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SOME OBSERVATIONS OF THE FLOW IN A CENTRIFUGAL SEPARATOR

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ABSTRACT

A numerical study has been conducted of the flow in a centrifugal separator geometry similar to that proposed by Dahlkild *et al* (1992). Initial results for no rotation have revealed an interesting flow behaviour in the region where particle separation occurs. Simulations which include rotation show the effect of inlet flow velocity on the separation process.

INTRODUCTION

Centrifugation is a simple and effective method for separation of particles from a fluid of a different density, or for separating fluids of different densities. In the simplest configuration the centrifuge consists of a rotating cylinder containing the particulate-laden or two-phase fluid. As the cylinder rotates, the heavier components collect toward the outside of the cylinder, and the lighter components move toward the axis.

The efficacy of the separation process is a function of a number of factors, including to a large degree the geometry of the centrifuge. A general introduction to the behaviour of suspensions and in particular the sedimentation process is given in Ungarish (1993). A number of studies (Greenspan and Ungarish (1985), Ungarish and Greenspan (1984)) have investigated various methods for improving the separation process in a rotating cylinder containing either two fluids of different density or a fluid containing particles with a different density to that of the fluid. However the simple cylindrical centrifuge, while an efficient separator, needs to be stopped so that the various fractions can be harvested. This interrupts the separation process - a method of continuous separation is desirable

Dahlkild *et al* (1992) investigated the possibility of continuous separation of particles from a fluid using a centrifugal spectrometer. An example of a simplified geometry for such a spectrometer is shown in figure 1. Two streams enter the device near the axis of rotation, the inner channel containing wash fluid, and the outer channel containing the particle laden fluid. Both channels lead to the bottom of the drum, then outward to the outermost region of the drum. In this region the flows are allowed to meet via a slot in the dividing wall. The particles settle towards the outside of the drum at rates according to their densities with respect to the density of the fluid. By taking into account these different settling speeds it is possible to arrange for the slot to accept those particles which settle the most rapidly (those with higher densities) and exclude those particles which settle slowly (those with lower densities) from the outer cylinder. In this fashion, with a number of concentric cylinders it is possible to separate out the various fractions, so that outflows with high concentrations of the required particles are obtained.

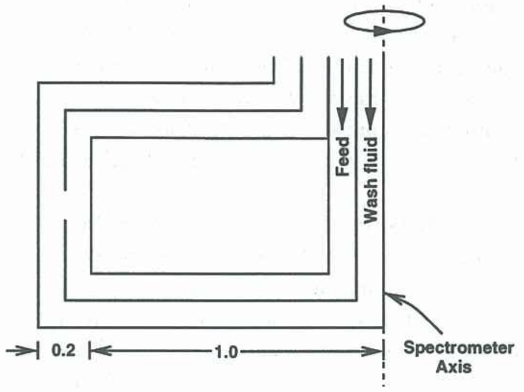

Figure 1: Centrifugal spectrometer half section.

Dahlkild *et al* (1992) conducted studies of a proposed centrifugal separator design. Initially the assumption of axisymmetry was used to investigate just the flow through the slot without the complications introduced by baffles distributed azimuthally around the drum. Their study examined the most efficient method of particle separation, and finished with an experiment whch confirmed the promise for this separation method indicated by their numerical results.

The following study is part of an investigation into

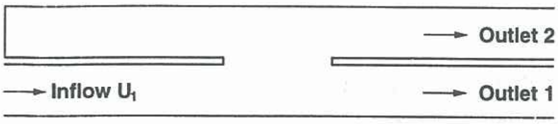

Figure 2: One inlet channel geometry.

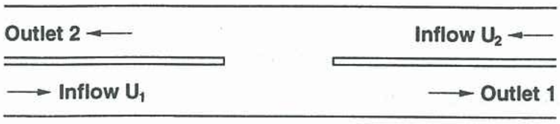

Figure 3: Two inlet channel geometry.

the flows possible in the centrifugal spectrometer geometry of figure 1. We are most interested at this stage in the flow behaviour around the slot itself, so the simple geometry of two channels joined by a hole, as shown in figures 2 and 3, is considered. These geometries represent a 2 dimensional idealisation of the outermost section of the centrifugal separator of figure 1.

Schaflinger *et al* (1986) demonstrated that a 2 dimensional analysis of the separation process does not sufficiently reproduce the flow in a real machine. The coriolis effect introduced by rotation interferes with the separation process, and hence radial baffles are required in order to prevent retrograde motions. However in this work we are concerned with the behaviour of the flow in the region of the slot, not the global separation process, and most of the cases presented here are purely 2 dimensional (as opposed to axisymmetric) as there is no rotational component.

NUMERICAL METHODS

Fluent, a commercially available computational fluid dynamics, code was used to generate most of the results presented here. The numerical method used by Fluent is based on an incompressible finite volume scheme.

Initially results for varying grids were obtained to determine the appropriate grid to use for the problem. A 219x69 compressed grid was found to give a result accurate to within 1% of the finest grid used (544x172). The grid was compressed at all boundaries, the element size at the boundary being one third that of the largest element. Convergence was assumed when the sum of the absolute values of the normalised pressure and velocity residuals was less than 5×10^{-5}.

Another method was used to generate solutions for the case of varying gap width. For this method discretisation of the equations was performed using the Galerkin finite-element method. Nine noded quadrilateral elements were used for the complete domain, and a penalty method was used in the formulation for pressure. In order to resolve the boundary layers that develop on the walls, the grid had Chebyshev compression towards all boundaries. The nonlinear set of equations were solved by Newton iteration, with the stopping criterion being that the norm of the velocity differences was less than 10^{-6}.

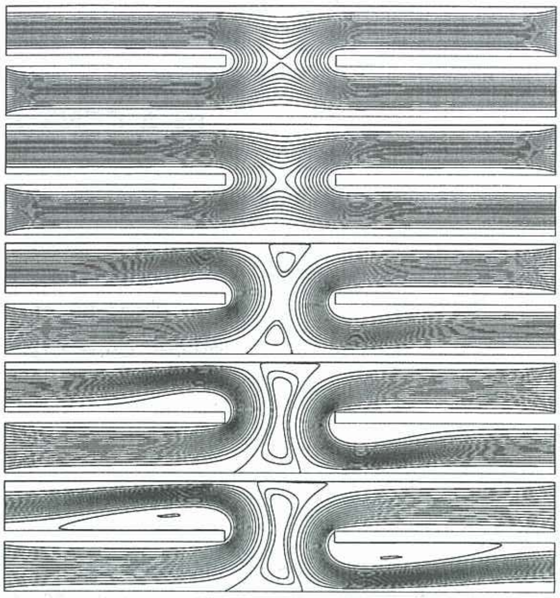

Figure 4: Results for two opposing inflows; $Re =$ 1, 10, 50, 100, and 200.

We present results for both no rotation and for rotation. The no rotation cases reveal characteristics of the two channel flows in general. Initial results for the rotating cylinder are presented in a later section.

THE NO ROTATION CASE

The first case (figure 2) is similar to that of Dahlkild *et al*'s (1992) initial case - one inflow and two outlets, with a wall in the outer (upper in the figure) channel at the inlet end.

The second flow condition (figure 3) has two inlets - one for each channel, and at opposite ends of the system. This configuration is different to that used in a working separator, but sheds light on the interaction of the two flows at the interface, as features of this flow are also seen in the separator flow. Each channel also has an outlet at the opposite end. The outflow is not specified at these outlets.

RESULTS FOR NO ROTATION

Results for the geometry in figure 3, and for various Reynolds numbers, are shown in figure 4, where the Reynolds number Re is defined as:

$$Re = \frac{\rho u d}{\nu}$$

where ρ is the density of the fluid, u the inlet velocity, d the height of one channel, and ν the viscosity.

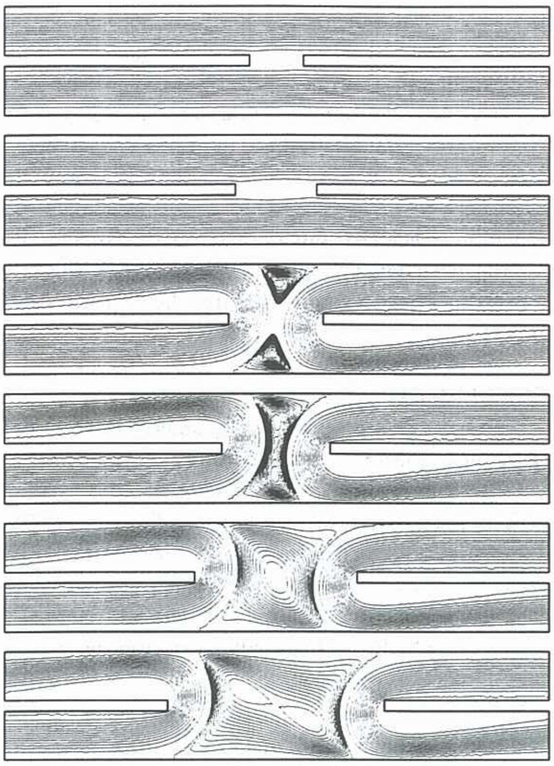

Figure 5: Varying gap size with finite plate thickness, $Re = 82.5$, gap width = 0.5, 0.75, 0.875, 1.0, 1.5 and 2.0 times the diameter of the two-channel system.

At $Re = 1$, the streamlines reveal that about half the flow transits through the entire channel on each side, and about half is entrained by the flow in the other channel. As Re is increased, more of the flow becomes entrained by the fluid in the other channel, until at $Re = 50$ the flow separates from the wall and a recirculation region evolves in the centre of the slot. This region then dominates the flow, and prevents flow straight through either channel - the flow on each side is turned 180 degrees and exits through the outlet directly above the inlet from which it originated.

Dahldkild *et al* (1996) did observe the beginnings of this recirculation in their study, but their geometry was that of figure 2 - there was no opposing inflow. As the flow diverted into the outer channel, a small recirculation region was observed to develop on the inner wall of the inner channel just above the slot. It was mentioned that the presence of such a region could only hamper the separation process.

Also of interest is the dependence of the flow on the size of the slot between the two channels. Figure 5 presents streamlines for slot sizes from h = 0.5 to 2.0, where h = 1 is the width of the two-channel system. It can be seen from these results that the slot size plays a large part in determining whether the fluid transits from one end of a channel to the other or turns through 180° and exits through the same end from which it originated.

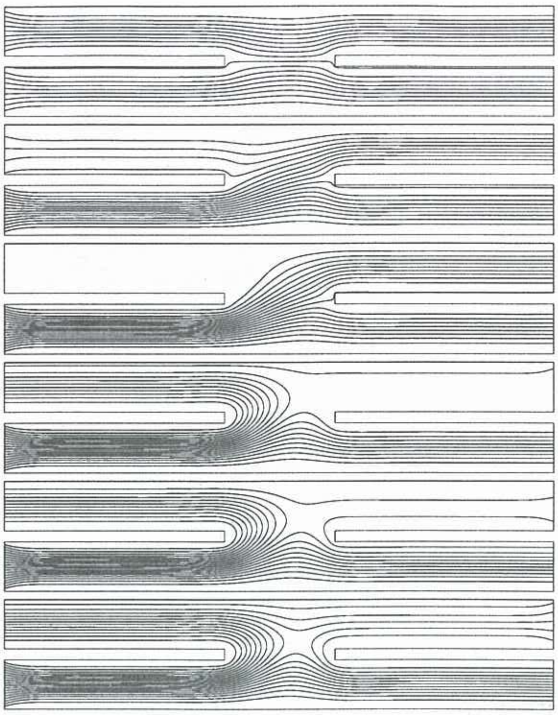

Figure 6: Opposing flows with varying velocities; U_2 = 100%, 25%, 0%, -5%, -10%, and -25% of U_1.

These results for varying slot size were generated using the other numerical code and show the same behaviour as was observed using Fluent. Another commercial code, CFX version 4.2, also revealed the same behaviour for these cases of opposing inflows. The results still await experimental validation however. (Other cases were also investigated, including the assumption of free slip on the boundaries. In this case the recirculation seen in the above figures was not observed at these Reynolds numbers.)

The plots in figure 6 show the effect of varying the velocity in the upper channel. The first 2 plots have U_2 = 100% and 25% of U_1, and the last 3 show results for U_2 = -5%, -10%, and -25% of U_1 respectively. $U_2 = 0$ is a similar configuration to that studied by Dahlkild *et al* (1992).

As U_2 decreases from 100% to 0, more of the flow in the lower channel diverts to the upper channel. As U_2 becomes negative the type of behaviour observed in figure 4 is again apparent - fluid from the lower channel becomes entrained by fluid in the upper channel. However, very little of the upper channel fluid enters the lower channel - almost all of it exits through the upper outlet, until U_2 = -25% when around a third of this fluid enters the downstream end of the lower channel, as in the last plot in figure 6.

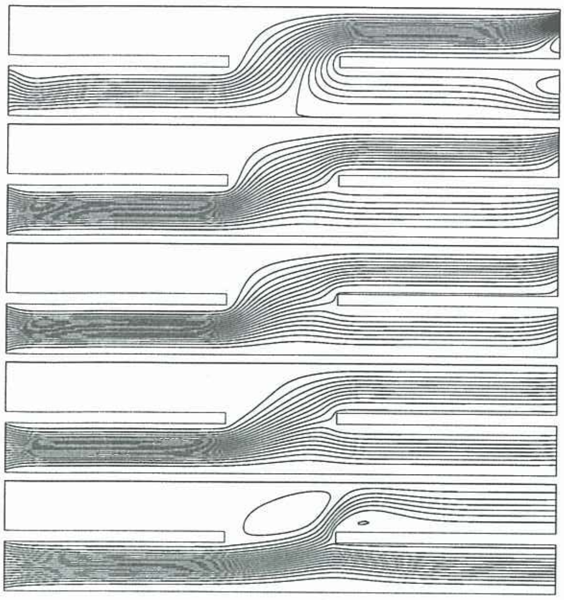

Figure 7: Rotating case with varying inlet velocities; Re = 0.1, 0.5, 1, 10, 100.

RESULTS FOR ROTATION

Next we include results from a study of the flow when the whole system is set rotating about an axis 10 channel diameters below the inner channel. Here the channels are rotating slowly (angular velocity = 0.1 rad/s) and the inflow is also slow (Re = 0.1 to 100) compared to the values used for an actual separator (rotation rate ~ 120 rad/s). The higher angular velocity cases will be considered in future work. In these initial results however we do see similar phenomena to those observed in other studies.

Figure 7 shows the case of a constant angular velocity, and changing inlet velocity. Here the lower channel (inner cylinder) has an inlet at the left, and an outlet at the right. The top channel (outer cylinder) also has an outlet at the right, but the left end is blocked by a wall, in the same fashion as in Dahlkild *et al*'s (1992) study. However, in the simulations presented here the outlet velocity is not specified - the outlets are pressure boundaries, and hence the flow is free to resolve itself at these boundaries in whatever fashion is necessary to satisfy continuity (eg. inflows at the outlets are allowed).

The results shown in figure 7 are qualitatively similar to those obtained by Dahlkild *et al* (1992) and are physically reasonable. For very low inflow rates compared to the rotation rate, as for the Re = 0.1 case, all of the flow diverts to the outer channel, and fluid even enters the domain from the outlet of the inner channel. As the inflow rate increases, more of the flow exits through the lower channel outlet, until at Re=100 the flow through the slot separates from the edge of the slot as it passes through, and recirculation regions develop. This flow configuration would be detrimental to the separation process. Hence there are two extremes, one where all of the flow is diverted to the outer cylinder, and the opposite extreme where little of the flow moves into the outer cylinder. Somewhere between these extremes an optimum combination of inlet velocity and angular velocity should exist for the most efficient particle separation - this case was more thoroughly investigated by Dahlkild *et al* (1992).

CONCLUSION

An investigation of the flow geometry relevant to a centrifugal spectrometer has been presented. These results suggest that certain inlet velocities produce recirculation in the region where the flows meet. Preliminary results for the cases with rotation imply the existence of an optimum combination of angular velocity and inlet flow rate for the most efficient separation of particles. The results presented here await experimental verification.

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