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Experimental Study of Discharge Variability on Impact Coefficient of Jet for Sustainable Development

Surendra H J [a] and Vinod B R [b]
[a] *Department of Civil Engineering, ATRIA Institute of Technology, Bangalore, Karnataka, India*
[b] *Department of Civil Engineering, BMS Institute of technology, Bangalore, Karnataka, India*

Abstract. Fluid flow emerges with high velocity referred as liquid jet. Water Jet having its applications in many fields includes agriculture and power generation and it has been widely utilized. Impact value of the jet is highly important, to generate maximum efficiency in operation. Many factors influence the impact value of jet and it depends on type of vane used such as: Flat, hemispherical, curved etc. The aim of this work is to investigate the impact coefficient of jet for various discharges by comparing theoretical forces as well as forces developed through experiments for different target vanes. A systematic estimation of theoretical forces, experimental forces and its error was done in this experiment. For this purpose, weigh balance, target plates, vanes, recirculation pipes and Rotameter were used. Result of this study indicate: discharge variability influences the impact value and for a particular discharge obtained values are within the limit.

Keywords. Discharge variability, Impact value, jet, vanes, impact coefficient

1. Introduction

Water emerges with high velocity due to decrease in the area referred as jet. These jet strikes the obstructions placed in the direction of flow. The obstructions may be in the form of vanes. Vanes are of different types: flat, Inclined and Hemispherical. Jet of water exert a force on vane known as Impact of Jet. This works on the principle of Impulse momentum equation. Here fluid is allowed to flow under pressure to strike the vane. Water impact on vane exerts a torque and enable to generate the power. Force exerted on the vane is equal to rate of momentum of fluid flow. Here force can be found for two conditions such as fixed and moving. In the case of fixed condition, liquid leaves the jet perpendicular to direction of the flow. In case of moving condition, vane moves in the direction of flow. In this case vane velocity is also considered along with jet velocity. In every case, impact coefficient of the jet will be calculated. To find the impact coefficient, both actual force and theoretical force are required. Actual force depends on vane angle, discharge and empirical force is depend on equation. To find the impact coefficient, critical investigation is necessary. These applications are widely used in power generation. Most of the researchers worked on impact of jet experiments and few of the previous study were highlighted here. [1] investigated the performance of the water rotor used in the pipeline to get the benefit of the fluid flowing in pipeline.

[2] carried out the study to reduce the jet noise for subsonic aircraft by achieving enhanced mixing rate. [3] conducted the experiment to compare the theoretical and actual forces exerted on various target vanes. [4] discussed the water wheel as a system for renewable energy. [5] designed breasts hot water wheel as efficient and ecological hydraulic converter. [6] developed a vertical axis-water turbine to generate the hydropower to harness inside the pipeline. [7] reveals the important design parameter of overshot and undershot water wheel. [8] explained the design and analysis procedure of jet impact on vanes. Here mainly focused on actual force, theoretical force and Error developed. [9] suggested the alternative source based economical and eco-friendly aspect of green energy for fluid flowing. [10] proposed a new technique for micro-power generation with the flow of super critical category in canals. In this work, impact coefficient is found for various discharges. For each discharge, actual force and theoretical force will be found out. The experiment will be conducted in laboratory using Rotameter and Jet apparatus. Trial will be done based on progressive discharge increase. From the experiment, value of impact coefficient for an optimum discharge will be found. Whole experiment will be applicable to stationary condition and in vertical direction.

2. Working Principle

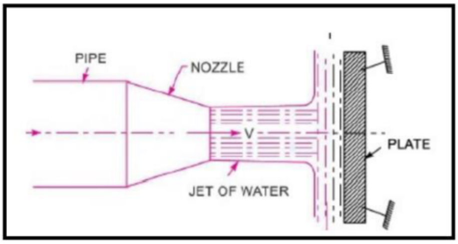

Figure 1. Jet of water striking the flat vertical stationary plate.

Figure 1, shows the working principle of jet of water striking the flat vertical stationary plate. Experiment is conducted based on the principal of Impulse momentum Equation. Fluid in motion exert a force on vane and its motion is analyzed using a control volume. Force strive by the fluid on the plate is calculated by considering the control volume in mass in-flow and mass out-flow condition. These flow rate can be determined by impulse momentum equation or from Newton's second law of motion. Forced exerted by the jet of water on vane is obtained, by considering initial velocity minus final velocity.

2.1. Equation Used

Forces in X-Direction = Rate of change of momentum

F_x=mass flow rate (velocity before striking – velocity after striking)

F_x= (velocity before striking – velocity after striking)

$F_x = \rho av(v-0)$

$F_x = \rho av^2$

For, flat plate= $F_{th} = \rho av^2 /g$

For, Hemispherical vaneF_{th} = $2\rho av^2/g$
For, Inclinedplate= $F_{th} = (\rho av^2/g) \times \sin 2\theta$
Here, Acceleration due to gravity(g) = 9.81m/sec^2
a = Jet area in m^2
ρ =Water density = 1000 Kg/m^3
V = Jet Velocity in m/sec=Q/A
F_{th} = theoretical force (parallel to the direction of jet)
F_{act} = Actual force (parallel to the direction of jet)

2.2. Description

Figure 2. Equipment used in the study.

Figure 2, show the experimental set up used in the study. Experiment setup consist of sump tank, pump arrangement, Nozzle arrangement and Vane chamber. Whole experiment will be conducted in closed chamber with system of re-circulation. Water will be supplied to the nozzle in vertical direction drawn from sump and followed to pump. Valve help to supply the water in to the nozzle in a controlled manner. From the nozzle, water will be emerging as jet. This jet strikes the vanes and corresponding force will be captured through digital indicator. Rotameter is used to measure the discharge and it is sensitive instrument. When jet strikes the vanes, actual force will be obtained through direct reading and theoretical force is obtained through formula. Weigh balance arrangement is made to counteract the force. The experiment setup is equipped to use different nozzle size and also with different shapes of vanes.

2.3. Specifications

Vane type and its shapes: In this experiment, Flat vanes are adopted with fixed condition.

Jets diameter: In this study 8mm diameter is used. However, other performance can also be conducted using 6mm and 10mm diameter.

Measurements: In this case, quantity of water collected in a particular time interval were considered and measured through Rotameter.

Type of Pump: Phase of the pump is single with 1 HP and starter is 230volt.

Type of Jet: chamber of jet is made up of stainless steel with circular arrangement.

Chamber of Jet: Fastened with toughened glass windows with arrangement of rubber gaskets (leak proof).

Figure 3. Jet striking vane.

Figure 4. Weigh balance arrangement.

Figure 3, shows the jet of water striking the flat vane for initial discharge (low discharge: trial 1). Vane is in fixed position and quantity of water striking the vane can be observed through glass chamber. Glass chamber is provided to avoid the splashing of water. Figure 4, shows the weigh balance arrangement. As jet of water strikes the flat vanes, it is counteracted by the weigh balance arrangement. This help to capture the capture force from the digital indicator. The force obtained is referred as actual force.

Figure 5. Jet and Vane arrangement.

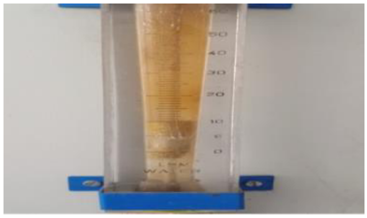

Figure 6. Rotameter used.

Figure 5, shows the nozzle and target plate arrangement. Plate is flat and placed in the direction of flow and it is fixed in motion. When the jet of water strikes the vane, it deflects through an angle perpendicular to the direction of flow. Hence final velocity is equal to zero. Figure 6, shows the arrangement of Rotameter to supply the discharge. Rotameter is device adopted to measure the flow rate and for each incremental discharge, we can measure the rate of momentum. It is sensitive in operation, hence with at most care need to be handled.

Figure 7. Jet striking vane for full discharge.

Figure 8. Actual force after striking the vane.

Figure 7, shows the jet of water striking the vane for full discharge. For full discharge, the impact force is high with more losses. Glass door has to be closed and sufficient precaution has to be ensured before initializing the full discharge. Figure 8, shows digital indicator which shows the actual value of force, when jet of water strikes the vanes. For each discharge, value of actual force can be obtained directly from the indicator.

2.4. Operational Procedure

1. Jet of known diameter is fixed initially and the vane of flat shape in position is placed.

2. Delivery valve will be closed and pump will be switch on position.

3. Experiment will be conducted in a closed Glass chamber having front transparent cover and has to be closed tightly.

4. Delivery valve will be in ON condition and corresponding flow rate will be adjusted through Rotameter.

5. Results were tabulated includes: diameter of the jet, area of jet, flow rate and forces obtained.

6. Different trials will be done for different flow rate.

3. Result Analysis

Table 1. Impact coefficient values for different discharges.

Trail no	Vane type	Actual Force (F_{act})in N	Actual discharge m^3/sec (Q_{act}) (1Cumecs =60,000 LPM)	Velocity of jet m/sec (V_{act})	Force in theoretical (F_t)in N	Impact Coefficient (k)
1	Flat	1.56	4.5×10-4	8.95	4.02	0.38
2	Flat	2.64	4.835×10-4	9.61	4.64	0.57
3	Flat	0.68	5×10-4	9.96	4.88	0.14
4	Flat	3.72	5.33 ×10-4	10.60	5.66	0.65
5	Flat	1.47	5.5×10-4	10.95	5.90	0.24
6	Flat	2.64	6×10-4	11.95	7.93	0.33
7	Flat	4.21	6.4×10-4	12.95	8.24	0.51

Result obtained for various discharges were presented in the table 1. Trail 1 was conducted for a discharge of 27 LPM (litres per minute). This will be the low discharge value assigned in the experiment. This will be converted to m^3 per sec and obtained discharge is designated as actual discharge. For this discharge actual force obtained is 1.56N. Velocity of fluid flow can be obtained by subtracting discharge with area of jet. For this trial, velocity is obtained as 8.95m/sec. theoretical force is obtained from empirical equation and found to be 4.02N. Value of the impact coefficient is 0.38. For trial 2, discharge of 29 LPM was used. For this discharge, actual force from the experiment was found to be 2.64N. Sine discharge is increased, velocity also increased to 9.61m/sec. theoretical force was found to be 4.64N. Impact value is increased to 0.57. For trail number 3, discharge was assigned to 30LPM. For this discharge, velocity was increased to 9.96m/sec and theoretical force was increased to 4.88N. Impact coefficient was found to be 0.14, which is very low compared to all trial. This is because the value of actual force is very low compared to theoretical force. For trial 4, discharge was assigned to 32 LPM. For this value, actual force obtained as 3.72N and theoretical value was found to be 5.66N. Velocity was found to be 10.60m/sec. impact coefficient is highest among all trials and found to be 0.65. For trial 5, discharge was assigned was 33LPM. For this value, actual force was found to be 1.47N and theoretical value was 5.90N. Velocity of the jet is 10.95 and obtained impact coefficient is 0.24. For trial 6, 36LPM discharge was supplied. For this discharge, actual force was obtained as 2.64N and theoretical was found to be 7.93N. Velocity of the jet was found to be 11.95m/sec and impact coefficient was found to be 0.33. For trial 7, rotameter discharge was found to be 38.5LPM. For this discharge, actual force was found to be 4.21N and theoretical force was found to be 8.24 N. Velocity of the jet was 12.95m/sec and obtained impact value is 0.51. Overall, we found that, velocity of jet is increased of each discharge along with theoretical force. But actual force was different for each trial, because of variation of jet of water with vane. Hence, value of impact coefficient was different for each discharge.

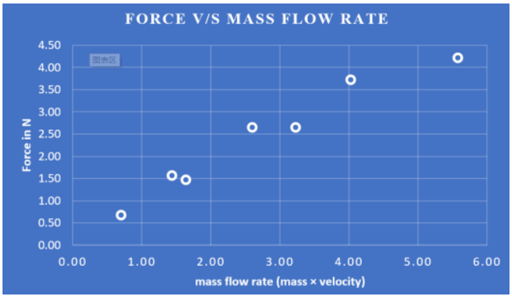

Figure 9. Slope of the line between mass flow rate and force.

Figure 9, shows the variation of force and mass flow rate referred as momentum. We observed that, force on vane is linearly related compared to mass flow rate. For trail 1, 2 and 3, obtained value are very close compared to trial 4, 5, 6 and 7. We calculated the forces for different discharges and rate of momentum through experiment. If the obtained experimental plotdoes not pass through origin, it will not affect he result. But theoretically it passes through origin.

SAMPLE CALCULATION (Trail number 1):

Jet diameter used=d=8mm

Corresponding jet Area=a= 50.26×10^{-6} m^2

Rotameter value of discharge= 27Lpm

Actual discharge $Q_{act} = 4.5\times10^{-4}$ m^3/sec

Velocity of water jet = $V_{act} = Q_{act}$/area of jet = 8.95m/s

Theoretical force = $F_t = \rho a v^2$ =4.028N

Actual force F_{act} =1.5696N

Co-efficient of impact = k = F_{act}/F_{th}=0.38

3.1. Discussion

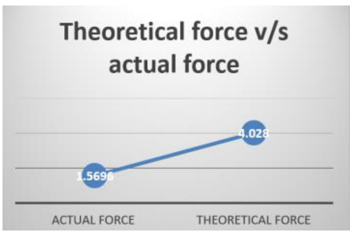

Figure 10. F_{th} and F_{act} for trail 1.

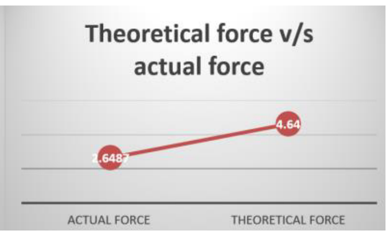

Figure 11. F_{th} and F_{act} for trail 2.

Figure 10, shows that values of actual force and theoretical force. Actual force was obtained from the experiment by balancing the weight and theoretical force was obtained from the empirical equation. For trail 1. Actual force was found to 1.56N and theoretical value was found to be 4.02N. Figure 11 shows the values of actual force and theoretical force for trial 2. Here the value of actual force was found to be 2.64N and theoretical force was found to eb 4.64N. Changes in the actual force is due to displacement of weight / counterforce during impact.

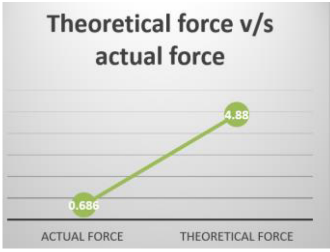

Figure 12. F_{th} and F_{act} for trail 3.

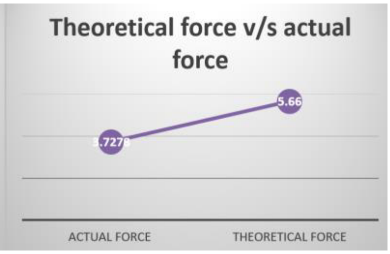

Figure 13. F_{th} and F_{act} for trail 4.

Figure 12, shows that values of actual force and theoretical force for trial 3.Actual force was found to 0.68N and theoretical value was found to be 4.88N. Figure 13 shows the values of actual force and theoretical force for trial 4. Here the value of actual force was found to be 3.77N and theoretical force was found to eb 5.66N. Changes in the actual force is due to displacement of weight / counterforce during impact. Here discharge was increased compared to previous trial resulting in increase of velocity, hence theoretical force was also increased. Theoretical force is linearly related to velocity, hence increase in velocity result in increase of theoretical force.

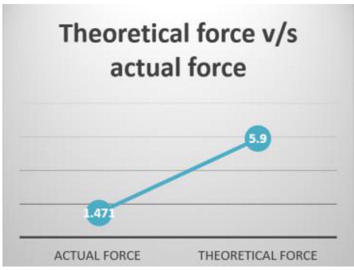

Figure 14. F_{th} and F_{act} for trail 5.

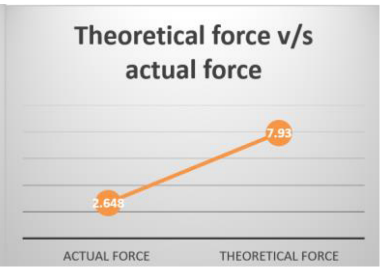

Figure 15. F_{th} and F_{act} for trail 6.

Figure 14, shows that values of actual force and theoretical force for trial 5.Actual force was found to 1.47N and theoretical value was found to be 5.9N. Figure 15 shows the values of actual force and theoretical force for trial 6. Here the value of actual force was found to be 2.64N and theoretical force was found to eb 7.93N.

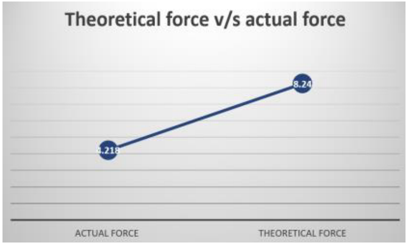

Figure 16. F_{th} and F_{act} for trail 7.

Figure 16, shows that values of actual force and theoretical force for trial 7. Actual force was found to 4.21N for a discharge of 38.5N and theoretical value was found to be 8.24N. For this higher discharge, value was found to be higher theoretically.

3.2. Error Analysis

Figure 17, shows the variation of actual discharge with respect to impact co-efficient. The value of actual force is depending on discharge. Total, seven trials were conducted, in each trial value of discharge is increased. Increase in the discharge value results in actual force. The actual force obtained is very less compared to theoretical force in each trial due to losses occurred during impact. Lower the value of k (impact coefficient) indicate the less losses occurred during impact. From the figure 17, it is observed the value of k for trial 3, was found to low compared to all. The discharge was 30LPM in Rotameter reading. Also, higher value of k, was found to be 0.65 for the discharge of 32LPM. Error occurred in each trial is due to displacement of weight during each impact.

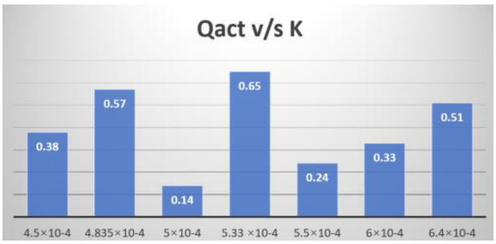

Figure 17. Variation of K with respect to actual discharge (Q_{act}).

4. Conclusions

In this work, an attempt has been made to find the influence of discharge parameter on impact coefficient. Experiment is conducted in laboratory using flat vane apparatus. Experimental set up consist of discharge measurement device with jet and plate arrangement. Total 7 trails were conducted for various discharges such as: 27LPM, 29LPM, 30LPM, 32LPM, 33LPM, 36LPM, 38.5LPM. In each trial, discharge was increased, result in the increase of velocity of the flow. It is observed that theoretical force is depend on empirical equation and actual force is depend on discharge. Obtained actual force is less in each trail compared to theoretical force due to displacement in weight balance as well as losses. It is found, force exerted and rate of momentum is positively related. Obtained actual force from the experiment are lesser compared to standard theoretical forces. For different discharges actual forces were determined and corresponding rate of momentum were found in the experiment. From the result, it is found that for the trial 30LPM, value of impact co-efficient is low and for the trial number 4, discharge value of 32LPM, Impact value. Optimum value of discharge was 30LPM with impact value of 0.14. Hence it is suggested that, optimum level supply of discharge will result lower loss of fluid and leads to sustainable development. Application of this study can be found in turbine and power generation.

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