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We can obtain approximate values of x and h_{n-1} by the following method, assuming $C = C_n$ = constant. Instead of [18] we obtain:

$$\Delta v = -\frac{b\,\Delta l c_n}{A}\sqrt{2gh_k}$$

and by means of [19]

$$\frac{b\,\Delta l c_n}{A} = \sqrt{\frac{h_n - h_k}{h_k}} - \sqrt{\frac{h_n - (h_k + \Delta h)}{h_k}}$$

or using the same abbreviations as before,

$$\sqrt{a - h_k} - \sqrt{a - h_{k+1}} = C\sqrt{h_k}\ldots\ldots\ldots[25]$$

Let

$$g_k{}^2 = a - h_k \quad \text{and} \quad g_{k+1}{}^2 = a - h_{k+1}$$

then

$$g_k - g_{k+1} = C\sqrt{a - g_k{}^2}\ldots\ldots\ldots\ldots\ldots[26]$$

or

$$g_k{}^2 - 2g_kg_{k+1} + g_{k+1}{}^2 - C^2(a - g_k{}^2) = 0$$

or

$$g_k{}^2 - \frac{2g_kg_{k+1}}{1 + C^2} + \frac{g_{k+1}{}^2 - C^2a}{1 + C^2} = 0$$

or

$$g_k = \frac{g_{k+1}}{1 + C^2} \pm \sqrt{\left(\frac{g_{k+1}}{1 + C^2}\right)^2 - \frac{(g^2{}_{k+1} - C^2a)}{1 + C^2}}\ldots[27]$$

For every value g_{k+1} we can calculate g_k and $h_k = a - g_k{}^2$. This value we can use as a first approximation and calculate a second approximation by means of Equation [20].

Discussion

W. E. Howland.[2] The writer has been interested in this problem in its relation to the design of filter laterals through which water is forced into the bottom of a filter for the purpose of washing the sand. It is important to maintain an approximately equal distribution of water in the base of the filter as expressed in rate of water applied per unit area of horizontal cross-section of sand. This means that for ordinary arrangements of piping the rate of water emitted per unit distance along the pipe should be approximately a constant. If the pressure distribution along the pipe were known, as well as the hydraulic characteristics of the orifice in the pipe under the conditions of the problem, then one could effect the desired uniformity of distribution either by varying the diameter of the holes or their spacing.

The importance of a correct prediction of the pressure distribution curve is of fundamental importance to this practical problem.

Such studies as this of Professor Kunz and the earlier one of Professor Enger throw considerable light upon the problem. The effect of the velocity in the main pipe upon the coefficient of the orifice shown by Professor Enger's studies is especially valuable. Fortunately the practical problem which the writer has named is much simpler than the one considered by Professor Kunz. It involves a differential equation of an ordinary type, and the very interesting method so ably presented by Professor Kunz does not appear to be required.

The fundamental hydraulics of the two problems are, however, the same. The assumptions made at the beginning of the analysis required further study, it is believed.

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Effect of Velocity Upon Coefficient of Discharge

Professor Enger's formula for coefficient of discharge fits the values determined from his experiment very well, but obviously it could not be correct for all cases even though dimensionally consistent as implied by Professor Kunz. Consider the case where the pressure in the pipe was equal to the velocity head. Then the numerator in the equation $c = \dfrac{y - \dfrac{v^2}{zy}}{y}\,c_c$ is zero. The formula would indicate that no water would flow from the pipe, and yet so long as there is static pressure at the hole, water obviously would flow from the pipe. This is not a criticism of the formula, but rather of the method used for rationalizing it given by the author.

It is to be noted that the author interprets the formula in a slightly different way from that given by Professor Enger. According to Professor Kunz, the formula should be $c = \dfrac{h_n - \dfrac{v^2}{zg}}{h_n}$, where h_n is the pressure at the closed end of the pipe. Considering the case where there is very considerable friction in the pipe—i.e., where the holes are widely spaced—then it is possible that at some orifice the pressure will be the same at the closed end of the pipe. If at this point the pressure were equal to the velocity head, as before, the formula would indicate no discharge, and yet surely there would be discharge from the orifice.

Energy Distribution at the Orifices

Both Professors Enger and Kunz have assumed that the velocity energy of the water in the pipe is largely dissipated. Consider the energy of that portion of the stream within the pipe which is about to leave an orifice. It is equal to $qw\left(h + \dfrac{v^2}{zy}\right)$, where q is the rate of flow from the orifice, w the weight of a cubic foot, h the pressure, and v the velocity. The author assumes that the water leaves the pipe at a rate proportional to $h^{1/2}$, as if the energy of the water leaving were pressure energy only. This would imply that the remaining part of this energy $qw\dfrac{v^2}{zy}$ is lost or is given to the stream of water in the pipe and remaining within the pipe. The author assumes that it is lost, for he says that the differential change in pressure along the pipe is merely $\left(\dfrac{vdv}{g}\right)$. Here he is considering an orifice of differential area. This effect is entirely the result of the change in kinetic energy of that portion of the water which remains within the pipe, as may be shown in the following way:

Let Q_1 be rate of flow of that portion of the water which remains within the pipe. The amount of energy possessed by this water will be considered a constant; i.e., the differential change in the energy of this water is zero. The energy of this water is $Q_1w\left(hp + \dfrac{v^2}{zy}\right)$

$$Q_1w\left(dhp + \frac{2vdv}{zy}\right) = 0$$

$$dhp = -\left(\frac{vdv}{g}\right)$$

The writer believes that this assumption may sometimes be wrong; that in many cases there is a significant transfer of energy from the side stream to the main stream which predominates over the loss of energy in the main stream in the vicinity

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of the orifice, thus producing a significant increase in pressure in the main stream which the simple Bernoulli equation used by Professors Kunz and Enger cannot explain. The writer is aware that this statement may not seem plausible, and so it is repeated for emphasis. The simple Bernoulli equation in the form of head is wrong as applied to manifold pipes. Actually there is a greater increase in pressure along the line of flow than can be accounted for by means of this equation. The total energy equation must be used to explain the phenomenon.

In support of this assertion the writer quotes the following experiments, with references appended:

(1) The Malishewsky experiments can be explained by assuming a recovery of approximately $^3/_4$ of the initial velocity energy of the water of each side stream. The Enger-Kunz theory does not explain the results of the experiment.

(2) The experiments of Professor Goodenough on the model of ventilation ducts of the Holland tunnel and subsequently upon the tunnel itself indicate that about 40 per cent of the initial velocity energy of the side streams is recovered.

(3) The Enger experiments are well explained by the theory to which the writer is objecting, but when he applies the assumption that 30 per cent of the initial velocity energy of the side stream is recovered he obtains results which are in close agreement with the results of the experiment, and the disagreement is less than the experimental error. In other words, the effect which the writer is mentioning in this case is too small to be significant.

(4) The experiments conducted at the laboratory at Munich under the direction of Thoma in divided flow on a single tee fitting show a noticeable gain in total head in the main stream, which the authors explain in the following way: "One can assume that through the side pipe a greater part of the slow-moving edge layers is scooped off."

This is a slightly different way of looking at the phenomenon from that of the writer and is believed to be of considerable merit, but in effect it is the same, for it assumes that the water leaving the orifice takes with it less than its proportion of the mean velocity energy and also that the water remaining possesses more than its proportional amount of energy. Thus it helps to explain the mechanism of transfer of energy from the side stream to the main stream.

This viewpoint may also help to compose the differences between the Enger and the Malishewsky experiments. In the Malishewsky experiments only about $^1/_{40}$th of the total flow was taken through a single orifice, for there were 40 orifices; in the Enger experiments $^1/_{12}$th. Thus in the Malishewsky experiments a larger portion of the "scooped off" water was obtained from the edge layer.

It is true, as shown by the experiments of Professor Enger, that cases do arise in which the effect which the writer is mentioning is of no practical consequence. But in other cases, particularly that of unequally spaced orifices designed to accommodate the large flows now demanded in water works practice, this effect of an additional velocity-head recovery will probably be very significant.

Further experimental studies of the problem are urgently needed.

References

(1) "Hydraulics of Filter Underdrains," by N. Malishewsky. *Jl. Am. W. W. Assn.*, June, 1927; also in *Water Works*, vol. 66, no. 10, October, 1927.

(2a) "New York's Automobile Tunnel," by Jorgen Aabye. *Ingenioren-Dansk Ingeniorforening*, no. 24, 1928, p. 293.

(2b) "Ventilation of Vehicular Tunnels," by Ole Singstad, paper no. 339 of the World Engineering Congress, Tokyo, 1929.

(3) "Pressures in Manifold Pipe," by M. L. Enger and M. I. Levy, *Jl. Am. W. W. Assn.*, vol. 21, no. 5, May, 1929.

(4) "Untersuchungen uber den Verlust in recht winkligen Rohrverzweigungen," by G. Vogel (in heft I) and "Der Verlust in schiefwinkligen Rohrverzweigungen," by Franz Peterman (in heft II), both from Mitteilungen des Hydraulischen Instituts der Technischen Hochschule, München.

M. L. Enger.[3] The discharge of jets from manifold tubes must be determined in many cases in engineering practice. When high velocities are used in manifold pipes, unexpected results will sometimes occur. The wash-water system of water filters should supply water uniformly over the entire filter area if the filter is to be washed effectively; and as it is often economical to use high velocities in the manifold pipes, the problem has

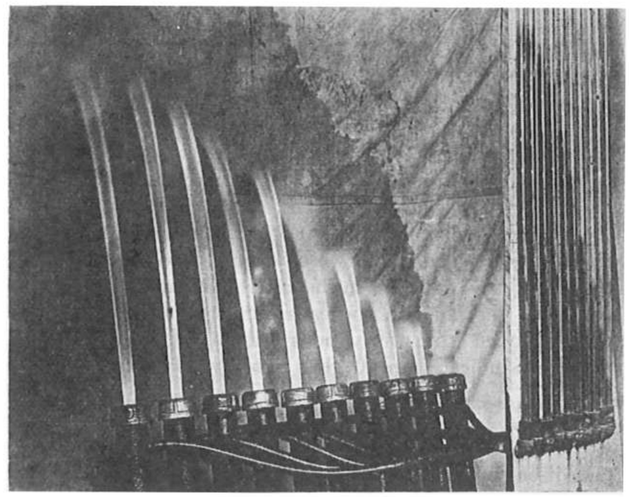

Fig. 2

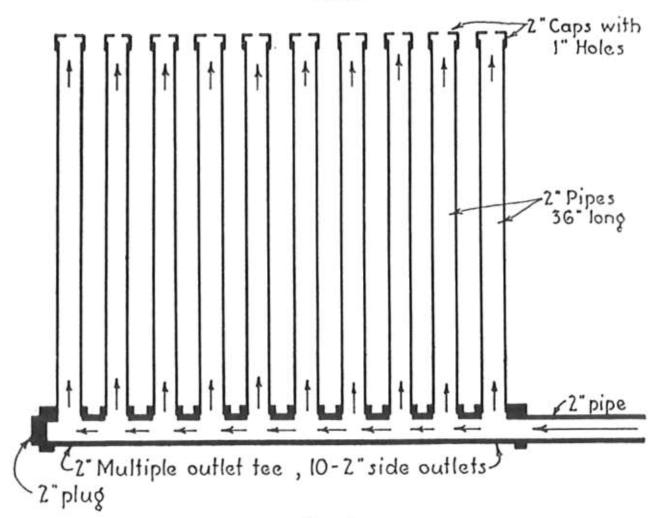

Fig. 3

been given much study in this connection. The problem of delivering the water uniformly beneath the filter bed has been solved in three different ways: (*a*) By the use of large manifold pipes, thus making the velocities small; (*b*) by the use of manifold pipes of a variable diameter, thus keeping the velocities in the manifold nearly constant; and (*c*) by the use of variable spacing of the discharge openings from the manifold pipes. The first two methods are too expensive except in the case of large, costly filter plants.

Another application occurs in hot-water heating when a num-

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ber of radiators are connected to one header. In this case the loss of head at the entrance is also a function of the velocity in the manifold as well as of the velocity of the diverted water.

The converse problem occurs in the case of the wash-water collecting pipe for pressure filters. The method used by the author can be applied to this case.

The writer is particularly interested in the derivation of the equation for the coefficient of discharge from openings in the manifold pipe in terms of the pressure and the velocity in the pipe. The equation is the same as the one derived by the writer from experiments and which was assumed to be purely empirical. Further experiments will soon be undertaken to determine whether the equation holds over a wide range of velocities and pressures.

An extreme case of the variation of pressure and discharge from a manifold pipe is shown in Fig. 2, which is from a photograph taken in the Hydraulics Laboratory of the University of Illinois. A diagrammatic sketch of the arrangement used is shown in Fig. 3. Ten 2-in. pipes, each 36 in. long, are connected to a manifold pipe, which was lined with cement to make its inside diameter exactly 2 in. On the ends of the 2-in. laterals are caps in which 1-in. holes have been drilled. The end of the manifold was plugged. The water entered from the right and flowed out of the 1-in. holes in the caps. The heights of the jets issuing from the holes in the caps indicated the quantities of water discharged from the various orifices. The heads on the orifices were indicated in 10 glass tubes which can be seen in Fig. 2.

Author's Closure

The discussion by W. E. Howland contains some valuable remarks, especially the bibliography of the subject, to which there should be added: "Friction Heads in One-Inch Standard Cast-Iron Tees," by F. E. Giesecke and W. H. Badgett, *Jl. Am. Soc. Htg. & Vent. Engrs.* The results of this latter investigation have been recalculated and show that the loss of head due to water flowing out of the side of a tee can be expressed over a large interval by $h = 0.91\ v^2/2g$ in accordance with our theory. In the paper the author has neglected the friction of the flowing liquid except in formula [15]. The analysis is therefore only a first approximation. Against the criticism of Mr. Howland, the author has to raise only few objections.

(1) The discharge coefficient c is equal to:

$$c = \frac{h_n - \dfrac{v^2}{2g}}{h_n} c_n = c_n \frac{h}{h_n};$$

c would only vanish if h were equal to zero. This cannot happen in the phenomenon studied; but if it did happen, then no liquid would flow through the given hole.

(2) Bernoulli's equation applies only to a given streamline, and not to dividing streamlines; it can therefore not be used in the present problem and Enger and the author have not used it.

(3) The author cannot understand the statement by Mr. Howland that in many cases there is a significant transfer of energy from the side stream to the main stream, which predominates over the loss of energy in the main stream in the vicinity of the orifice. How is this compatible with the principle of conservation of energy?

(4) In the theory of N. Malishewski there are found the formulas

$$dh = \frac{K(Q + qx)dx}{d^5}, \qquad h = \frac{K}{d^5}(Q_1 + 0.55Q_2)^2$$

which the author does not understand. But the phenomenon, which he observed, agrees qualitatively at least with the author's theory.

A comprehensive critical review of the present literature will be presented in a later paper, the author hopes.

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