AE 204 FLUID MECHANICS

VORTEX EXPERIMENT / EXP3

2024

OBJECTIVE

A vortex can be seen in the spiraling motion of air or liquid around a center of rotation. Circular current of water of conflicting tides form vortex shapes. In this experiment, through the generating of free and forced vortex, we can compare the properties of vortices.

THEORY

Forced vortex

In a forced vortex the fluid essentially rotates as a solid body. The motion can be realized by placing a dish of fluid on a turntable rotating.

Navier-Stokes Equation (r-component) $\frac{v_0^2}{r} = \frac{1}{\rho}\frac{\partial\rho}{r}$

Solid boundary rotation $v_0 = \omega r \Rightarrow \rho\omega^2 r = \frac{\partial\rho}{\partial r}$ ω: angular velocity

Navier-Stokes Equation (z-component) $0 = -g - \frac{1}{\rho}\frac{\partial\rho}{\partial z} = -g - \frac{1}{\rho}\frac{\partial\rho}{\partial h}$

Hydrostatic condition $\frac{\partial\rho}{\partial h} = -\rho g = -\gamma$

Substitute into the differential

$$dp = \frac{\partial\rho}{\partial r}dr + \frac{\partial\rho}{\partial h}dh = \rho\omega^2 r dr - \gamma dh$$

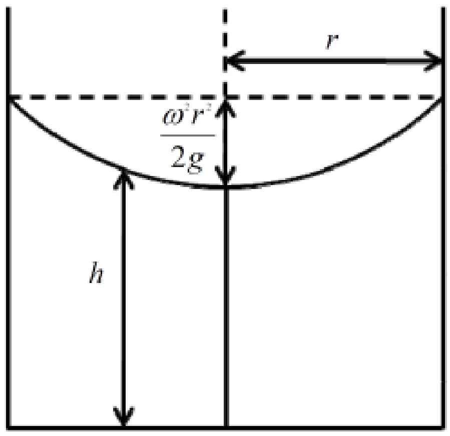
Integrate to obtain

$$\rho = \rho\frac{\omega^2 r^2}{2} - \gamma h + C$$

Boundary conditions $r = 0$, $h = h_0$, $p = p_0$

Result $$p - p_0 = -\gamma(h - h_0) + \rho\frac{\omega^2 r^2}{2}$$

Free surface location, $p = p_0$ $\Rightarrow$ $$h = h_0 + \frac{\omega^2 r^2}{2g}$$



Free vortex motion

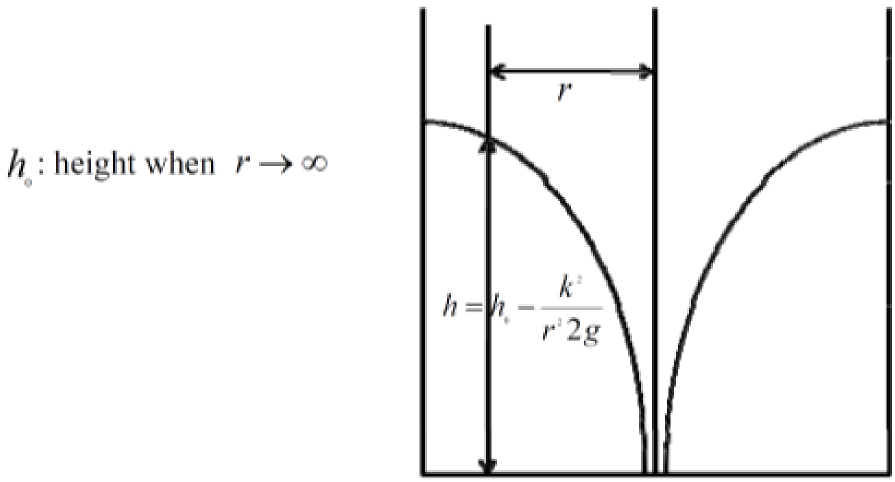
If the motion of the particles is purely translational, the flow is irrotational and the vorticity is presented as $$\frac{\partial v_y}{\partial x}\frac{\partial v_x}{\partial y} = \text{constant}$$

Each particle moves in a circular path with speed varying inversely as the distance from the center. The tangential velocity is given by $$q = \frac{k}{r}$$

In the steady state flow condition, Bernoulli's equation is applied
$$\frac{p}{\rho g} + \frac{q^2}{2g} + z = \text{constant}$$

Free surface condition, $p = 0$, $h = h_0 - \frac{k^2}{r^2 2g}$, $k = qr = v_\theta r$

Flow velocity (tangential) $q = \sqrt{2gH}$ H : Hydraulic head



DESCRIPTION OF APPARATUS

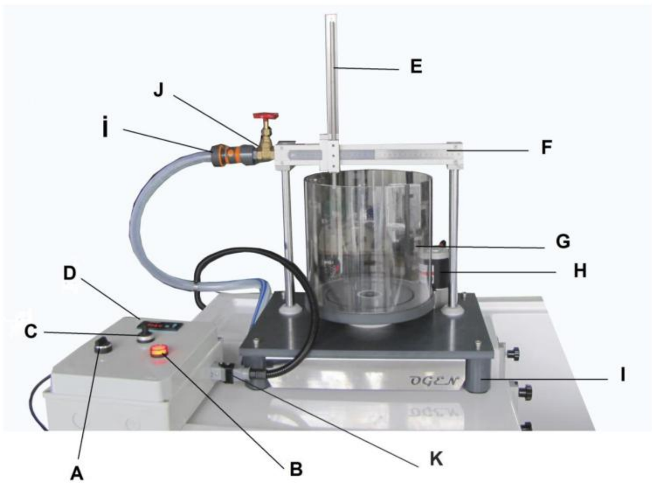


Figure 1. Experimental Apparatus

Experimental apparatus consists of;

In control module;

A: On/off switch,

B: Energy control lamb,

C: Engine speed (rev/s) switch,

D: Engine speed (rev/s),

K: Energy connector.

Measurement module;

E: Vernier caliper scale for depth measurement,

F: Vernier caliper scale for diameter measurement,

G: Transparent water reservoir,

H: Engine that rotates the transparent water reservoir,

I: Module legs,

İ: Water filling joint coupling,

J: Vane for the flow rate adjustment.

PROCEDURE

1. Insert the vortex test module carefully onto the channel in the Hydrology Main Unit.
2. Fit the power connector (K) by placing the control panel in a suitable place.

PART 1: FREE VORTEX EXPERIMENT

3. If you are going to perform a **free** vortex experiment, install the appropriate discharge nozzle and let the tapping sit in its seat.
4. The discharge vents that can be used for free vortex are shown as follows.

Figure 2. Discharge vents

5. Fill the device with water to the appropriate level by connecting the water to the device (I).
6. Pull out the plug to create a free vortex. Water will drain from the channel into the main unit's tank.
7. Make your measurements and save them in the data sheet table.

PART 2: FORCED VORTEX EXPERIMENT

8. If you are going to perform a **forced** vortex experiment, insert the drain plug attachment into the housing. After filling the water up to the desired level (I) plug in the device.
9. Switch on the main switch (A).
10. Set the appropriate speed from the engine speed switch.
11. You can check the engine speed from the display (D).
12. During the experiment, make measurements using the vernier ruler (E, F).
13. Make your measurements and save them in the data sheet table.
14. After the test, stop the engine (C) and switch off the power switch (A).

REFERENCES

1. http://ocw.snu.ac.kr/sites/default/files/NOTE/11258.pdf , Access date: Mar 5th, 2024.
2. Munson, B.R. et al., Fundamentals of Fluid Mechanics, 7th Ed., (2013).

VORTEX EXPERIMENT / LAB 3 DATA SHEET DATE:

STUDENT NAME, SURNAME:

SIGNATURE:

Forced Vortex

Radius (m)	Rotation Speed (rpm)	h_0 (m) (Minimum height)	Measured height, h (m)	Calculated height, h (m)

Free Vortex
Circle in Discharge Vent: 1 (large) 2 (moderate) 3 (small)

Rotation Speed (rpm)	Radius (m)	h_0 (m) (Maximum height)	Measured height, h (m)	Calculated height, h (m)	Flow velocity, q (m/s)

Calculation steps:

1. Fill in the tables above (BE CAREFUL ABOUT THE UNITS!)
2. Calculate height, h, using equations given in experiment sheet for both free and forced vortices.
3. Calculate flow velocity, q, using equations given in experiment sheet for free vortex.
4. Plot the water surface profile (h vs. r) for the free vortex.
5. Discuss the reason of difference between calculated results with measured data.

LAB RULES:
•Each group should submit one report.
•Each group should write each part by their own and get together with their group members to merge all of them.
•Reports are due to next Monday. They must be submitted to the corresponding assistant **till 17:00** on the next Monday.
•Students must sign the data sheet from the lab assistant at the end of each experiment and the signed sheet must be attached with the report. Reports without the signed data sheet will not be graded.
•Students are advised to read the detail of each experiment sheet before coming to the corresponding lab class.

LAB REPORT FORMAT (HANDWRITTEN EXCEPT COVER PAGE, TABLES AND PLOTS):
The lab report (no longer than 15 pages – all included –) should include the followings (unless otherwise specified):

1. Objective
2. Theory
3. Procedure
4. Results
5. Sample calculation
6. Necessary plots
7. Discussion on results, errors and graphs
8. Conclusion