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Technical Notes

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Experimental Investigation of the Pressure Drop in a Sink–Swirl Flow Within Two Disks

Ali M. Jawarneh,* G. H. Vatistas,† and Yasser Aboelkassem‡
Concordia University, Montreal, Quebec H3G 1M8, Canada

Nomenclature

A_{in}	=	total inlet area, $n\pi r_{in}^2$
A_0	=	cross sectional area of the disk, πr_0^2
C_p	=	dimensionless pressure drop, $2\Delta P/\rho q_{in}^2$
D_e	=	diameter of the exit port, $2r_e$
D_{in}	=	diameter of the inlet port, $2r_{in}$
D_0	=	disk diameter, $2r_0$
H	=	gap height
n	=	numbers of the inlet holes
P_{in}	=	static pressure at the inlet
p_{out}	=	static pressure at the outlet
Q	=	volumetric flow rate
q_{in}	=	total average velocity vector through the inlets
Re	=	Reynolds number, HU_{in}/ν
r_e	=	exit port radius
r_{in}	=	inlet hole radius
r_0	=	disk radius
S	=	inlet swirl ratio
U_{in}	=	inlet radial velocity component
V_{in}	=	inlet tangential velocity component
ΔP	=	static pressure difference, $P_{in} - P_{out}$
μ	=	dynamic viscosity
ν	=	kinematic viscosity
ρ	=	density of the fluid
φ	=	inlet angle

I. Introduction

THE flow between two disks has received much attention due to its significant relevance to technical applications in many areas, such as turbomachinery, heat exchangers, valves, bearings, lubrication, viscometry, and power transmission systems. Most of research deals with the flow over a rotating disk,[1] between a stationary and a rotating disk,[2] over both disks rotating,[3,4] and between two stationary disks with pure radial flow.[5,6] Few works deal with inlet swirl flow between two stationary disks.[7]

The present paper deals with the influence of swirl generators on the pressure drop in inward-swirl flow imparted between two stationary disks with aspect ratio (defined as the disk diameter/gap height ratio) equal to 60. Dimensional analysis suggests that the dimensionless pressure drop to be a function of the Reynolds number, the aspect ratio, and the inlet flow angle. Measurements confirm the finding.

II. Experimental Apparatus

The present experiments have been conducted using a jet-driven swirl generator, shown schematically in Fig. 1. It consists of two stationary parallel disks of diameter 762 mm with a gap of 12.7 mm. The upper disk with a concentric hole was connected to a suction compressor. The exit area is adjusted by replacing hole plates with different exit sizes. Three swirl generators (Fig. 2) with three inlet angles, $\varphi = 30, 40$, and 60 deg, were used for the experiments. When air is sucked through the swirl generator, in addition to the radial velocity, it also develops a tangential component that depends on the value of the inlet angle. Each generator had 48 holes with diameter $D_{in} = 6.35$ mm. Measurements were made at different inlet airflow rates, 0.009, 0.0117, 0.014, 0.0164 and 0.0187 m^3/s, which correspond the five Reynolds numbers $Re\,(= HU_{in}/\nu)$ of 2663, 3328, 3994, 4660, and 5357, respectively, where U_{in} is the inlet radial velocity. The contraction ratio (r_0/r_e), defined as the ratio of the radius of the disk r_0 to the radius of the exit hole r_e, was varied from $r_0/r_e = 24$, 28.6, to 34.3. The value of the mean static pressure ($P_{in} - P_{out}$) was then obtained using a well-type manometer containing Meriam oil with specific gravity equal to one. The estimated uncertainty for the pressure drop measurements is between 2 and 4%. Air at standard temperature was the working fluid. The volumetric flow rate was recorded using a calibrated variable area rotameter, which was located between the outlet of the experimental apparatus and the inlet (suction) of the compressor. This was calibrated at standard conditions (1 atm and 0°C). For the flow rates used, the uncertainty was estimated to be from 1.4 to 2.0 %.

III. Analysis

To reduce the experimental effort and at the same time to present our results in a generalized form, we performed a dimensional analysis. The expected functional relationships for the pressure drop are

$$\Delta P = f_n(\rho, \mu, q_{in}, D_e, D_0, H, A_{in}, \varphi) \tag{1}$$

where $\Delta P = P_{in} - P_{out}$ is the static pressure difference between the inlet and outlet pressure. Buckingham's π-theorem provides the

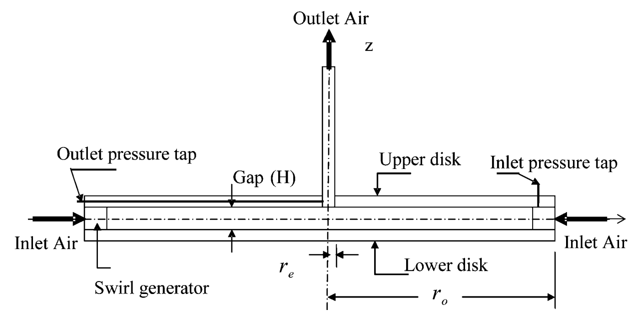

Fig. 1 Schematic of experimental setup.

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*Research Assistant, Department of Mechanical and Industrial Engineering, 1455 Demaisonneuve Boulevard West.

†Professor, Department of Mechanical and Industrial Engineering, 1455 Demaisonneuve Boulevard West. Senior Member AIAA.

‡Research Assistant, Department of Mechanical and Industrial Engineering, 1455 Demaisonneuve Boulevard West.

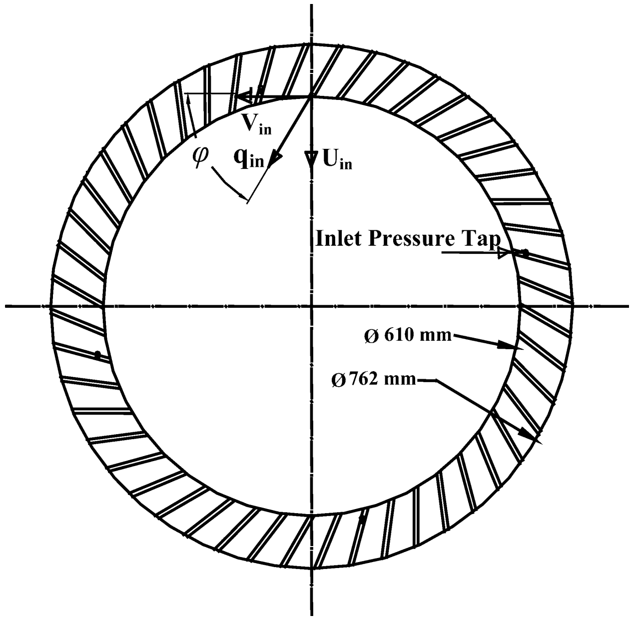

Fig. 2 Swirl generator.

functional relations among the main dimensionless parameters,

$$C_p = f_1[R_E, (H/D_0), (D_e/D_0), (A_{in}/A_0), \varphi] \tag{2}$$

where

$$C_p = 2\Delta P \Big/ \rho q_{in}^2, \qquad R_E = \rho q_{in} D_0/\mu \tag{3}$$

The flow rate Q, inlet radial U_{in} and tangential V_{in} velocities are given by

$$Q = q_{in}A_{in}, \qquad U_{in} = q_{in}\sin(\varphi), \qquad V_{in} = q_{in}\cos(\varphi) \tag{4}$$

If the inlet swirl ratio S is defined as

$$S = V_{in}/U_{in} = \cot(\varphi) \tag{5}$$

and the Reynolds number Re as

$$Re = R_E(H/D_0)\sin(\varphi) = HU_{in}/\nu$$
$$(D_e/D_0) = (D_e/H)(H/D_0) \tag{6}$$

then at specified aspect ratio D_0/H and area ratio A_{in}/A_0 the dimensionless pressure drop C_p is a function of three dimensionless groups:

$$C_p = g[Re, (H/D_e), S] \tag{7}$$

All of the experimental observations were treated using the preceding functional relationship that was suggested by dimensional analysis considerations. The results are shown in Fig. 3. Note that, given the swirl inlet angle, the corresponding test data collapse into a single curve. Furthermore, the individual effects of Re and H/D_e can be combined into just one variable, ReH/D_e. As expected, the dimensionless pressure drop depends strongly on the inlet angle. The latter confirms the original hypothesis. In addition, the generalized relationship among the most important geometrical and fluid properties is made available through a chart.

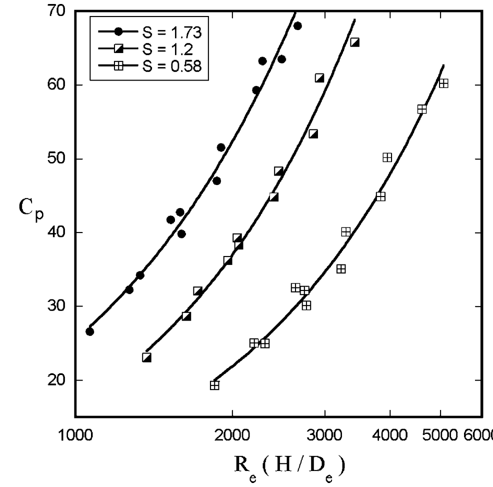

Fig. 3 Nondimensional pressure drop vs the dimensional groups.

IV. Conclusions

We presented results from the application of a dimensional analysis to predict the functional relations among the main dimensionless parameters. The dimensionless pressure drop C_p is a function of the Reynolds number, aspect ratio, and inlet swirl ratio. It is evident that, given the inlet swirl ratio, the corresponding test data collapse into a single curve.

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