tube to cut the depletion cone of the other, then the point of intersection of the two depletion cones represented the new spring level for the two tubes, and the distance which this point of intersection was below natural spring level represented roughly the additional head required to obtain the same discharge from each of the two tubes that had been obtained from one.

Mr. Nicholson referred to the tube well at Dera Ghazi Khan and, as Mr. Montgomery had explained the circumstances of the case, he had nothing further to add, except that the straining material used in that tube consisted of fine brass gauze supported on a galvanized iron wire screen of eight or ten meshes to the lineal inch, and was protected by a covering of galvanized iron wire netting. He wondered if anyone could elucidate whether the action which caused the decomposition of the galvanized wire screen and netting, and formed an impermeable matrix of sand and iron oxide on the brass gauze meshes, resulted from chemical action or from electric action, as the electroscope showed no movement.

Captain Battye, Mr. Montgomery and Rai Bahadur Ganga Ram had referred to the air-lift system. Mr. Brownlie thought that Mr. Montgomery's experience with this system must have

been some years ago, as, during the last few years, considerable develpments had taken place in this method of raising water, and he had had the opportunity of studying some of these in use in England which had been working for the past few years thoroughly well and economically, at depths up to and over nine hundred feet. Rai Bahadur Ganga Ram stated that for the successful working of the air-lift system a submersion of air nozzle of at least two to one unit lift was essential. This, however, was not the case, as many plants were worked economically on a ratio of one to one, and that for economical working each individual case must be carefully considered and the amount of submersion calculated on the requirements of the situation; if this was done, satisfactory results, which would compare most favourably with any existing form of deep well pump, would be obtained.

Regarding Rai Bahadur Ganga Ram's criticism, that the author had erred in saying that the yield of wells varied directly as the head, experiments carried out by the Public Works Department, as well as his own experiments, proved this to be correct, provided the critical velocity of the well was not exceeded, and wells should never be worked at a rate exceeding their critical velocities. Rai Bahadur Ganga Ram also mentioned that he thought the figures given for friction on page 51 of his paper were excessive, but a reference to any of the well known formulæ for friction in tubes would suffice to show that his figures corresponded closely with these.

The author agreed with Mr. Schönemann that the yield of wells varied directly with the head, when worked within the critical velocity only; and that the discharge from a tube well could be increased by increasing the water-way area of the tube, either by an increase in diameter, or by an increase in length, but preferably by both, because an increase in length only meant greatly increased friction, and an increase in diameter only meant a reduced velocity of upward flow in the tube, which might be too low to remove any foreign matter finding its way into the tube. Such increases, of course, requiring a head increased to overcome sand friction.

In reply to Sardar Lehna Singh, Mr. Brownlie mentioned that as a tube well water supply was at most one-eighth of the cost of a similar supply from ordinary wells, the extra expense required for additional sinking to instal the air-lift system was a very small item, and that the additional depth of boring required need not necessarily be as much as the speaker had mentioned, but would depend entirely on the local conditions.

The last speaker asked for particulars of how the depletion cone was measured. This was done by sinking a line of plain tubes to depths below spring level, at intervals of a few feet, from the tube well, and from the ordinary well, the first tube in each case being close to the well, the last tube being a hundred to a hundred and fifty feet away from the well, and on the unaffected spring level area. Levels were taken of the water surface in each tube while the tube well and ordinary well were worked to the same head ; the plotted levels giving the depletion cone for each. The speaker disagreed with the author's explanation of the possible reason why th e was more horizontal than vertical flow in sand, and gave as . probable solution the direction of flow into a cavity at the b .tom end of a plain pipe passing through an impervious strat .m. Mr Brownlie stated that the speaker evidently referred to artesian supplies or at any rate to, a plain tube with an open end only, under which a cavity was formed ; and that, under these circumstances, the conditions were entirely different to those when a strainer tube well was employed.

Mr. Varma referred to a patented method for removing the fine sand and leaving only the coarse sand surrounding the tube well strainer, but he defied any one to remove the fine sand and leave coarse sand behind in many parts of the Central and United Provinces, simply because there was no coarse sand in the subsoil to be left, but in his recent publication he had described how he had shrouded tube wells in these districts by introducing an artificial screen of coarse sand round the tube well.