NOTE ON TUBE WELLS.

By JOHN ASHFORD, M. I. Mech. E.

Superintending Engineer, Central Canal Workshop, Amritsar.

Introduction—Comparison between percolation wells and tubes—Infiltration head—Diameter of tube wells—Nature of soil and yield—Estimating the yield—Apparatus used for testing the soil—Preparation of diagrams—Design of strainer—Starting pumping—Spacing of tube wells—Pumps.

Introduction.

The development of the tube well, as we know it, is of quite recent date, yet it has taken such an important place in this country as a means of procuring water, that no apology is necessary for making it the subject of a paper to place before the Punjab Engineering Congress.

The experimental work carried out at Amritsar by the author, which has been so fruitful in developing this branch of engineering, had its origin in a note written by Sir John Benton, K.C.I.E., as Inspector-General of Irrigation in 1906, wherein he dealt with the problem of unwatering land which had become water-logged by seepage from the Upper Bari Doab Canal. In the note, he recommended that the author's attention should be drawn to the problem, and that experimental work should be undertaken with a view to ascertain some satisfactory means of pumping from the subsoil by power driven pumps, the power being generated for the purpose at canal falls. Thus it was that the author's attention was directed to the subject, with results that are known to most of the members of the Congress.

The experimental work has been divided into two main branches, first, the development of the tube well itself, and secondly, the development of pumps specially suitable for use with tube wells.

As the length of this paper must be limited, the author is reluctantly obliged to refrain from placing before the members a detailed description of the many experiments he has made, interesting and instructive though they have been, with their successes and mistakes, so that he may deal with certain present day questions that must be answered by the engineer who has to install tube wells for water supplies. The scope of the paper

will accordingly be limited to a consideration of certain of these questions, instead of scanning more or less incompletely the whole range of the subject, and it is hoped that the notes will prove of practical value to members of the Congress.

Comparison between Percolation Wells and Tubes.

It has been a matter of surprise to many that such large volumes of water can be obtained from tube wells, and the author has frequently been asked to explain the seeming phenomenon, comparison naturally being made with the yield obtained from ordinary percolation wells. That there is cause for surprise will be acknowledged ; for whereas an ordinary masonry well will usually only yield from 2,000 to 4,000 gallons per hour, the author has obtained as much as 71,640 gallons per hour from a tube well.

The explanation initially lies in the fact that the water approaching the infiltration area of a masonry well has to move through the soil chiefly in a vertical direction, whereas the direction of approach to a tube well is horizontal ; and it is an indisputable fact that water will flow more readily and with less resistance in a horizontal than in a vertical direction, through sandy alluvial soils which have been deposited in a natural manner. If the grains of sand were true spheres, mixed with other material, it would be reasonable to suppose that the resistance to water flowing through the interstices would be the same in any direction, but the grains are not true spheres. They are, in fact, minute pebbles, with similar irregular shapes, many of the grains being somewhat flat in form. Alluvial soils also contain a considerable quantity of mica in small flat pieces, which, when sinking through water, in the way that alluvial soils are deposited, come to rest in a horizontal position. They consequently present their broadest faces in opposition to vertically flowing water, whereas only their thin edges are presented to water flowing horizontally. Further, the subsoil is not one homogeneous mass, but is composed of layers of material, such as alternating strata of sand and clay, with occasional beds of kunker. The clay beds are frequently mere horizontal streaks running through the sand, perhaps only an inch or two in thickness, and while they effectually prevent the vertical flow of water through the sand, they have little effect upon horizontal flow.

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The bottom of a masonry well can only be presented to a single stratum of sand, whereas a tube well, penetrating more deeply into the ground, passes through and taps several water yielding strata.

Infiltration Head.

There is still another important factor, namely, the infiltration head, which causes the water to flow into the well. In a masonry well this is very limited, owing to the fact that the inflowing water tends to carry the sand with it, and if the critical velocity is exceeded, the sand boils or blows in with the water, causing cavitation, with danger to the structure of the well. This fact limits the head of infiltration in such wells to the neighbourhood of five to seven feet ; on the other hand, the construction of a tube well is such that the sand is prevented from entering the tube in any considerable volume, even though a very much higher infiltration head is used, and hence, as the volume of water a given well will yield is directly proportional to the infiltration head, and as a much greater head can be applied to a tube well, the rate of infiltration per unit area will be so much greater. An infiltration head as great as twenty-six feet has been applied to an Ashford patent tube well without harm resulting. It must be borne in mind, however, that the higher the infiltration head the greater the cost of pumping, so that it is preferable to engineer an installation to give the required quantity of water with a low head, though in some cases water is so valuable that it may pay to pump harder in order to secure a larger volume.

Figure 1 is the curve of discharge from a tube well, with different infiltration heads obtained by actual experiment. From the foregoing remarks it will be obvious that for free infiltration of water and consequent easy pumping, length of strainer is of greater importance than diameter.

Diameter of Tube Wells.

On the other hand the importance of diameter must not be belittled. Too small a diameter will mean too high a velocity through the last few inches of sand round the tube, with consequent frictional resistance. Increase in length taps new water, while increase in diameter allows that tapped to enter more easily. There is no definite proportion between length and diameter. Sometimes a short strainer of large diameter must be used owing to the water-bearing stratum being of shallow depth,

but when there is freedom of choice a very satisfactory proportion is to make the length of the strainer one hundred and fifty times its diameter.

Nature of Soil and Yield.

A tube well cannot manufacture water. It can but enable us to obtain from the soil that water which it will yield. The main controlling factor which regulates the volume of water obtainable from a tube well is the nature of the soil from which the water flows. The coarser the grit and the freer and more open the soil, the more readily will it part with its water to the tube well, but before an estimate of the water yield can be framed, a knowledge of the subsoil must be available to furnish data in the form of a correct classification of the soil, with a complete geological section of the boring.

This may be obtained by putting down a small diameter tube to sample the soil, but such a procedure is not generally advisable, as it is usually an additional expense which can be avoided. Experience shows that in most alluvial soils, water yielding strata can be found, and that it is only a matter of boring deep enough to find them. There is a limit to the depth to which a small diameter tube can be driven into the ground, and if good water-yielding soil is not found within that range, the matter is left in the unsatisfactory position of being unable to push the investigation far enough. By starting upon the investigation with a tube large enough to admit of the insertion of the tube well strainer, the single boring serves the double purpose of sampling the soil and sinking the tube well. On the other hand, if good soil is not found within the depth to which a small pipe could have been put down, the investigation can be carried to a still greater depth by passing a smaller tube through the centre of the larger one, and by testing down to three or four hundred feet completely settling the question of the suitability of the site for a tube well. Sampling the soil with only a small boring pipe may cause the abandonment of a project owing to the investigation not being pushed far enough. In the majority of cases, in the Punjab alluvium, good water-yielding sand can be found within a depth of two hundred feet. The author has found cases, however, where the results were most discouraging to that depth, but on going deeper most excellent water-yielding sand was found, from which the water rose to within a few feet of the surface.

It is the author's practice, when making a boring, to have careful notes kept of all changes of strata, with measurements from ground level, and to have samples of soil taken from every stratum; also when the stratum exceeds five feet in thickness to have a sample of the soil taken every five feet. Each sample must be sufficient to fill a cubical box of four inches side, and should be carefully marked with the depth at which it was taken. The samples are used to estimate the water yield that may be expected at the site.

Estimating the Yield.

The problem usually presented to the tube-well engineer is to install a well to give a specified quantity of water, and he has to decide what size strainer and plant to use. An easy way to solve the problem would be to take a low rate of infiltration per unit area, such as could be obtained from the poorest soil, and to calculate the size of strainer accordingly. Such a method plays for safety, but it almost certainly involves the buyer in a greater expense than should be necessary.

The author has given this branch of the subject close attention, and has accumulated much data as an aid to such estimating. At quite an early stage in his work he felt the need of some definite method of determining the probable water-yield, and to this end it is clear that there must be a simple yet accurate method of classifying the soils and recording the same for reference.

Direct experiment, by passing water through the sand, is not possible, as the actual conditions under which the soil is deposited and packed cannot artificially be produced. The only true basis on which an estimate can be made is a knowledge of the gradation and proportion of the sands and clay contained in a boring, and Kennedy, by his experiments on silt, has provided the basis for solving this problem.

A classification of soils might be accomplished by the mechanical process of sifting, to find the quantity of sand of different grades contained in a sample, but such as two would be altogether too slow and laborious. Kennedy ent are ed a method of classification by gravitating the sa ating the column of water, and recording the times required ne sands, through a standard height of water column. Blaker carefully work further, and made it more useful for the present p nterstices directly connecting the velocity of the falling grains sufficient size. The following table was accordingly compiled :— l flow of

TABLE COMPILED FROM CURVES

GIVING PERCENTAGE OF SILT PER GRADE IN EACH SAMPLE.

Grade in meshes per lineal inch.	Kennedy Grade.	Sample Number. 1	2	3	4	5	6
		Position of sample from surface.					
		20′/24′	24′/32′	34′/52′	52′/68′	76′/90′	90′/100′
Above ... 200	0·000 / 0·025	9·3	7·8	15·2	7·1	11·4	2·6
Above ... 140	0·025 / 0·05	4·7	1·6	14·5	1·5	11·8	2·4
Above ... 86	0·05 / 0·10	33·4	32·6	36·3	21·0	21·1	4·9
Above ... 54	0·10 / 0·20	42·4	44·1	28·4	46·3	28·6	46·5
Above ... 42	0·20 / 0·30	8·2	11·6	3·4	15·5	15·3	26·0
Below ... 42	Below ·30	2·4	2·3	2·2	8·6	11·8	17·0
Total ..	1	100·0	100·0	100·0	100·0	100·0	100·0

It is obvious that if a soil, which is a mixture of clay and of different grades of sands, is allowed to gravitate through a column of water, the larger grains of sand will fall more quickly than the smaller ones, and the grains of clay, being still smaller in size, will come down last. Thus the accumulation at the bottom of the column will be in truly graduated sizes, with the coarsest at the bottom and the finest at the top. The rate of velocity of fall, as determined, then indicates the graduation of the grains of sand as to size.

Apparatus used for Testing the Soil.

The apparatus used consists of a tapering tube, clamped in a vertical position, and terminating at its lower end in a cylindric glass, graduated in fluid ounces. The length of the tube used by the author, together with the glass vessel, is six feet four inches. Two observers are necessary to conduct the tests. The tube is filled with water to a height of six feet, and the specimen

having been dried and all lumps crushed, so that the particles are free, is filled into an open cylinder placed on a small flat plate laid on top of the tube. The capacity of this cylindrical measure is exactly the capacity of ten graduations on the glass vessel.

On a signal from one observer, the other slips out the plate, allowing the specimen to drop into the water, while the first, watch in hand, observes the time taken by the sand to collect in the glass vessel. As the particles settle, gradually filling the glass, this observer calls out the time as the sand reaches each successive graduation mark, and this is noted down by his companion.

Preparation of Diagrams.

This information is then recorded on a diagram on squared paper (Fig. 2) in which the base scale is the time in seconds, and the vertical scale the volumes represented by the graduation marks on the glass vessel. The time in seconds, taken by the sand to accumulate in the glass up to each mark, is plotted against these graduation marks and a curve drawn through the points so obtained. This curve is characteristic of the sand, and is a record by which the sand can be classified.

Upon the diagram (Fig. 2) four curves have been drawn, each taken from an actual test. They have been selected as representing both extreme and mean cases.

Curve A is useless from a water yielding point of view.

Curve B represents a poor sand, which will yield water slowly.

Curve C is a medium quality sand.

Curve D is an exceedingly good sand which will give water freely.

These curves in themselves, however, do not tell us how fast water may be obtained from the soil. They are merely a means of classification, for comparison with other curves for which the rate of water yield has been experimentally determined. As two curves rarely agree exactly, experience and judgment are necessary so that they may be successfully used for estimating the water yield. The proportion of coarse, medium and fine sands, together with the clay present in a specimen, must be carefully noted, because fine sand and clay tend to close the interstices between the larger sand grains, and if clay is present in sufficient volume it will effectually seal the passages and pr event all flow of

water, while very fine sand may be equally obstructive, or nearly so. Fortunately, the natural conditions favourable to the deposition of coarse sand are unfavourable to the deposition of clay and fine sand, hence it is not often that there is a dominating preponderance of fine material present with the coarser sands.

As a preliminary to estimating the yield likely to be obtained at a particular boring, a geological section (Fig. 3) must be prepared, together with the characteristic curve of the soil in each stratum. The rate of yield is then estimated for each stratum, with due regard to its thickness, and the whole summed together to complete the estimate for the whole well.

As a guide to such estimating, a full series of sand curves for a well are reproduced in Figs. 4, 5, 6 and 7, and the actual curve of the water yield for the whole range of infiltration heads (Fig. 1). This particular well had a hundred and twenty feet of Ashford strainer, ten inches in diameter, with its head forty feet from ground level.

When arranging the details of a tube well, unfavourable or contaminated strata may be blanked off, by coupling plain pipe between lengths of strainer. It is not infrequent to find that the water nearest the surface is brackish, while deeper strata yield good potable water, and in such a case the brackish water may be kept out of the well by putting plain piping in that part.

Design of Strainer.

The construction of a strainer may affect the water yield at a given site. In the author's experience, a strainer which has slit-like openings is less likely to choke than one having woven wire mesh or small holes. To get the best results, a strainer must be neither too close nor too open. It should be sufficiently open for fine sand and clay to be washed through while stopping the coarser sand. When it is so made, a quantity of fine material will come away when pumping begins, thereby increasing the porosity of the zone of sand surrounding the tube, and adding to the freedom of infiltration. The washing out of this fine material will not continue indefinitely, but only until the sand has been cleared to the radius at which the velocity of the inflowing water is below that necessary to dislodge the fine material from between the larger sand grains. Washing out in this way does not cause cavitation, as the fine material is only removed from the interstices between the larger grains. If the strainer were so open that the larger sand grains could enter, cavitation would result.

If the strainer is too fine to allow the finer sand and clay to pass through, these are liable to accumulate against the strainer, and choke it. With a wide strainer, water may be obtained by limiting the infiltration head, but if that limit is exceeded cavitation results. The manner of pumping has also an important bearing upon the allowable openings of the strainer. When the pump action causes a continuous steady flow, a more open strainer can be used than when the flow is jerky, as with a reciprocating pump. With a steady flow, the openings of the strainer may be equal to, or slightly wider than, the size of the sand grains to be excluded, because they will arch over the openings, and remain steady. On the other hand pulsating flow breaks down such arching, and the sand enters the strainer, so that a strainer for use with a reciprocating pump must have finer openings than are necessary with a centrifugal pump with its continuous flow.

From the foregoing it is clear that there is a correct width of strainer opening for each gradation of sand, but, as it is scarcely a manufacturing proposition to make a strainer of special mesh for each stratum in each tube well, it is found convenient to make the strainer suitable for average grades, and when it has to be used for finer sands, to pack the outside of the strainer with a zone of coarse sand. This is done by feeding the coarse sand in measured quantities, into the annular space between the strainer and the sinking tube when the latter is being withdrawn.

Starting Pumping.

When starting up a tube well, it is advisable at once to apply the maximum infiltration head by pumping to the fullest extent. This washes out the fine sand and clay from the zone surrounding the strainer, clearing it for its work. If this cannot be done without an incursion of coarse sands, and consequent cavitation, the strainer is too wide.

Spacing of Tube Wells.

When arranging a series of tube wells for one installation, the question must arise as to how close they may be placed without interfering with each other. As an aid to the settlement of this point, we must know something of the effect created upon the subsoil waters when pumping from a tube well. When water is pumped a depression is created in the neighbourhood of the tube well, which is termed the cone of depression. The curve of the depressed cone is approximately hyperbolic, but not quite so, especially as the tube is more nearly approached. This

departure may be due to a change in the texture of the sand, consequent upon the washing out of the finer grains and clay.

If two wells are placed closer together than twice the radius of the cone of depression, the depressed area may be likened to an elliptical cone of depression, with the two wells at the foci of the ellipse. Such an ellipse will yield more water than a single cone, but always less than two independent cones, and the proportion must be that of the containing ellipse as compared with the circle of corresponding radius. Two cones of depression are plotted in the diagram on Fig. 8, one yielding 1·93 cusecs, and the other 0·28 cusec. The author has no actual records of curves of depression where two or more wells are situated so closely as to interfere with each other.

It is clear from the depression curves on the diagram (Fig. 8) that when tube wells are placed as closely together as is customary in water works, there must be serious interference, and each well gives less water than it would, if they were more widely separated. The further fact, that water pumped from deep tube wells is already filtered, removes part of the necessity for concentrating the whole of the wells for a supply system at one spot, as is now usual, and points to the desirability of placing tube wells at different sites within, or adjacent to the supply area. Such an arrangement would lead to economy in water mains, for large pipes starting out from one centre, possibly at a distance from the supply area, would no longer be necessary. Instead, there would be several pumping stations, each of small area, comprising a tube well, pump, and balancing tank, with a connection to the service mains. When electric power is available, the pumps could be electrically driven with automatic switch gear, which would start and stop the pump suitably to the fluctuating level of the water in the balancing tank. Where electric power is not already available, it might be economical to install it specially for the water supply, as a central generating plant, distributing power by wires to the several pumping stations, would be cheaper than large water mains from one water-works pumping centre to supply the whole area. This would also dispense with the large and expensive masonry works comprising sumps, connecting tunnels, etc., usually found in existing water works systems. The author put this proposal for separate pumping stations before the late Municipal Engineer of Lahore, several years ago, as a means of avoiding the necessity for relaying with larger mains the service to part of the supply area, where

the demand for water had greatly increased, and the proposal was carried into effect.

Properly engineered, the tube well has brought within the sphere of practical politics, a pure water supply for small communities, whereas formerly water works schemes were limited to the large towns.

Pumps.

The development of the tube well has led to the further need for pumps specially suitable for use with them. The type of pump available on the market has many deficiencies, not the least of which are its low efficiency and its unsuitability for lifting water from a considerable depth. Failing to find a satisfactory type of pump, the author set to work on the problem, and has, with the help of his assistant Mr. Leggett, produced a suitable series for all purposes and conditions connected with tube well engineering. A tube well with an unsuitable pump may be a poor investment, but, if properly arranged and fitted with a good pump, it will give satisfaction.

These pumps, which have been carefully thought out to ensure satisfaction, working under the conditions that obtain in this country, have been patented. They can be arranged for any kind of drive, whether electric, steam or oil engines, bullock or even hand power, and are found to give an efficiency as high as seventy-five per cent. They are so designed that they can be used at any depth below ground, and do not require foot valves.

The sinking of a masonry steining into the ground, especially to a considerable depth, is often a troublesome matter. Unless the work is well done the masonry may crack, thereby providing an opening for the incursion of surface water and sand. Such cracks are difficult to staunch, particularly so if they are below spring water level. To surmount this trouble, a pump has been designed to work inside the tube, and thereby entirely dispense with any steining. These pumps can be arranged for any reasonable pumping head or depth of spring water level.

Research Laboratory

DISCUSSION.

MR. BROWNLIE, in introducing his paper, said that it was written chiefly with the object of drawing a discussion at the Congress in order to get some information. One reason for writing the paper was to remove a more or less common idea amongst people in India that tube wells were a new invention. They had been in use in America for the last fifty years at least, and might even be much older, as some one had suggested an early form of tube well in Moses striking the rock so that the water gushed forth.

MR. ASHFORD said that when he was asked to write a paper on tube wells, he felt himself in a little difficulty, because the subject was so big that it was impossible to deal with it in one paper, and he had to consider what branch of the subject he would tackle. He might have given a detailed description of his many experiments, or some notes on well boring, or even information on the more mechanical side of the subject, such as pumping installations, &c., but he felt it would be useful to explain the methods he employed in seeking an answer to the question generally put to him by those requiring information on tube wells, namely, what size of tube well and engine must be put down to get a certain quantity of water. He had spent a considerable amount of time and effort in dealing with this problem, in the course of his investigations, in which he had endeavoured to develop a method of answering this question with some measure of certainty. It was obvious that in installing a tube well it must be suited to the conditions of the site. The tube well could not manufacture water ; it could only help in getting as much water out of the subsoil as the subsoil would yield. He had explained the method followed in estimating the yield of water from sand in any stratum, and as the results obtained by that method had been useful he had put them before the Congress for criticism which might be useful to them all.

MR. HADOW noticed that the two diagrams given for the cones of depression did not agree, particularly near the well, and enquired whether the authors could give any reason for this. Both diagrams showed that at a distance of about three hundred feet from the well the depression was negligible, and if this were so, what effect would a pumping installation, such as that at Amritsar, have on the subsoil level, seeing that the depression would only extend to a cone of about three hundred feet radius round each well.

MR. ASTBURY, with reference to Mr. Ashford's statement that the tube wells of water-works were usually placed too close together, pointed out that an increase in the spacing would involve an increase in the capital cost and the maintenance, because the suction-main and the barrel containing it would have to be longer, and the loss by friction would be increased. The disadvantage of close spacing was interference, which meant that, when one well was pumped, it was said to interfere with the other if the water level in the latter dropped. The disadvantage was then that the second well started work with an initial loss of head. Economy of well spacing would thus depend on finding a minimum value for the sum of these two disadvantages, and unless Mr. Ashford could support his statement by calculation based on data from existing water works it would not carry definite weight.

The advantages to be derived from a system of water works, consisting of tube wells dotted about the area of distribution, each with its own independent pumping plant, had also been advocated by Mr. Ashford—the principle advantage being that the earth was made to do duty for the main line of distribution, and only the subsidiary lines of pipe had to be laid. There were, however, some disadvantages. In water works practice it was not usual to pump directly into the distributing mains, and water usually reached the consumer by gravitation from an elevated reservoir. In Lahore it so happened that there were old mounds in the area of distribution, which made convenient sites for elevated reservoirs, and this system of unit wells at the foot of these mounds was likely to be most useful for supplementing the main supply from the elevated reservoirs in the city. At Sialkot and elsewhere there were no such mounds in the area of distribution. There was only the one natural high site for a reservoir, and that was one reason why in this instance the unit system was not adopted. Other reasons were the question of supervision and the duplication of pumping plant.

Mr. Brownlie mentioned that a tube well of the Thompson or Buildings and Roads type had been a failure at Dera Ghazi Khan, where he said the water was somewhat saline, and that, as a result, the copper gauze screens were completely corroded. He stated that the iron oxide in combination with the silica formed practically an impervious matrix on the surface of the screen. This tube well was sunk in 1912, and as the water supply was, to some extent, under the speaker's control as Sanitary Engineer he

wished to mention some further details. Two tube wells had been sunk at two hundred feet centres ; one, that mentioned by Mr. Brownlie ; the other, a five inch Ashford strainer of a type which is now obsolete. The former delivered into a sump well, while the suction pipe was directly coupled to the Ashford strainer. It was hoped at the time they were sunk that, by having two tubes of different patterns, some practical experience would be gained by the comparison of their relative performances, and, when tested in March 1913 the two wells yielded practically identical discharges under equal heads, about 160 gallons a minute with an eight foot head. In 1914 the Buildings and Roads type strainer was replaced by a Brownlie convoluted strainer, and in 1917 the discharge of this new strainer was about sixty per cent. of its original discharge, while the original Ashford strainer had ceased to yield any water at all. The direct coupling of the Ashford strainer prevented its being cleared by the water jet method, which could be used on the Brownlie strainer as it discharged into a sump.

The Ashford strainer had broken in an attempt to withdraw it from the well, but members could see from the topmost piece, which he had brought with him, how completely it was clogged, but on treating with hydrochloric acid the gauze was cleared of all clogging and stood out clear and bright as new. The deposit had been analysed by the Chemical Examiner and found to consist of thirty-two per cent. of carbonate of lime and sixty-eight per cent. of insoluble earthy matter, so that he ventured to think that Mr. Brownlie was not quite correct in saying that the clogging was due to iron oxide in combination with silica, or that corrosion of the copper gauze took place. The available evidence went to show that the cause of deposit was chemical action resulting from a reduction of pressure. The water contained a large amount of calcium carbonate and carbon dioxide in solution ; the effect of pumping was to reduce the pressure on the water and cause some of the carbon dioxide to pass out of solution, which caused a precipitation of calcium carbonate.

It would be evident to members of the Congress that the experience at Dera Ghazi Khan afforded no evidence as to the relative merits of the two strainers—the Brownlie and the Ashford. It did, however, show that water existed which was unsuitable for extraction from the soil by means of a strainer of any pattern.

A paper by the late Mr. Barnes had been quoted in which he said that the percentage of iron in tube well waters increased with the distance from the hills, and that Dera Ghazi Khan was the worst offender, but the evidence for the correlation between the percentage of iron and the distance from the hills did not seem to warrant the statement, and Mr. Barnes' paper did not actually work out any correlation factor.

At a previous Congress a paper was read by Mr. E. S. Heard on the Sialkot Water Works where there were six five-inch Ashford tubes in use with a total length of 350 feet of strainer. A careful log had been kept of the behaviour of these wells since they were brought into use, and so far there was no evidence of any tendency for the discharge to lessen. The Sanitary Branch was much indebted to Messrs. Ashford and Brownlie for their skill and energy in having made tube well strainers available for general use in this country.

MR. IQBAL HUSAIN wished to criticise the use of tube wells as a remedial measure for water-logging. His study of water-logged areas gave no hope that tube wells could ever serve this purpose. Fig. 3 was a geological section where water-logging was not expected to take place, and Mr. Ashford had shown the head of his strainer forty feet below ground, while in water-logged areas he proposed to keep it not less than twenty feet below ground in order to prevent the admission of air which would destroy the efficiency of the pump. His own experience was that in water-logged areas the clay stratum was not very deep, in fact not much lower than fifteen to sixteen feet below ground level, which would shut off a strainer twenty feet down, so that it could not affect the water-logging. Even if the strainer were kept higher it would quickly be choked by the surface soils, which contained more than fifty per cent. of clay and fine dust. In any case the reduction in the water level would be so infinitesimal as to render a tube well useless as an instrument for unwatering water-logged lands. Perhaps Mr. Ashford could give some figures illustrating the effect of the Amritsar hydro-electric pumping installation in checking the rise of the water level, with the discharge, the depth of the strainer below ground and the geological formation at the site, together with the main factors which led to its selection.

MR. BAINES thought that some notes he had made of Mr. Ashford's first tube well, comparing it with a tube of the

Cook Well Company of America, might be of interest. The Cook tube gave more satisfactory results as regards discharge, but its great superiority was in its construction, which Mr. Brownlie had described. Mr. Ashford's tubes had doubtless improved since his first attempt, but the principle was the same, and their uncertainty had been proved by tubes failing to give satisfactory results, due, either to their being too tightly wound, or the reverse, and much valuable time would have been saved if Mr. Ashford had adopted the Cook Well Company's tube instead of being under the impression that a tube had yet to be invented. His first tube well and the Cook tube were sunk in Amritsar, fifteen feet apart, the former to a depth of 48 feet and the latter 133 feet; both strainers were in excellent water bearing sand of much the same quality. Mr. Ashford's strainer was 30'-7" long and 5" outside diameter. The Cook tube was 64' long and 3½" inside diameter. Both tubes were connected to a three-inch centrifugal pump (driven by an electric motor) with an arrangement of valves such that either tube could be pumped from separately, or both together. The resistence through the strainer in the Ashford tube was found to be 8·4 feet as compared with 2·5 feet in the Cook tube, so that the latter was not discharging anything approaching its full capacity owing to the resistance of the suction pipe and the small size of the pump. This was borne out by the following table :—

Tube well.	Volts.	Amperes.	E. H. P.	Discharge.	Discharge per H. P.
Mr. Ashford's	175	8	1·88	0·22 cusecs	0·12 cusecs
Cook Well Co's	170	10	2·28	0·38 „	0·17 „
Both tubes together.	170	10·5	2·39	0·40 „	0·17 „

MR. DORMAN said that Mr. Ashford had given as one reason for a tube well having a better discharge than a masonry well, that the approach to the tube was horizontal whereas to the masonry well it was chiefly vertical, but did this hold good beyond the immediate neighbourhood of the well? Would not the stream lines in both cases be somewhat of the nature of the curves shewn on page 38? Again it was pointed out on page 50 that laminated particles, in settling through still water,

lay flat on the bottom, and consequently alluvial soils offered a greater resistence to water running in a vertical direction than in a horizontal. If this were the case would not the converse also hold true, namely that where the grains could move, after the finer particles had been washed out, would they not gradually rearrange themselves with their flat surfaces at right angles to the stream lines, and would not this partly account for the falling off in the discharge mentioned by Mr. Brownlie on page 39 ? The difficulty in estimating the yield of a tube well had been exemplified by recent experience at Pasrur, where, after Rs. 900 had been spent on a trial boring, taken down 222 feet, through what was pronounced a good water bearing stratum of coarse sand, forty feet thick, some 200 ft. below the surface, and which was promised to yield under ten feet head, 10,660 gallons an hour from a ten inch tube, after sinking this tube through the sand, at a cost of Rs. 7,731, a discharge of only 2,600 gallons was obtained. This was attributed to the water bearing stratum being only a sand pocket, but was this a sufficient explanation ? Would not the indications of a sand pocket be rather a full discharge gradually diminishing as the limited reservoir was pumped dry ? Towards the end of his very interesting paper, Mr. Brownlie mentioned that the Agricultural Department had been able to materially augment the supply of ordinary percolation wells by inserting small tubes till these wells were able to irrigate on an average ten acres at an outlay of less than Rs. 100 per well. What was the average size and length of the tube inserted and the approximate increase in yield ? The speaker had recently made enquiries regarding the cost of a tube to irrigate twenty acres, and the only quotation received amounted to something like Rs. 1,700.

Last year a primitive type of perforated wooden tube had been produced at the Congress, with the suggestion that such tubes could be used for zamindars' wells ; and when one remembered the extent to which continuous wooden stave pipes from two inches in diameter upwards had been used in America, one wondered whether, while metal tubes were so difficult to get, something similar could not be used for tube wells in this country. With spiral winding, the strainer might almost be formed by closing up the winding, round a perforated pipe, longitudinally grooved on the outside. When one thought of the brine wells of Tzuliutsing in Chengtu—* some of them three to

* Scientific American Supplement, November 18th, 1916.

four thousand feet deep—yielding something like 300,000 tons of salt a year, where the same old primitive plant, mainly of bamboo pipes and ropes, had been in use for the past thousand years, one felt there were possibilities for wood pipes in India.

RAI SAHIB AMAR NATH NANDA thought that Mr. Brownlie's statement that tube wells could be spaced five to six hundred feet apart without interfering with one another required some modification in order to secure ultimate economy in the cost of tube well installations. When a battery of tube wells was to be put down, the question of interference depended not only upon the spacing of the wells, but also upon their size, the radius of their circles of influence when operated singly, and upon the "draw-down" or the depth to which the water was lowered by pumping. Two aspects of the case presented themselves. First, when two or more wells penetrated the same stratum and were placed near one another and operated simultaneously—in that case the yield per well was bound to be less relatively than the yield of a single well pumped to the same level. Secondly, the maximum amount of water obtainable from these wells would be available when they were spaced far enough apart so that their circles of influence would not overlap, but on account of the cost of piping, the duct, and a long suction main, the loss of head by friction, and the cost of land, an economical spacing had to be determined.

The speaker deprecated the use of brickwork sump wells in connection with tube wells, on account of their cost and their liability to admit contaminated water drawn from near the surface. He considered that Mr. Ashford's pump, working inside the plain pipe attached to the strainer, was a great improvement on the method of pumping from a masonry sump. When pumping direct from the strainer he thought it advisable that the draw-down should be increased very gradually, otherwise the risk of sucking in sand was greatly increased.

LALA WAZIR CHAND related his experience with a tube well at Nathuwala. An estimate for a masonry well had been sanctioned, but it was decided to try a tube well in the rest house compound, where the spring level was 51 feet deep. This was the first experiment of its kind on the Lower Bari Doab Canal, if not in the Province, and consequently Mr. Ashford's help was invited and the well was sunk, but no water. The defect was said to be in the pump, but all efforts to rectify matters having failed, the well was abandoned after spending

Rs. 1,000 on it. Another tube was sunk to a depth of 94 feet the length of the strainer being twenty feet, while the pump was placed at a depth of 64 feet from the ground. This well was persuaded to give five gallons a minute after several attempts, or about half the discharge of an ordinary percolation well and one-tenth of the yield estimate by Mr. Ashford (page 50). The experiment was carried out by Mr. Ashford's men and took three years to complete, at a cost of Rs. 2,500, whereas a percolation well could have been sunk in a month for Rs. 1,000, and all the water required drawn by a single man in a bucket, as compared with four men required to work the pump on the tube well.

No figures had been given of the cost of working a tube well as compared with an ordinary well for different lifts, and though the former might give a discharge of from seventeen to thirty-five times that of the latter, there was nothing to shew that the ultimate cost of a tube well might not be equal to forty masonry wells.

MR. WOODS felt that Messrs. Ashford and Brownlie had discussed the problem of pumping from tube-wells mainly from the mechanical and geological points of view, but had not sufficiently considered the question of the source and magnitude of the underground water supply. Mr. Brownlie writes :— "The quantity of water which can be withdrawn from the subsoil by a tube-well depends primarily on the texture of the soil and secondly on the superficial area of the soil over which the water is to be withdrawn . . . . Tube-wells may be placed from five to six hundred feet from one another without any appreciable effect on the water level or power-loss . . . . Assuming that the critical velocity of the subsoil is not being exceeded, the question arises, what is the economical discharge to take from a tube-well in a particular soil ? This resolves itself into a question of the subsoil water level only, and in districts where the subsoil water level is low, it is much more economical to pump large discharges than in districts where the subsoil water is close to the ground surface."* Here the idea seemed to be that discharges of any magnitude could be obtained from an inexhaustible subsoil reservoir, and that the only limits to pumping arose from considerations of economy or geology. Mr. Ashford also seemed to assume an inexhaustible source of ground water, since he writes :—"In the majority of cases, in the Punjab alluvium, good water bearing sand can be found within

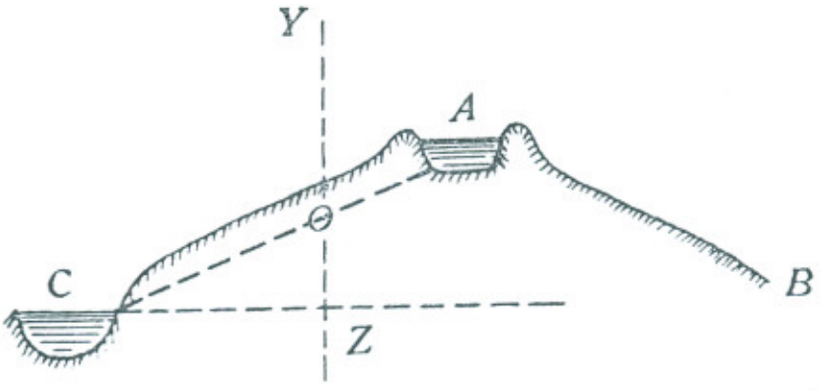
* *Vide* pages 37-40.

a depth of two hundred feet",* and from his Fig. 8 it appeared that he contemplated spacing wells of two cusecs discharge about eight hundred feet apart, or forty to the square mile.

It was desirable to make the aim of the tube-well clear. If it were required to furnish a potable water supply to a city, town, or village, it was advisable to draw its water from a great depth, for the water there would be purer, the volume of water to be pumped would be relatively small, and the consumers could afford to pay much for it. Regarded as a means of irrigating the ground surface, it might safely be said that in the Punjab canal doabs, the tube well could not compete successfully with irrigation by flow from canals.

If, however, the primary aim of the tube-well be to reduce water-logging of the ground surface, by lowering the subsoil water level, the design of the tube-well system must take into account the source and volume of the underground water supply, and must aim at pumping out not more than a very small fraction of the perennial underground flow in any particular locality.

In the Punjab doabs, the rise of the subsoil water table, which ultimately caused water-logging, was mainly due to percolation from canals and from rainfall. The sketch below might be taken to represent a cross section of a doab, *B A C*



with a canal on the watershed at *A*, and a line of percolation *A O C* draining into a river valley at *C*. Supposing that the percolation flow from a given length of the canal towards the river amount to *x* cusecs, and also supposing that a set of tube-wells be installed on a line parallel to the canal at *Y O Z*, if the aggregate discharge of these wells be *x* cusecs, there will be no flow to the left of the line *Y O Z*, and the level of the subsoil water-table will progressively sink from the line

*Page 52.

O C till it attains a dead level at C Z. Even if the dis of the wells be considerably less than *x* cusecs, the flow to C will diminish, the gradient O C will flatten, and the O of the subsoil water stable will be lowered. The leve the subsoil water-table *must* be lowered, if the object of the well installation be to prevent threatened or existing cond of waterlogging of the soil. In projects of this nature necessary, therefore, to endeavour to estimate the prol volume of flow of the subterranean stream in the tracts with, as a guide to the design of the tube-wells.

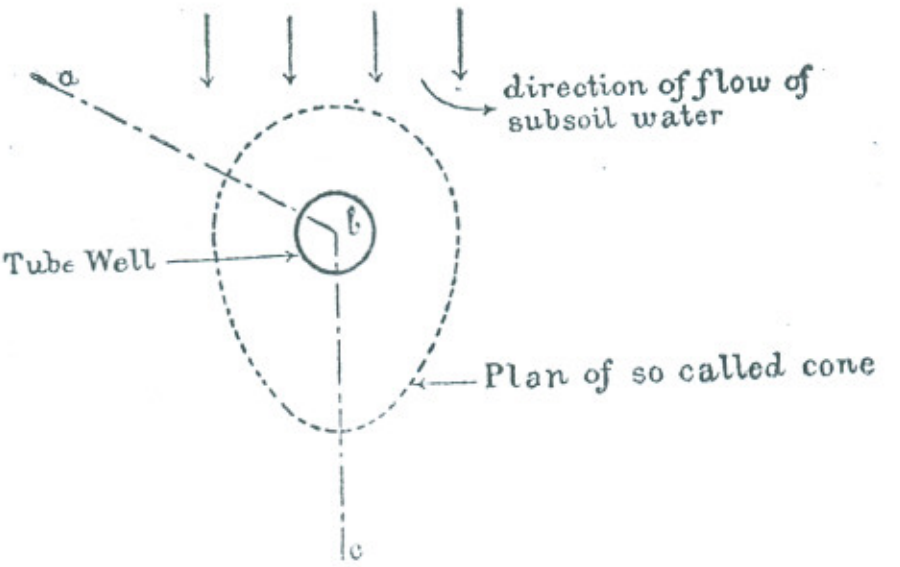
Messrs. Ashford and Brownlie contemplated appare drawing from eighty to a hundred and fifty cusecs from subsoil of each square mile of land. Such supplies could possibly be obtained continuously from the percolation flow, wh had its sources in canals and rainfall, without lowering the le of the subsoil water-table to an undesirably great extent. F the purpose of obviating waterlogging of the ground surface any given tract, it would probably suffice to pump one or tw cusecs from each square mile of area ; whilst to pump more tha that amount would be unnecessary for sanitation, and needlessl expensive for agriculture, if the water bearing strata tapped b the pumping were those at the surface of the subsoil water-table

MR. MONTGOMERY said that a large tube-well had lately been put down in the Minto Park, Lahore, fitted with one of Mr. Ashford's pumps, but it had only been worked for a short time, as an experiment. He had heard that a similar type of pump had been fitted to a well sunk in Cantonments, which had given considerable trouble owing to a quantity of sand drawn into the tube cutting the bearings of the vertical pump. If this were correct, he would be grateful if Mr. Ashford would give him any hints about how to work the vertical spindle pump in the Minto Park, which was more or less in his charge as Superintending Engineer. Could this danger be obviated, and what was the explanation of the influx of sand into the canton-ment well ?

MR. SANGSTER wrote drawing attention to an * article on "The Tube Well and Irrigation Possibilities" by F. H. Vick, Agricultural Engineer in the United Provinces, in the course of which he stated that the tube-well was a sound investment with a big future before it in the United Provinces where con-ditions were so eminently suitable.

* The Agricultural Journal of India, Volume XI, Part III (July 1916), page 296.

MR. BROWNLIE, replying to Mr. Hadow's remark that his diagram for a cone of depression did not agree with Mr. Ashford's, said that this was probably due to an insufficiency of records for cones in various subsoils ; or to the difference in density of the soils. The shape of the cone depended also on the direction in which the levels were taken, as it was not a true cone, but was influenced in shape by the velocity of the subsoil water, and its plan was something like this :—



consequently levels taken on the line *ab* would show an entirely, different curve from that plotted from levels taken on the line *bc*, and a sufficient number of observations had not yet been made to determine the average curve, which would of course vary according to the nature of the subsoil. As regards the tube well at Dera Ghazi Khan, the straining material consisted of a fine brass gauze supported on a galvanized wire netting of small square mesh, and protected by an outer covering of hexagonal galvanized wire netting. This tube was supplied only as a temporary measure as the standard form of his convoluted tube was not available ; he had guaranteed the life of the temporary tube as six months, and the estimated discharge had been obtained for that period. When the temporary tube was subsquently taken out, the brass gauze was intact, but the galvanized wire nettings had disappeared, and the meshes of the gauze were sealed up as described in his paper, but whether this was due to the action of iron oxide in combination with silica or some other reason was a matter for chemists to decide. Mr. Astbury could not be quite right in his assumption, as the permanent convoluted tube should

have failed entirely in the same time as the temporary tube, but the permanent tube had now been giving a discharge for five years. This showed that a tube could be made to deal with saline waters.

He did not consider tube wells a panacea for water logging caused by pouring canal water on to the soil. The replacement of canal by tube well irrigation, in water logged areas, prevented the unnatural rise in subsoil water level caused by canals, but the cure was not due to the tube wells, but to the removal of the cause of water logging. As pointed out, the reduction of subsoil water level by tube wells was only local, and valueless in itself as a cure for water logging.

He was not quite in agreement with Mr. Baines's opinion that the Cook tube was all that could be desired, since this tube possessed a defect which necessitated an unnecessary length for a given discharge, while it was difficult to manufacture and consequently high in cost. Other forms of American tubes also possessed various disadvantages, and after studying these he had designed and patented in 1911 the first large discharge tube well in India, known as the convoluted tube well, which purported to eliminate many of these defects. How far this assumption was correct might be judged by the fact that there were now over six hundred of these in use in India, many of which had been sunk to replace tubes of a less satisfactory nature, while the convoluted tube was gradually being adopted in the United States—the home of tube wells. No alteration had been made in the design of the convoluted tube, since the first one was manufactured, and its cost was considerably less than the Cook tube. In view of these facts he considered that there was ample room for improvement in tube well design at the time of which Mr. Baines spoke, and probably there was room for still further improvement at the present time.

In reply to Mr. Dorman he stated that in augmenting the supply from ordinary percolation wells the standard type of convoluted tube had been used ; the size being 2½ inches diameter, while the length generally varied between eight and sixteen feet ; the yield from this tube was generally from two to three thousand gallons per hour, and in some cases considerably more. The tube which was to have cost Rs. 1,700 was probably of a larger size, and for a situation where an ample supply of water had to be guaranteed, so that the conditions were hardly similar.

He did not agree entirely with Rai Sahib Amar Nath Nanda that a pump working inside the plain pipe of a tube well was an improvement over a pump working in a brickwork sump. The question of liability to contamination from surface water finding its way into a sump could be entirely neglected, and he never had the least trouble in rendering sumps perfectly water tight. In cases where the water level was near the ground surface, the masonry sump cost little if any more than a plain pipe, while it permitted the use of a horizontal spindle pump which was considerably cheaper than a vertical pump of the same capacity and efficiency, and in irrigation projects economy combined with efficiency was the first consideration. Where the water level was at a considerable depth from the ground surface, he emphatically recommended the use of vertical spindle pumps working in the plain pipe, but no definite rule as to the type of plant could be laid down and each case had to be considered on its merits, efficiency and economy being the aim.

In the case mentioned by Lala Wazir Chand where the subsoil water level was fifty feet from the ground surface and a small tube well had been put in to be worked by a hand pump, he considered that a great mistake had been made in installing a hand pump which required four or more men to work it.

The spacing of one tube well from another, discussed in his paper, referred to conditions where a comparatively large supply of water was required from one area for a public water supply, and this was a rough guide to the area of land required for the purpose, but Mr. Woods had evidently interpreted these figures to mean that he recommended the extraction of 80 to 150 cusecs per square mile. Considering that these figures were from forty to seventy-five times more than the water allowance of the Canal Department for irrigation purposes, it was hardly necessary to discuss the effect of pumping such large supplies.

MR. ASHFORD said that, before replying to the various criticisms, he wished to thank those members who had come forward and related their experience. It was not to be supposed that all the problems to be met with in the installation of tube wells had yet been fully solved, and, therefore, it wasa mistake to jump to conclusions when a first attempt was made to solve a new problem. Only collected experience could lead to the true solution of the problems. Attention had been drawn to the difference between the cones of depression presented by

Mr. Brownlie and himself. Undoubtedly cones would vary at different sites, largely owing to the difference in the porosity of the soils, the diameter and length of the tube well, its distance below ground the volume of water pumped and the time pumping had continued. In the case presented by himself, the water levels were carefully measured down a series of tubes driven into the soil on a radiating line from the well, and the measurements were made after pumping had continued for a long time so that a condition approaching equilibrium had been reached. It was evident that with two wells close enough to interfere with one another, their discharge must be less than twice that of a single well. The cones of depression from two such tubes, working together, would combine to form an elliptic cone of depression with the tubes as foci, and the tubes would give a discharge probably proportionate to the circumference of this ellipse, as compared with that of a circle of similar radius round a single tube. Where a group of tubes was desired at a waterworks, the arrangement that would probably give the greatest supply would be a straight line running transversely to the natural underground stream.

As regards the problem of unwatering water logged areas, he had worked out a scheme at Amritsar, but on doing so found himself faced with the conflicting demands of the need to unwater the soil and at the same time to pump water from the soil for irrigation purposes at a cost that would pay. These demands conflicted, because the greatest unwatering effect would be produced by a large number of shallow tube wells covering the area, each with a pump, which meant heavy capitalization, whereas the most economical arrangement for pumping would be fewer, and much deeper wells, each with a larger yield and pumping unit, at a less capitalization. These conflicting demands led to a compromise favouring lower expense and cheap pumping, so that the maximum unwatering effect could not be expected. Sufficient data had not yet been accumulated to determine the effect of such pumping upon waterlogging, and it should be remembered that the scheme was not yet complete. At present there were only fifteen pumps at work, whereas ultimately, when complete, there would be upwards of fifty, for which there would be sufficient power.

Mr. Woods had apparently misunderstood the remarks on the spacing of tube wells when he suggested that it was contemplated to pump from eighty to one hundred and fifty cusecs from each square mile. The remarks on the spacing of

tube wells had particular reference to water-works, where it was desired to get the water needed from the smallest area of land. For irrigation purposes, two wells, each of 2 to 2½ cusecs per square mile, should suffice.

The Dera Ghazi Khan experience was interesting, indicating, as it did, that the quality of the water obtainable, although potable, required special treatments for the strainer. Possibly, by sinking much deeper at this site, water could be found free from the objectionable salts, the deposit of which had caused choking.

Mr. Baines had communicated a note from which he apparently wished conclusions to be drawn, but he had not pointed out that the facts were incomplete and therefore misleading. The experiments in question had been carried out by the author, Mr. Baines acting as his assistant. The first Ashford well was made and put down before the Cook tube arrived and when the latter came to hand, it was put down next the Ashford tube so that it could be connected to the same pump, sluice valves being introduced to make it possible to put either or both tubes into connection with the pump.

The first test was as stated by Mr. Baines, but the water from the Ashford tube was drawn through a long suction pipe of small diameter, which gave considerable friction. This suction pipe was altered, and further tests made, with the following results :—

Test No.	Tube Well.	Volts.	Pumps.	Totals H. P	Net H. P.	Discharge in cusecs
1	Ashford ...	215	9·5	2·73	1·59	0·27
2	Cook ..	215	10·5	3·02	1·88	0·34
3	Neither ...	227·5	3·75	1·14	...	...
4	Both ...	215	11·5	3·31	2·17	0·43

Test No. 3 was with both tubes shut off and the pump running without discharge, when the pump absorbed 1·14 H.P. Deducting this figure from the total horse power in tests Nos. 1 and 2, the net horse power expended in pumping was obtained. In the first set of tests mentioned by Mr. Baines, it would be noticed that the voltage of the current was very low, whereas in the second series it was more nearly correct for the motor, which was built for 220 volts. The motor was therefore running lose to its best efficiency. The result of altering the suction

pipe was that the discharge of the Ashford tube rose from (to 0·27 cusecs, whereas the Cook tube fell from 0·38 to (cusec, owing to a fall in the spring water level. Mr. Baines g the respective lengths of the two tubes as 30′-7″ and 64′- The outside diameter of the Ashord tube was $4\frac{3}{4}$″, and not 5″ stated, while the outside diameter of the Cook tube was $3\frac{1}{4}$ The gross areas of the two tubes were Ashford 37·9 and Co 62·2 square feet, and the water obtained ·0071 and ·005 cusec respectively per square foot of gross area. This better di charge was obtained by the Ashford tube, although its length was less than half that of the Cook tube, and as mentioned in the paper, length was of greater importance than diameter in getting water from the soil. A further point of some importance was that the Ashford tube was far cheaper than the Cook tube.

Attention had been drawn by Lala Wazir Chand to a hand pump put down to draw water from a considerable depth The first attempt was a failure, owing to the incursion of sand, but the important lesson was learnt that a strainer, suitable for use with a pump giving a continuous discharge, was not suitable for use with a reciprocating pump giving a pulsating discharge. The tube was withdrawn, and a much finer one put down, which corrected the defect. It was not to be expected that a pump, placed 64′-0″ below ground and working against a head of nearly sixty feet, would be easy to work by hand, yet this speaker's remarks indicated that he expected it to work with perfect ease It also appeared that the hand wheel, which had a counter weight cast on it, was so placed on the shaft that the weight added to the resistance, instead of counterbalancing the weight of the rods, but, since the wheels had been fitted to a squared portion of the shaft, the matter was easy to correct. How the figures of cost had been arrived at, the author was unable to say.

In reply to Mr. Montgomery's remarks regarding a well sunk at Lahore Cantonment, the quantity of sand pumped indicated mechanical damage to the strainer, probably due to the weight of the rising pipe having been allowed to rest upon it ; and as the total depth of the well was three hundred feet, this weight was considerable. A second well sunk at the same site to the same depth was giving excellent results, and attention might here be drawn to the need for keeping tube wells in suspension, when lowering them down the sinking pipes, until the sinking pipe had been withdrawn. A column of pipes three hundred feet long, if allowed to rest on the bottom, might be expected to buckle