LOSSES IN QUADRANT EDGE ORIFICE METERS

BY
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Introduction

Whenever a new meter is standardised, information regarding losses has to be invariably furnished. "Quadrant Edge Orifice meter" has been retained for international standardisation by the International Standards Association. However, the discharge coefficients have not been standardised. A project has been undertaken here at the Indian Institute of Science to study the various characteristics of this meter, especially at high velocity flows. This paper mainly deals with the losses incurred by such orifice meters for different contraction ratios. In order to compare with the losses of other standard pressure differential meters, losses are expressed in percentages of the differential heads across the meter. Further, it has been attempted to express the loss coefficients in terms of discharge coefficients in terms of discharge coefficients by simple expressions which hold good for the practical possible ranges of Reynold Numbers when the fluid involved is water. The losses across these meters are expressed in terms equivalent lengths of pipes of different roughness.

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Quadrant edge orifice meter

The Quadrant-Edge Orifice plate is an orifice plate with nozzle shaped entrance on the upstream side whose quadrant-edge radius "r" is equal to the thickness of the orifice plate.

The plates tested in the present investigation have the following specifications. These are similar to the one of Koennecke [1] and those of the ones tested at Cornell University [2].

* β ratio	$\frac{r}{d}$	Manometer tappings
0.225	0.100	D-D/2 tappings
0.400	0.114	»
0.500	0.135	»
0.600	0.210	»
0.630	0.380	»

* Notations are explained at the end of this paper.

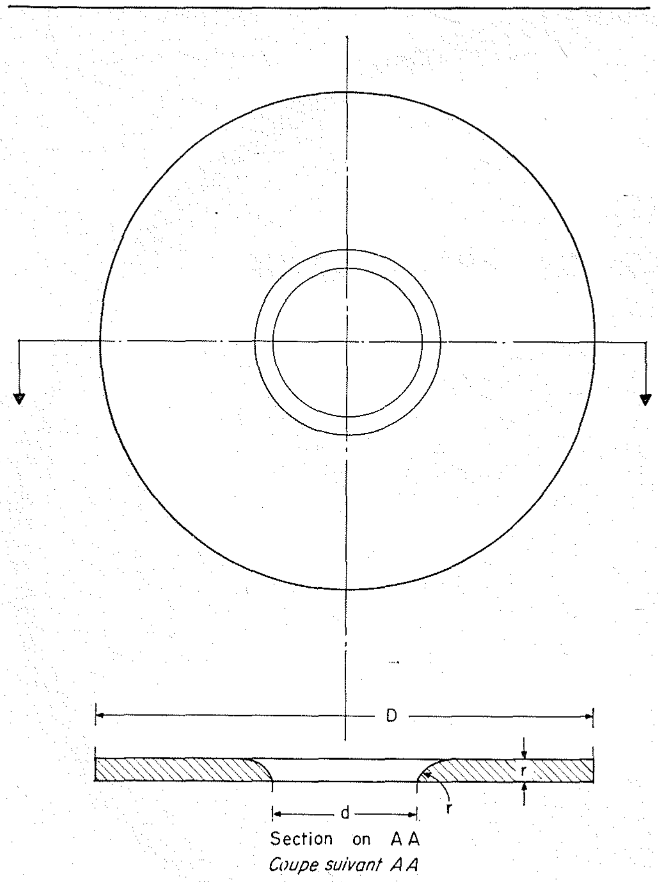

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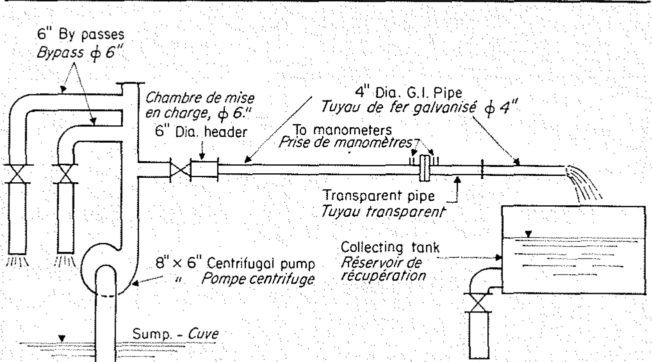
Figure 1 shows a plate of this type

Experimental set up

The set-up is shown in Figure 2. A centrifugal pump of capacity of 900 g.p.m. at a head of 120′ was used to supply water for the system. Two by-passes of 6″ dia. each were used to by-pass the surplus water. The test section consisted of 20′ upstream section with 4″ dia. G. I. pipe and about 25′ downstream section with 4″ dia. pipe out of which 4′ was made of transparent perspex sheet and the rest of G. I. The water was collected in a calibrated tank of capacity of 150 cubic feet.

Separate manometers were installed to measure the upstream and downstream pressures across the meter.



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Analysis of the data

(a) *Loss Coefficient* K_L: Referring to the definition sketch Figure 3, the loss coefficient K_L can be derived as follows, with certain assumption as:

1. The pressure at sections (1) and (2) are the same throughout the cross section;
2. $\alpha_2 = \alpha_1 = 1$ (for highly turbulent flow);
3. $C_c = 1$.

Expressing the loss across the meter as:

$$K_L (V_2^2/2g),$$

we can write Bernoulli's Equation applied for sections (1) and (2) as

$$\frac{p_1}{\gamma} + \alpha_1 \frac{V_1^2}{2g} = \frac{p_2}{\gamma} + \alpha_2 \frac{V_2^2}{2g} + K_L \frac{V_2^2}{2g} \qquad (1)$$

$$\frac{p_1 - p_2}{\gamma} = h = \frac{V_2^2}{2g} (1 - \beta^4 + K_L) \qquad (2)$$

With known pressure differentials across the meter, and the discharge, the loss coefficient K_L can be calculated for various β ratios. The values of K_L have been plotted against the values of discharge coefficients for various β ratios in Figures 4, 5, 6, 7 and 8. All the curves turned out to be straight lines. This is not accidental but may be explained as follows:

The coefficient of discharge C is defined as in the following equation:

$$Q = \frac{CA_2 \sqrt{2gh}}{\sqrt{1 - \beta^4}} \qquad (3)$$

Combining equations (2) and (3), we get:

$$C = \frac{\sqrt{1 - \beta^4}}{\sqrt{1 - \beta^4 + K_L}} \qquad (4)$$

Squaring and rearranging again, we get

$$K_L = (1 - \beta^4) \left[\frac{1}{C^2} - 1 \right] \qquad (5)$$

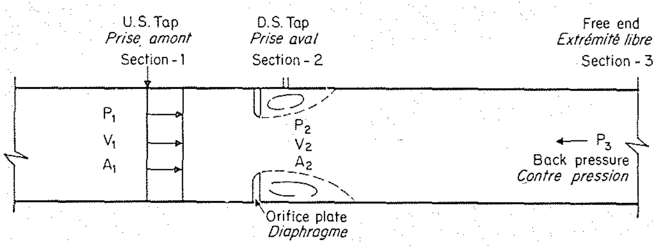
Equation (5) indicates that K_L is a function of $[(1/C^2) - 1]$ for a particular plate. But the variation of C for a particular plate is very small for a wide range of high Reynolds' Numbers, and the practical values lie in a very small segment of the curve $K_L V_s$ $[(1/C^2) - 1]$ which could be approximated to a straight line. Table I gives the range of values of C for various β ratios.

TABLE I [3,4]

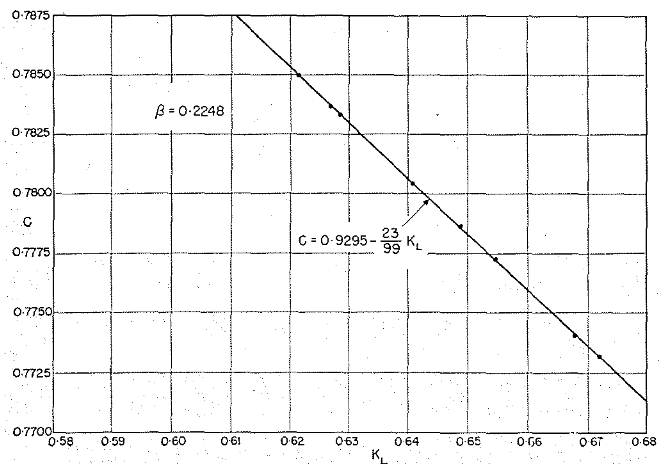
RANGE OF REYNOLDS' NUMBER	β	RANGE OF VALUES OF C
1 000 - 600,000	0.630	0.885 - 0.928
1 000 - 600,000	0.580	0.856 - 0.900
1 000 - 500,000	0.480	0.824 - 0.860
1 000 - 400,000	0.390	0.780 - 0.805
1 000 - 150,000	0.225	0.770 - 0.790

Figures 4 to 8 mat be used to find the loss across the meter for any practical range of Reynolds' Numbers. For any Reynolds' Number, C can be found out from the discharge coefficient curve and hence the value of K_L.

(b) *Overall loss in the meter:* In order to find the overall pressure loss a simplified procedure is adopted. The valve at the downstream end of the test section is removed and the water is allowed to discharge freely into the atmosphere (Ref. Fig. 2). Now the pressure recorded by the upstream pressure is the overall loss of the meter and the frictional loss of head in the pipe after the jet expands to the full cross section of the pipe. It has been found from experiments that in the small β ratios, the jet expands to the fuall cross section within 2 feets downstream of the meter and the frictional loss of head in the 25 feet of downstream section is about 2 % of the differential head. For large β ratios, the jet expands within about 9″ downstream of the meter and the loss of head due to friction in downstream length is within 5 % of the total manometric head. Since the error involved in not considering the downstream section where the jet diverges will be within the experimental error of the investigation, the overall pressure loss may be taken to be the difference of pressure recorded at the upstream tap minus the frictional loss in 25′



3/ Definition sketch.
Schéma de définition.



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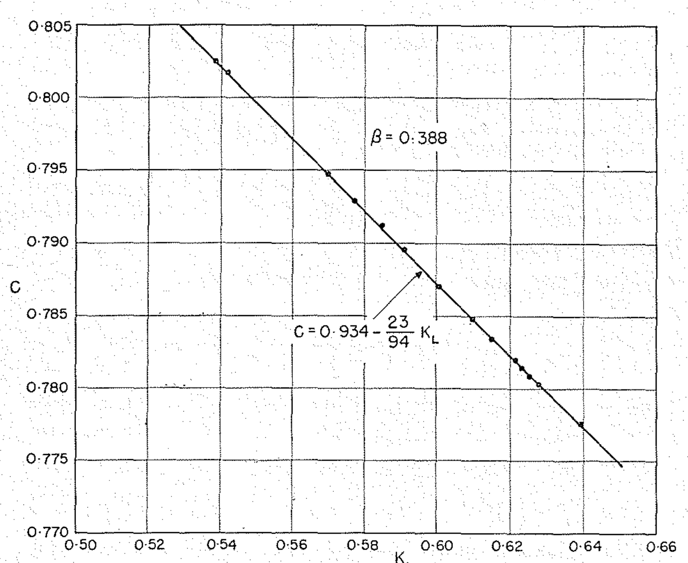

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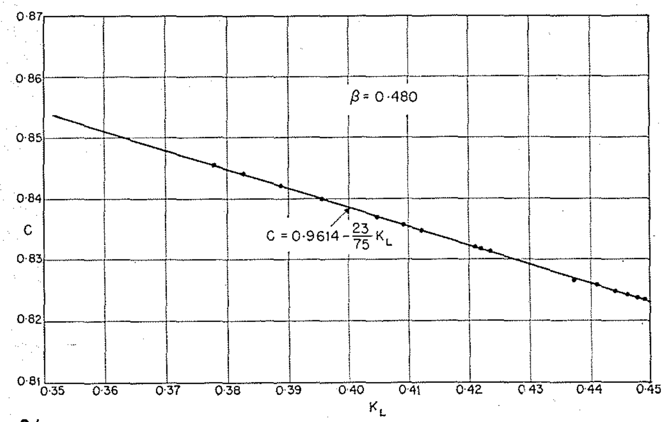

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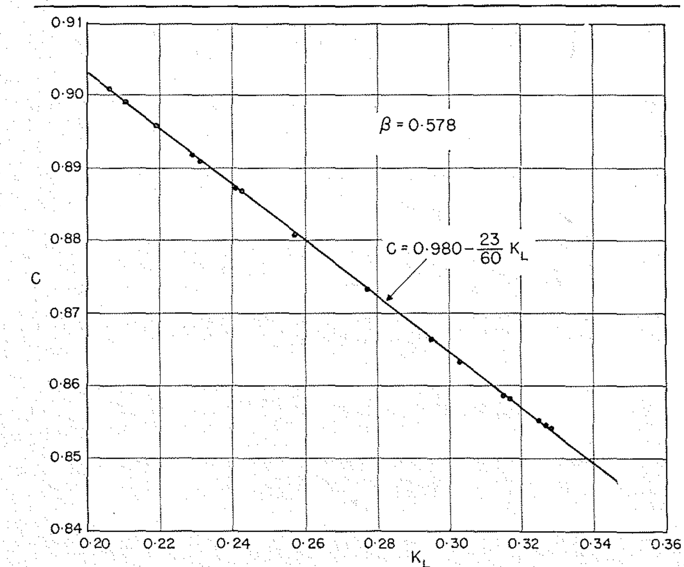

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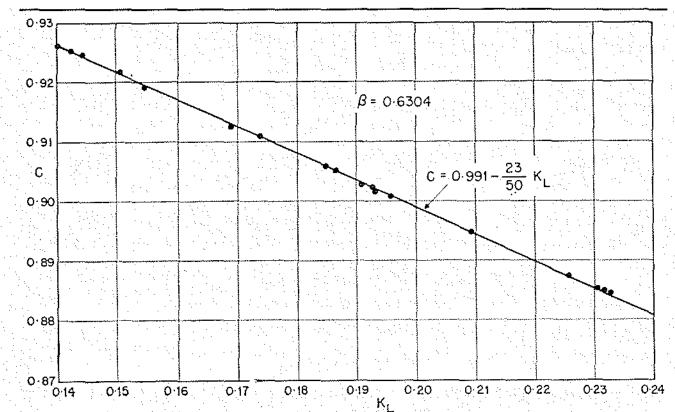

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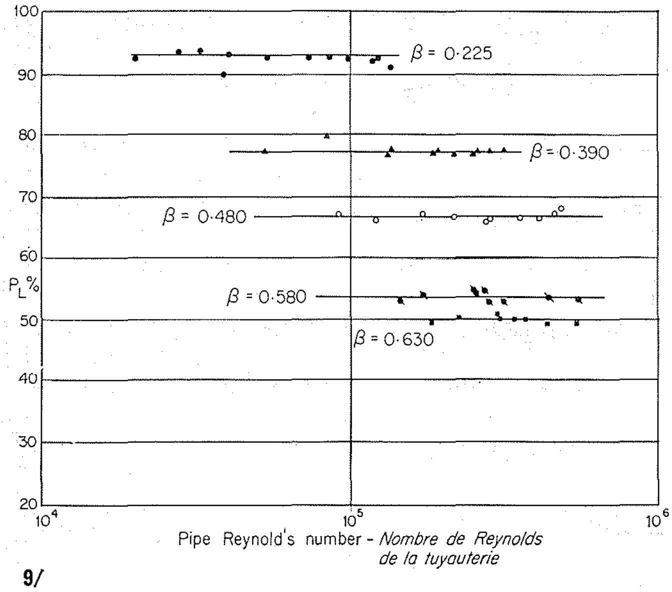

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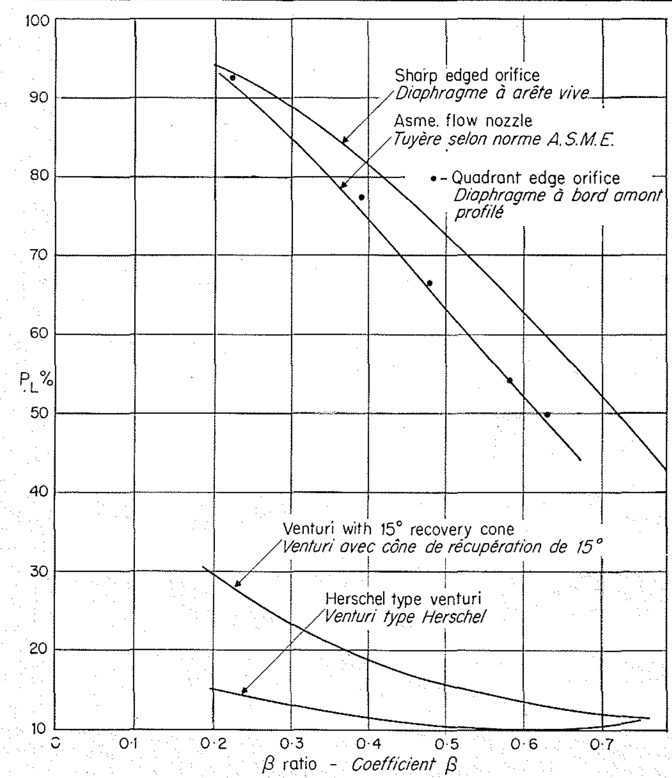

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of downstream section. Calculations were accordingly made and the overall pressure losses were found out.

Figure 9 shows the overall pressure loss, p_L expressed as a percentage of the differential head plotted against pipe Reynolds' Number for various β ratios. It may be noticed that this percentage of overall pressure loss, p_L % is independent of the pipe Reynolds' Numbers. This may be reasoned out as follows: The coefficient of discharge is a function of Reynolds' Number and hence also the differential head across the meter [Ref. Eqn. (3)]. Again the losses in the meter are also a function of Reynolds' Number and probably these two hold the same functional relationship with R_D that their ratios become independent of Reynolds' Number. Such constant values are plotted against β in Figure 10. In order to compare this with that of other primary pressure differential meters, data of p_L % for sharp edged orifice, flow nozzle, venturimeters are also shown in the same figure. These data are taken from reference [5]. It is to be noted that the losses in the quadrant edge orifice meter are just same as that of the flow nozzle for various β ratios under similar conditions.

Equivalent length of pipe

Figure 10 does not permit the designer to pick out the loss for any β ratio because one has to predetermine what would be the differential head for the given conditions of flow if he were to use this figure. In order to overcome this tedious process, the losses are expressed as those that would be incurred a straight length of pipe.

$$\frac{flv^2}{2\,gD} = p_L h \tag{6}$$

where l is the equivalent length of pipe in which similar loss could be expected.
Let

$$l = x, D \tag{7}$$

From equation (3)

$$h = \frac{V_1^2\,(1-\beta^4)}{\beta^4 2\,gC^2} \tag{8}$$

Substituting for h and l in eqn. (6) we get:

$$\frac{fxDv_1^2}{2\,gD} = p_L\,\frac{V_1^2\,(1-\beta^4)}{\beta^4 2\,gC^2} \tag{9}$$

Hence,

$$x = \frac{p_L\,(1-\beta^4)}{\beta^4 C^2 f} \tag{10}$$

Equation (10) allows the computation of x for various R_D, types of pipes, D and β. Here, in this paper computations for only smooth, drawn tubes and galvanised iron pipes are chosen and for diameters of pipes from 1″ to 6″ are presented. This covers the range of practical use of this type of orifice meter.

Values of x are plotted in Figures 11, 12 and 13, with diameter of pipe and types of pipes as parameters. If a designer is to use a Quadrant-Edge orifice meter in any system, he could pick out the value of x correspondingly and add this length to his system to take care of the extra losses incurred by the installations of this type of meter.

Distribution of loss across and downstream of the meter

Now that the losses across the meter and overall loss in the meter have been analysed, it could be of interest to have and idea of their distribution. Values of losses across the meter are found out knowing the values of K_L for various β ratios, and expressed as a percentage of the differential head. Under similar conditions, the p_L % being also known from Figure 10, the ratios of losses downstream of the meter to the losses across the meter have been computed and plotted in Figure 14. It can be seen that for β ratio = 0.400, the two losses are more or less the same and for lower and higher β ratios than 0.400, the losses are more in the expansion and turbulence of the emerging jet than across the orifice plate itself.

Conclusions

1. The loss coefficients, K_L, have been experimentally found out and related with the coefficient of discharge in simple empirical equations which very well hold good in the practical range of Reynolds' Numbers.

2. The overall loss expressed as % of the differential head is independent of Reynolds' Number.

3. The overall loss in the quadrant-edge orifice meter is just similar to that of A.S.M.E. flow nozzle under similar conditions.

4. The overall losses are expressed as equivalent lengths of pipe which can be more readily used than when they were given as percentages of differential head.

5. β ratio of 0.400 experiences the loss across the meter and downstream of the meter equally while other contraction ratios suffer more losses due to the expansion of the jet and the consequent turbulent than across the meter itself.

Acknowledgement

The authors express their deep gratitude towards Prof. N. S. Govinda Rao for his valuable guidance and encouragement in this investigation.

Notations

β : d/D;

C : Coefficient of discharge;

d : diameter of throat;

D : diameter of pipe;

R_D : pipe Reynolds' Number;

A_1, A_2 : Area of pipe section (1) and area of the throat respectively;

p_1, p_2 : pressures at section (1) and (2) respectively;

v_1, v_2 : velocity at section (1) and (2) respectively;

C_c : Coefficient of contraction;

α_1, α_2 : Kinetic Energy correction factor at section (1) and (2) respectively;

Q : Rate of discharge;

K_L : Loss coefficient;

x : Equivalent length pipe expressed in diameter of the pipe;

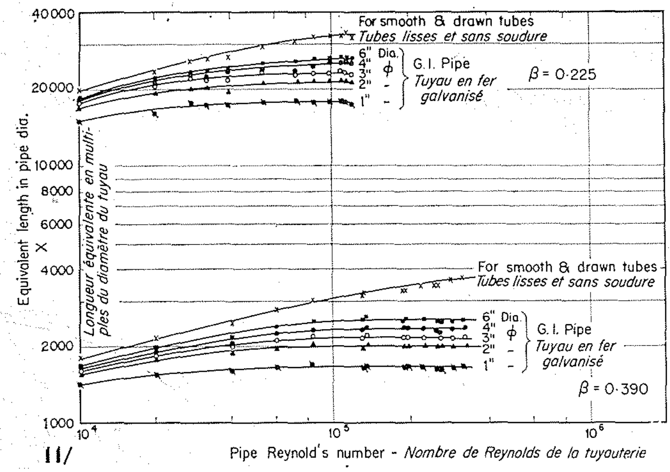
r : radius of the Quadrant Edge;

γ : specific weight of the fluid;

p_L : ratio of overall loss to the differential head;

p_L % : same as above expressed in %;

f : friction factor.



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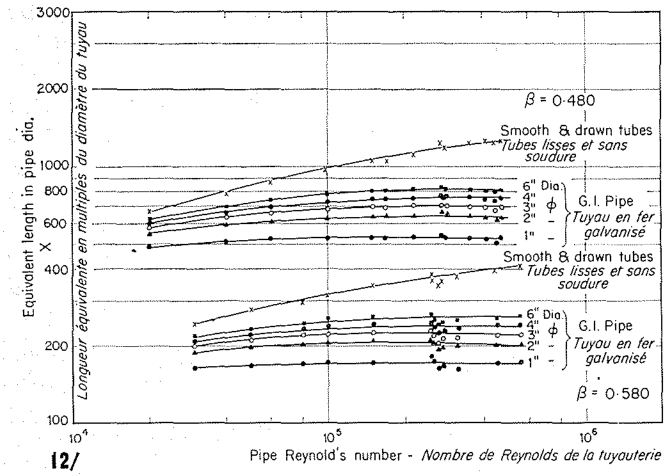

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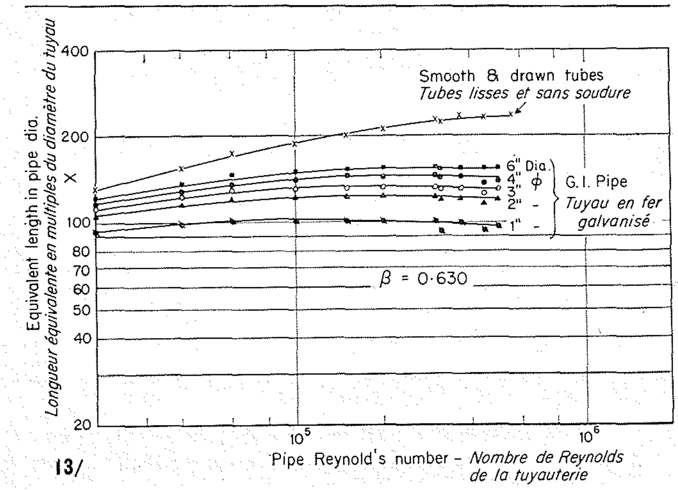

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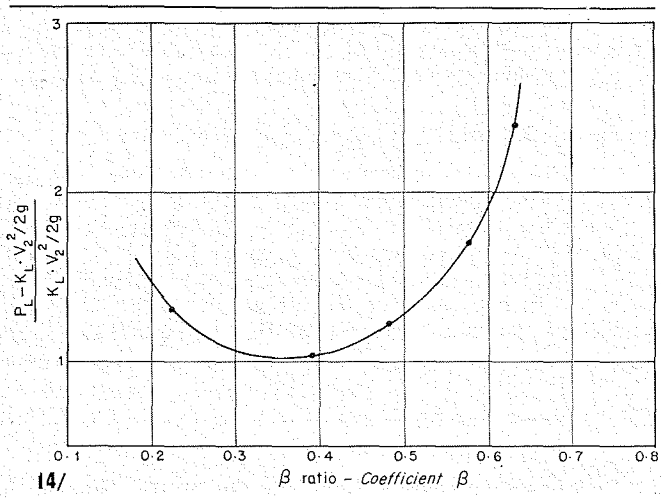

14/

References

[1] KOENNECKE (W.). — Neue Duesenformen Fuer Kleinere und mittlere Reynolds-Zahlen. *Forschung- V.D.I.*, May-June 1938.

[2] BOGEMA and MONKMEYER. — The Quadrant-Edge Orifice. A fluid meter for low Reynolds' Numbers, paper No. 56-A-140. *ASME Transactions*, Dec. 1959.

[3] MARVIN BOGEMA, BRADFORD SPRINGS, RAMAMOORTHY (M. V.). Quadrant-Edge Orifice Performance. Effect of upstream velocity distribution. Paper No. 61-WA-28. *Trans. A.S.M.E.*, Dec. 1962.

[4] RAMAMOORTHY (M. V.) and SEETHARAMAIAH (K. S.). — Quadrant-Edge Orifice-Performance at very high Reynolds' Numbers. (Under publication.)

[5] Fluid Meters- Their theory and application, Fourth Edition. *A.S.M.E. Research Publication,* V Edition, 1959.

Résumé

Les pertes de charge par un débitmètre-diaphragme à bords profilés

par
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et
K. Seetharamaiah **

Le diaphragme-débitmètre à bords profilés, illustré par la figure 1, a été retenu par l'I.S.O. en vue de sa normalisation internationale. Le présent article a trait, essentiellement, aux pertes de charge de l'écoulement par un tel diaphragme.

L'installation expérimentale est représentée par la figure 2.

ANALYSE DES DONNÉES. — Le schéma de définition de la figure 3 permet la détermination du coefficient de perte de charge K_L par le procédé décrit par la suite, et sur la base des hypothèses suivantes :

1. Aucune variation de charge dans une section donnée;
2. $\alpha_2 = \alpha_1 = 1$ (en régime fortement turbulent);
3. $C_c = 1$.

Soit la perte de charge du débitmètre définie par $K_L . (V_2^2/2g)$; en appliquant l'équation de Bernoulli aux sections (1) et (2), nous obtenons, pour K_L :

$$\frac{p_1 - p_2}{\gamma} = h = \frac{V_2^2}{2g}(1 - \beta^4 + K_L) \qquad (2)$$

Le coefficient de débit C est défini tel qu'il apparaît dans l'équation :

$$Q = \frac{CA_2\sqrt{2gh}}{\sqrt{1-\beta^4}} \qquad (3)$$

Nous obtenons ensuite, à l'aide des équations (2) et (3), les valeurs du coefficient de perte de charge K_L correspondant à différentes valeurs du rapport β, et nous portons ces valeurs de K_L en fonction de C dans les figures 4, 5, 6, 7 et 8. Les équations des droites sont indiquées sur les figures correspondantes.

Les figures 4 à 8 permettent la détermination des pertes de charge du débitmètre correspondant à n'importe quelle gamme de nombres de Reynolds d'utilité pratique, les valeurs de C étant obtenues à partir de la courbe des coefficients de débit correspondant au nombre de Reynolds en question.

Perte de charge globale du débitmètre

Une étude expérimentale a été faite en vue de la détermination de la perte de charge à l'intérieur du débitmètre. La figure 9 représente la perte de charge globale p_L, exprimée comme pourcentage de la différence des hauteurs de part et d'autre du débitmètre, et en fonction du nombre de Reynolds pour diverses valeurs du rapport β. On remarque que le pourcentage p_L % est indépendant du nombre de Reynolds du tuyau.

De telles valeurs constantes sont représentées en fonction du rapport β dans la figure 10. Afin d'en permettre la confrontation avec les pourcentages p_L % relatifs aux diaphragmes à bords vifs, aux tuyères et aux venturimètres, les pourcentages p_L % correspondant à ces derniers sont également portés sur cette même figure. On remarque que les pertes de charge du diaphragme-débitmètre à bords profilés sont exactement les mêmes que celles de la tuyère, pour différentes valeurs du rapport β, et dans des conditions semblables.

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Longueur du tuyau équivalente

La figure 10 ne permet pas de distinguer la perte de charge correspondant à une valeur quelconque du rapport β, car pour ceci, il faudrait savoir d'avance quelle serait la hauteur différentielle correspondant au régime d'écoulement donné, si l'on employait cette même figure. Afin d'éviter ce procédé laborieux, on traduit les pertes par celles qui se produiraient dans un tronçon de tuyau rectiligne :

$$\frac{flv_1^2}{2\,g\mathrm{D}} = p_\mathrm{L}h \qquad (6)$$

dans laquelle l désigne la longueur de tuyau équivalente capable de donner lieu à des pertes de charge semblables. Soit $l = x.\mathrm{D}$. Suivant l'équation (3) :

$$h = \frac{v_1^2\,(1-\beta^4)}{\beta^4 2\,g\mathrm{C}^2} \qquad (8)$$

En faisant intervenir ces différentes valeurs de h et de l dans l'équation (6), nous obtenons :

$$x = \frac{p_\mathrm{L}\,(1-\beta^4)}{\beta^4\mathrm{C}^2 f} \qquad (10)$$

L'équation (10) permet de calculer les valeurs de x correspondant aux différentes valeurs de $\mathrm{R_D}$, pour divers types de tuyaux, et pour diverses valeurs de D et de β. Ces calculs ont été effectués pour les cas des tubes lisses sans soudure et des tubes en fer galvanisé, pour des diamètres compris entre 1″ et 6″; les résultats sont indiqués sur les figures 11, 12 et 13. Ainsi, dans une installation quelconque comportant un diaphragme-débitmètre à bords profilés, on peut tenir compte des pertes de charge complémentaires correspondant à cet organe, en prévoyant dans l'installation une longueur de tuyau supplémentaire correspondante.

Répartition des pertes de charge de part et d'autre du débitmètre, et à l'aval de celui-ci

La détermination des pertes de charge de part et d'autre du débitmètre se fait à partir de valeurs de $\mathrm{K_L}$ connues, en fonction des valeurs du coefficient β, ces pertes étant exprimées comme pourcentage de la hauteur différentielle. Les valeurs de p_L % se déterminent, dans des conditions semblables, à partir de la figure 10; les valeurs des rapports entre les pertes à l'aval du débitmètre et celles de part et d'autre de celui-ci, ont été calculées, et sont portées sur le graphique de la figure 14.