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BRIEF COMMUNICATION

FLOW BEHIND LOW POROSITY GRIDS IN A PIPE AT LOW REYNOLDS NUMBERS

TAKEO NAKAGAWA
Department of Civil Engineering, Kanazawa Institute of Technology, Nonoichi, Kanazawa 921, Japan

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INTRODUCTION

In many cases of the flow through porous grids, one may consider the flow to be made up of a number of jets passing through openings of the grid. These jets may be separated by a series of wakes behind the solid parts of the grid. This region behind the grid will be called "jet-wake region" hereafter. The physical mechanism of coagulation of the jets appears to depend upon the entrainment of fluid by individual jet from the wakes around it.

The majority of previous investigations (e.g. Pinker & Herbert 1967; Gad-el-Hak & Corrsin 1974; Reynolds 1969) on the flow through grids have been concerned with measurements of the pressure loss and its variation with the grid porosity k, the grid Reynolds number Re_M based on the mean incident velocity U_∞ and grid mesh size M, and Mach number; it has been normally assumed that the pressure is discontinuous at the grid itself and that the pressure loss coefficient C_p defined by $\Delta p/(\frac{1}{2}\rho U_\infty^2)$, where Δp is the pressure drop across the grid and ρ the fluid density, provides sufficient information. It must be, however, noted that variations in grid dimensions could lead to significant effects on the pressure loss in particular for fine-mesh screens (Simmons & Cowdrey 1945). The grid may also liable to contamination from dust and dirt, which could also contribute to geometrical non-uniformities of the grid, and thus to changes in the porosity.

It is known that in certain cases there appears to be some instability of the flow behind the grid, i.e. the flow varying with time at a given point, together with a spatial variation. The word "instability" of the flow is used here to describe these flow conditions. It would appear that for given flow conditions, there might be a critical grid porosity below which instability of the flow may be expected and above which the flow may be regarded as completely stable. Baines & Peterson (1951) and Morgan (1960) have discussed the instability of the flow behind low porosity grids. The first theoretical and experimental work on this subject, however, was by Bohl (1940), who was able to obtain the critical grid porosity of 0.54, below which the flow behind the grid became unstable. Bohl (1940) has also pointed out that the degree of instability of the flow increases with reduction in the grid porosity. It is, however, almost certain that the critical porosity for instability of the flow is also influenced by the grid Reynolds number and the grid geometry.

The present paper is concerned with the flow properties behind low porosity grids placed normal to the axis in a pipe and the pressure drop across the grid at the low pipe Reynolds number Re_p based on the mean incident velocity U_∞ and pipe diameter D_p. How the flow behind low porosity grids below the critical porosity found by Bohl (1940) and the pressure loss coefficient depend upon the grid porosity and grid Reynolds number is examined here. The results are presented and discussed in the text.

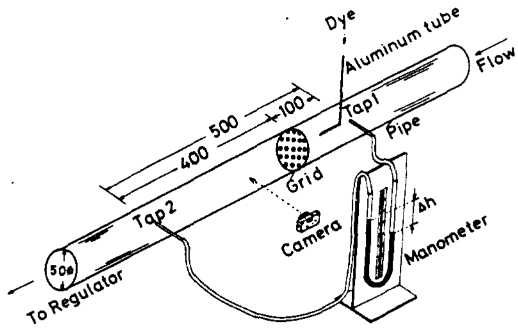

Figure 1. Schematic diagram of the experimental set-up. (units: mm)

EXPERIMENT

Figure 1 shows a schematic diagram of the present experimental set-up. Flow goes through a circular porous grid of 50 mm dia., 2.8 mm thick, having 21 circular holes, which are arranged as depicted in this figure. The grid plane is normal to the central axis in a pipe of 50 mm i.d., 56 mm o.d. and 20 m length and each grid is set at the middle section of the pipe.

White (1968) has indicated that the entrance length for turbulent pipe flow is much shorter than that for laminar pipe flow. Thus, in order to know the maximum entrance length, it may be sufficient to estimate the entrance length for the laminar pipe flow. White (1968) has provided a formula of the entrance length for the laminar pipe flow in the form

$$x_L \simeq 0.08 D_p \, \mathrm{Re}_p + 0.7 D_p.$$

It is found that the present entrance length x_L has a maximum value of 9.235 m when $D_p = 50$ mm and $\mathrm{Re}_p = 2300$. It is clear that the present length of 10 m between the pipe entrance and grid is longer than the maximum entrance length. Hence, it is considered that the present pipe flow is fully developed before it goes through the grid holes. It has been, however, assumed that the fully developed incident flow can be characterized by the mean velocity across the pipe section.

Turbulence upstream from the grid has been minimized by using a bell-mouth and honeycomb grid placed at the entrance to the pipe. In all three grids used, the mesh size was common, but the hole diameter and porosity were different from each other as listed in table 1. Each centre of the grid holes was marked carefully on the circular plate before boring the holes in it and then each of these holes were bored successively with commercially available drills.

For the flow-visualization, Methylene blue and Rodamine B were used. Each of the dyes was released into the flow in the pipe with an aluminum tube of 0.2 mm o.d. and 0.1 mm i.d., respectively. In each experiment, in addition to the careful observation, the length of streamwise extent of the jet-wake region and flow rate were measured by a rule and weighting the water, respectively.

For the measurements of the small pressure drop across the grid, a micro-pressure manometer was designed with two kinds of liquid: One is the water and the other is

Table 1. Dimension of grids

	Outer diameter D[mm]	Mesh size M[mm]	Hole diameter d[mm]	Porosity k
Grid 1	50.0	10.0	2.5	0.0525
Grid 2	50.0	10.0	5.0	0.2100
Grid 3	50.0	10.0	7.0	0.4116

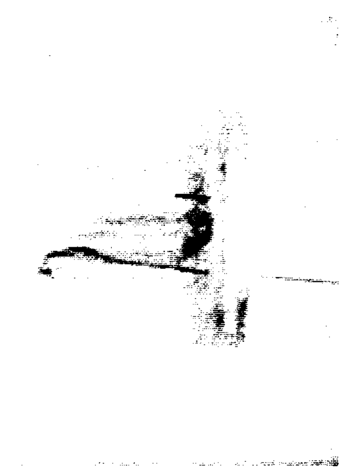

Figure 2. Laminar jet-wake flow behind grid 1. $k = 0.0525$, $\mathrm{Re}_M = 39$, $a/M = 3.10$.

Chlorobenzene (density 0.9978 g/cm^3 at 22°C) filled in the U-shaped tube. Two holes of 6 mm dia. were drilled at the pipe wall for pressure taps. One of the holes was 100 mm upstream from the grid and the other hole was 400 mm downstream from the grid. These pressure taps were connected to the respective end of the U-shaped tube with a vinyl tube.

RESULTS

Figure 2 is a photograph of laminar jet-wake flow behind grid 1, with details identified in figure 3. The flow was visualized with the two dyes released through the aluminum tubes held at each centre of the grid holes. It may be noted that particles of the fluid were carried downstream first, then turned and arrived at the grid plane. It was observed that in the region just behind the grid the flow was made up of a number of jets passing through openings of the grid and that these jets were separated clearly by a series of wakes behind solid parts of the grid.

Figure 4 shows how the normalized length a/M of streamwise extent of the jet-wake region behind the grid changes depending upon the grid Reynolds number for each grid porosity. In figure 4, data for the three grids are plotted concurrently and the shaded symbols denote the respective initial length of the jet-wake region. In the case of grid 1, the laminar jet-wake flow appears first at $\mathrm{Re}_M = 15$, below which the flow almost follows the surface of the grid. The length of the jet-wake region, however, increases with the Reynolds number until $\mathrm{Re}_M = 46$ and becomes the maximum. However, once the Reynolds number exceeds the peak value, the jet-wake combined flow becomes turbulent and the length of the jet-wake region decreases as the Reynolds number increases. Note that this peak grid Reynolds number $(\mathrm{Re}_M)_p$ of 46 is very close to the cylinder Reynolds number $\mathrm{Re}_c(\simeq 50)$,

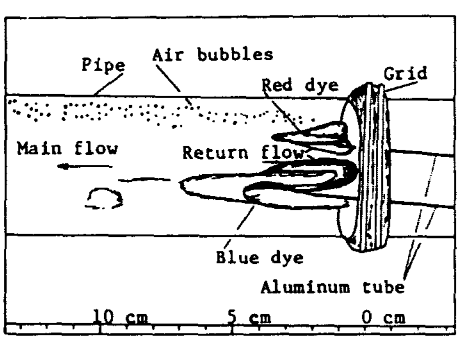

Figure 3. Identification for figure 2.

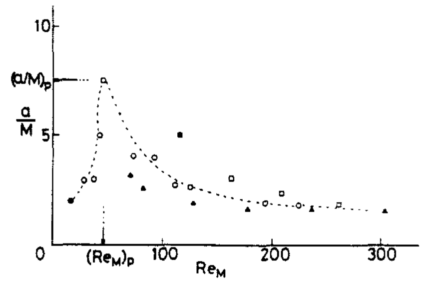

Figure 4. Normalized length a/M of streamwise extent of jet-wake region behind grid vs the grid Reynolds number Re_M for each grid porosity k. ○; $k = 0.0525$, △; $k = 0.2100$, □; $k = 0.4116$.

based on the mean incident velocity U_∞ and cylinder diameter D_c, from which the vortex shedding starts behind the cylinder (Roshko 1954). Furthermore, it seems that the length of the jet-wake region tends to approach to an asymptotic value of one and a half of the grid mesh size.

On the other hand, in the cases of grids 2 and 3, no laminar jet-wake flow was observed, but the turbulent jet-wake flow appeared from the beginning. The turbulent jet-wake flows behind grids 2 and 3 appeared first at the grid Reynolds numbers 72 and 118, respectively. Since both of these Reynolds numbers are larger than the peak value of 46, both lengths of the jet-wake region decrease as the Reynolds number increases. It is observed that these jet-wake flows consist of the grouping together of the adjacent jets immediately behind the grid, thus causing wildly eddying flow. The adjacent groups then join until at a short distance downstream from the grid. Thus there is little evidence to show the flow has originated from a regular row of jets. The phenomena are found to be irregular, i.e. the same pairs of adjacent jets do not always unite first. It may be also noted in figure 4 that as the porosity increases, the Reynolds number from which the jet-wake flow appears first as well as the initial length of the jet-wake region increases.

Figure 5 shows the relation between the pressure loss coefficient and the grid Reynolds number at each grid porosity. It may be noted that the pressure loss coefficient fluctuates up to the grid Reynolds number of approx. 500, beyond which it becomes almost constant, and the pressure loss coefficient increases as the porosity decreases. In the course of the measurements, instability of the flow was, indeed, observed in form of sudden changes in the pressure after a period of apparent steadiness when the Reynolds number was smaller than approx. 500. It was at first thought to be due to irregularities coming from upstream of the grid or even due to some basic experimental faults. Thus, great care was taken to prevent any possible irregularities. It is, however, realized that the changes in pressure with time still persisted. In this connection, it may be worth noting that the larger the grid

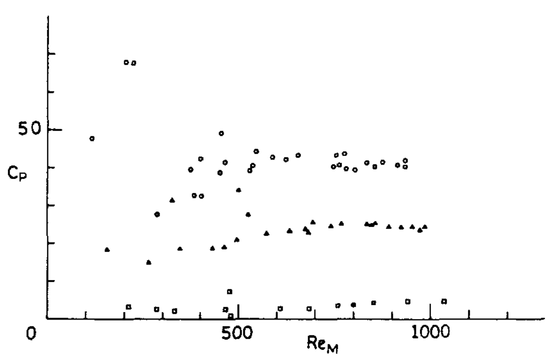

Figure 5. Pressure loss coefficient C_p vs the grid Reynolds number Re_M for each grid porosity k. See figure 4 for the legends.

porosity was, the less time it took for the pressure reading to settle down a steady value, and that fluctuations of the pressure loss coefficient for the lower porosity grid were larger than those for the higher porosity grid.

DISCUSSION

It is interesting to point out analogies between the jet-wake flow behind the grid and the flow in the separation bubbles over the blunt plate. Lane & Loehrke (1980) have observed the flow over blunt plate aligned parallel to the free stream. They found that the leading edge separation bubble is formed once the plate Reynolds number Re_t based on the mean incident velocity U_∞ and plate thickness t exceeds a certain limit. The steady laminar separation bubble on a long plate $L/t = 8$, where L, the plate length, grows in size with the Reynolds number and reaches the maximum streamwise length at $Re_t = 325$. Then, it is reported that the free shear layer dividing the separation bubble and free stream becomes unsteady, and the separation bubble shrinks in size with further increase in the Reynolds number. It is interesting to note that variation of the streamwise length and flow characteristics of the separation bubbles with the Reynolds number is quite similar to the variation of those of the present jet-wake region behind grid 1.

It has been already shown in figure 5 that the pressure loss coefficient fluctuates up to the grid Reynolds number of approx. 500, but it becomes almost constant once the grid Reynolds number exceeds that value. Since the ratio of the grid mesh size to the pipe diameter is 1/5 for all the three grids as shown in table 1, it is clear that the grid Reynolds number $Re_M = 500$ corresponds to the pipe Reynolds number $Re_p = 2500$. Hence, it is suggested here that the transition from the laminar flow to the turbulent flow in the region between the pipe entrance and grid might play an important role on the fluctuations of the pressure loss coefficient: When the incident flow to the grid is laminar the fluctuations are greater, whereas when the incident flow is turbulent they are smaller.

CONCLUSION

When the grid porosity is of 0.0525, it is observed that the flow behind the grid consists of a jet-wake combination which remains laminar up to the peak grid Reynolds number of approx. 46, beyond which the jet-wake combined flow becomes turbulent: When the flow is laminar, the length of streamwise extent of the jet-wake region increases with the grid Reynolds number, whereas when the flow is turbulent, the length decreases with the grid Reynolds number. On the other hand, when the grid porosity is larger than 0.2100, the laminar jet-wake flow has not been, however, observed, but the turbulent jet-wake flow has appeared from the beginning.

It is found that the pressure loss coefficient fluctuates up to the grid Reynolds number of approx. 500, beyond which it becomes almost constant, and that the pressure loss coefficient increases as the porosity decreases. It is found that the pressure fluctuations for the smaller porosity grid are larger than those for the higher porosity grid.

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