ISSN 2229-5518

Vortex Flow Analysis Due to Jet Impingement and its Effect on Air Entrainment

Swarnim Srivastava - Birla Institute of Technology, Mesra (Student)
Kshitij Vijay - Birla Institute of Technology, Mesra (Student)
Ambar Srivastava - Birla Institute of Technology, Mesra (Student)

ABSTRACT- The aim of the paper is to determine the various factors effecting the angular velocity of vortex flow i.e. angle with the surface of water, velocity of jet, cross section area of nozzle and distance from center. These relations will further be used in enhancing the air entrainment in liquid and hence has the potential of being implemented in various industries, primary chemical and pharmaceutical industries. This project will include experimental data and determination of various relation derived from those data.

INDEX TERMS - Biphasic zone, Coalescence, Entrainment, Energy Audit, Jet Impingement, Residence Time, Vortex Flow

1) INTRODUCTION

IJSER

Vortex flow : It is the flow of fluid along a curved path or a flow of rotating mass of fluid.
Variation of pressure with radius and height: $dP = (\rho v^2/r)dr - \rho g dz$
Where ρ = density
v = linear velocity at radius r
r = radius
g = acceleration due to gravity

Vortex flow is of two types:

1) **Forced vortex flow** : Forced vortex flow is defined as the type of flow in which some external torque is required to rotate the fluid mass. The fluid mass in this type of flow rotates at constant angular velocity.
$\dot{\omega} = v/r = \text{constant}$

2) **Free vortex flow** : When no external force is required to rotate the fluid mass, then that type of flow is called free vortex flow. E.g flow of fluid through a small circular opening at the base of container.

2) VORTEX FLOW DUE TO JET IMPINGEMENT

A Forced vortex flow can be created by impinging a jet of liguid on water in cylindrical container.

External torque applied by the jet

Variables : ρ = density of liquid
A = area of jet
v = velocity of jet (initial)

Final velocity of jet will be zero. If Θ is the inclination of jet from the surface of water then,
According to impulse momentum theory , force of jet along the surface is :

ρ A v (v-0) cosΘ = ρ A v^2cosΘ

Torque = ρ A v^2 cosΘ X r

Variation in Angular velocity ($\dot{\omega}$) depend on various operating condition of jet. The angular velocity of vortex flow increases with increase in applied torque by the impingment of jet .For a particular container of fixed dimension the angular velocity depends on following factors.

2.1 Radius of Jet impingement – Increase in radius keeping all other Parameter constant increases the applied torque.

$\dot{\omega} \propto (\tau = \rho A v^2 \cos\Theta\ r)$

$\dot{\omega} \propto r$ --------------(i)

2.2 Inclination from surface of water : Increase in inclination means decrease in angle (Θ)

$\tau = \rho A v^2 r \cos\Theta$

$\dot{\omega} \propto \tau\ \alpha \cos\Theta$

$\dot{\omega} \propto \cos\Theta$ ---------(ii)

2.3 Discharge: When discharge increases by keeping velocity constant , the torque increases and therefore the angylar velocity .

$\tau = \rho Q V \cos\Theta$

$\dot{\omega} \propto \tau\ \alpha\ Q$

$\dot{\omega} \propto Q$ -------------(iii)

2.4 Velocity : Keeping discharge and other parameter constant , τ increases by increase with increase in velocity and thererforethe angular velocity.

$\dot{\omega} \propto (\tau = \rho A V r \cos\Theta)$

$\dot{\omega} \propto v$ --------------(iv)

2.5 Density of jet : $\tau \propto \dot{\omega}\ \alpha\ \rho$-----(v)

Combining equation (i) , (ii), (iii), (iv) and (v)

$\dot{\omega} = k_1 \rho Q v r \cos\Theta$

where k_1 is constant depending upon dimension and the type of fluid.
As the liqud jet is in equilibrium $\dot{\omega}$ remains constant, the applied torque must be equal to resistive torque generated by water.
As the liquid is viscous, each layer of fluid resists to transfer the movement from its upper layer.

Resistive torque $\propto \dot{\omega} \times \rho \times h \times d$
Resistive torque = Applied torque

$K_1 \times \dot{\omega} \times \rho \times h \times d = \rho A v^2 \cos\Theta$
$= Q v r \cos\Theta$ (since A x v = Q)

$\dot{\omega} = (k_1 / h d) Q v r \cos\Theta$

$\boldsymbol{\dot{\omega} = K Q v r \cos\Theta}$

K is constant depending on dimension of container but not on the type of fluid

IJSER

$K \propto \rho^0$
$K \propto h^{-1}$

3) EXPERIMENTAL VALIDATION OF ABOVE POSTULATES

Experimental setup – A cylindrical container without its base and top is immersed in a big rectangular jar full of water. Now jet is impinged in this container in various conditions. Through rigorous experiment and fitting suitable curve based on experimental data, the following relations is concluded.

$\dot{\omega} = k\ r\ Q\ v \cos\Theta$

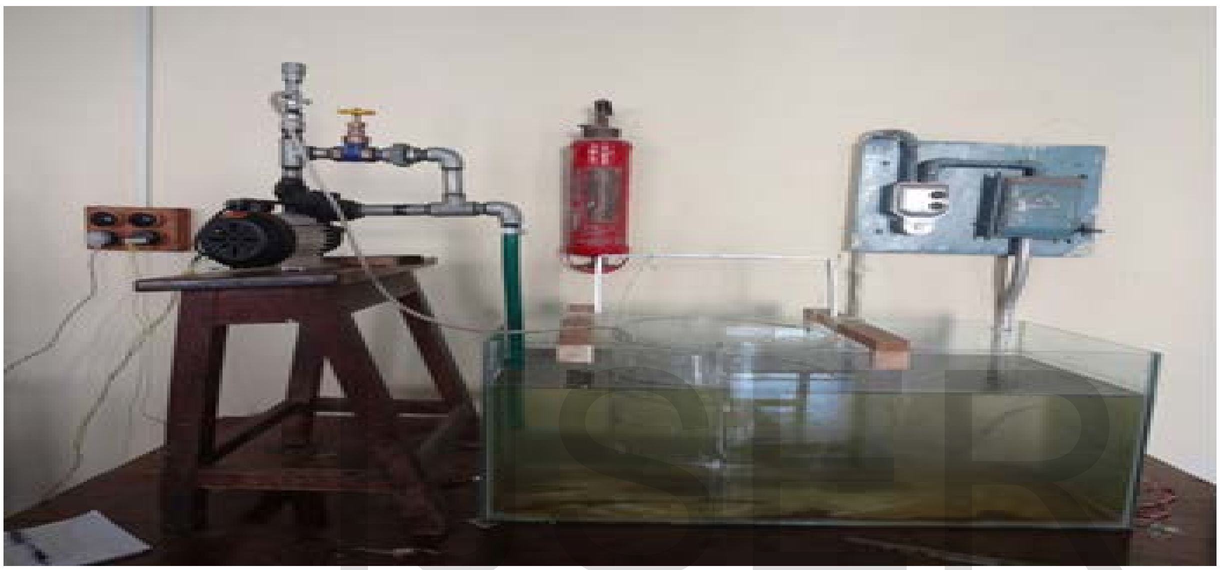

Fig 1: Experimental Setup

4) ENERGY AUDIT

Output power (Rotational kinetic energy of water per unit time) = $\tau \times \dot{\omega}$

$$= (\rho A v^2) \times (r \cos\Theta\ \dot{\omega})$$

Input power (Kinetic energy of jet per unit time) = $\frac{1}{2} \rho A v^3$
Effiency of conversion = (output power) / (input power)

$$= (\rho A v^2 r \cos\Theta\ \dot{\omega}) / (\tfrac{1}{2} \rho A v^3)$$

$$\eta = (2 r \dot{\omega} \cos\Theta) / (v)$$

5) APPLICATION OF VORTEX FLOW

5.1 Enhancement of air entrainment

The air bubble created through liquid jet impingement on surface of liquid goes inside due to initial momentum of the jet and comes out due to the buoyancy force exerted by the liquid. The bubbles creates a cone in its journey.

d = depth of penetration
w= width of penetration

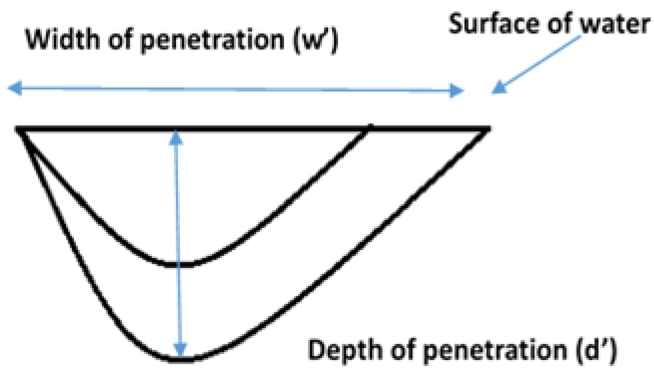

Fig 2: Trajectory of Air Bubbles

The entrainment of air bubble will depend on:

5.1.1 **Projected area of jet on the surface**: More projected area means more volume of air bubble entering the liquid and thus more will be entrainment. The projected area will be a ellipse with semi-minor axis as radius of jet and semi-major axis will be function of inclination angle of jet.

r = radius of inclination of jet
ϴ = inclination of jet from surface.

IJSER

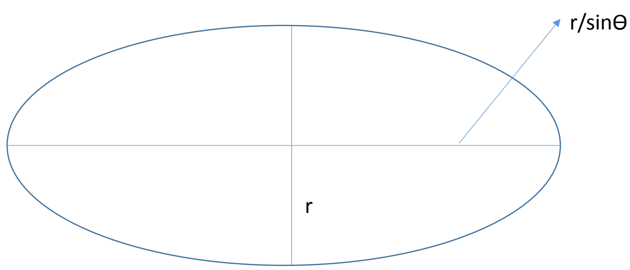

Fig3: Relation of radius with angle of Inclination

$$\text{Area} = \pi \times r \times (r/\sin\theta) = (\pi r^2/\sin\theta)$$

5.1.2 **Residence time:** It is the time for which the air bubble stays inside the liquid .

The residence time will depend on :

- **Vertical component of velocity** - From the concepts of projectile motion , the residence time will be more when vertical component of velocity is more.

ISSN 2229-5518

$$Time = 2\, u \sin\Theta / g$$

Θ = inclination of jet

- **Coalescence** - Due to coalscence th eair bubble merge together and hence a greater buoyancy force is exerted on them. Colescence of bubble will decrease the residence time abrubtly.

Therefore the main challenge in the entrainment is to reduce the coalescence by dispersion of bubble.

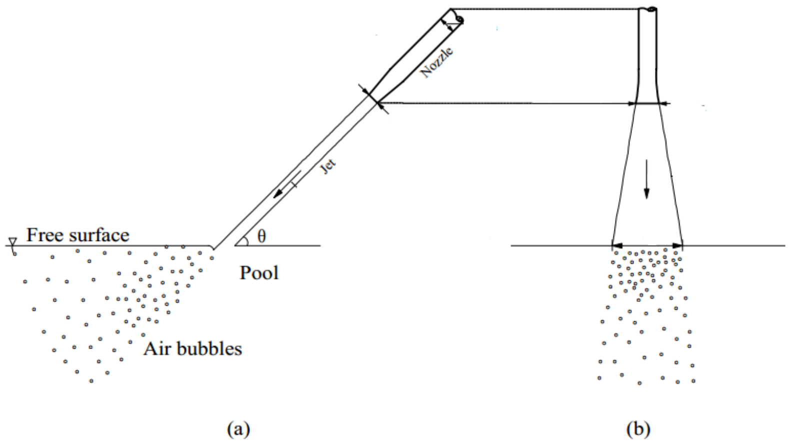

Fig 4: Difference in coalscence of air bubbles with angle of inclination

Effect of vortex flow on coalescence

IJSER

Due to vortex flow created through jet, the depth of penetration remains the same while the width of penetration increases due to streching of biphasic zone in horizontal direction by the vortex.

Thus the same bubbles creates cone with larger volume than without vortex. This causes the dispersion of bubble. Thus the chance of coalescence decreases significantly through dispersion created by vortex flow.

The dispersion of bubble wil be more if the angular velocity of vortex flow is more.

$d' = d$

$w' > w$

5.2 Washing machine

In washing machine vortex flow is created by the electrical energy. In places where head of water is available , vortex flow can be created by th jet og high velocity. Thus electrical energy can be replaced by the potential energy of water.

6) CONCLUSION

There are certain situations, where there is necessity of vortex flow. Conventionally, this vortex is created by electrical or mechanical energy. This project can be utilized to create vortex with available head of water without using conventional source of energy. This project does not claim to achieve higher efficiency but uses primary source of energy (water head).

ISSN 2229-5518

The main obstruction in air entrainment is coalescence of bubbles which has to be reduced as far as possible ,therefore to reduce the coalescence the air bubbles need to be dispersed. This can be done by strectching of biphasic cone.

With the help of forced vortex flow which we have created without any additional source of energy, the width of penetration increases while the depth of penetration remains the same. This causes the biphasic cone to be stretched in horizontal direction. Thus the air bubbles get dispersed resulting in less buoyancy force ,thus more residence time, moreover because of dispersion the entrainment becomes more homogenous.

7) ACKNOWLEDGMENT

We are grateful to our Fluid Mechanics teacher Dr. A. K. Roy for helping us on the theoritical concepts of our project.

IJSER