# Experimental Study of Loss of Head in a Closed Pipe Carrying Clay Slurry[1]

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*Taking as a basis for his calculations the formulas presented in a previous paper by an American investigator on the loss of head in a closed pipe carrying clear fluids, the author, a Belgian engineer, seeks to apply them to a fluid carrying a heavy proportion of solid materials. The author takes the conclusions in the original paper, which he assumes seem at first sight somewhat contradictory, and shows that no anomalies exist, and further brings out some precise deductions on the loss of head in a pipe carrying muddy water.*

An intensely interesting study published in the June, 1927, number of *Mechanical Engineering* allows us, in using the method that we have proposed for the calculation of loss of head,[3] to examine in what measure these formulas for homogeneous fluids can be applied to a fluid holding in suspension a large proportion of solid materials. Having had occasion to conduct the experiments on a sufficiently large scale with a view to determine the losses of head in a pipe 4 in. in diameter supplied by a centrifugal pump, pumping a muddy water more or less charged, W. B. Gregory, professor at Tulane University in America,[4] has furnished some very complete experimental information and has brought forth certain important conclusions—although at first sight they apparently are contradictory.

In following the analysis of results by means of our method, we have been able to dispel these anomalies and to bring out some precise deductions concerning the calculation of the loss of head in the particular case of muddy waters.

The experiments have been made on a cast-iron pipe measuring in length 112.5 meters, with the amount by weight of the material in suspension varying from 0 to 35 per cent, the specific weight being respectively from

1000 at 0.0%
1130 at 18.6%
1175 at 23.4%
1225 at 29.05%
1255 at 32.5%
1285 at 35.3%

The experiments made on the new pipe with clear water have shown that the losses of head were slightly greater than those which would be calculated by means of the formula proposed by us.[5]

The unforeseen result, after this pipe had been placed in service with the muddy water, was that the losses of head were found reduced to those which are observed in a smooth pipe. It is thus that the experiments made with turbid water and of a density practically equal to unity have given values which agree exactly with those deduced from our formula

$$10^8\beta = \frac{271.8}{\sqrt[3]{\alpha}} + 3.4$$

applicable to smooth pipes.

These results can be explained by admitting that the deposit on the walls of the pipe of a coating of the materials held in suspension has had the effect of transforming the rough surface of the pipe to a practically smooth surface.

We have already been led to make an analogous observation in the case of pumping petroleum oils; the formula applicable to iron pipes must be replaced by those for smooth pipes when the fluid used is relatively very viscous and adheres perfectly to the walls.[6]

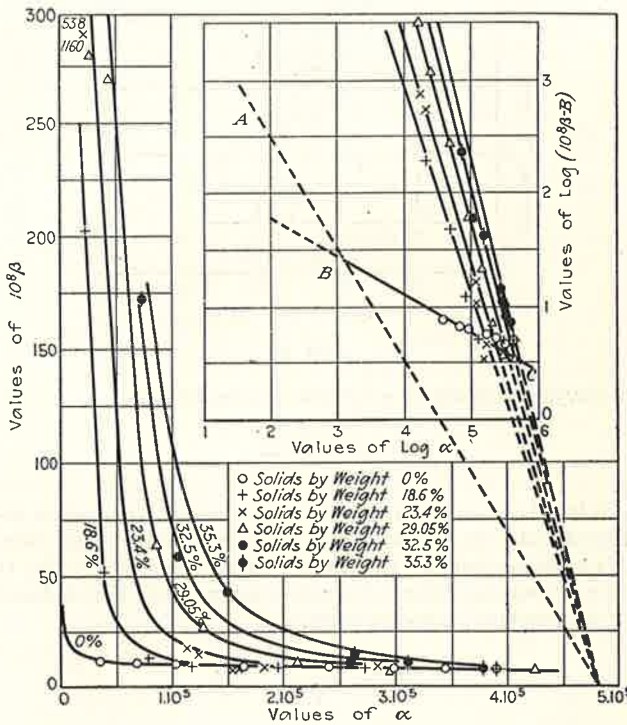


Fig. 1

Another unforeseen result is that for a certain value of the Reynolds coefficient varying with the amount of matter in suspension, the coefficient $10^8\beta$ which fixes the loss of head is found to be strictly equal to that observed in a pipe with smooth walls through which clear water is forced.

In other words, beginning with a certain critical value of $\alpha_c$, turbulent flow is established and the loss of head is no longer influenced, beginning from this moment, by the presence of the suspended matter.

This conclusion does not seem likely to be general; we cannot hold it to be true, for the lack of verification of the most general conditions, of materials in suspension heavily charged and for materials in excess of 35 per cent, in round numbers.

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[1] Translation of extract from *Revue Universelle des Mines*, February 1, 1928, 7th series, vol. xvii, no. 3.

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Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

[3] See *Revue Universelle des Mines*, September 1, 1897, 7th series, vol. xv, no. 5.

[4] Tulane University, New Orleans, La.

[5] See *Revue Universelle des Mines*, February 1, 1922, 6th series, vol. xii, no. 3.

[6] See "Annales de l'Association des Ingéneurs sortis des Écoles spéciales de Gand," 5th series, vol. xvii, first number, 1927.

It is known that the loss of head in meters of fluid flowing is given by the formula

$$h = 10^4\beta \frac{w^2}{d} L$$

To use this formula we transformed the differences of pressure indicated by the author in height of meters of pure water to heights with the density of the fluid used in the experiment.

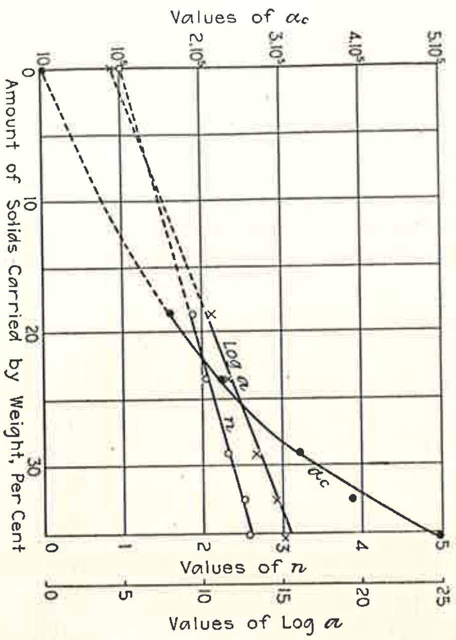


FIG. 2

In carrying as abscissas $\alpha$ furnished by the formula

$$\alpha = \frac{10\delta wd}{\mu}$$

($\mu$ being the viscosity of the clear water at the temperature indicated and $\delta$ the specific weight of the mixture) we have been able to deduce from the experiments the curves of $10^8\beta$ of Fig. 1; the curve corresponding to 0 per cent, being exactly that deduced by our formulas for smooth pipes, is

$$10^8\beta = \frac{271.8}{\sqrt[3]{\alpha}} + 3.4$$

From these curves we have been able to deduce the position of the asymptotes, 3.4 to the common curve, then to calculate

$$\log\,(10^8\beta - 3.4)$$

In carrying these values as ordinates and the log $\alpha$ as abscissas we have obtained the curve $BC$ of Fig. 1, which shows that, beginning with a certain value of $\alpha_c$, variable with the amount of material carried, the law changes completely.

Admitting that at the attainment of this value $\alpha_c$ the appreciable formula is that of viscous flow ("régime laminaire")

$$10^8\beta = \frac{a}{\alpha^n}$$

we have calculated log $10^8\beta$ and carried the results as ordinates.

As the dotted curve $AB$ represents the law of viscous flow for clear water, it may be admitted that as the weight of material carried diminishes, the inclination of the line representing the law of variation of log $10^8\beta$ diminished as it approaches the dotted line. We propose for lack of something better and in recognition that the results given are insufficient to obtain in a relatively sure method the direction of the curve, the law of variation of $\alpha_c$ as a function of the weight of materials in suspension represented by the curve of Fig. 2.

It follows from this for the lower values of $\alpha_c$ that the formula to apply is that of viscous flow, and must be

$$10^4\beta = \frac{a}{\alpha^n}$$

the coefficients $a$ and $n$ being given by the curves of Fig. 2. ($a$ is given by log $a$.) It is seen that for materials carried from 18 per cent to 30 per cent the least value of $n$ is equal to 2, then for clear water $n = 1$; $10^8\beta = \frac{a}{\alpha}$. This explains the direction of curves of the loss of head given by the author, which shows that these are independent of the velocity below a certain value of $\alpha$, varying with the amount of solid material carried.

In fact, if in the formula for the loss of head $h = 10^4\beta\frac{w^2}{d}$ we introduce the value found $10\,^8\beta = \frac{a}{\alpha^n}$ applicable below the critical velocity, then we will have

$$h = 10^{-4}\,\frac{a}{\left(\frac{10\delta d}{\mu}\right)^n w^n}\,\frac{w^2}{d}$$

which will furnish for $n = 2$ a value of $h = a$ constant, whatever

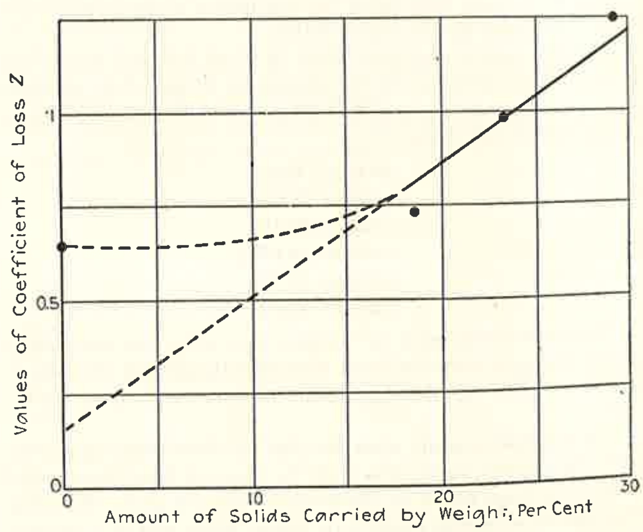


FIG. 3

is the velocity, from the moment when the critical velocity is not exceeded. This conclusion is only truly evident for the amount of material between 18 and 30 per cent, for which the average value of $n$ stays equal to $n = 2$.

This manner of considering the total of the experimental results leads us to suppose that the presence of solid particles in suspension tends to maintain longer the viscous flow ("régime laminaire"), but that the particles in increasing the friction surfaces cause an increase in unusual proportions of the resistance to flow and consequently the loss of head. As soon as the turbulent flow is established, on the contrary the loss of head is maintained constantly equal to that which would be observed in a smooth pipe through which runs a fluid having the viscosity of water and the same average density as the mixture.

These results deduced with our method, in terms of Reynolds' coefficient, are extremely curious because they indicate that the phenomenon of the flow of a fluid holding in suspension some particles does not depart essentially from the usual phenomenon of flow of a homogeneous fluid in the region of viscous flow at least.

This conclusion is nevertheless only true for straight pipes. For the curved pipes the results furnished by the experiments of Mr. Gregory show that the losses, if one compares them with those through which the clear water flows under the same conditions, increase rapidly with the weight of material in suspension. This difference in the assumed conclusions suggests that the deviation of the filaments has an effect to provoke a separation of the particles of the fluid themselves and to lead to a concentration of solid particles at the exterior walls. It is no longer possible from this moment to apply relatively simple laws to translate the results of the experiments.

Fig. 3 gives the value of the coefficient $Z$ of the classic formula of supplementary losses due to an elbow

$$h = Z \frac{w^2}{2g}$$

The curve traced as a function of the per cent of solids by weight shows that the coefficient $Z$ is proportional to the per cent of solids beginning at 18 per cent. For the observed loss with turbid water, carrying only a small quantity of solids, the author has obtained the figure 0.64 indicated on the axis of ordinates. This very high figure explains with difficulty as the one generally indicated in the formulas for a curve at 90 deg., and a corresponding value $\frac{d}{r}$ is equal to 0.15. If this last figure should be considered as the true figure for clean water in a clean pipe, we must conclude that the coefficient $Z$ increases proportionally with the per cent solids by weight; the absence of points between 0 and 18 per cent does not permit us to venture an opinion in this regard.

This conclusion, which concerns the intersection of losses with the per cent of solids by weight, is confirmed by the figures observed for the manometric height furnished by the pump during the tests on the pipes.

In evaluating the heights observed in meters of fluid having the average density of the liquid pumped, we have been able to calculate the manometric height as a function of the discharge, the peripheral velocity remaining constant. The curve 1 (Fig. 4) refers to clear water, curve 2 to 18.6 per cent, curve 3 to 23.4 per cent, curve 4 to 29.05 per cent solids by weight.

For the curves 2, 3, and 4 the points observed group themselves relatively well on the mean curve; furthermore these curves indicate a loss of head rapidly increasing with solids carried in the passages of the impeller and of the volute.

Finally, if the law stated apropos of straight pipes remains true for curved passages, we must observe, at least in the region of the turbulent flow, a unique curve for all the per cents of solids carried up to 29 per cent.

For the per cents of solids carried below 29 per cent, the points observed are absolutely scattered, and it will be impossible to rely upon them for continuous curves; this holds true that the more and more complete separation of solid particles at the time of the passage on the blades of the wheel makes the local densities very much higher than the mean densities and that all the deductions made to define that which one expects regarding manometric heights and least discharge cease to be significant from this moment.

## Conclusions

In admitting, for lack of something better, the diagram of 2 for the values of $\alpha_c$, $a$, and $n$, one sees that the calculation of the loss of head for muddy water containing up to 35 per cent of material in suspension may be made in the following manner:

If $\alpha$ is greater than $\alpha_c$, we have in meters of fluid pumped

$$h = 10^4 \beta \frac{w^2}{d}$$

with

$$10^8\beta = \frac{271.8}{\sqrt[3]{\alpha}} + 3.4$$

the coefficient $\alpha$ being calculated for the density equal to that of

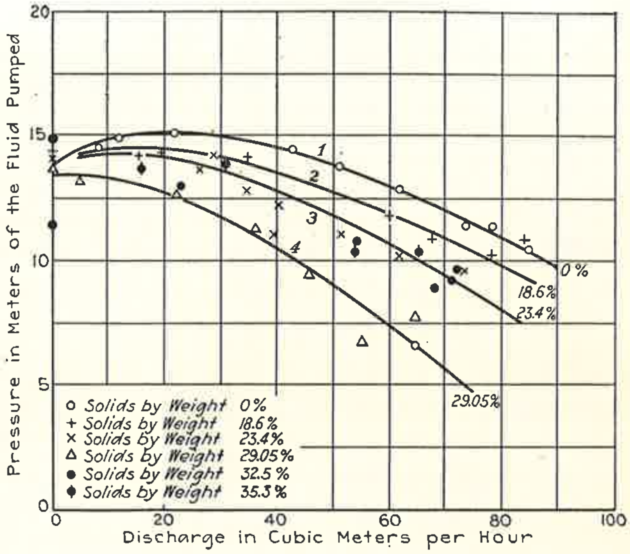


Fig. 4

the fluid pumped, and for viscosity equal to clear water at the temperature given.

If $\alpha$ is less than $\alpha_c$, we have still

$$h = 10^4\beta \frac{w^2}{d}$$

but with

$$10^8\beta = \frac{a}{\alpha^n}$$

the coefficient $\alpha$ being calculated as in the first case and the coefficients $a$ and $n$ being furnished by the diagrams of Fig. 2.

It is possible to use the formulas giving directly the values of $10^8\beta$ in noting that all the lines representing the viscous flow for different percentages for solids carried converge toward the same point (see Fig. 1).

This point being characterized by

$$\log \alpha = 6.88, \log 10^8\beta = -2.366$$

the relation

$$\log 10^8\beta = \log a - n \log \alpha$$

furnishes

$$\log a = 6.88\, n - 2.366$$

it follows that

$$\log 10^8\beta = n(6.88 - \log \alpha) - 2.366$$

The coefficient $n$ being furnished as a function of the weight of solids $x$ per cent of the materials in suspension, by the linear law,

$$n = 0.045\,x + 1$$

it will be possible to deduce a relation between $10^8\beta$ and $\alpha$ which will fix directly the value of $\beta$ as a function of $x$ and of $\alpha$.

$$\log 10^8\beta = 0.31x + 4514 - (0.045x + 1) \log \alpha$$

Grouped under this form, the results of these very complete tests made by Mr. Gregory present a general interest which will escape none, being given in such a way that they may be considered, in my opinion, as valuable in all their applications, whatever be the nature of the solid particles entering the problem, at least if they have small enough dimensions to remain in suspension even at a low velocity.

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