Figure 3 shows the critical speeds expressed as a multiple of the values for concentric cylinders, using the mean curves drawn in Figures 1 and 2. At 50% eccentricity ratio, the critical speed for both cylinders is about 45% higher than for the concentric position. The effect of clearance ratio is seen to be small except at high eccentricity ratios, but results at other clearances are necessary before firm conclusions can be drawn. The author's earlier results (4) are shown for comparison: the disparity presumably arises from the different flow regime (the present results are for a compressible viscous flow, the earlier results for an incompressible viscous flow, although for these clearances compressibility effects should not be large) and from the different length-diameter ratio (based on inner cylinder diameter, 2.7 and 2.3 for the present results and 9.3 for the earlier results).

Conclusion

The hot wire anemometry technique has given satisfactory indications of the onset of Taylor vortices despite the qualitative nature of the anemometer readings.

Although the large number of results presented here confirms the earlier reporting of the effect of eccentricity on the critical speed at which Taylor vortices appear, a great deal of work remains to be done, particularly on the significance of end effects and on the quantitative role of clearance ratio; however, it may be possible to clarify the position further when this paper is presented at the Conference.

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EXPERIMENTS ON THE SUSPENSION OF SPHERES IN INCLINED TUBES

I - Suspension by Water in Turbulent Flow*

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ABSTRACT

Experiments have been made on the suspension of single spheres by water in tubes of diameters 0.970, 1.280, 2.489 and 5.133 cm. The angle of inclination of the tubes to the horizontal could be varied from 0 - 90°. Measurements were made on the liquid velocities required to support the spheres and the pressure drops associated with these velocities. In general, four regimes of suspension prevailed: at low angles of inclination the spheres became still and remained in this condition until they reached a 'bounce-point'. This was the point at which friction between the sphere and the tube was reduced to zero. At larger angles the spheres bounced radially, until at angles very close to the vertical the spheres were freely suspended and rotated slowly at several r.p.m. free of the boundary. A fifth regime was noted for a certain diameter ratio range, approximately 0.8 - 1.0 and angles of inclination greater than about 20-30°. In this regime the spheres tended to spiral and rotate very rapidly.

The drag coefficients were calculated and analysed in terms of diameter ratio and pipe Reynolds number. In the still region it was found that the drag coefficient was independent of Reynolds number.

The velocity and pressure drop data correlated well with other physical parameters of the system.

* The full text of this paper is obtainable on request in micrographed form from the publishers.

Conclusions

An experimental investigation of the suspension of spheres by water in inclined tubes has been carried out using spheres whose density ranged from 1.19 - 8.75 gm./c.c. Five flow regimes were noted :

1) At low angles of inclination usually 0-20° a gentle transverse rocking motion took place.

2) At higher angles of inclination usually 20-65° the spheres became still and the relationship between the square of the suspension velocity and the sine of the angle of inclination was linear indicating that the drag coefficient was independent of Reynolds number in this region.

3) At the end of the still region a bounce regime was evident.

4) At an angle of inclination of 90° the spheres were freely suspended rotating slowly. The suspension velocity at this point was in general markedly different to extrapolated values of the still and bounce regimes.

5) For diameter rates above about 0.79 the spheres could rotate around the inside periphery of the tubes very rapidly; depending upon the suspension velocity this could vary between a few hundred r.p.m. to in excess of two thousand r.p.m.

The drag coefficient in the still region was dependent on the diameter ratio only. The lift coefficient was approximately half the value of the drag coefficient over the diameter ratio range 0.1 - 1.0.

The amount of energy possessed by the spheres in the state of spiralling rotation is relatively high but the amount of excess pressure energy (over the support pressure energy) to maintain the state is relatively small. It may be that the effect of spiralling rotation could be found to have application as a fluid-solid oscillator.

The pressure drop and velocity data for the still regions were successfully correlated in terms of the angle of inclination, the tube diameter, the apparent density ratio and the diameter ratio.

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