PAPER No. 263

A NEW TREATMENT OF THE PRINCIPLES OF FLOW

By Philip Claxton, Formerly of the Punjab Irrigation

1. I wish to start by asking whether friction or eddies are the cause of resistance in flow ?

Friction is popularly accepted, but since the filaments of water are free to slide over each other this opinion will not bear examination. For instance, consider oil lubricating the faces of machines ; a film adheres to each face of contact, and sliding then takes place between the other filaments. Friction is thus ruled out, at least for practicable purposes. So for water, except for viscosity which I shall consider later, a film would adhere to the boundaries of contact, and sliding between the other filaments would then take place. As a matter of fact, as we shall see, the nature of flow is completely altered by the appearance of eddies.

2. How then do we account for the familiar V^2 which expresses the law for retardation ? We shall be able to answer when we study the experiments of an expert physicist, Osborne Reynolds.

3. He first enunciates two leading features of fluid motion, direct and sinuous. He then states that the relation between the resistance encountered by and the velocity of water moving through a tube presents itself in one or two simple forms. The resistance is generally proportional to the square of the velocity, or if this is not the case, it takes the simpler form and is proportional to the velocity. Again, the internal motion assumes two broadly distinguishable forms, either the filaments are direct or sinuous. If a streak of colour be added, the colour will be drawn out in even bands, whereas if there are eddies these will be curled and whirled about as smoke. A connection between these two motions had been long suspected, and this he proceeds to discover.

4. He had noted the effect of oil in calming waves by producing eddies below the surface. He then experimented with glass and other tubes, and ultimately determined that though the tendency of internal viscosity is to keep direct motion stable, yet, owing to the presence of the boundary, the motion becomes unstable. In other words, boundaries are the cause of eddies, and at a certain critical velocity the steadying force of viscosity is overcome and direct flow breaks

up into eddies. Up to this point resistance had been proportional simply to the velocity, but at it resistance suddenly changes to be proportional to the square of the velocity, and for higher velocities the law remains unaltered.

Viscosity it should be noted, which. before the formation of eddies had worked against their formation, now works in the same degree to help them to continue. For this reason the effect of viscosity is eliminated.

5. Since the appearance of eddies and the law that resistance varies as V^2 come in together, resistance, or the energy of eddies, varies as V^2. We therefore realise that the familiar V^2 which enters all hydrodynamic formulae is an expression of eddying energy and not of friction.

6. The cause of change is the presence of the boundary. Whereas stiffness in the walls is unimportant, inextensibility or tangenital resistance is essential. This is evident from the effect of oil which spreads out into an indefinitely thin film, which offers only one of the characteristics of a solid boundary, *viz.*, resistance, however slight, to extension. This does not destroy, but alters the whole character of motion.

7. Thus, Osborne Reynolds lays down the principle that boundaries are the cause of eddies. Incidentally, from the film of oil we learn that inextensibility and not roughness is the condition. There may be boundaries with every degree of inextensibility, such as air, which a stream has for its surface boundary, where the line of maximum velocity is depressed, but for rigid boundaries in general, the exponent of V lies roundabout 2.

8. In this connection two other experimenters of California, Gilbert and Murphy, draw attention to the rhythm or wave motion of flow in water. By careful observation in relation to a fixed point, rhythm will be found to permeate every function of the current. In fact, we should correctly conceive of free flow as motion oscillating about the direct, each filament developing a wave length or periodicity of flow. This seems to be a fundamental law.

9. It will not then be difficult to understand what happens when boundaries are imposed. The wave formation by being laterally restrained cannot complete itself, and the filaments jostle each other and bring about eddying motion.

10. Yet if the boundary is itself regular, as that of a pipe, it is possible for periodicity to read just itself to the conditions imposed, and rhythm to become regular again. Gibson at Niagara appears to have measured discharge through pipes by calibrating it to the periodicity developed for different calibres of pipe.

11. Now active flow necessarily involves two forces, and we know little about it till we consider both together. For instance, we talk of acceleration of gravity impelling flow, but until we have resistance equal and opposite to this force, we do not have velocity, observed more or less as a constant. Velocity is merely the condition at which the acceleration of gravity is balanced by the equal and opposite internal resistance ef eddies.

12. The problem in flow is therefore one connected with variables. For instance, the impelling force of gravity is a variable, and it creates internal resistance, another variable. Moreover, these variables, by action and reaction, are always in a state that approaches the limit zero in the process of eliminating each other at a constant velocity V.

Thus, if x be the impelling force of gravity and y the internal resistance of eddies.

Then limit $(x-y)$ as V approaches a constant $=0$

And in the limit $x=v$ when V is constant.

This is the exact expression for flow, and since the forces are variables always in a state of balance, we should bear it in mind.

13. I wish to explain that observed V here is the mean velocity of all the filaments on any chosen width of cross section. It is only approximate to the true V which we are considering. At the end when we have considered all the conditions of flow, including the carrying of silt loads, I shall show how the discrepancy between observed V and true V may be removed. Till then, however, we shall consider V as true, because it is only true V which can give us a law. It only remains to notice that V can clearly not apply where there is acceleration, as down the slope of a rapid. It is the V of all streams observed to be more or less constant over selected reaches.

14. It is not enough to consider only the forces but the work done by them which we may measure. The expression V^2 is the result of one such measurement. To find another, let α be the angle of the gradient.

Then the impelling force will be $g \sin \alpha$

And the work done by this force $= g \sin \alpha \times d$

where d is the depth.

We arrive at this by considering any cross section. The action of gravity will be constant, for however the gradient may alter from point to point longitudinally, for that cross section of gravity will be the same. As then we have assumed

the gradient at the cross section to be α the work done through depth d on unit mass $m = mg \sin \alpha$ for this is the same as if we lifted mass m through d against the force $g \sin \alpha$.

15. But at velocity V this work is neutralised by eddies which come in as impulses. The work done in their destruction varies as $m\ V^2$

$$i.\ e.,\ mg \sin \alpha \times d\ \alpha\ mv^2$$

$$\text{or } g \sin \alpha = c\frac{v^2}{d}$$

16. Had we remembered the first principles of dynamics we might have arrived at the same result at once by calculus :

$$\text{Thus acceleration } a = \frac{dv}{dt} \quad i.e.\ dv = ad_t$$

$$\text{Integrating } V = at$$

$$\text{Again } a = \frac{dv}{dt} = d\ \frac{\frac{ds}{dt}}{dt} = \frac{d^2s}{dt^2}$$

$$\text{Integrating } \frac{ds}{dt} = at$$

$$\text{Integrating again } S = \tfrac{1}{2}\ at^2$$

$$i.\ e.\ 2as = V^2$$

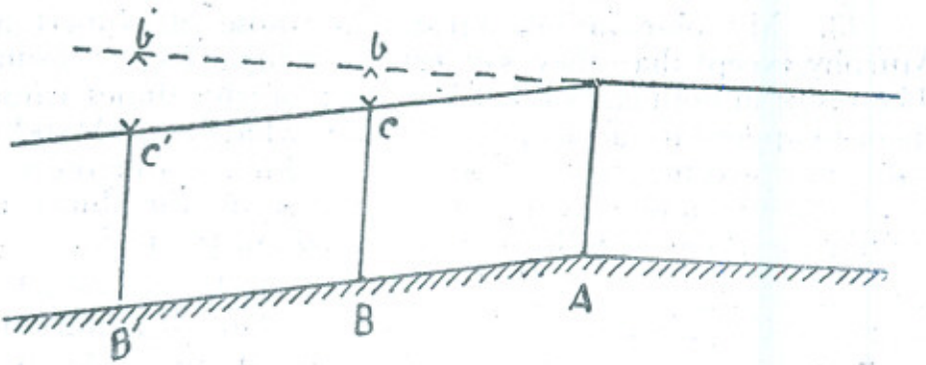
$$\text{or work done } mas = \tfrac{1}{2}\ m\ V^2$$

This is fundamental and cannot change. Yet flow is expressed by all sorts of empirical formulae. The fact is true V cannot be observed. Mean V in the first place is an approximation. Further the low velocities close to the bed, merging in rolling along the bed, cannot be observed either by velocity rods or meter. Observed V for this reason alone would be higher than true V. As I have said I shall show how these errors may be removed at the end, but before that we need to carry our investigation a step further.

17. I have already defined the law of flow, but I may restate it and say : the forces of acceleration and resistance when equally balanced give us a constant which we call velocity. I may then say : the work done by these forces also gives us a constant which I choose to call Potentity. We need such a term because it is only by work that we can measure the forces, as we have done in para 15. We shall also see as we proceed that without this term it would be very difficult to express the problem when silt load enters it.

18. Potentity then is the condition or index at which work is balanced by work. As acceleration at every point is balanced by resistance for constant velocity, so work done by acceleration at every point is balanced and measured by the work done by resistance to give us constant Potentity.

19. What suggested the term will become clearer when I illustrate the conditions of flow by a diagram.



The diagram shows a stream starting from a still water lake. From A it travels down to a point B. It is evident that at B it acquires the power of borrowing "potential head" approaching in the limit to b c, which it cannot borrow at A. A little lower down at B′ this limit will have grown to b′ c′. In fact at A no "potential head" is available, but lower down its availability quickly grows till it becomes, for our purposes at least, limitless.

20. We may express this condition by saying: limit "potential head" as Potentity approaches a canstant = 0. Potentity approaches this constant as the surface slope becomes an even line. When therefore the slope becomes an even line Potentity is constant. Potentity varies with change of section in the same way that velocity varies with change of section. As for a narrower section velocity is increased, so is Potentity, or for a wider section velocity and Potentity will be decreased.

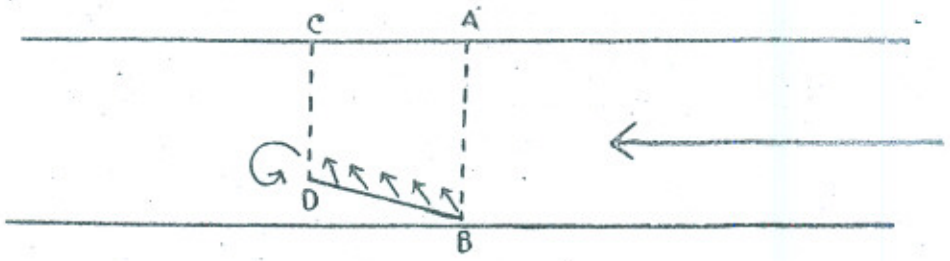
21. Hitherto we have been considering flow without silt load, but usually we have to deal with silt load that it carries. Gilbert and Murphy give us an interesting set of observations showing what happens when silt load is introduced. They show how silt dunes are formed over the bed which at first travel down-stream, erosion occurring on their upstream faces. This is followed by a smooth stage, after which the dunes develop a second rhythmic stage when the dunes are eroded on their down-stream faces and appear to travel upstream.

22. Earlier I had made observations independently on a stream in "regime," *i.e.* in the third phase of dune action of the G and M experiments. I had noticed that particles were rolled along the bed having a tendency to accumulate in dunes, or else a hollow was originated by eddies and started a fresh dune. As each dune grew, acceleration over its upstream face was generated, catching up particles increasingly, till at the crest scour resulted. This arrested further

development and created a hollow behind the dune. From here rolling again started to form the next dune.

23. My observations agree with those of Gilbert and Murphy except that they say erosion where I say "scour". The result in both cases is cutting back of the dunes causing them to appear to move upstream. But what G and M did not note impressed me most. This was the intense differences of local velocities and eddying action created by the dunes and confined to them, not distributed throughout the mass.

24. At the bank these differences had also impressed me when carrying out an experiment with a plane B D hinged to the bank of a stream. When thrown out at an angle to the



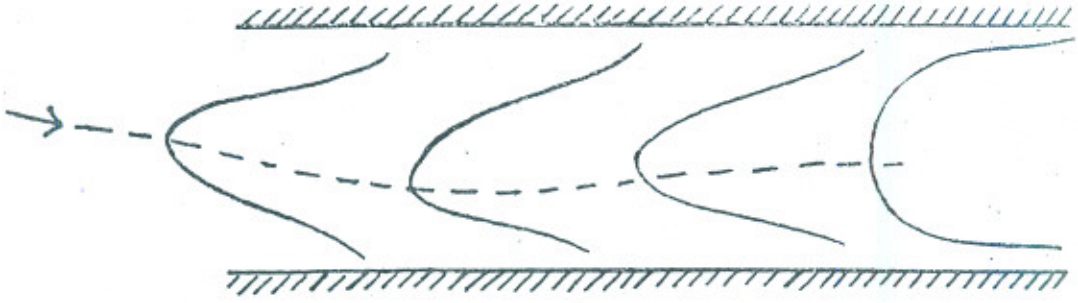
line of flow, the plane evinced afflux with quickened velocity outwards all along the face and violent eddying at the nose. Now a rough bank actually consists of projections as such planes. Each projection sustains afflux with resulting velocity outwards away from the bank accompanied by eddying action. Floating particles are thereby thrown out into the stream and do not cling to the bank. During floods a heavy line of rubbish and foam may be seen floating down the centre of the stream due to the centring action of the banks. It is particularly noteworthy that the quickened velocity was not distributed throughout the stream but was confined to the plane itself. For instance, the width at C D is less than at A B and the velocity must be greater. But the increase is effected, not across the whole stream from A B to C D but along B D, being greatest at B D.

25. Now at the bank we can note afflux which gives us these differences, but at the bed we note only the differences and cannot observe any afflux. Its effect is certainly there, but it itself is lost in the body of the water above. This would be difficult to express had I not defined Potentity (which is available). Potentity may not be observed as head, but is nevertheless operative in giving us these intense differences of velocity with their accompanying eddying action. At the bank we had argued from afflux, or visible cause, to these phenomena, but at the bed we must argue from the phenomena to their cause.

26. While Gilbert and Murphy give us observations of silt introduced into a clear stream, I once had the opportunity of observing silt introduced into a stream already loaded. We had made a diversion for an inundation canal through a sandy reach. On opening the canal the banks of this diversion caved in so heavily that a shoal threatened the flow of the canal, as we thought. We brought the shoal under observation by taking soundings. We then found that it had shifted down-stream. It was too large to be dissipated all at once but kept on travelling down-stream by successive removals till it reached a distributary head, twenty miles lower down. This it silted up permanently.

27. The observation has its points to explain how Potentity functions. In the canal we were miles below the off-take and Potentity was fully available and kept the shoal moving. But at the distributary head its availability was in defect and the head silted up permanently.

28. We seldom get excess loads in canals that are straight to give us such travelling shoals. The banks do not usually cave in to supply them, but the silt is dealt with by the dunes over the bed in rhythmic regular formations. Even then larger formations suggestive of shoals may be seen across the bed as shown in the figure:—



Here as velocity falls off towards the banks these larger formations take on these inverse contours. Their depression here represents the line of maximum velocity.

29. On the other hand on rivers that are tortuous heavy bank erosion occurs at each bend, and shoals in proportion appear. But the river has the option of going round the shoals, and its behaviour forms a separate study dealt with elsewhere.

30. Gilbert and Murphy also experimented with a gradually increasing silt load introduced into a clear stream. They found that though the gradient become steeper, enough to double the velocity on a clear stream, it was not increased more than 14% over the silted bed, owing to the resistance

of eddies raised by the dunes. On other experiments they showed how the vertical velocity curves were also altered. Since the velocity of approach was not given, and since we do not know how the outfall affected the experiments we cannot evaluate them fully.

While a steeper gradient from off-take to outfall is possible for short streams, we know that the reach is limited, since Potentity soon rises to its full capacity for that grade of silt and carries it on at a flatter gradient, which may be almost anything.

The tail reach may again need to be steeper because of irregular flow. For rivers entering the sea a delta forms, over which the water wanders haphazard, now in one direction, now in another.

Between these reaches, however, Potentity is available and able to deal with any load. This it does in the way I have tried to explain, by the formation of dunes and increased eddying.

31. Summing up these remarks on silt load: on the bed we have now studied examples of dune formation on the bed. We have also studied the affect of bank irregularities. The latter, for our purposes, are unimportant, but the former need close attention. In these studies Gilbert and Murphy give us very interesting experiments with the introduction of silt load. They trace it through three stages. In the first, which is unstable, dunes are laid down tentatively and travel down-stream. This is followed by an intermediate smooth stage which gives place to a third stage which is stable, when the dunes appear to travel upstream. My own observations confirm this third stage, and it is the one we usually observe. The dunes formed by it we have observed give us intense differences of local velocity, indicating Potentity. Each dune, in fact, by the creation of eddies, raises and helps to carry on the silt by additions of Potentity, distributed over the whole bed.

32. It is these additions which we have to consider when silt enters the problem. When this distribution becomes perfectly even Potentity from point to point approaches a constant. Thus in the limit Potentity becomes constant. The stream would then be in perfect "regime". Whether it reaches such a stage is another question, but the important point for us to remember is that a stream always strives to reach it, and is always very near to it, so long as additions of load are not received "en route". This is evident from the fact that on streams carrying a steady load of silt V is fairly constant as observed over any reach. Potentity then must also be fairly

constant, and this agrees with the conditions that the stream is carrying steady load. Should the load increase by erosion from banks, I have shown how it is dealt with on a canal. On a river the course becomes tortuous.

33. Return now to the fundamental law

$$mg \sin \alpha = \frac{cmV^2}{d}$$

When silt load is introduced, mass m will now be expressed by ml *i.e.* mass with load. On the left ml will be heavier than m since silt is heavier than water. On the right the effective eddying power will be reduced since some water has been displaced by silt which moreover now obstructs free eddying. For both these reasons, *viz.*, increased weight on the left and reduced eddying power on the right, the power to maintain flow will have to be increased. This can only be obtained by additional Potentity, which I have shown comes into being by the creation of dunes.

34. Let us then examine any formula which takes silt load into account. Outstanding is the formula by Mr. R. G. Kennedy, once Chief Engineer of the Punjab Irrigation. He obtained it by direct observations on channels in perfect regime. The formula, therefore, cannot be said to be empirical but an observed law expressing the relation of d to V. Mr. Kennedy found this relation to be constant, thus:—

$V = c^1 d^{\cdot 64}$ (c^1 being a constant) This may be written $c^1 = \frac{V^{1.36}}{d}$

so as to compare it with the fundamental formula.

Here c^1 on the left replaces the expression. This is still perfectly in order, since for a stream in "regime" $g \sin \alpha$ becomes constant for all sections in that reach.

35. The formula is, however, no longer rational, as the power of V is no longer 2 but 1·36. Wherein then has it grown irrational? It would seem in the observation of V which at best is an approximation, as we have already shown.

36. Observations as carried on by Mr. Kennedy will still be needed, but once these have been made we may reduce the relation found for V and d to the form given in para 34. We may then write (true $V)^2 =$ (observed V) power derived. This would determine true V, and the rational law would be applicable.

37. This finishes with the investigation on which I had set out to express a law for flow, free from empirical encumbrances which make it irrational. Its application to the

design of artificial channels, such as canals, is outside the scope of the investigation, but before leaving it I should like to touch on a difficulty that confronts the irrigation engineer at the outset. As I have shown in para 19 there is a lack of Potentity in the head-reach. It has puzzled irrigation engineers not a little why gradients steeper than indicated by the tables must be allowed. My explanation in para 19 ought to help them, but it has its limitations. The example, for instance, assumes a constant still-water off-take, whereas we have to consider streams with velocity of approach, such as those debouching from the hills, or branching off from a Parent. As artificial channels, particularly canals, are of the latter type we need only consider them.

38. Now the conditions of off-take are of permanent importance since once a canal has passed the difficulties presented by the head-reach it is able to look after itself, Potentity then taking full control. Yet the practice is to choose a non-silting gradient from the table for the whole canal, and may allow a somewhat steeper gradient at the head by guess. It would be sounder to give much more attention to the head and allow the rest of the canal to guess. Certainly much flatter gradients than shown by the tables could be used for the lower reaches, say 1 in 8,000, or even 1 in 10,000, where now 1 in 5,000 to 1 in 6,666 prevail. The extra head allowed at off-take would thus be more than compensated by the flatter gradient lower down. If the observations made by Mr. Kennedy where "regime" was constant somewhere on a lower reach could be made in the head-reach all guess work might be avoided, but Potentity here is varying, since it is rising, and "regime" in consequence is not constant.

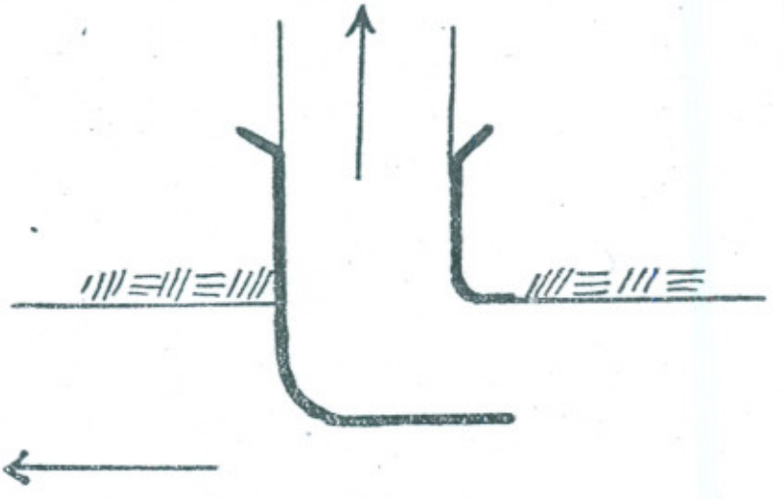
39. Besides this, even if the head-reach had been designed to allow for this condition, there is another which is also varying. The load of silt carried by the Parent channel varies. It may be increased by a freshet or flood in the river, and pass down to an off-taking canal, and distributaries. Suppose the load has increased, silt will be laid down as a delta or wedge in the Branch, the gradient will be increased and depth d at off-take will be reduced. This condition will tend to grow permanent, for even after normal conditions in the Parent have been restored, the wedge of silt in the Branch can only be removed when silt has been picked up more slowly, action beginning at the tail of the wedge and moving up to off-take by retrogression of levels. Meanwhile another freshet may intervene, and restart the trouble, and even increase it.

40. This particular difficulty is emphasised on inundation canals with heads open to the river with no masonry work to

regulate and control the in-take of silt. The delta or wedge of silt grows to proportions which threaten the very existence of the canal. For this reason the off-take must be chosen very carefully in some reach of the river comparatively clear of silt load. But even then the danger exists. For this reason a simple device which I applied for years on the Indus river at Dera Ghazi Khan may be of interest.

41. It was the construction of a groyne below the off-take. In time we became fairly expert in choosing its alignment, and by making use of creeks and neighbouring islands maintained it through many dangers even though we had nothing better than sand or earth, and brushwood. The result was very marked, for we practically eliminated the need for silt clearance in the head-reaches which themselves were often scoured deeper than designed.

42. For Perennial canals the divide wall in the head regulation takes the place of the groyne, though different in many important details. For Branches from the canal or distributaries the groyne would simply be an extension of the down-stream wing, which would be carried upstream a little way to form a pocket in the Parent as shown by the sketch. In



this pocket head would be conserved and returned to the Branch with little loss of Potentity. The dangerous backwater indraw would at the same time be cut off by the groyne. The Branch is thus relieved of the disadvantages attending the head-reach, and the silt load is carried on under more normal conditions. Wherever I have used such groynes I have found the results satisfactory.

43. Here I shall leave the discussion with the hope that others will find it helpful and carry on the application of the principles suggested.

DISCUSSION

In the absence of Mr. Claxton, the Paper was introduced by K. B. S. I. Mahbub. He gave a brief review of the Paper and thanked Mr. Claxton, on behalf of the Congress, at having retained sufficient interest in the Congress to have contributed a Paper 10 years after his retirement.

Dr. N. K. Bose stated that it was a pity that the Author of the Paper was not present at the meeting. The ideas expressed by the Author in the beginning of the Paper showed some acquaintance with the modern theories of fluid movement. The Author initiated the Paper with the query " Whether friction or eddies have the cause of resistance in flow " ? The reply given by the Author to this query showed that he was conversant with the recent developments of fluid dynamics.

The Paper, however, deteriorated as one proceeded further. The Author got himself involved in such ideas as " Potentity."

The definition of velocity given under para 17 on page 66 was equally vague—" the forces of acceleration and resistance when equally balanced give us a constant which we call velocity." The Author forget that the constant velocity was obtained because the forces of acceleration and resistance did not balance previously. If they had balanced at the very beginning of motion, there would have been no velocity.

From para 18 onwards " Potentity " governed all the ideas and without a proper definition of " Potentity " it was impossible to understand these ideas.

Dr. Malhotra remarked that Mr. Claxton had attempted a very interesting and difficult problem in the Paper, which was largely a revised edition of the Paper he read before the Punjab Engineering Congress in 1925, on " Transportation of silt by flowing water."

In para 4, Mr. Claxton referred to the affect of oil in calming waves by producing eddies below the surface. Actually what happened was that " when the wind acted on a portion of the oily surface, it urged the oil forward leaving a comparatively pure water surface behind. Hence there was a backward pull on the surface set in motion by the wind and this pull tended to stop the motion. Even when waves had been formed, they died down as they passed over that part of the surface which had been greased, for the wave motion entailed stretching of the surface layer of the water and at any instant the stretching was greater at some parts of the wave than at others. A pull was exerted on the less stretched by

the more stretched portions of the surface, and hence the energy of the wave was used up in producing motion in the surface layer of water? (Edser's General Physics, 1926, p. 298). It was thus a surface tension phenomenon.

He went on to say that the critical velocity, referred to in para 4, was directly proportional to the viscosity; and inversely proportional to the density of the liquid. Thus a high viscosity tended to produce orderly motion and a high density tended to produce turbulent motion.

Also when the critical velocity was exceeded, the pressure required to drive a liquid through a tube was independent of the viscosity and depended mainly on the density of the liquid. The question of viscosity working to help continue the turbulent motion did not therefore arise.

In para 6, Mr. Claxton ascribed the formation of eddies to the tangential resistance of the boundaries, whether the latter were rigid or extensible. The point was: Did the nature of the boundary, *i.e.*, its frictional property, affect the value of the critical velocity and consequently the formation of the eddies?

The Author might have given some further details about Gibson's discharge measurements of Niagara, to which he alluded in para 10.

In para 14, Mr. Claxton had introduced a depth, d. Was this the mean depth over a cross-section? The derivation of the work done was not very clear and required to be elaborated.

In para 16, the Author considered that owing to the difficulty of measuring the bed velocities, the observed mean velocity for a section was likely to be higher than its true value.

When the velocity-depth curves were plotted, the bed-velocity could always be obtained by extrapolation, and from an analysis of a large number of such plots in the Institute, the mean velocity point on a vertical had been found to be very nearly at 0·6D, which conformed to the standard practice. The difference between true and observed V was, therefore, not likely to be appreciable.

Mr. Claxton had introduced in paras 17-18, the new concept of 'Potentity'. Dr. Malhotra remarked that in his opinion it would be simpler to replace 'Potentity' by 'Energy'. Thus when the work done by acceleration at every point was balanced and measured by the work done by the resistance, a condition of constant 'Potentity' or constant 'Energy' was obtained.

It was easily seen after reading paras 19 and 20, that the replacement of " Potentity ' by ' Energy ' clarified the position. A narrower section increased the energy and a wider section would lower it.

In para 23 the Author referred to ' intense differences of local velocities and eddy ing action created by the dunes '. Unless the stream was carrying clear water, it was difficult to see how these velocity differences near the bed could have been observed.

In para 24 a rough bank was compared to planes jutting out into the stream. It was forgotten that a bank is a continuous affair and that for each projection there is a counterpart in the other direction, where the afflux is partially dissipated and a sort of backwater formed.

Para 25 was not very clear. It was not correct to indulge in a bit of inductive logic, when the phenomena themselves were not fully observed.

Paras 26-27 simply meant that the silt carrying capacity of a channel was a function of its velocity, *i.e.*, of its energy.

The last three lines of para 28 were not very clear and Dr. Málhotra hoped that the Author would kindly intimate what he meant by ' their depression represents the line of maximum velocity ?

In para 32, the Author defined ' regime ', as a condition of constant ' Potentity ' in other words, of constant ' Energy '.

In para 33, silt was stated to obstruct ' free eddying '. This needed elucidation.

It was rather difficult to accept the Author's contention in para 34 that Kennedy's empirical formula derived from 17 observations on Upper Bari Doab Canal system had the validity of a law. If we took Lacey's formula $f = 3/4\ V^2/R$, the index of V came to the value required in para 35. Did this mean that a velocity for Kennedy's formula was not true and that for Lacey's was as argued in para 36 ?

In para 38 a canal was stated as being able to look after itself, once it had left the head reach behind, the ' Potentity ' then taking full control. Why was remodelling necessary in that case ?

The Author wished to flatten the slopes in the lower reaches and steepen them in the head reaches. This was likely to lead to silting up of the off-takes.

The difficulties mentioned in para 39 were not likely to occur on modern weir-controlled canals fitted with silt excluders at head. The silt-free water in winter also helped to

wash down whatever silt collected in the branches during the silt season.

With all the changes that went on in the river conditions, it was difficult to ensure that the off-take of an inundation canal would always lie in a silt free reach of the river. The construction of a groyne really meant diverting the side water into the canal through a curved approach flume, and was, therefore, likely to be successful.

The Author, had he believed, constructed a number of such groynes while in charge of Bhatinda Division of the Sirhind Canal. Perhaps some of his successors would be able to say how they had worked in the meanwhile.

R. B. Wazir Chand Chopra remarked that this discussion, on an absentee's Paper reminded him of the technical Paper by another absentee, Mr. R. A. Molloy. He was an Executive Engineer in the Punjab Irrigation, was long on the Indus River, and was evidently a keen observer of its 'physique'. In 1901 he wrote a Paper called 'Memorandum on the Physics of the River Indus and their influence on the Design of its training works'. There was a certain degree of obscurity in the Paper, as any one would feel on its first reading.

This Paper and further development of its ideas in a longer Paper by Mr. Molloy in 1902 by way of a review of the 'Memorandum of the Indus and the Dera Ghazi Khan District' by Mr. R. D. Oldham of the Geological Survey of India', might have remained neglected because of the obscurity mentioned above, but unfortunately these Papers fell into the hands of Mr. F. T. E. (later Sir Francis) Spring, then Chief Engineer, India State Railways, when he was engaged on the final revision of his famous book 'River Training and Control on the Guide Bank System'. Mr. Spring made full use of Mr. Molloy's work and fully acknowledged it in his own book, which was published as Railway Technical Paper No. 153.

Thus the valuable work of Mr. Molloy which perhaps might have been lost to the profession on account of a certain degree of obscurity had been preserved by Sir Francis Spring's labours. Mr. Claxton had similarly been on the Indus River and had evidently been a keen observer of flow of water. He similarly gave us a new term "Potentity' and introduced the idea that 'resistance in flow' was caused not by 'friction' but by 'eddies'. A perusal of Mr. Molloy's Paper of 1901 and of Mr. Claxton's Paper of 1942 would reveal a family resemblance between the two.

It would be a pity if the valuable work of Mr. Claxton was lost simply because it is embodied in a Paper which was rather obscure.

R. B. Chopra expressed the hope that one of our able Engineers in active service, might prove a present day Francis Spring and give shape and meaning to Mr. Claxton's ideas. It might be Mr. Mahbub, who had so nicely kept up the 'objectivity' of Mr. Claxton's Paper in introducing it. Or it might be Mr. Kanwar Sain or Mr. Khosla, the former having gained very valuable knowledge by his association with the Indus River Commission and the latter having made the subject of River-conditions both 'Super-bed' and 'infra-bed' his life study. And whoever considered it worth his while to undertake this work, should read Papers No. 118 and 153 mentioned above and the relative parts of the work of the French Engineers Pasquieu and Dausse mentioned in them.

He went on to say that, in a sense, he happened to be a joining link between Messrs. Molloy and Claxton, in space and time though not in mentality. Mr. Molloy was his first Executive Engineer with whom he spent the first four months of his service, although he wrote his Paper two years after; and Mr. Claxton was one of his Executive Engineers when he first became Superintending Engineer on the same Canal (Upper Bari Doab Canal) over 20 years later, and he then explained to him the ideas of his groyne and the divide-wall given in paras 41 and 42 of his Paper. This divide-wall at Distributary Heads was common feature now, and he wondered if it was ever employed before 1921.

In his written reply, **Mr. Claxton** thanked K. B. S. I. Mahbub for introducing his Paper. His presentation was clear and indicated that the Author's principles were generally well understood.

He failed to follow the argument of Mr. Dr. Bose. Paras 18 to 20 of the Paper gave the definition of Potentity at some length.

Referring to Dr. J. K. Malhotra's remarks, he said that stretching of the surface layer implied tangential resistance. Osburn Reynalds said that this caused eddies below the surface and so dissipated the energy of the waves. This appeared sounder than Edser's explanation that it dissipated the energy by producing motion in the surface layer.

If pressure or energy to drive liquid through a tube was independent of viscosity after the critical velocity was reached, viscosity effect was eliminated. This was what the Author had said, d was the mean depth, though d observed was only an approximation to the true depth generally assumed.

He stated that energy could not be substituted for potentity. Potensity was not a force but a condition or index of work done, as velocity was an index of the forces involved. The Authors observations referred to by Dr. Malhotra were made in a clear stream.

The shape of the projections did not matter, but the degree of roughness which the projections introduced. The velocity was the index at which two forces balanced and Potentity the index at which the work done by these forces balanced.

Kennedy's formula was not emperical but was built up on actual observations, in which the entities v and d, coming into the fundamental formula, occurred. It of course dealt only with particular conditions, *i.e.*, grade of silt and approximately perfect regime.

Lacey's formula was not applicable, as R did not occur in the fundamental formula.

Remodellings should take the condition of available Potentity (growing with distance from the offtake) into account. The Author had worked with much flatter gradients then those usually allowed in the lower reaches down to 1 in 10,000 and flatter.

In Mespotamia gradients as low as 1 in 24,000 occurred.

Flattening the slopes in the lower reaches could induce silting at head, unless its affect as afflux, reached the offtake. The head reach assumed a steeper gradient of itself.

A few groynes at distributary heads were constructed in the Bhatinda Division, but river groynes on a very large scale were constructed across river creeks at the heads of Inundation Canals in Dera Ghazi Khan and revolutionised the practice of Inundation.

Referring to R. B. Wazir Chand Chopra's remarks, the Author sincerely hoped that an engineer would be found to investigate the lines of flow on sound scientific lines.

His term 'Potentity' seemed to have caught the imagination and the fact that some of Dr. Malhotra's queries would lead one away from the truth. Investigation indicated that this term was justified. First, velocity should be visualised, not as a force but as a condition or index and then flow with silt load added should be considered. The transportation of silt involved work done in addition to the dissipation of the internal forces of a clear stream. That was why Potentity seemed to be needed as a term to express this. Of course it could be avoided by saying energy ; but this would be clumsy if repeated as it would have to be. Potentity covered the phrase and more also for it visuaises not only velocity from which it was derived, but indicated that the work done by the forces was involved and not the forces themselves.

If engineers get down to these fundamental ideas than the great advances of silt problem and design of channels mentioned by K. B. S. I. Mahbub would have better prospects of development.

Copy of an airgraph letter dated 20th January 1944, from Mr. P. Claxton, 104 Cumberland Road, Hanwell, London W. 7, to Dr. J. K. Malhotra, Irrigation Research Department, P.W.D., Secretariat, Lahore.

I wrote* to the Punjab Engineering Congress about certain amendments to Paper 263 and I have been thinking much about them. To para 19 I now add this "When silt enters the problem the stream has the power of borrowing potential head from the available supply in the stream. The rate at which it does so I call by a new term, 'Potentity.' Para 20, I rewrite as follows "Since Potentity raises additional eddies it follows that it influences velocity. Potentity and velocity in fact are inter-related, for which potentity influences velocity by additional eddies, velocity influences potentity by determining the rate at which they are produced." I hope this will clear the position. I have had the idea of potentity all along in my mind as may be judged by what follows in my Paper, but I admit I defined it wrongly. Now light came to me when I thought of it as the rate at which potential head is borrowed, *i.e.*, at which the resultant eddies due to this borrowing come in as impulses. I am now speaking of observations as actually made, and not of any ideas which I have formed as theories of my own. I am sure the transportation of silt can only be dealt with in this way.

Thanking you for your very useful remarks.

* Not received in the Office of Punjab Engineering Congress.

THE PUNJAB ENGINEERING CONGRESS

Instructions for preparation of diagrams to accompany papers.

All drawings should be submitted in actual size for reproduction ; the limit of size is 7½ inches in height and 5 inches in length. Those limits should on no account be exceeded.

All drawings should be in one colour only. In addition to a complete drawing a tracing on the mat side (not the glossy side) of the cloth but without any lettering or printing should also be sent. The lettering will be arranged by the Honorary Secretary.

These tracing should be in good black ink (Pelican Waterproof Ink is recommended) and should be rolled, not folded.

The salient points of a diagram are more easily appreciated if there is a little printing on it. Accordingly the explanations should be given in the text and not on the diagram and all dimensions that are not essential should be omitted.

The number of plates of drawings to be submitted with each paper should not exceed six, unless the Council agree to allow an increase in any special case.