STUDY OF IMPACT OF JET ON DIFFERENT VANES FOR MEASURING FLOW RATE AND IMPACT FORCE

A THESIS SUBMITED TO THE DEPARTMENT OF “MECHANICAL ENGINEERING”
IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF
BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

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STUDENT DECLARATION

This is to certify that the thesis entitled **"STUDY OF IMPACT OF JET ON DIFFERENT VANES FOR MEASURING FLOW RATE AND IMPACT FORCE"** is an outcome of the investigation carried out by the author under the supervision of **Dr. Md. Quamrul Islam,** Professor, Department of Mechanical Engineering, MIST. This thesis or any part of it has not been submitted to elsewhere for the award of any degree or diploma or other similar title or prize.

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SUPERVISOR'S DECLARATION

I hereby declare to the Department of Mechanical Engineering, Military Institute of Science & Technology (MIST), Dhaka, Bangladesh that the thesis "**STUDY OF IMPACT OF JET ON DIFFERENT VANES FOR MEASURING FLOW RATE AND IMPACT FORCE"** submitted by authors, have been accepted as satisfactory for partial fulfilment of the requirements for the degree of Bachelor of Science in Mechanical Engineering.

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ABSTRACT

The objectives of the thesis paper are to conduct an investigation into the reaction force generated by the impact of a jet of water onto various target vanes and to compare between experimental and theoretical forces which are exerted by the jet. The procedure for this experiment is to bring the weight cup in the initial position by applying weight when the flow rate is varied. The same experiment can be repeated by changing different target vanes. Moreover, the effect of different target vanes can be seen at constant flow rate by changing the type of target vanes and applying different amounts of weights to bring the weight cup in the initial position. The vanes used in this experiment can be categorized into four geometries. Flat, inclined, spherical and conical vanes are used for this experiment. Experimental and theoretical forces and the percentage of error can be calculated in this experiment. Here, the theoretical forces are depended upon weights applied on the weight cup and the experimental forces are depended on flow rate, nozzle exit velocity, impact velocity and shape of the vanes.

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CHAPTER 1

INTRODUCTION

1.1 Introduction:

Water turbines are widely utilized throughout the world for power generation. Here, fluid under pressure is allowed to strike the vanes of a turbine wheel. Mechanical work can be engendered from this. Rotational motion is then engendered by the force generated as the jet strikes the vanes. One of the most conventional types of water turbine is the pelton wheel. Here, water jets are tangentially directed on to buckets or vanes that can be fastened on the rim of the turbine disc. The impact of water on the vanes engenders a torque on the wheel causing it to rotate and to develop power. The output of a pelton wheel can be easily expressed and it is possible to determine its optimum rotational speed. Moreover, it is possible to understand how the deflection of the jet engenders a power on the vanes or buckets and how the force is related to the rate of momentum flow in the jet. The aim of this paper is to determine the impulse momentum theorem as it applies to the impact of a water jet on vanes with different geometrical shapes.

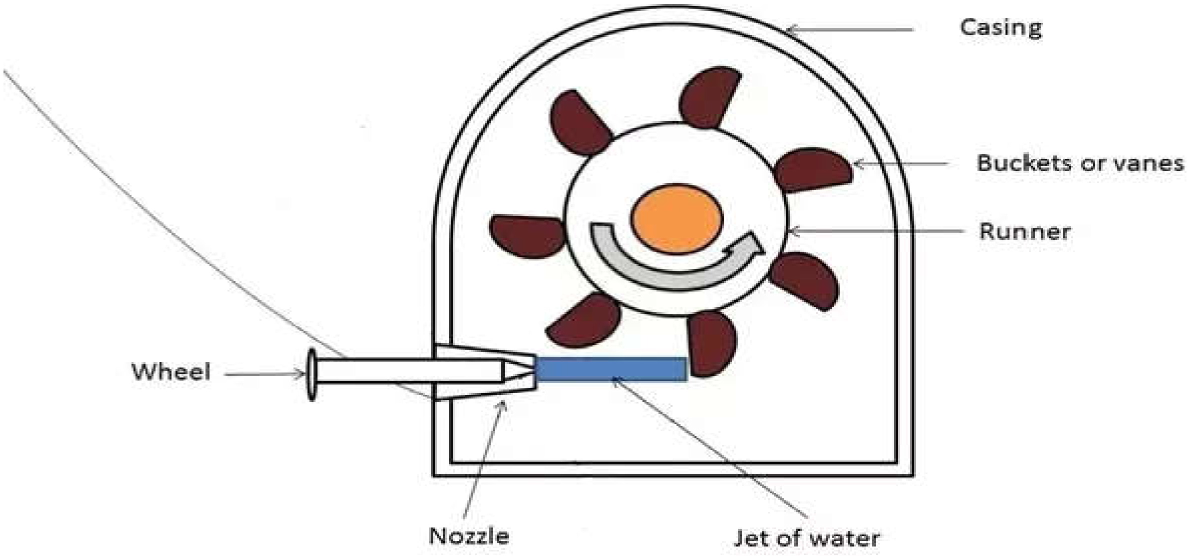

Figure 1.1: Pelton Wheel

1.2 General Analysis:

When a jet of water flowing with a steady velocity hits a solid surface, the water is deflected to flow along the surface [1]. Unlike the impact of solid bodies, there is no rebound and unless the flow is highly turbulent, there will be no splashing [1]. If friction is neglected by assuming an inviscid fluid and it is also assumed that there are no losses due to shocks then the magnitude of the water velocity is unchanged, the pressure exerted by the water on the solid surface will everywhere be at right angles to the surface [1]. Newton's second law of motion states that a mass that is accelerated required a force that is equal to the product of the mass and acceleration [1]. The analogy to Newton's second law in fluid mechanics is known as the momentum equation [1].

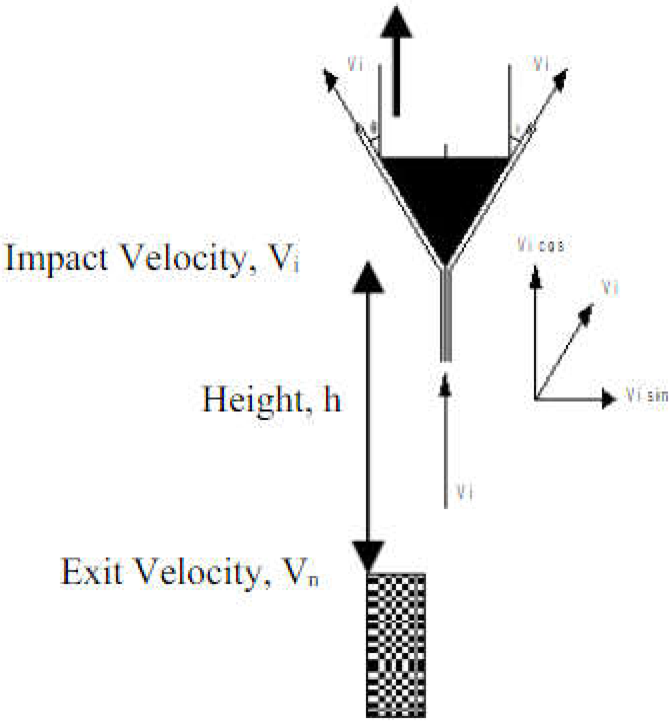

Figure 1.2: Impact of a Jet

Consider a jet of water which impacts on to a target surface causing the direction of the jet to be changed through and angle θ as shown in Figure 1.2 above [1]. In the absence of friction, the magnitude of the velocity across the surface is equal to the incident velocity V_i [1]. The impulse force exerted on the target will be equal and opposite to the force which acts on the water to impart the change in direction [1].

Applying Newton's Second law of motion in the direction of the incident jet,

$$\begin{aligned}
\text{Force} &= \text{Mass} \times \text{Acceleration} \\
&= \text{Mass Flow Rate} \times \text{Change in velocity} \\
-F_x &= M\Delta V \\
-F_x &= \left(MV_{x,out} - MV_{x,in}\right) \\
-F_x &= M(V_i\cos\theta - V_i) \\
F_x &= MV_i(1 - \cos\theta) \\
\text{But } M &= \rho Q \\
\text{So, } F_x &= \rho Q V_i(1 - \cos\theta) \\
\frac{F_x}{\rho Q V_i} &= 1 - \cos\theta
\end{aligned}$$

1.3 Application to Impact of Jet Apparatus:

There are various applications of impact of jet apparatus, which are discussed below:

In each case it is assumed that there is no splashing or rebound of the water from the surface so that the exit angle is parallel to the exit angle of the target [1].

1.3.1 Effect of Height:

The jet velocity can be directly calculated from the measured flow rate and the nozzle exit area.

$$V_n = \frac{Q}{A}$$

However, as the nozzle is below the target, the impact velocity will be less than the nozzle velocity due to interchanges between potential energy and kinetic energy [1].

Applying the Bernoulli equation between nozzle and plate:

$$\left(\frac{P_n}{\gamma}\right) + \left(\frac{V_n^2}{2g}\right) + (Z_n) = \left(\frac{P_i}{\gamma}\right) + \left(\frac{V_i^2}{2g}\right) + (Z_i)$$

Since the jet is open to the atmosphere,

$$\left(\frac{P_n}{\gamma}\right) - \left(\frac{P_i}{\gamma}\right) = 0$$

And,

$$(Z_n) - (Z_i) = h$$

So,

$$(V_i^2) = (V_n^2) - 2gh$$

Where, h is the height of target above the nozzle exit.

1.3.2 Impact on Normal Plane Target:

For the normal plane target θ is 90º. Therefore, cosθ = 0

$$\frac{F_x}{\rho Q V_i} = 1 - \cos\theta = 1$$

1.3.3 Impact on Conical and Inclined Plate Target:

The cone target angle θ is 80º. Therefore, cosθ = 0.766

$$\frac{F_x}{\rho Q V_i} = 1 - \cos\theta = 0.234$$

For 60º inclined plate,

$$\frac{F_x}{\rho Q V_i} = 1 - \cos\theta = 0.13397$$

1.3.4 Impact on Semi-Spherical Target:

The target exit angle is 180º. Therefore cosθ = - 1

$$\frac{F_x}{\rho Q V_i} = 1 - \cos\theta = 2$$

By using the above equation, it is possible to compare experimental and theoretical force value of target with different angle.

Theoretically,

$$F = ma$$

Experimentally,

$$F = \rho Q V_i \times (1 - \cos\theta)$$

CHAPTER 2

LITERATURE REVIEW

2.1 Previous Study:

There have been several studies on impact of jet. The previous studies related to the impact of jet are shown below:

A report made for Swinburne University which was uploaded by Roshane Nanayakkara [1] used impact of jet apparatus with hydraulic bench. The apparatus was located on top of the hydraulic bench. The higher water jet velocity produced a higher force exerted onto the target vane. When the graphs of theoretical force vs experimental force were plotted, all the vanes except the hemispherical one gave a gradient very close to 1. The hemispherical one gave a gradient of 1.92. Most of the experimental errors were below 25%. It was also observed that the experimental force was at all instances higher than the theoretically required force. The experimental results and the theoretically calculated values were similar within experimental error and proved the law of conservation of momentum.

Qusai Waleed Al-Qudah [2] investigated the impact of jet by using flat plate and hemispherical cup. The objective of the investigation was to experimentally determine the force required to keep a flat plate at a datum level while it is subjected to the impact of jet and to compare the experimentally measured force with the analytically calculated force from the control volume form of the linear momentum equation. According to the investigation, when the volumetric flow rate was increased, the force resulted from the impact of the jet on both the flat plate and the hemispherical cup was increased. Some measured value of the jet force showed larger values than the predicted one due to errors in taking the reading and losses in the experiment apparatus. These losses were used in calculating the experiment efficiency which showed values of 0.8 for the flat plate and 0.83 for the hemispherical cup.

Stephen Mirdo [3] experimentally investigated the impact of jet. The objective of the investigation was to determine the force exerted by a jet of water on a stationary vane and compare the experimental results to the theoretical results. By controlling the velocity vector of the fluid jet, the Pelton bucket was able to extract more energy from the moving fluid by changing its linear momentum. The theoretical and experimental forces had a significant percentage of error. Most of this error was due to the theoretical calculations neglecting the force of gravity on the jet of water. However, after the fluid obtained any height above the nozzle, the force of gravity acted on it and decreased the velocity. The reduction in velocity was determined by using Bernoulli’s equation.

Ravi Agarwal [4] investigated the impact of jet by using flat plate and hemispherical vane. The aim of the investigation was to determine the impulse momentum theorem as it applied to the impact of a water jet on vanes with different geometrical shapes. The force on the jet for different weights and shape of vanes was calculated theoretically and observed experimentally. It was found that the force for the hemispherical vane was more than that of the flat plate.

Vrushiket Patil [5] also investigated the impact of jet by using flat plate and hemispherical vane. The aim of the investigation was to study the relation between the force produced and the change of momentum when a jet strikes a vane and to compare between force exerted by a jet on a flat plate and on a hemispherical surface. It was found that experimentally force exerted by jet on hemispherical vane was more than that of flat plate and almost double to that of flat plate force. When the weight on the plates increased, higher impact velocity or jet velocity was required to counter balance the force.

A report uploaded by John Conor [6] shows the experimental investigation of impact of jet. The aim of the investigation was to study the jet forces impacting against stationary deflectors. Plate, hemisphere and slope deflectors were used for this investigation. Before the investigation was carried out, a quick inspection was performed to ensure that unit was in proper operating condition. When comparing the three types of deflectors, the flow rate for the hemisphere was found to be the lowest and thus required a longer time for the volumetric tank to rise from 20 to 30 litres.

Shaho abdul qadir [7] investigated the impact of jet. The objective of the investigation was to study the relation between the force produced and the change of momentum when a jet strikes a vane. Moreover, a comparison was made between force exerted by a jet on a flat plate and on a hemispherical surface. It was seen that the hemispherical cup was more efficient for using in a turbine than the flat plate. Moreover, the water exiting the cup was collided with water entering the cup which could reduce the force. So, the cup was made in angles less than 180◦. The predicted value of the Jet force showed larger values than the measured one.

CHAPTER 3

EXPERIMENTAL SETUP

3.1 Experimental Setup:

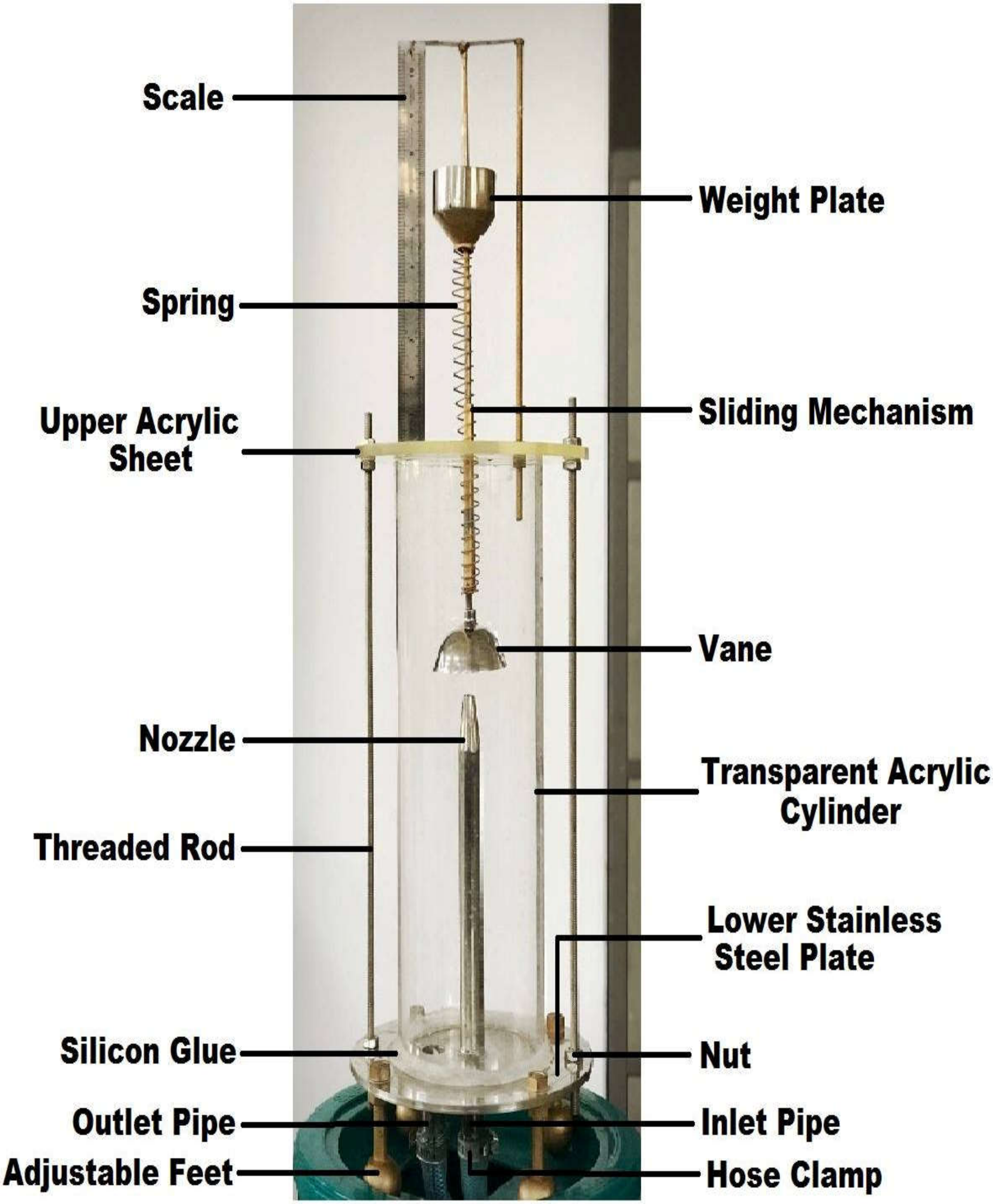

Figure 3.1: Experimental Setup

3.2 Equipments Used:

- Transparent Acrylic Cylinder
- Upper Acrylic Sheet
- Lower Stainless Steel Plate
- Nozzle
- Vane
- Sliding Mechanism
- Spring
- Scale
- Weight
- Weight Cup
- Nut Bolts
- Threaded Rod
- Hose Clamp
- Hose Pipe
- Inlet and Outlet Pipe
- Adjustable Feet
- Water Container
- Silicon Glue

3.3 Description of the Equipments Used:

3.3.1 Transparent Acrylic Cylinder:

Acrylic or acrylic glass is the synthetic polymer of methyl methacrylate [8]. It is a transparent thermoplastic often used in sheet form as a lightweight or shatter-resistant alternative to glass [8]. Acrylic is an economical alternative to polycarbonate when tensile strength, flexural strength, transparency, polish ability and UV tolerance are more important than impact strength, chemical resistance and heat resistance [8]. It is often preferred because of its moderate properties, low cost, easy handling and processing [8]. Acrylic is sometimes able to achieve high scratch and impact resistance [8]. Here, an acrylic cylinder of 16 inch height, 14.1 cm inner diameter and 3 mm thickness was used.

Figure 3.2: Transparent Acrylic Cylinder

3.3.2 Upper Acrylic Sheet:

An acrylic sheet of circular shape is used at the top. One hole is drilled at the center of the sheet of diameter 4.1 cm which is used for inserting the sliding system and two holes of diameter 1.1 cm are drilled at the edge to support the whole mechanism using two threaded rods. The thickness of the sheet is 9 mm and the diameter is 23.7 cm. It carries almost all the weight of the upper part.

Figure 3.3: Upper Acrylic Sheet

3.3.3 Lower Stainless Steel Plate:

A plate of stainless steel is used at the bottom which is of circular shape. Two holes are drilled of diameter 2.1 cm, one at the center which is used as inlet and the other one is used as outlet. A slot is grooved of thickness 14.2 cm, which is used for fixing the cylindrical acrylic sheet using silicon glue. Two holes are drilled at the edge to support the whole mechanism using two threaded rods. Stainless steel does not readily corrode, rust or stain with water as ordinary steel does [9]. However, it is not fully stain-proof in low-oxygen, high-salinity, or poor air-circulation environments [9]. Stainless steel has resistance to corrosion and staining, low maintenance which make it an ideal material for many applications [9].

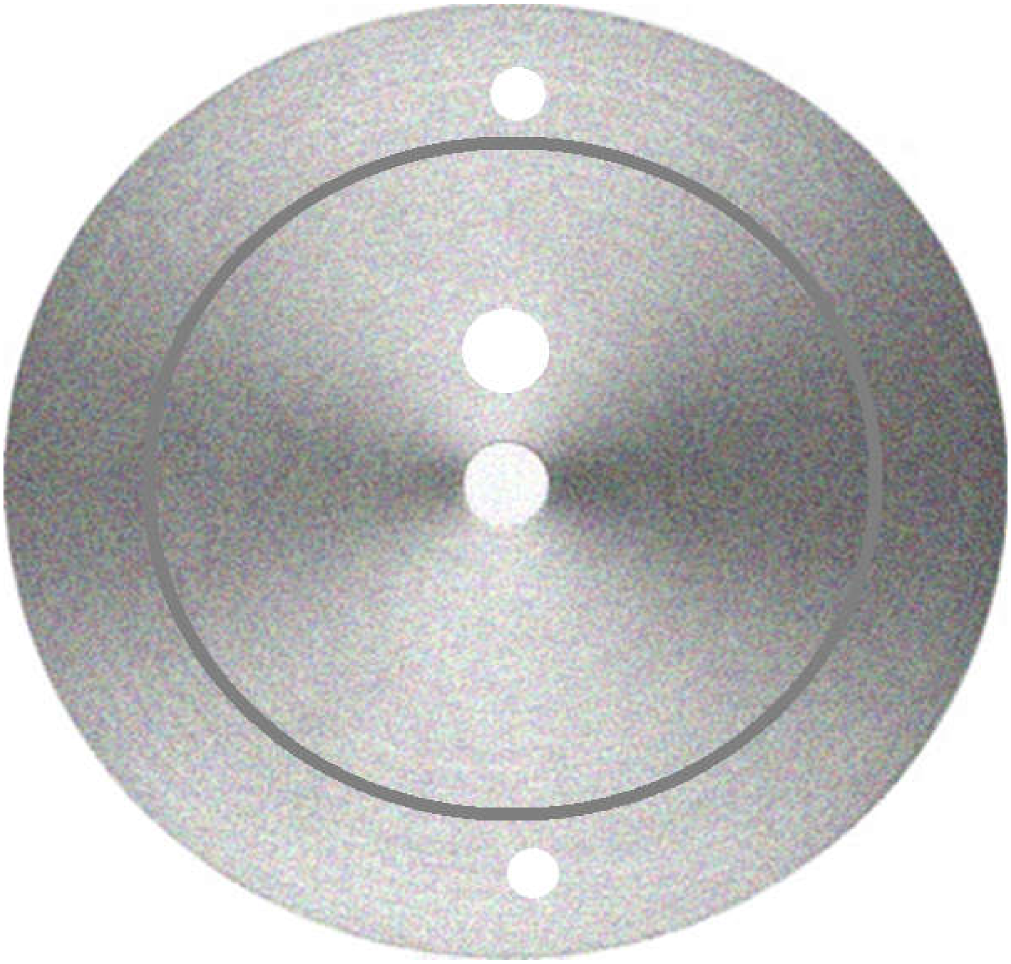

Figure 3.4: Lower Stainless Steel Plate

3.3.4 Nozzle:

A nozzle is a device designed to control the direction or characteristics of a fluid flow as it exits or enters an enclosed chamber or pipe [10]. Nozzles are frequently used to control the rate of flow, speed, direction, mass, shape, and the pressure of the stream that emerges from them [10]. In a nozzle, the velocity of fluid increases at the expense of its pressure energy [10]. A convergent nozzle of 10 mm exit diameter is used at the top of the inlet pipe.

Figure 3.5: Nozzle

3.3.5 Vane:

Different shaped vanes are used to determine theoretical impact force and experimental impact force for each. When a jet of fluid strikes a vane, it will undergo a change in velocity, with a corresponding change in momentum of the jet [11]. As the water flows across the face of the vane after impinging, the reaction of the vane will be normal to the inclined surface. All vanes are made of stainless steel. Flat, inclined, spherical and conical vanes are used.

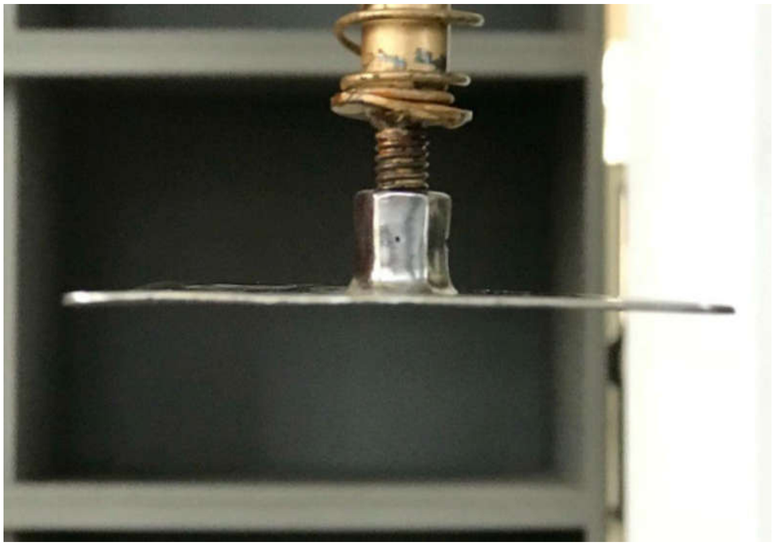

Figure 3.6: Flat Vane

Figure 3.7: Inclined Vane

Figure 3.8: Spherical Vane

Figure 3.9: Conical Vane

3.3.6 Sliding Mechanism:

Two cylinders are used in the sliding system, where one is smaller and another one is larger in diameter. The smaller one has 9 mm diameter and 24.6 cm length. The larger one has 1.2 cm diameter and 12.5 cm length. The larger cylinder which is hollow can smoothly slide over the smaller one which is solid due to the impact force of the jet. The smaller cylinder is attached within the larger one which will help it to slide upto a certain distance. A compressive spring is attached at each end of the sliding mechanism using washers which is fixed by welding. The measurement of the displacement due to jet force can be determined by this mechanism. So, the sliding mechanism is the main part of the experiment.

Figure 3.10: Sliding Mechanism

3.3.7 Spring:

A spring is an elastic object that stores mechanical energy. Springs are typically made of spring steel [12]. When a conventional spring, without stiffness variability features, is compressed or stretched from its resting position, it exerts an opposing force approximately proportional to its change in length [12]. Compression spring is designed to operate with a compression load, so the spring gets shorter as the load is applied to it [12]. A compressive spring is used in the sliding system to measure the impact forces for various vanes.

Figure 3.11: Spring

3.3.8 Scale

Scale is used for measuring the displacement caused by the impact force of the jet. When water flow from the jet strikes the vane, the impact force on the vane will make the displacement of the sliding mechanism. Weights are applied gradually for bringing it to the initial position. This displacement is measured with the help of the scale.

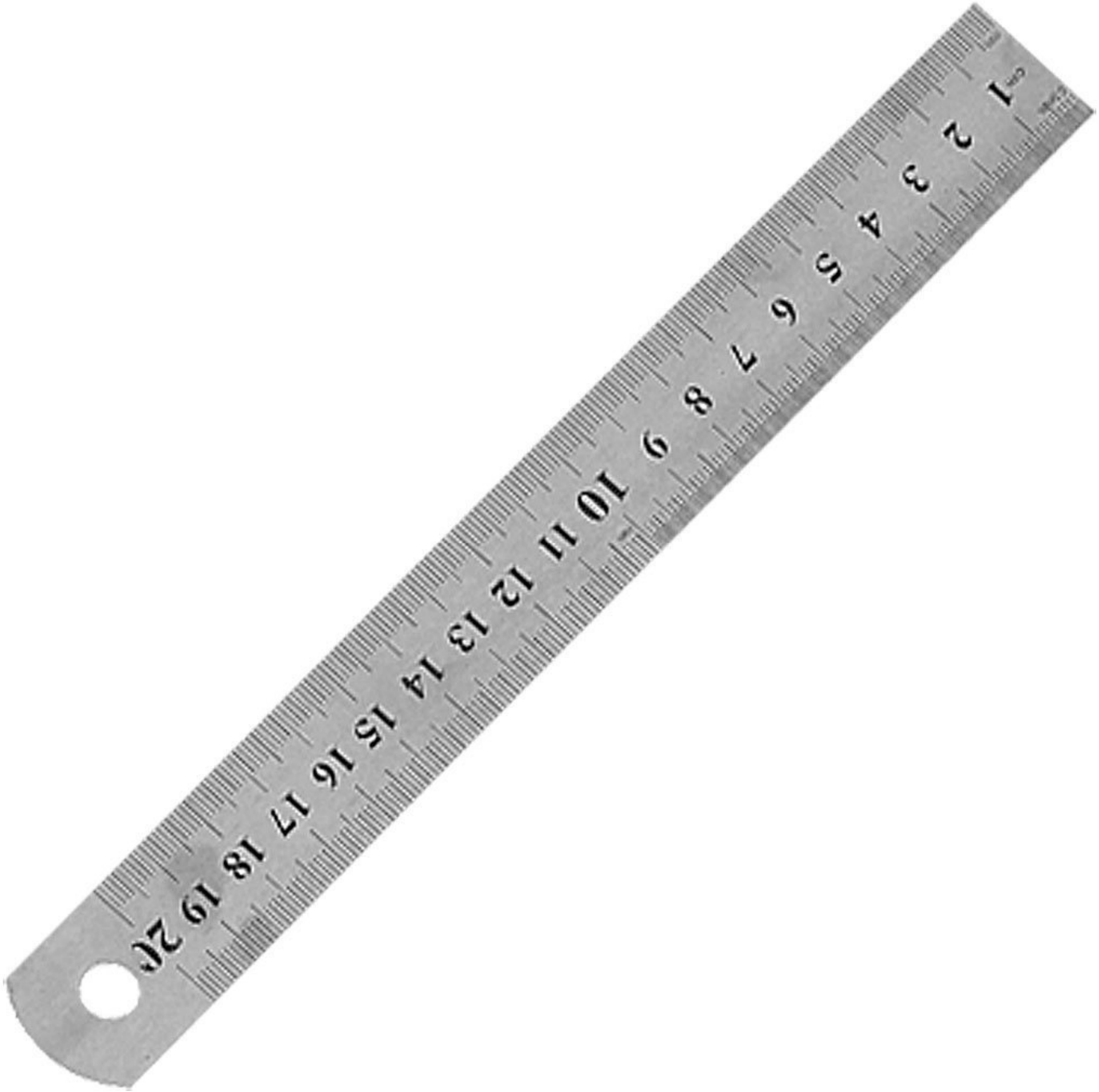

Figure 3.12: Scale

3.3.9 Weight:

Weight is used in measuring the amount of impact force on the vane. Weights are used to balance the displacement and bring back to the initial position. Two weights were used, one is ball type and another one is circular type.

Figure 3.13: Ball weight

Figure 3.14: Circular weight

3.3.10 Weight Cup:

Weight cup is used to hold the weight. It moves vertically by applying load.

Figure 3.15: Weight Cup

3.3.11 Nut and Bolt:

A nut is a type of fastener with a threaded hole [13]. Nuts are almost always used in conjunction with a mating bolt to fasten multiple parts together [13]. The two partners are kept together by a combination of their threads' friction, a slight stretching of the bolt and compression of the parts to be held together [13].

Figure 3.16: Nut

3.3.12 Threaded Rod:

A threaded rod is a long rod that is threaded on both ends; the thread may extend along the complete length of the rod [14]. Two threaded rods are used to support both upper acrylic sheet and lower stainless steel plate with the help of nuts. The diameter of the threaded rod is of 0.8 cm and length of 47 cm. Two holes were drilled at the edge of both upper acrylic sheet and lower stainless steel plate to insert these threaded rods.

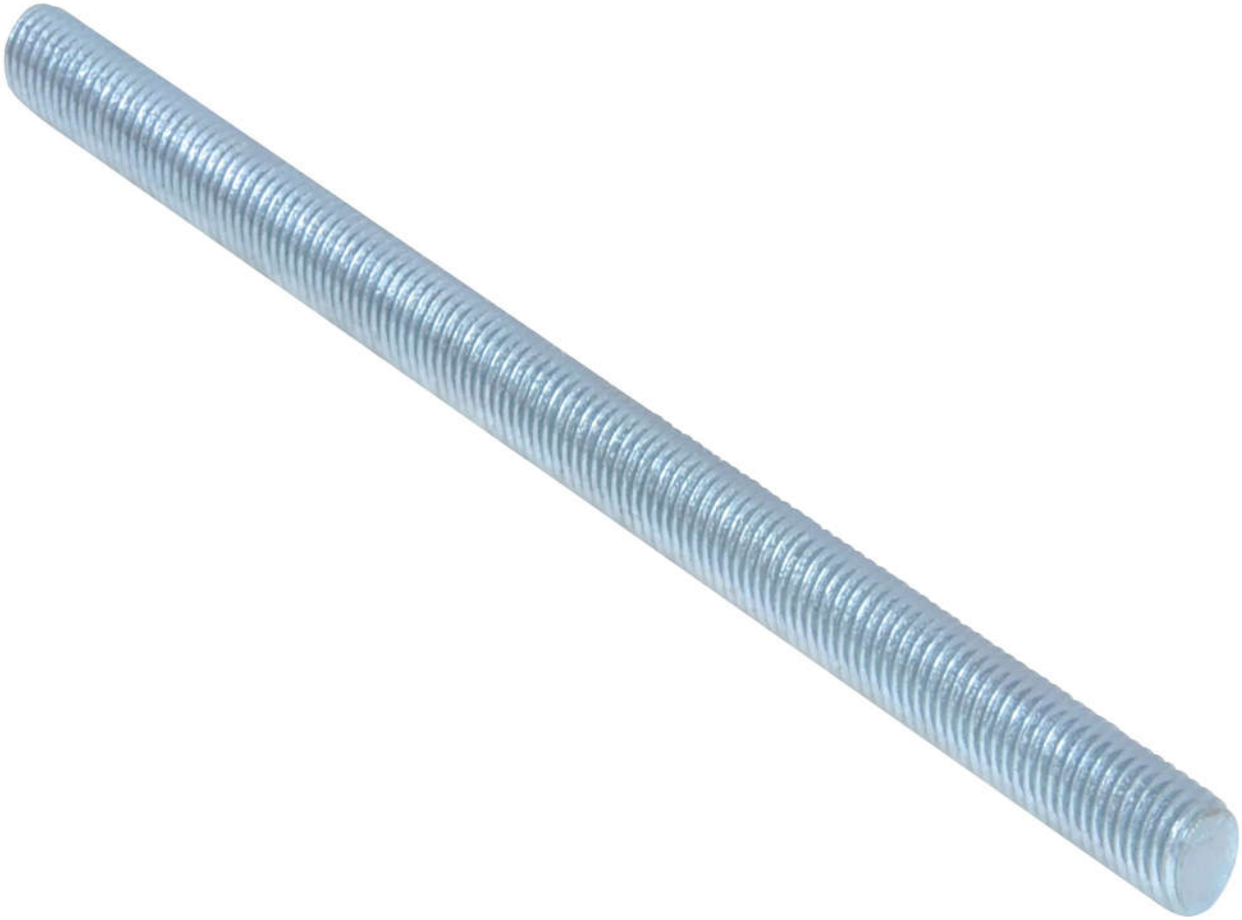

Figure 3.17: Threaded Rod

3.3.13 Hose Clamp:

Hose Clamps are mechanical devices used to hold hoses or tubes in place on the ends of pipe spuds. Hose clamps are used for preventing the water leakage. It is round in shape and was fixed with the hose pipe to prevent the flow of water coming outside which is necessary to maintain a constant flow rate. They are made in many sizes and materials, including metal or plastic, depending on the application and can be designed as single-use or as reusable devices.

Figure 3.18: Hose Clamp

3.3.14 Hose Pipe:

Generally hose pipe is robust, flexible, ultra light. It’s soft and flexible technology provides superb resistance to kinking. Hose pipe is weather proof with UV and it has frost protection. Hose pipe was used for water circulation. The diameter of the hose pipe was 2.12 cm. The total length of the hose pipe was 20 feet, where 12 feet was used for inlet housing and 8 feet was used for outlet housing. Hose pipe was used in outlet housing for discharging the water outside of the experimental area. Hose pipe was attached tightly with the inlet housing by using nozzle.

Figure 3.19: Hose Pipe

3.3.15 Inlet and Outlet Pipe:

Two pipes of stainless steel are used, one for inlet and the other for outlet. The inlet pipe allows the water to enter which comes from the hose pipe and the outlet is used for discharge. Both pipes are of diameter 2.1 cm. At the top of the inlet, a convergent nozzle is welded which is used to increase the velocity of the water flow.

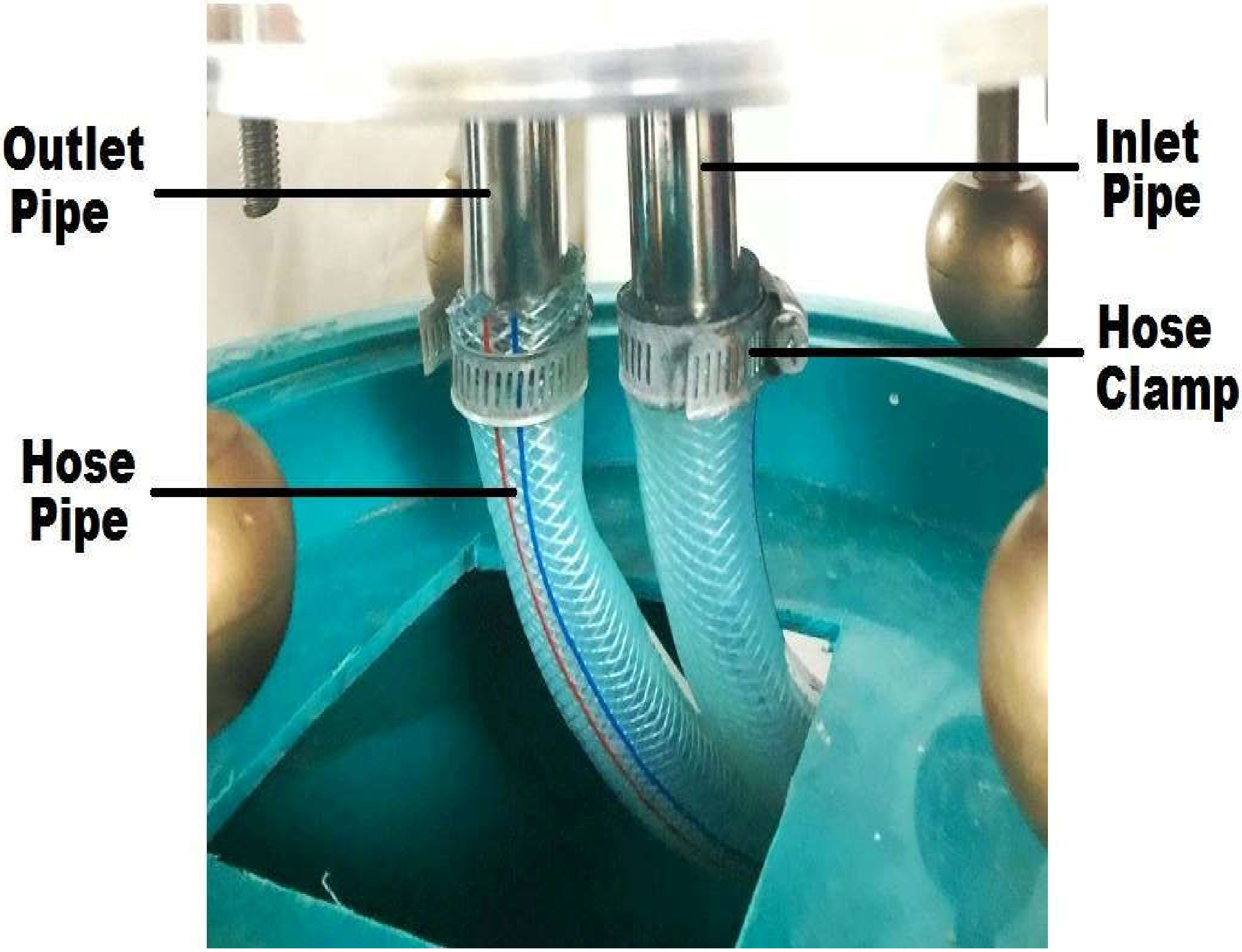

Figure 3.20: Inlet and Outlet Pipe

3.3.16 Adjustable Feet:

It is used to carry the weight of the whole setup. In the experimental setup, four feet are used to balance. Each foot can be adjusted using two nuts over the threaded part and the height can easily be increased or decreased according to the requirement.

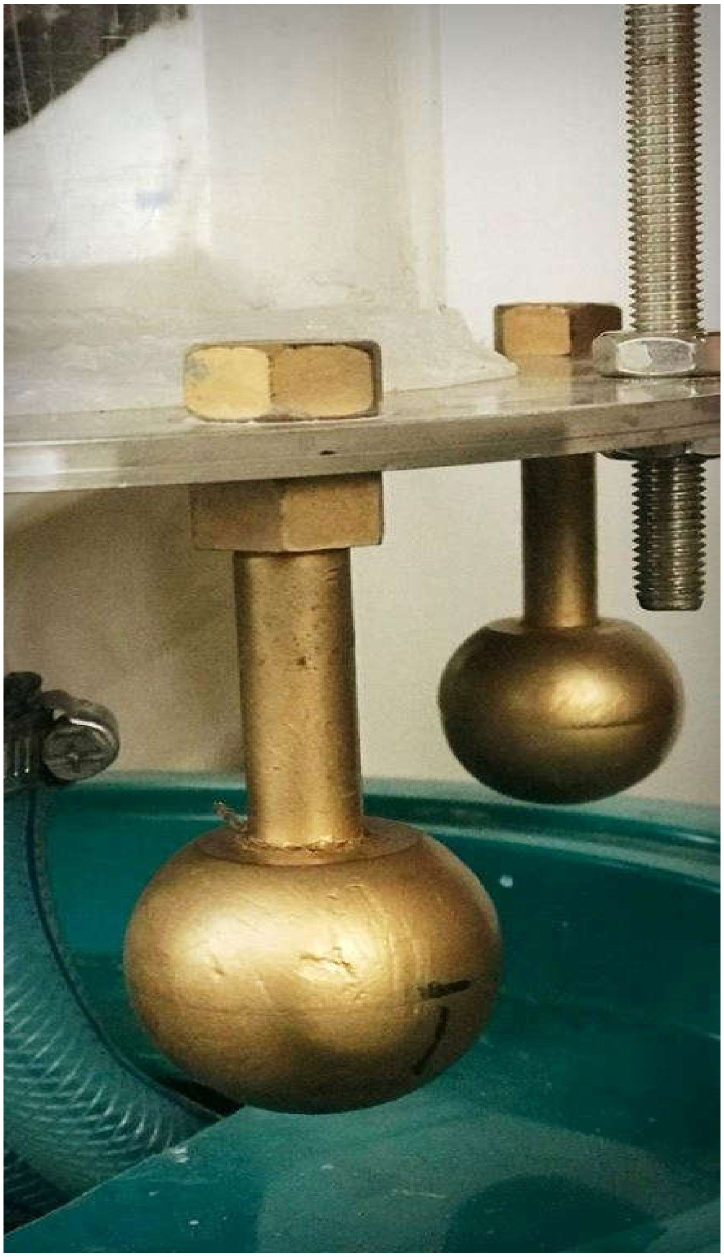

Figure 3.21: Adjustable Feet

3.3.17 Water Container:

Generally water container is used for water reservation. In the experimental study, a certain flow of water was needed. That's why it was necessary to reserve water. So, a water container was used in this experiment which helped to measure the flow rate of water with a stopwatch.

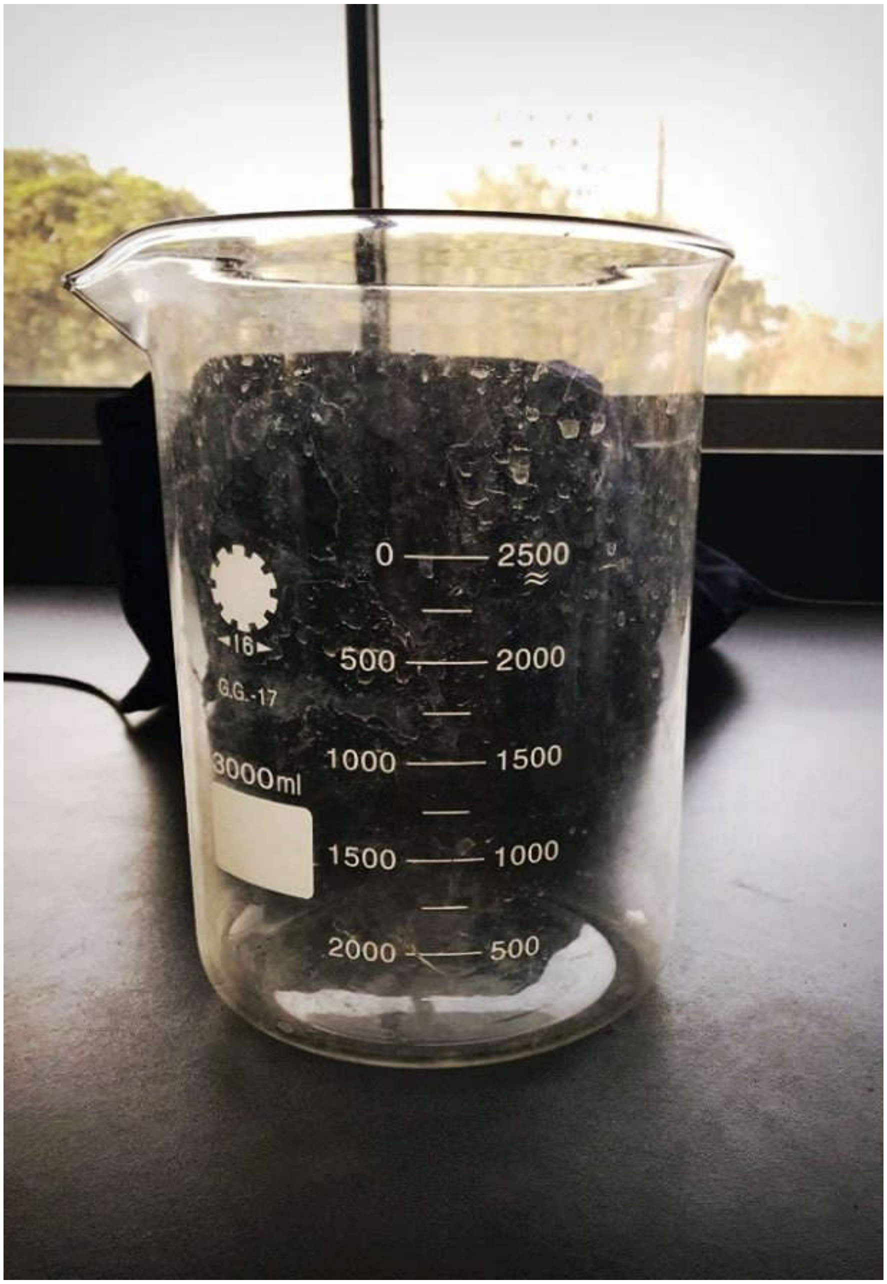

Figure 3.22: Water Container

3.3.18 Silicon Glue:

Silicon glue or sealant is a substance used to block the passage of fluids through the surface or joints or openings in materials [15]. It is a type of mechanical seal that helped in avoiding any sort of leakage in the experiment [15]. Sealants may be weak or strong, flexible or rigid, permanent or temporary [15]. It can provide thermal, electrical, acoustical insulation and is effective in waterproofing processes by keeping moisture out or in the components in which they are used. Silicon glue has a proven long life and is unaffected by UV or extremes of weather or temperature.

Figure 3.23: Silicon Glue

CHAPTER 4

EXPERIMENTAL PROCEDURE & ANALYSIS

4.1 Procedure:

- Note down the diameter of the nozzle.
- Note down the value of h which is the distance between the nozzle and the target.
- Bring the weight in the zero position.
- Now open the flow control valve.
- The water flow from the jet will strike the target point of the vane.
- The vane will now be deflected by the impact of the jet.
- The vane along with weight cup will be raised upto a certain height.
- Bring the level of the vane and weight cup to the original position using the weights.
- The flow rate is measured and the result is recorded on the test sheet, together with the corresponding value of weight.
- Collect water in the measuring bucket and note down the collection time.
- The weight of the water is recorded from the platform scale of the measuring bucket.
- The weight on the weight cup is changed and balance of weight cup is maintained by regulating the flow rate.
- Each time record the value of flow rate and weight on the weight cup.
- The control valve is closed and the pump is switched off.
- The experiment is repeated with different target vanes.

4.2 Analysis:

- The results are recorded on the result sheets.
- The flow rate is calculated.
- Area is calculated.
- Nozzle exit velocity is calculated from the flow rate and area.
- Impact velocity is calculated from the nozzle exit velocity and value of h.
- Experimental force is calculated.
- Theoretical force is calculated.
- Experimental and theoretical forces are compared.
- Error is determined from the experimental and theoretical forces.
- Graphs are drawn of theoretical forces versus experimental forces for each of the vanes.
- Graphs are drawn of flow rate versus both experimental and theoretical forces for each of the vanes.
- A graph is drawn of theoretical forces versus experimental forces for combination of the vanes.
- A graph is drawn of flow rates versus experimental forces for combination of the vanes.
- A graph is drawn of flow rates versus theoretical forces for combination of the vanes.
- More analysis can be done by keeping constant flow rate.

CHAPTER 5

RESULT & DISCUSSION

5.1 Flat Vane:

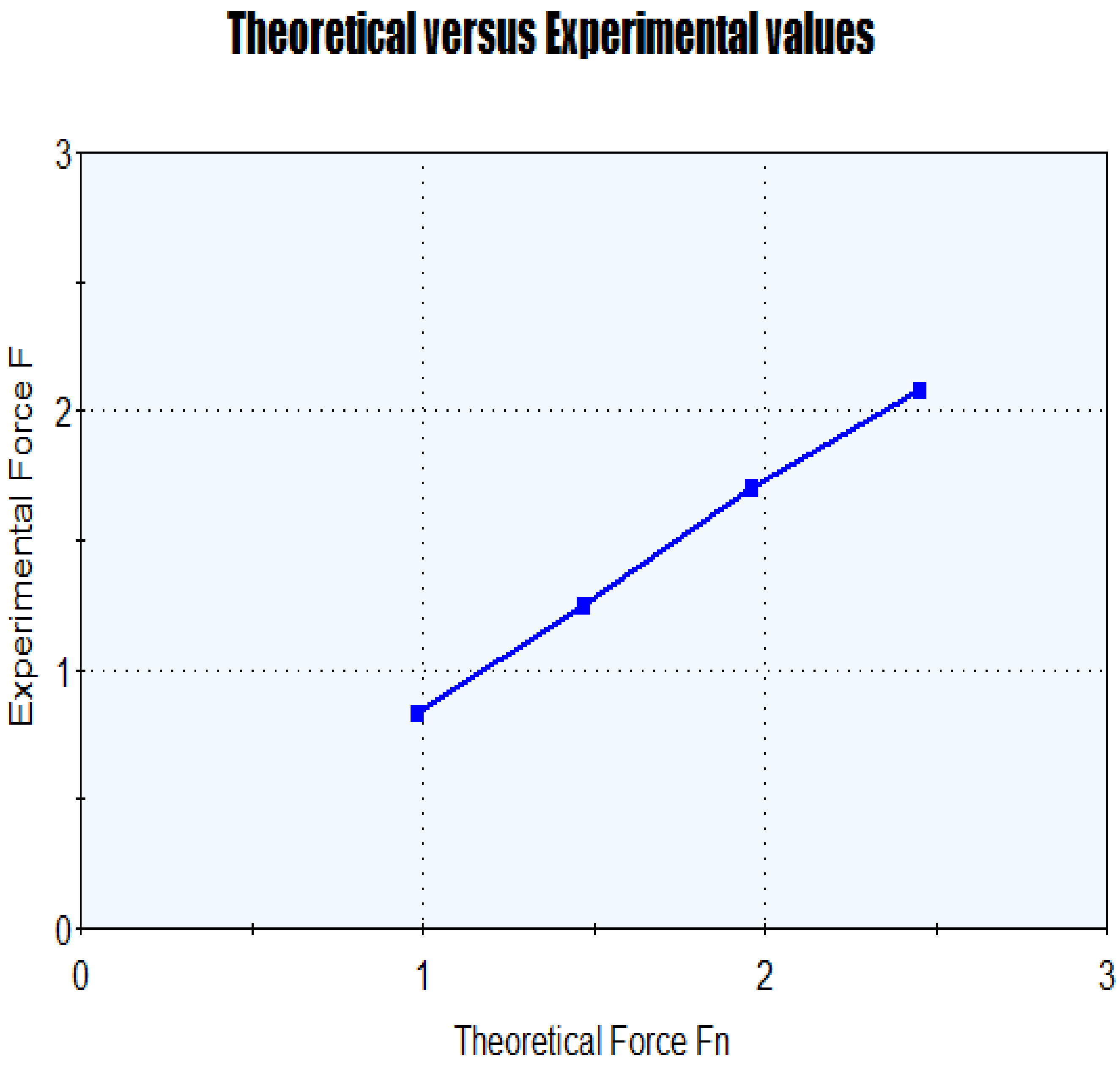

Figure 5.1: Variation of Theoretical Forces with Experimental Forces for Flat Vane

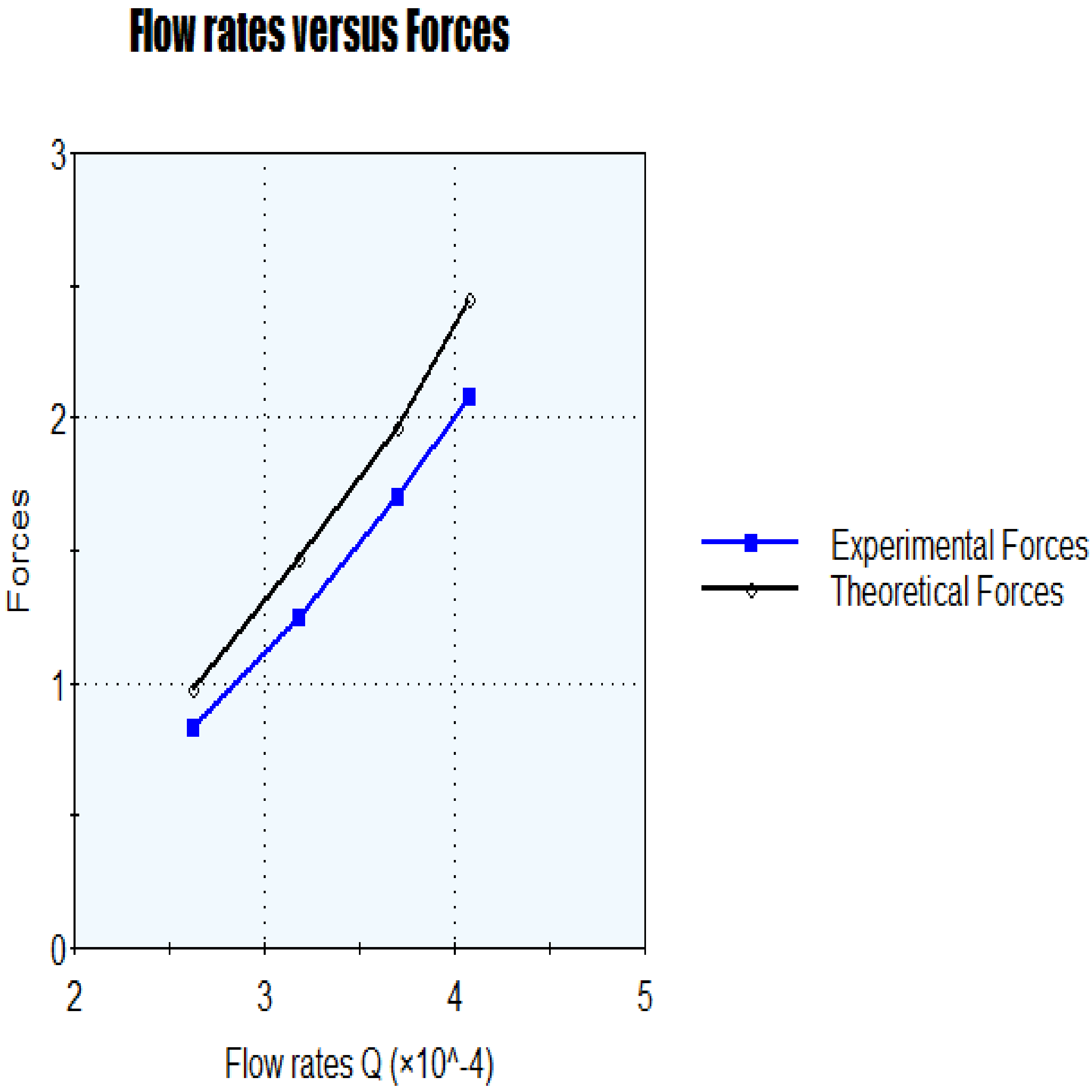

Figure 5.2: Variation of Flow rates with Forces for Flat Vane

5.2 Inclined Vane:

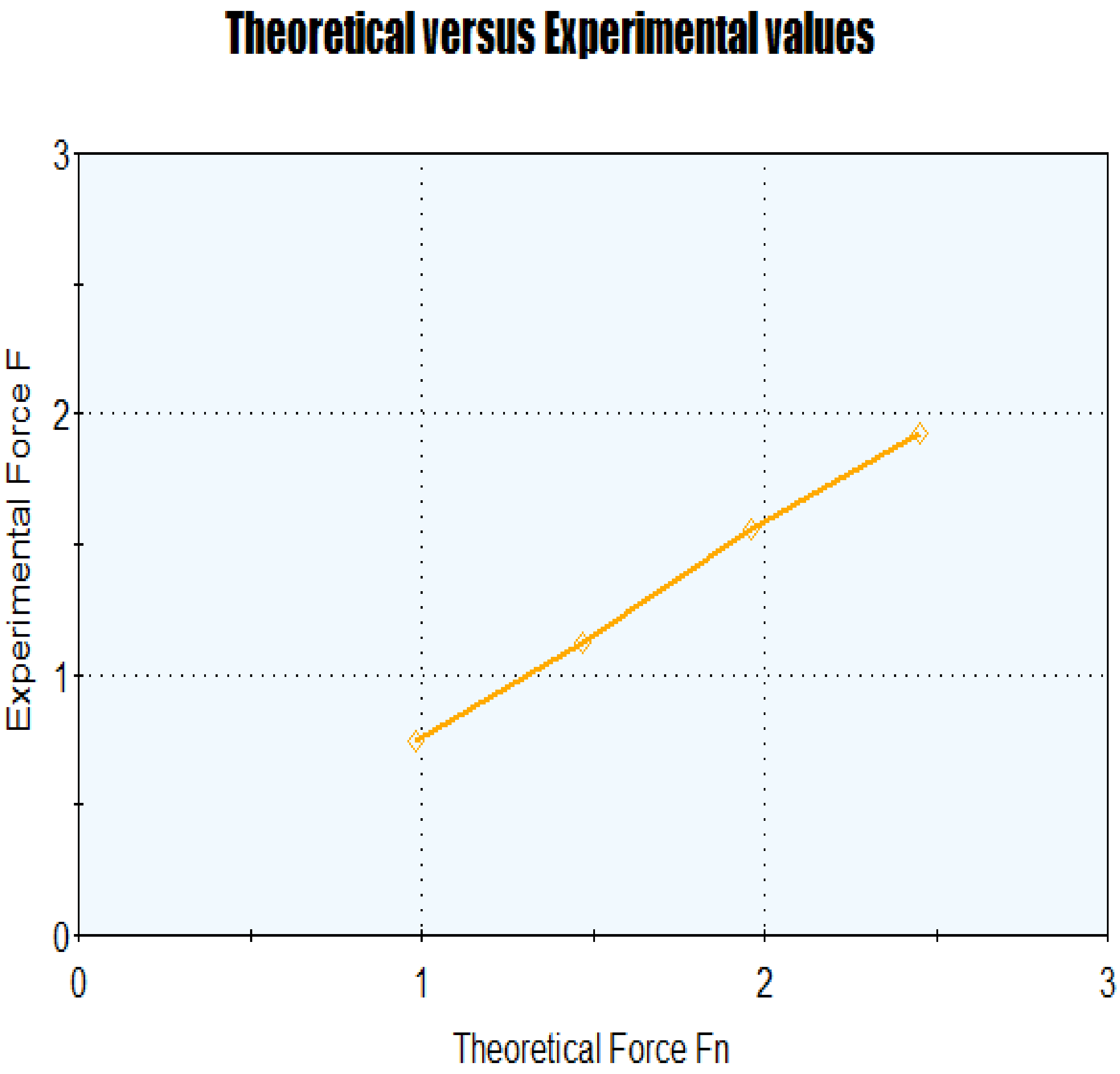

Figure 5.3: Variation of Theoretical Forces with Experimental Forces for Inclined Vane

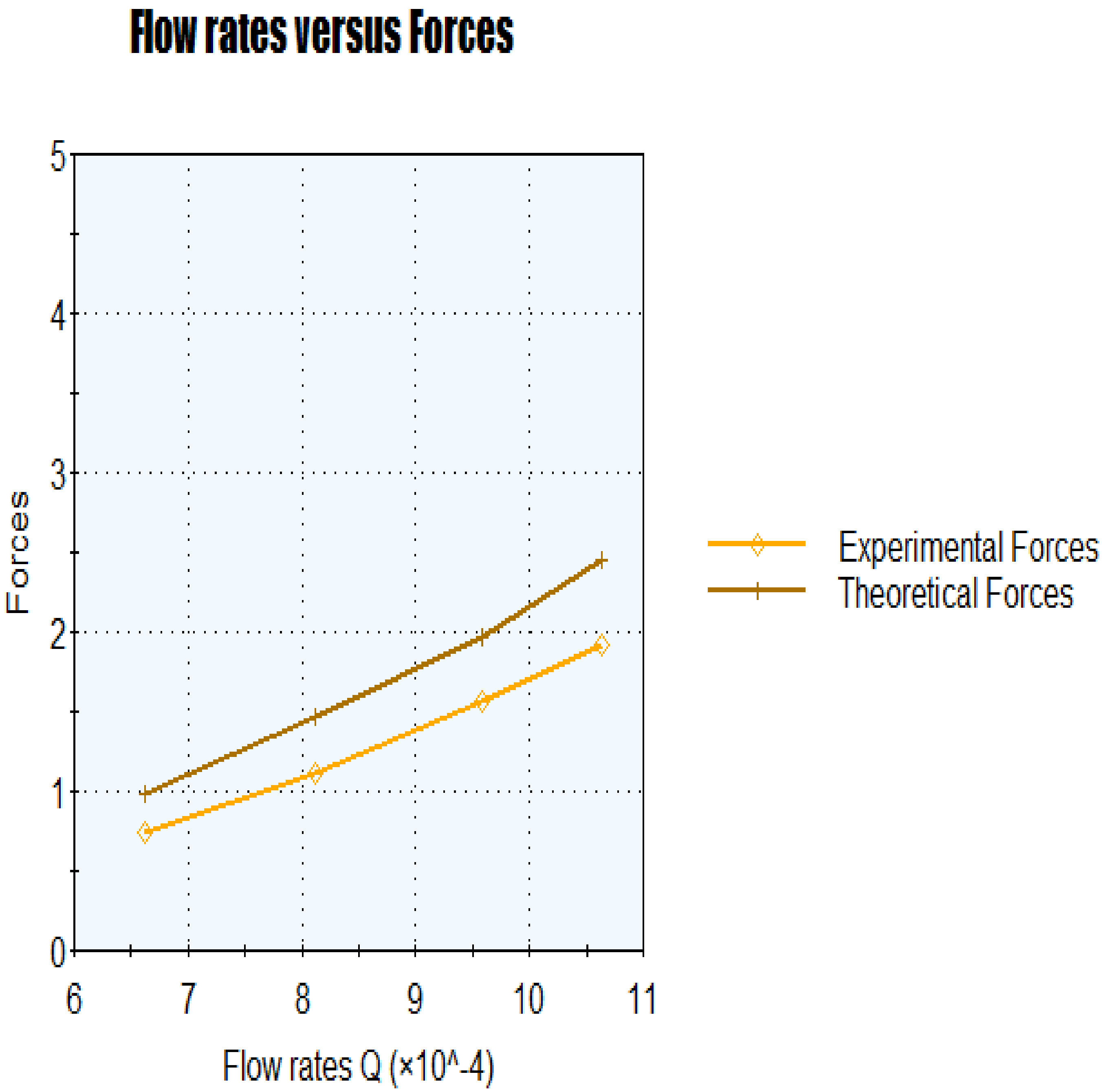

Figure 5.4: Variation of Flow rates with Forces for Inclined Vane

5.3 Spherical Vane:

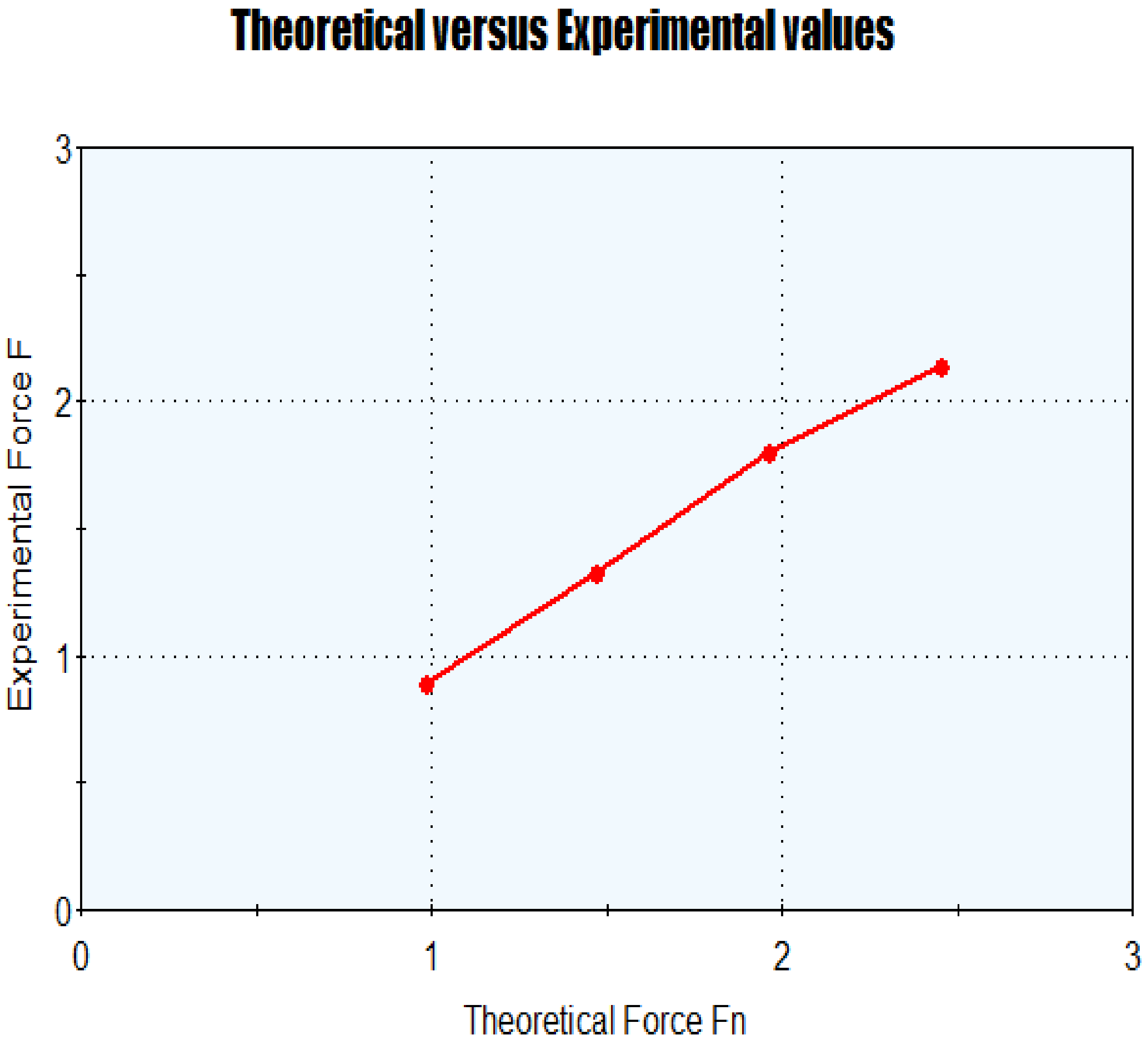

Figure 5.5: Variation of Theoretical Forces with Experimental Forces for Spherical Vane

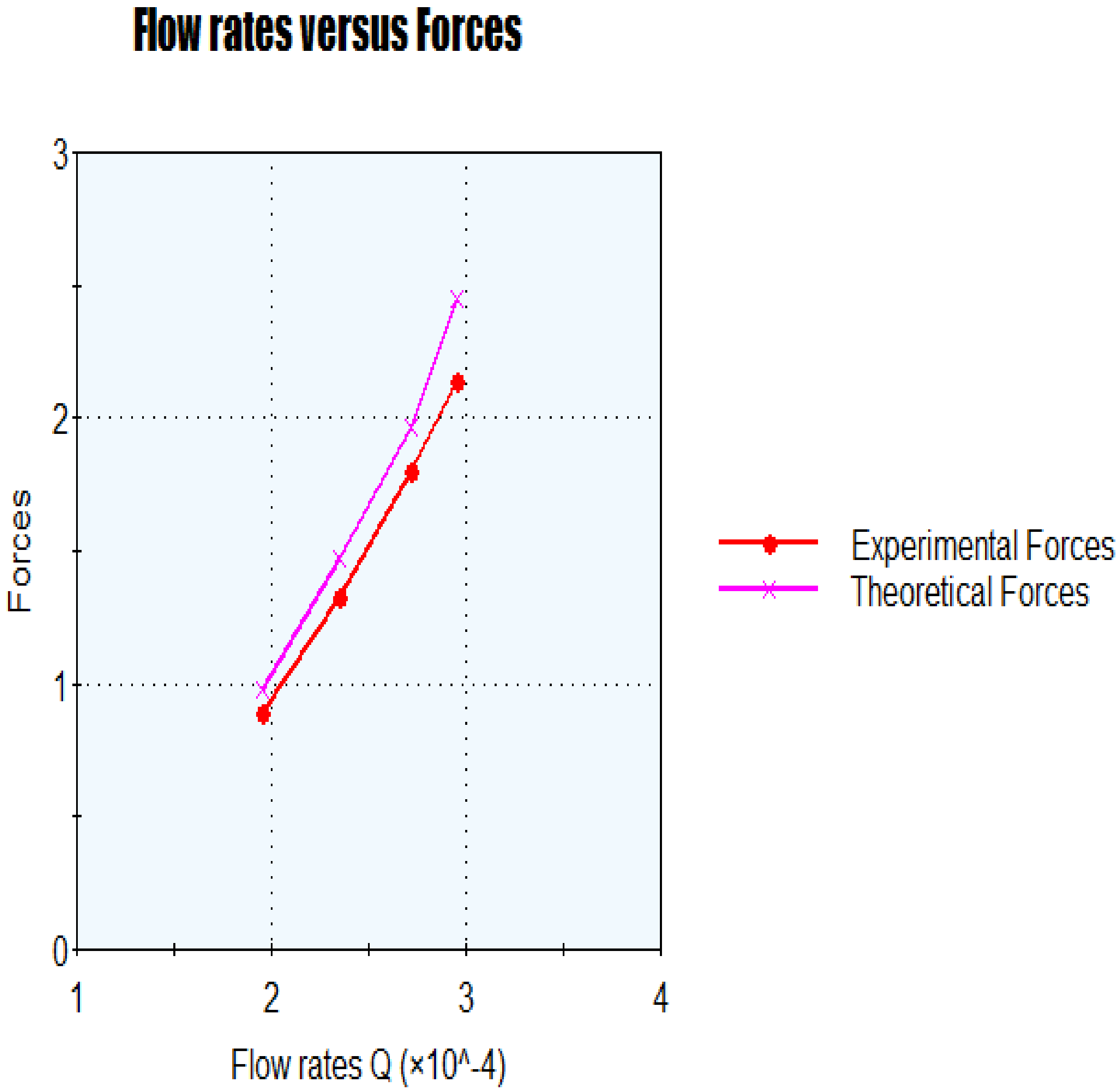

Figure 5.6: Variation of Flow rates with Forces for Spherical Vane

5.4 Conical Vane:

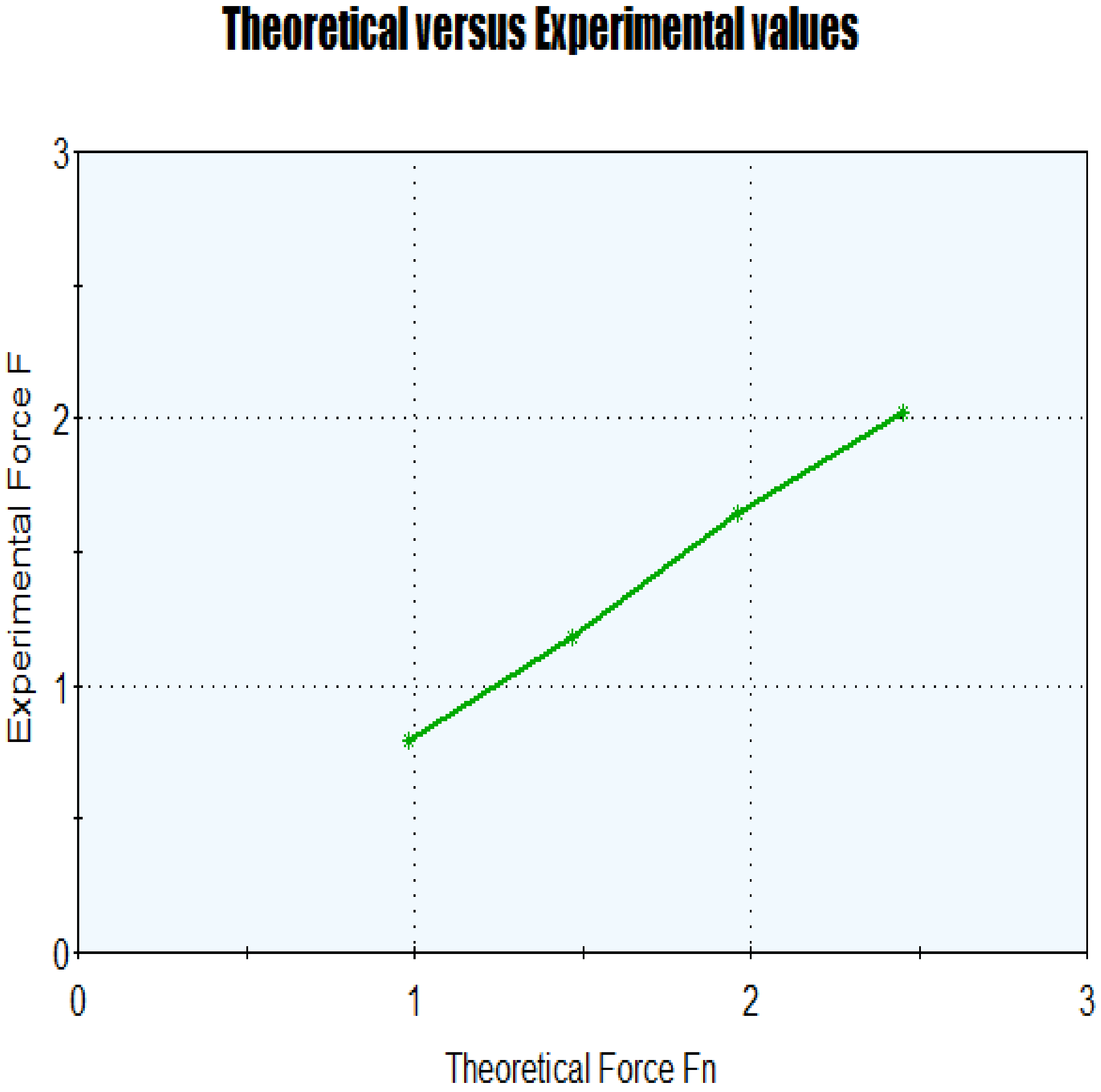

Figure 5.7: Variation of Theoretical Forces with Experimental Forces for Conical Vane

‘

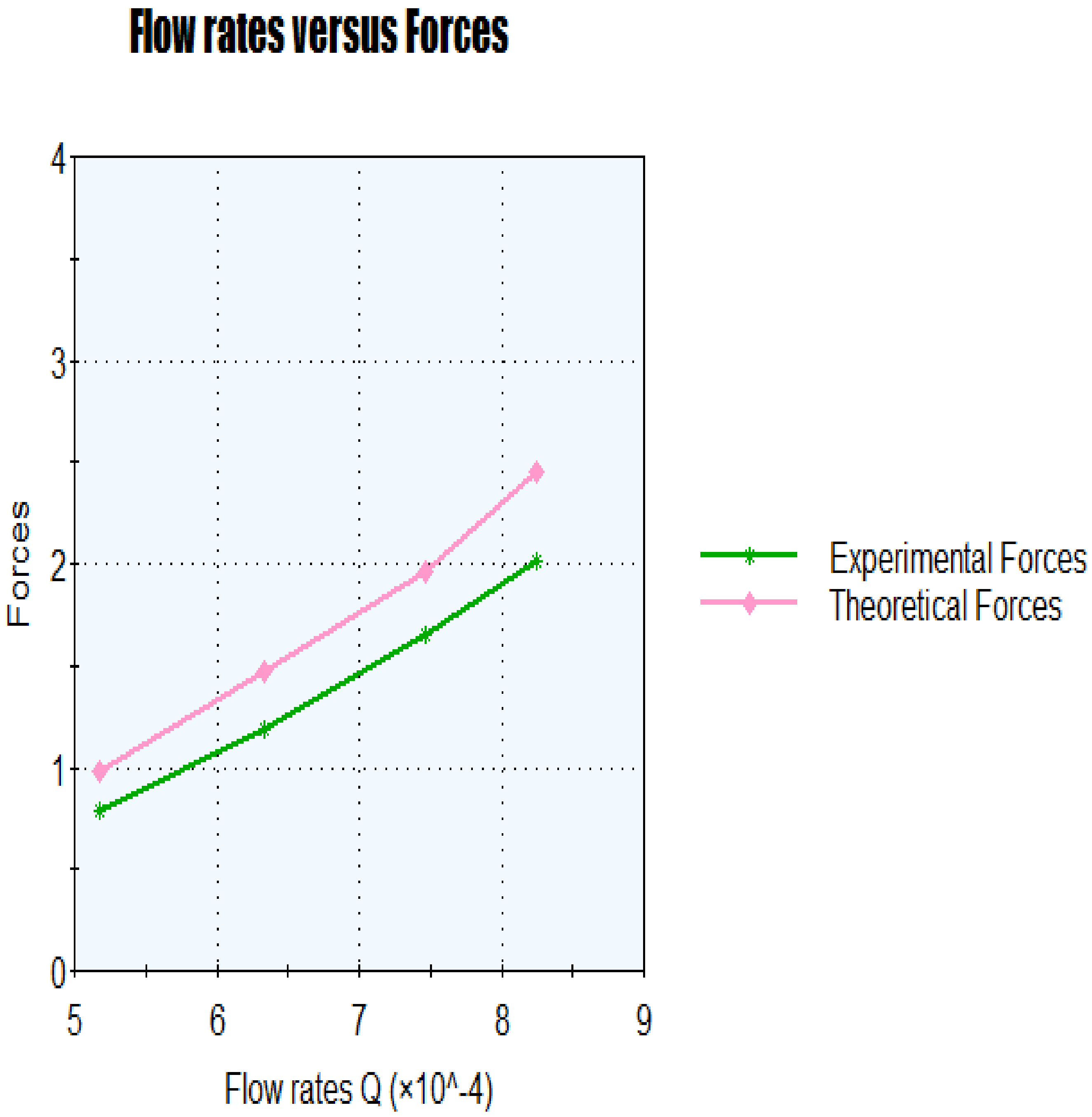

Figure 5.8: Variation of Flow rates with Forces for Coniical Vane

5.5 Combination of four Vanes:

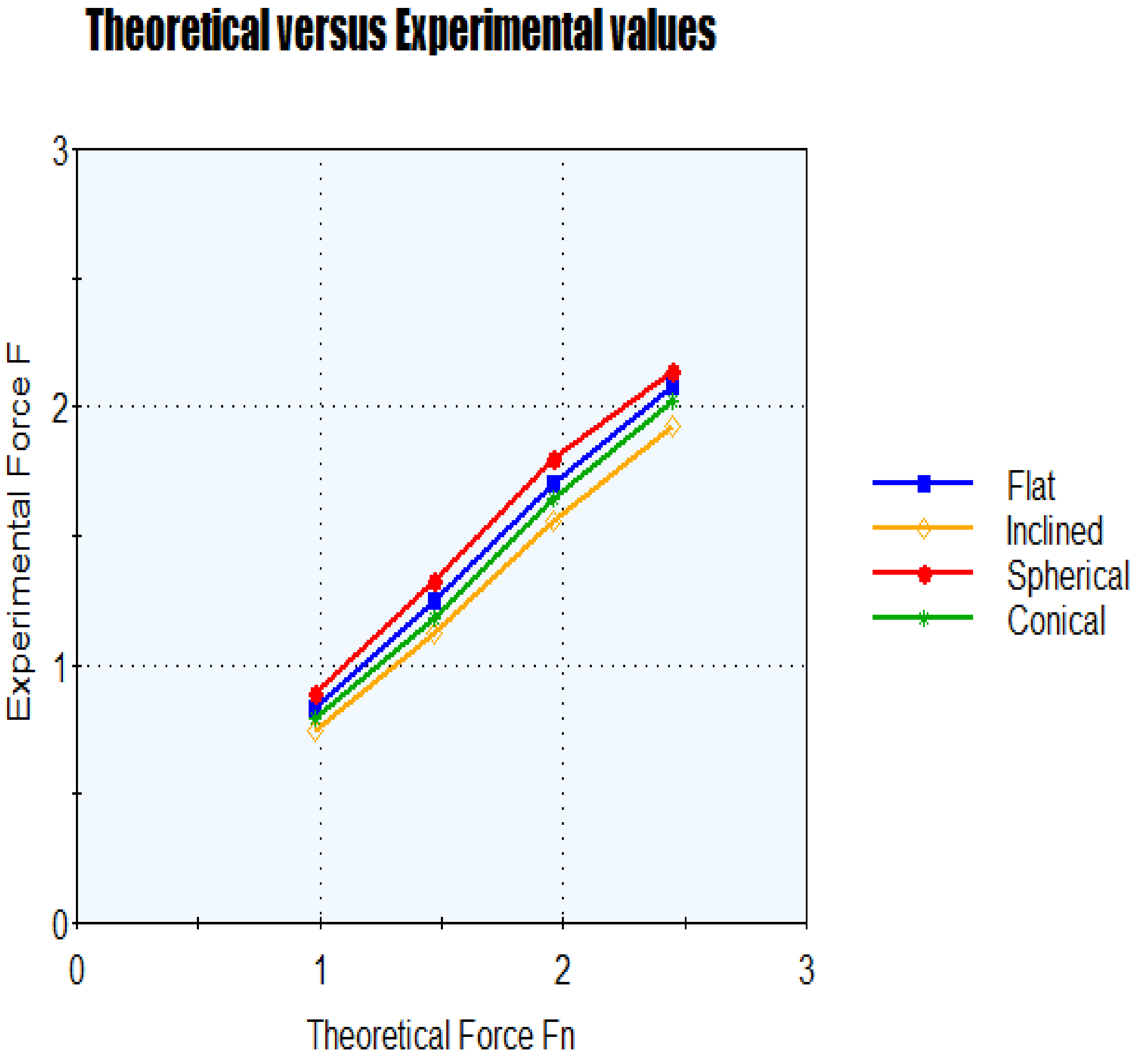

Figure 5.9: Variation of Theoretical Forces with Experimental Forces for Combination of four Vanes

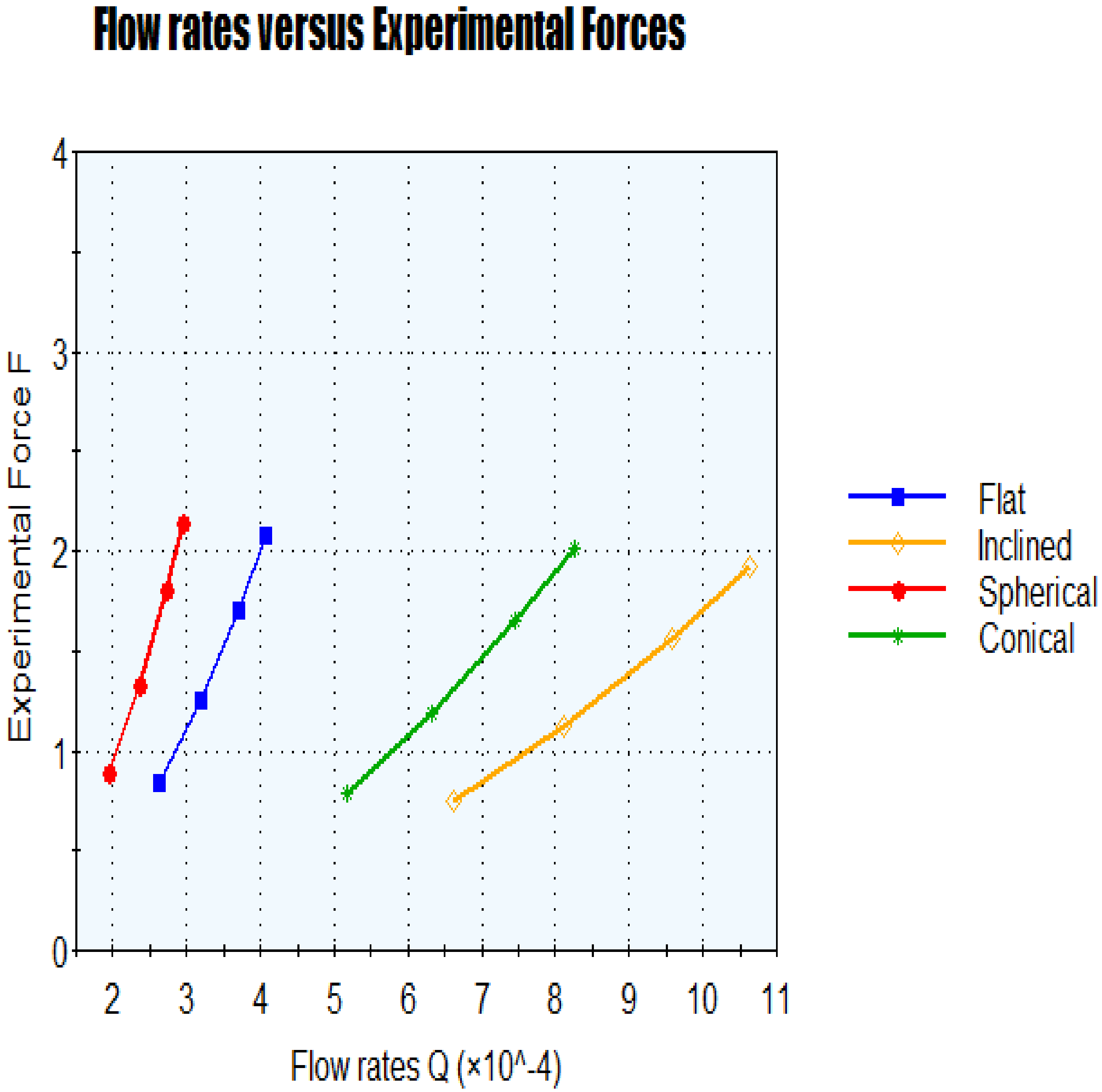

Figure 5.10: Variation of Flow rates with Experimental Forces for Combination of four Vanes

Theoretical forces are kept fixed at **0.981 N**, **1.4715 N**, **1.962 N** and **2.4525 N**.

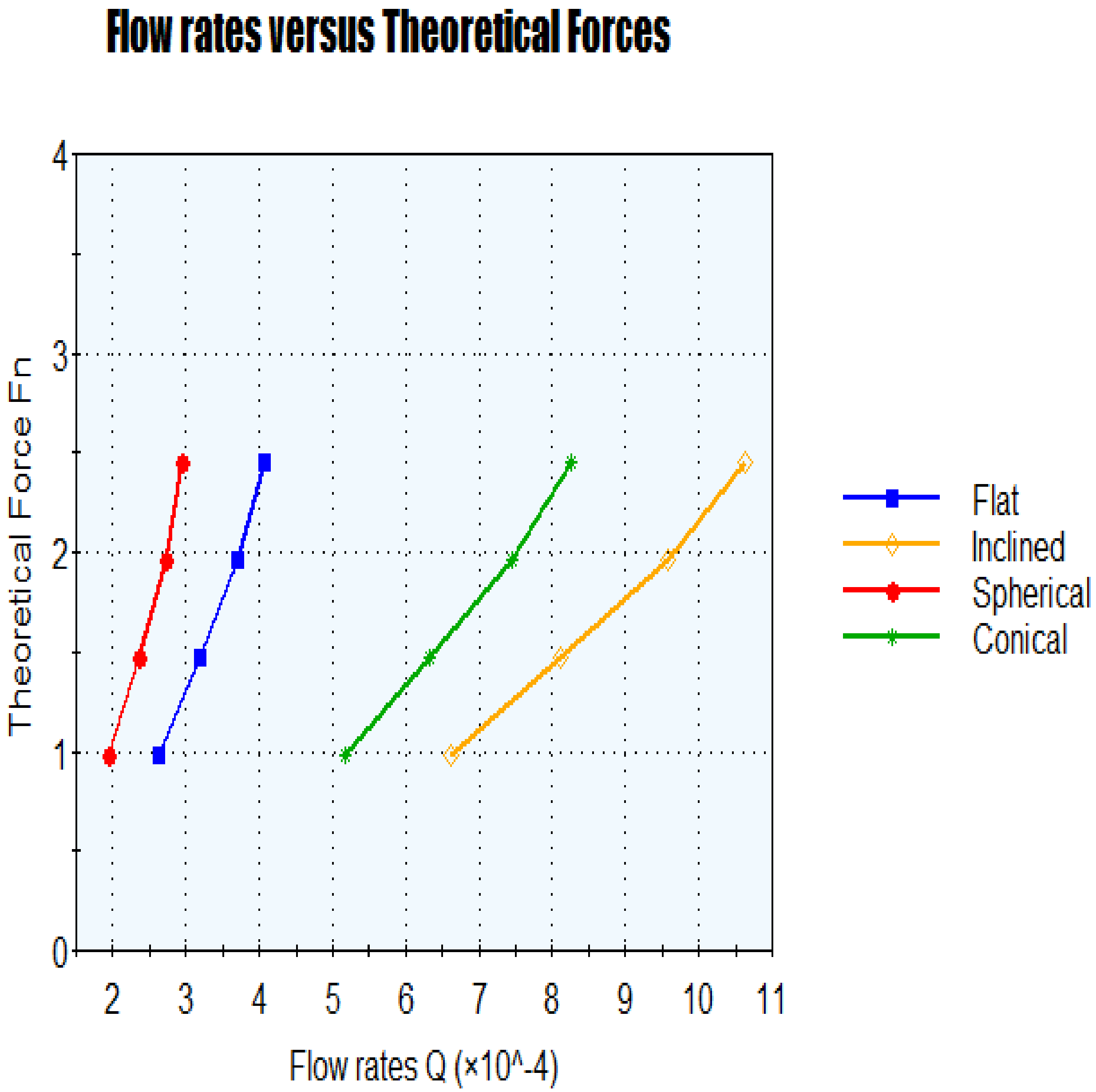

Figure 5.11: Variation of Flow rates with Theoretical Forces for Combination of four Vanes

5.6 Observations:

- Maximum experimental forces are obtained for spherical vane.
- Minimum experimental forces are obtained for inclined vane.
- Experimental forces for flat vane are greater than inclined and conical vane but less than spherical vane.
- Experimental forces for conical vane are greater than inclined vane but less than spherical and flat vane.
- Minimum amount of flow rates are required for spherical vane.
- Maximum amount of flow rates are required for inclined vane.
- Flow rates for flat vane are greater than spherical vane but less than conical and inclined vane.
- Flow rates for conical vane are greater than spherical and flat vane but less than inclined vane.
- It was also observed that the experimental forces were lower than the theoretically required force.
- Theoretical forces are greater than the experimental forces because the friction inside the pipe.

5.7 Analysis for fixed flow rate:

When Q = $\mathbf{3.7 \times 10^{-4} m^3/s}$ (Fixed)

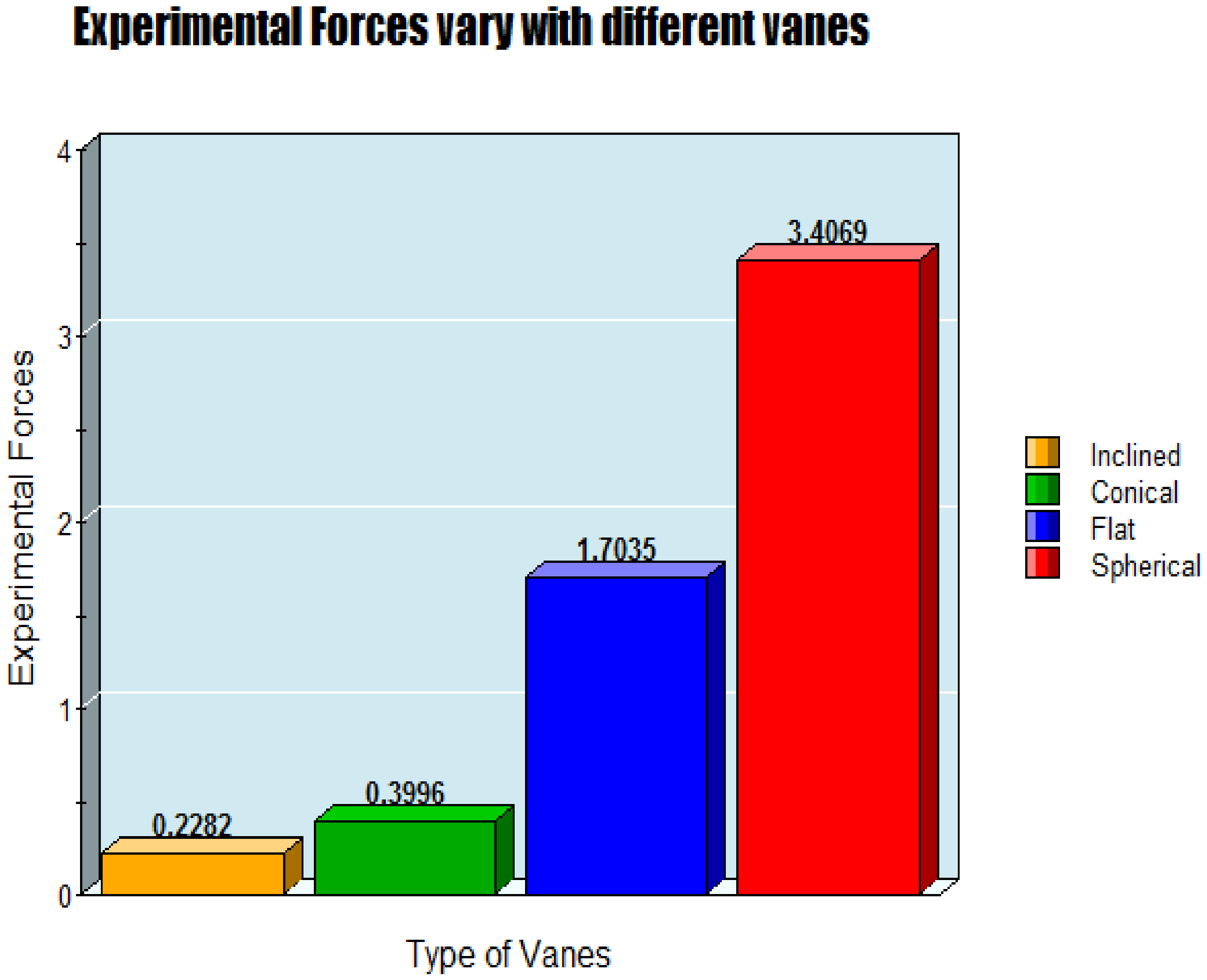

Figure 5.12: Experimental Forces vary with different vanes

For a constant flow rate, it is clearly seen that inclined vane gives minimum experimental force but spherical vane gives maximum experimental force. Moreover, at a constant flow rate, the experimental force for conical vane is greater than inclined vane but less than flat and spherical vane.

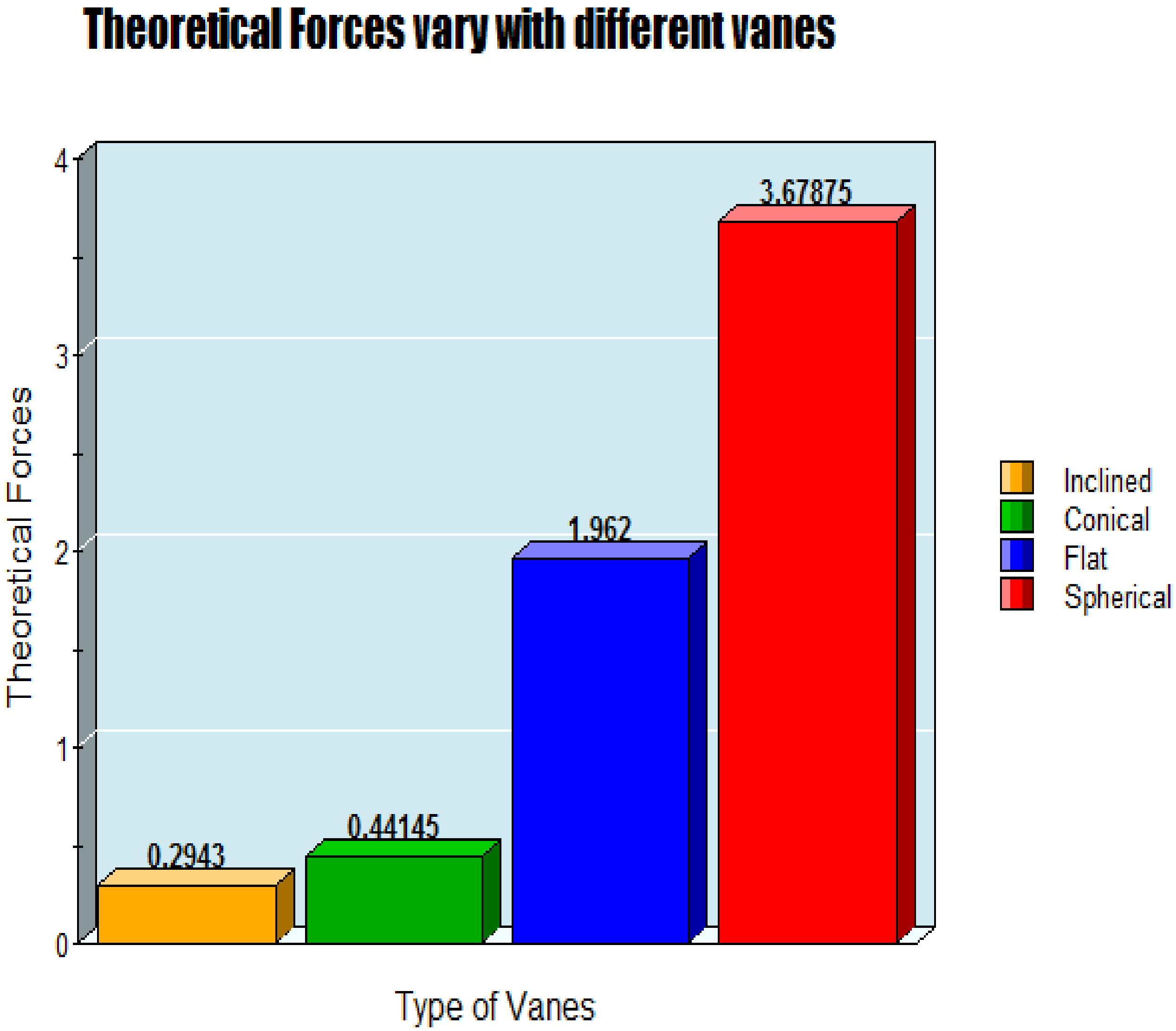

Figure 5.13: Theoretical Forces vary with different vanes

For a constant flow rate, it is clearly seen that inclined vane gives minimum theoretical force but spherical vane gives maximum theoretical force. Moreover, at a constant flow rate, the theoretical force for conical vane is greater than inclined vane but less than flat and spherical vane.

CHAPTER 6

CONCLUSION & RECOMMENDATION

6.1 Conclusion:

This project is focused on experimental analysis of impact of water jet on vanes. Impact of jet apparatus is used to demonstrate the way in which fluid force is being used to generate a force that can turn a turbine; that is converting the kinetic energy in a flowing fluid from a nozzle to a rotary motion of the turbine with the help of vanes fitted on shaft of the turbine. The jet is directed to vane of turbine wheel that is rotated by the force generates due to change of momentum of the fluid according to Newton's second law of motion. The principle is used in designing impulse turbine; part of the fluid energy is transformed to kinetic energy in a nozzle that issues a jet of fluid at high speed.

The experiment was done successfully, even though the data collected were a little bit difference compared to the theoretical values. These variations are due to human and servicing factors such as parallax error.

Possible sources of errors:

- The height between the nozzle and the target of the spring tension should be a constant value. This value can fluctuate due to parallax errors and also inaccuracy of measuring instruments.
- The height between the nozzle and the vane can also change due to the change of vanes as all vanes do not have equal heights and weights.
- At all instances the nozzle and the vane have to be concentric. In practice this does not always happen as there is a slight play between the weight platform and the cylinder that holds it and it can move around slightly due to the action of the force of the water.
- There could also be a frictional force between the weight platform and where it is fixed. This could be one reason why a higher force than the calculated was required to support the vane.
- The reason the spherical vane gives a higher discrepancy than the others could be because once the water hits its center the only way it can travel is downwards and hence come in the way of the water coming from the jet.
- Bubbles present in the water can be a reason to get inaccurate readings as well.
- The water which hits the vane could flow downwards and hit the jet again which will give a momentum in the opposite direction and hence give false values.
- Water container may be dirty.
- Error may be introduced due to stop watch use.
- Error may be introduced due to viscosity effects.
- Non-uniform flow rate due to fluctuation in water supply of pump.

6.2 Recommendation:

In order to reduce the differences between the theoretical and experimental value of forces, the following recommendations may be taken:

- The position of the observer's eye must be 90° perpendicular to the focusing object.
- It is necessary to ensure that the apparatus functioning perfectly in order to get an accurate result.
- It is necessary to ensure constant water supply of pump.
- The time should be measured very carefully with the help of stop watch.
- It is necessary to ensure that no bubble is present in the water.
- The jet must impinge at the center of the vane.
- The flow rate must be measured very carefully.
- The weights must be recorded very carefully.

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APPENDIX

Appendix A

Sample Calculation:

Flat Vane:

For **100** gm weight:

Average Time, t = $\mathbf{60\ sec}$

5.725 sec time needed for 1.5 liters

So, Volume = $\left(\frac{1.5\times60}{5.725}\right)$

$= \mathbf{15.72\ litre/min}$

Flow Rate, Q = V/t

$= \left(\frac{15.72\ \times0.001}{60}\right)$

$= \mathbf{2.62\times10^{-4}\ m^3/s}$

Nozzle Diameter, D = $\mathbf{10\times10^{-3}\ m}$

Area, A = $\pi D^2/4$

$= \frac{\pi\times(10\ \times10^{-3})^2}{4}$

$= \mathbf{7.854\times10^{-5}\ m^2}$

Exit Velocity, V_n = Q/A

$= \frac{2.62\ \times10^{-4}}{7.854\times10^{-5}}$

$= \mathbf{3.3359\ ms^{-1}}$

Impact Velocity, $V_i = \sqrt{V_n^2 - 2gh}$

$= \sqrt{3.3359^2 - 2 \times 9.81 \times 0.05}$

$= \mathbf{3.185\ ms^{-1}}$

Experimental Force, $F = \rho Q V_i (1 - \cos\theta)$

$= 1000 \times 2.62 \times 10^{-4} \times 3.185 \times (1 - \cos 90°)$

$= \mathbf{0.834\ N}$

Theoretical Force, $F_n = mg$

$= (100/1000) \times 9.81$

$= \mathbf{0.981\ N}$

Error (%) $= \left| \frac{F_n - F}{F_n} \right| \times 100$

$= \left| \frac{0.981 - 0.834}{0.981} \right| \times 100$

$= \mathbf{14.99}$ %

For **150** gm weight:

Average Time, $t = \mathbf{60\ sec}$

4.72 sec time needed for 1.5 liters

So, Volume $= \left(\frac{1.5 \times 60}{4.72} \right)$

$= \mathbf{19.08\ litre/min}$

Flow Rate, $Q = V/t$

$= \left(\frac{19.08 \times 0.001}{60} \right)$

$= \mathbf{3.18 \times 10^{-4}\ m^3/s}$

Nozzle Diameter, D = $\mathbf{10 \times 10^{-3}\ m}$

Area, A = $\pi D^2/4$

$$= \frac{\pi \times (10 \times 10^{-3})^2}{4}$$

$$= \mathbf{7.854 \times 10^{-5}\ m^2}$$

Exit Velocity, $V_n = Q/A$

$$= \frac{3.18 \times 10^{-4}}{7.854 \times 10^{-5}}$$

$$= \mathbf{4.0489\ ms^{-1}}$$

Impact Velocity, $V_i = \sqrt{V_n^2 - 2gh}$

$$= \sqrt{4.0489^2 - 2 \times 9.81 \times 0.05}$$

$$= \mathbf{3.9239\ ms^{-1}}$$

Experimental Force, $F = \rho Q V_i (1 - \cos\theta)$

$$= 1000 \times 3.18 \times 10^{-4} \times 3.9239 \times (1 - \cos 90°)$$

$$= \mathbf{1.2478\ N}$$

Theoretical Force, $F_n = mg$

$$= (150/1000) \times 9.81$$

$$= \mathbf{1.4715\ N}$$

Error (%) = $\left| \frac{F_n - F}{F_n} \right| \times 100$

$$= \left| \frac{1.4715 - 1.2478}{1.4715} \right| \times 100$$

$$= \mathbf{15.20}\ \%$$

For **200** gm weight:

Average Time, t = $\mathbf{60\ sec}$

4.054 sec time needed for 1.5 liters

So, Volume = $\left(\frac{1.5\times60}{4.054}\right)$

$= \mathbf{22.2\ litre/min}$

Flow Rate, Q = $\mathrm{V/t}$

$= \left(\frac{22.2\ \times0.001}{60}\right)$

$= \mathbf{3.7 \times 10^{-4}\ m^3/s}$

Nozzle Diameter, D = $\mathbf{10 \times 10^{-3}\ m}$

Area, A = $\pi \mathrm{D}^2/4$

$= \frac{\pi \times (10\ \times10^{-3})^2}{4}$

$= \mathbf{7.854 \times 10^{-5}\ m^2}$

Exit Velocity, $\mathrm{V_n}$ = $\mathrm{Q/A}$

$= \frac{3.7\times10^{-4}}{7.854\times10^{-5}}$

$= \mathbf{4.711\ ms^{-1}}$

Impact Velocity, $\mathrm{V_i} = \sqrt{\mathrm{V_n^2} - 2\mathrm{gh}}$

$= \sqrt{4.711^2 - 2 \times 9.81 \times 0.05}$

$= \mathbf{4.604\ ms^{-1}}$

Experimental Force, F = $\rho \mathrm{QV_i}(1 - \cos\theta)$

$= 1000 \times 3.7 \times 10^{-4} \times 4.604 \times (1 - \cos 90°)$

$= \mathbf{1.7035\ N}$

Theoretical Force, F_n = mg

$= (200/1000) \times 9.81$

$= \mathbf{1.962\ N}$

Error (%) = $\left| \frac{F_n - F}{F_n} \right| \times 100$

$= \left| \frac{1.962 - 1.7035}{1.962} \right| \times 100$

= $\mathbf{13.18}$ %

For **250** gm weight:

Average Time, t = $\mathbf{60\ sec}$

3.676 sec time needed for 1.5 liters

So, Volume = $\left(\frac{1.5\times60}{3.676}\right)$

$= \mathbf{24.48\ litre/min}$

Flow Rate, Q = V/t

$= \left(\frac{24.48\times0.001}{60}\right)$

$= \mathbf{4.08 \times 10^{-4}\ m^3/s}$

Nozzle Diameter, D = $\mathbf{10 \times 10^{-3}\ m}$

Area, A = $\pi D^2/4$

$= \frac{\pi \times (10 \times 10^{-3})^2}{4}$

$= \mathbf{7.854 \times 10^{-5}\ m^2}$

Exit Velocity, $V_n = Q/A$

$$= \frac{4.08\times10^{-4}}{7.854\times10^{-5}}$$

$$= \mathbf{5.1948\ ms^{-1}}$$

Impact Velocity, $V_i = \sqrt{V_n^2 - 2gh}$

$$= \sqrt{5.1948^2 - 2 \times 9.81 \times 0.05}$$

$$= \mathbf{5.098\ ms^{-1}}$$

Experimental Force, $F = \rho Q V_i(1 - \cos\theta)$

$$= 1000 \times 5.1948 \times 10^{-4} \times 5.098 \times (1 - \cos 90°)$$

$$= \mathbf{2.0799\ N}$$

Theoretical Force, $F_n = mg$

$$= (250/1000) \times 9.81$$

$$= \mathbf{2.4525\ N}$$

Error (%) = $\left| \frac{F_n - F}{F_n} \right| \times 100$

$$= \left| \frac{2.4525-2.0799}{2.4525} \right| \times 100$$

$$= \mathbf{15.19}\ \%$$

Inclined Vane:

For **100** gm weight:

Average Time, t = $\mathbf{60\ sec}$

2.266 sec time needed for 1.5 liters

So, Volume = $\left(\frac{1.5\times60}{2.266}\right)$

$= \mathbf{39.72\ litre/min}$

Flow Rate, Q = $\mathrm{V/t}$

$= \left(\frac{39.72\times0.001}{60}\right)$

$= \mathbf{6.62\times10^{-4}\ m^3/s}$

Nozzle Diameter, D = $\mathbf{10\times10^{-3}\ m}$

Area, A = $\pi D^2/4$

$= \frac{\pi\times(10\times10^{-3})^2}{4}$

$= \mathbf{7.854\times10^{-5}\ m^2}$

Exit Velocity, V_n = Q/A

$= \frac{6.62\times10^{-4}}{7.854\times10^{-5}}$

$= \mathbf{8.4288\ ms^{-1}}$

Impact Velocity, $V_i = \sqrt{V_n^2 - 2gh}$

$= \sqrt{8.4288^2 - 2\times9.81\times0.05}$

$= \mathbf{8.3704\ ms^{-1}}$

Experimental Force, $F = \rho Q V_i(1 - \cos\theta)$

$= 1000 \times 6.62 \times 10^{-4} \times 8.3704 \times (1 - \cos 30°)$

$= \mathbf{0.7424\ N}$

Theoretical Force, $F_n = mg$

$= (100/1000) \times 9.81$

$= \mathbf{0.981\ N}$

Error (%) = $\left| \frac{F_n - F}{F_n} \right| \times 100$

$= \left| \frac{0.981 - 0.7424}{0.981} \right| \times 100$

$= \mathbf{24.32}\ \%$

For **150** gm weight:

Average Time, t = $\mathbf{60\ sec}$

1.847 sec time needed for 1.5 liters

So, Volume = $\left(\frac{1.5 \times 60}{1.847}\right)$

$= \mathbf{48.72\ litre/min}$

Flow Rate, $Q = V/t$

$= \left(\frac{48.72 \times 0.001}{60}\right)$

$= \mathbf{8.12 \times 10^{-4}\ m^3/s}$

Nozzle Diameter, $D = \mathbf{10 \times 10^{-3}\ m}$

Area, $A = \pi D^2/4$

$= \frac{\pi \times (10 \times 10^{-3})^2}{4}$

$= \mathbf{7.854 \times 10^{-5}\ m^2}$

Exit Velocity, $V_n = Q/A$

$$= \frac{8.12 \times 10^{-4}}{7.854 \times 10^{-5}}$$

$$= \mathbf{10.3387\ ms^{-1}}$$

Impact Velocity, $V_i = \sqrt{V_n^2 - 2gh}$

$$= \sqrt{10.3387^2 - 2 \times 9.81 \times 0.05}$$

$$= \mathbf{10.2911\ ms^{-1}}$$

Experimental Force, $F = \rho Q V_i (1 - \cos\theta)$

$$= 1000 \times 8.12 \times 10^{-4} \times 10.2911 \times (1 - \cos 30°)$$

$$= \mathbf{1.1195\ N}$$

Theoretical Force, $F_n = mg$

$$= (150/1000) \times 9.81$$

$$= \mathbf{1.4715\ N}$$

Error (%) = $\left| \frac{F_n - F}{F_n} \right| \times 100$

$$= \left| \frac{1.4715 - 1.1195}{1.4715} \right| \times 100$$

$$= \mathbf{23.92}\ \%$$

For **200** gm weight:

Average Time, t = $\mathbf{60\ sec}$

1.57 sec time needed for 1.5 liters

So, Volume = $\left(\frac{1.5 \times 60}{1.57}\right)$

$$= \mathbf{57.48\ litre/min}$$

Flow Rate, $Q = V/t$

$$= \left(\frac{57.48 \times 0.001}{60}\right)$$

$$= \mathbf{9.58 \times 10^{-4}\ m^3/s}$$

Nozzle Diameter, $D = \mathbf{10 \times 10^{-3}\ m}$

Area, $A = \pi D^2/4$

$$= \frac{\pi \times (10 \times 10^{-3})^2}{4}$$

$$= \mathbf{7.854 \times 10^{-5}\ m^2}$$

Exit Velocity, $V_n = Q/A$

$$= \frac{9.58 \times 10^{-4}}{7.854 \times 10^{-5}}$$

$$= \mathbf{12.1976\ ms^{-1}}$$

Impact Velocity, $V_i = \sqrt{V_n^2 - 2gh}$

$$= \sqrt{12.1976^2 - 2 \times 9.81 \times 0.05}$$

$$= \mathbf{12.1573\ ms^{-1}}$$

Experimental Force, $F = \rho Q V_i (1 - \cos\theta)$

$$= 1000 \times 9.58 \times 10^{-4} \times 12.1573 \times (1 - \cos 30°)$$

$$= \mathbf{1.5604\ N}$$

Theoretical Force, $F_n = mg$

$$= (200/1000) \times 9.81$$

$$= \mathbf{1.962\ N}$$

Error (%) = $\left| \frac{F_n - F}{F_n} \right| \times 100$

$= \left| \frac{1.962 - 1.5604}{1.962} \right| \times 100$

$= \mathbf{20.47}$ %

For **250** gm weight:

Average Time, t = $\mathbf{60\ sec}$

1.41 sec time needed for 1.5 liters

So, Volume = $\left(\frac{1.5 \times 60}{1.41}\right)$

$= \mathbf{63.78\ litre/min}$

Flow Rate, Q = V/t

$= \left(\frac{63.78 \times 0.001}{60}\right)$

$= \mathbf{10.63 \times 10^{-4}\ m^3/s}$

Nozzle Diameter, D = $\mathbf{10 \times 10^{-3}\ m}$

Area, A = $\pi D^2/4$

$= \frac{\pi \times (10 \times 10^{-3})^2}{4}$

$= \mathbf{7.854 \times 10^{-5}\ m^2}$

Exit Velocity, V_n = Q/A

$= \frac{10.63 \times 10^{-4}}{7.854 \times 10^{-5}}$

$= \mathbf{13.5345\ ms^{-1}}$

Impact Velocity, $V_i = \sqrt{V_n^2 - 2gh}$

$= \sqrt{13.5345^2 - 2 \times 9.81 \times 0.05}$

$= \mathbf{13.4982\ ms^{-1}}$

Experimental Force, $F = \rho Q V_i (1 - \cos\theta)$

$= 1000 \times 10.63 \times 10^{-4} \times 13.4982 \times (1 - \cos 30°)$

$= \mathbf{1.9223\ N}$

Theoretical Force, $F_n = mg$

$= (250/1000) \times 9.81$

$= \mathbf{2.4525\ N}$

Error (%) $= \left| \frac{F_n - F}{F_n} \right| \times 100$

$= \left| \frac{2.4525 - 1.9223}{2.4525} \right| \times 100$

$= \mathbf{21.62}$ %

Spherical Vane:

For **100** gm weight:

Average Time, t = $\mathbf{60\ sec}$

7.69 sec time needed for 1.5 liters

So, Volume = $\left(\frac{1.5\times60}{7.69}\right)$

$= \mathbf{11.7\ litre/min}$

Flow Rate, Q = $\mathrm{V/t}$

$= \left(\frac{11.7\ \times0.001}{60}\right)$

$= \mathbf{1.95 \times 10^{-4}\ m^3/s}$

Nozzle Diameter, D = $\mathbf{10 \times 10^{-3}\ m}$

Area, A = $\pi D^2/4$

$= \frac{\pi \times (10\ \times10^{-3})^2}{4}$

$= \mathbf{7.854 \times 10^{-5}\ m^2}$

Exit Velocity, V_n = $\mathrm{Q/A}$

$= \frac{1.95\times10^{-4}}{7.854\times10^{-5}}$

$= \mathbf{2.4828\ ms^{-1}}$

Impact Velocity, $V_i = \sqrt{V_n^2 - 2gh}$

$= \sqrt{2.4828^2 - 2 \times 9.81 \times 0.0508}$

$= \mathbf{2.273\ ms^{-1}}$

Experimental Force, $F = \rho Q V_i (1 - \cos\theta)$

$= 1000 \times 1.95 \times 10^{-4} \times 2.273 \times (1 - \cos 180°)$

$= \mathbf{0.8866\ N}$

Theoretical Force, $F_n = mg$

$= (100/1000) \times 9.81$

$= \mathbf{0.981\ N}$

Error (%) = $\left| \frac{F_n - F}{F_n} \right| \times 100$

$= \left| \frac{0.981 - 0.8866}{0.981} \right| \times 100$

$= \mathbf{9.63}$ %

For **150** gm weight:

Average Time, t = $\mathbf{60\ sec}$

6.38 sec time needed for 1.5 liters

So, Volume = $\left(\frac{1.5 \times 60}{6.38} \right)$

$= \mathbf{14.1\ litre/min}$

Flow Rate, $Q = V/t$

$= \left(\frac{14.1 \times 0.001}{60} \right)$

$= \mathbf{2.35 \times 10^{-4}\ m^3/s}$

Nozzle Diameter, D = $\mathbf{10 \times 10^{-3}\ m}$

Area, A = $\pi D^2/4$

$$= \frac{\pi \times (10 \times 10^{-3})^2}{4}$$

$$= \mathbf{7.854 \times 10^{-5}\ m^2}$$

Exit Velocity, $V_n = Q/A$

$$= \frac{2.35 \times 10^{-4}}{7.854 \times 10^{-5}}$$

$$= \mathbf{2.9921\ ms^{-1}}$$

Impact Velocity, $V_i = \sqrt{V_n^2 - 2gh}$

$$= \sqrt{2.9921^2 - 2 \times 9.81 \times 0.0508}$$

$$= \mathbf{2.82\ ms^{-1}}$$

Experimental Force, $F = \rho Q V_i (1 - \cos\theta)$

$$= 1000 \times 2.35 \times 10^{-4} \times 2.82 \times (1 - \cos 180°)$$

$$= \mathbf{1.3257\ N}$$

Theoretical Force, $F_n = mg$

$$= (150/1000) \times 9.81$$

$$= \mathbf{1.4715\ N}$$

Error (%) = $\left| \frac{F_n - F}{F_n} \right| \times 100$

$$= \left| \frac{1.4715 - 1.3257}{1.4715} \right| \times 100$$

$$= \mathbf{9.91}\ \%$$

For **200** gm weight:

Average Time, t = $\mathbf{60\ sec}$

5.515 sec time needed for 1.5 liters

So, Volume = $\left(\frac{1.5\times60}{5.515}\right)$

$= \mathbf{16.32\ litre/min}$

Flow Rate, Q = $\mathrm{V/t}$

$= \left(\frac{16.32\ \times0.001}{60}\right)$

$= \mathbf{2.72 \times 10^{-4}\ m^3/s}$

Nozzle Diameter, D = $\mathbf{10 \times 10^{-3}}$ **m**

Area, A = $\pi\mathrm{D}^2/4$

$= \frac{\pi \times (10\ \times10^{-3})^2}{4}$

$= \mathbf{7.854 \times 10^{-5}\ m^2}$

Exit Velocity, $\mathrm{V_n}$ = $\mathrm{Q/A}$

$= \frac{2.72\times10^{-4}}{7.854\times10^{-5}}$

$= \mathbf{3.463\ ms^{-1}}$

Impact Velocity, $\mathrm{V_i} = \sqrt{\mathrm{V_n^2} - 2\mathrm{gh}}$

$= \sqrt{3.463^2 - 2 \times 9.81 \times 0.0508}$

$= \mathbf{3.316\ ms^{-1}}$

Experimental Force, F = $\rho\mathrm{QV_i}(1 - \cos\theta)$

$= 1000 \times 2.72 \times 10^{-4} \times 3.316 \times (1 - \cos180°)$

$= \mathbf{1.804\ N}$

Theoretical Force, F_n = mg

$= (200/1000) \times 9.81$

$= \mathbf{1.962\ N}$

Error (%) = $\left| \frac{F_n - F}{F_n} \right| \times 100$

$= \left| \frac{1.962 - 1.804}{1.962} \right| \times 100$

$= \mathbf{8.05}\ \%$

For **250** gm weight:

Average Time, t = $\mathbf{60\ sec}$

5.085 sec time needed for 1.5 liters

So, Volume = $\left(\frac{1.5 \times 60}{5.085}\right)$

$= \mathbf{17.7\ litre/min}$

Flow Rate, Q = V/t

$= \left(\frac{17.7 \times 0.001}{60}\right)$

$= \mathbf{2.95 \times 10^{-4}\ m^3/s}$

Nozzle Diameter, D = $\mathbf{10 \times 10^{-3}\ m}$

Area, A = $\pi D^2/4$

$= \frac{\pi \times (10 \times 10^{-3})^2}{4}$

$= \mathbf{7.854 \times 10^{-5}\ m^2}$

Exit Velocity, $V_n = Q/A$

$$= \frac{2.95\times10^{-4}}{7.854\times10^{-5}}$$

$$= \mathbf{3.756\ ms^{-1}}$$

Impact Velocity, $V_i = \sqrt{V_n^2 - 2gh}$

$$= \sqrt{3.756^2 - 2 \times 9.81 \times 0.0508}$$

$$= \mathbf{3.621\ ms^{-1}}$$

Experimental Force, $F = \rho Q V_i (1 - \cos\theta)$

$$= 1000 \times 2.95 \times 10^{-4} \times 3.621 \times (1 - \cos 180°)$$

$$= \mathbf{2.1364\ N}$$

Theoretical Force, $F_n = mg$

$$= (250/1000) \times 9.81$$

$$= \mathbf{2.4525\ N}$$

Error (%) $= \left| \frac{F_n - F}{F_n} \right| \times 100$

$$= \left| \frac{2.4525 - 2.1364}{2.4525} \right| \times 100$$

$$= \mathbf{12.89}\ \%$$

Conical Vane:

For **100** gm weight:

Average Time, t = $\mathbf{60\ sec}$

2.9 sec time needed for 1.5 liters

So, Volume = $\left(\frac{1.5\times60}{2.9}\right)$

$= \mathbf{31.08\ litre/min}$

Flow Rate, Q = $\mathrm{V/t}$

$= \left(\frac{31.08\ \times0.001}{60}\right)$

$= \mathbf{5.18 \times 10^{-4}\ m^3/s}$

Nozzle Diameter, D = $\mathbf{10 \times 10^{-3}\ m}$

Area, A = $\pi\mathrm{D}^2/4$

$= \frac{\pi \times (10\ \times10^{-3})^2}{4}$

$= \mathbf{7.854 \times 10^{-5}\ m^2}$

Exit Velocity, $\mathrm{V_n}$ = $\mathrm{Q/A}$

$= \frac{5.18\times10^{-4}}{7.854\times10^{-5}}$

$= \mathbf{6.595\ ms^{-1}}$

Impact Velocity, $\mathrm{V_i} = \sqrt{\mathrm{V_n^2} - 2\mathrm{gh}}$

$= \sqrt{6.595^2 - 2 \times 9.81 \times 0.045}$

$= \mathbf{6.528\ ms^{-1}}$

Experimental Force, $F = \rho Q V_i(1 - \cos\theta)$

$= 1000 \times 5.18 \times 10^{-4} \times 6.528 \times (1 - \cos 40°)$

$= \mathbf{0.7911\ N}$

Theoretical Force, $F_n = mg$

$= (100/1000) \times 9.81$

$= \mathbf{0.981\ N}$

Error (%) $= \left| \frac{F_n - F}{F_n} \right| \times 100$

$= \left| \frac{0.981 - 0.7911}{0.981} \right| \times 100$

$= \mathbf{19.35}$ %

For **150** gm weight:

Average Time, $t = \mathbf{60\ sec}$

2.37 sec time needed for 1.5 liters

So, Volume $= \left(\frac{1.5 \times 60}{2.37}\right)$

$= \mathbf{37.98\ litre/min}$

Flow Rate, $Q = V/t$

$= \left(\frac{37.98 \times 0.001}{60}\right)$

$= \mathbf{6.33 \times 10^{-4}\ m^3/s}$

Nozzle Diameter, $D = \mathbf{10 \times 10^{-3}\ m}$

Area, A = $\pi D^2/4$

$$= \frac{\pi \times (10 \times 10^{-3})^2}{4}$$

$$= \mathbf{7.854 \times 10^{-5}\ m^2}$$

Exit Velocity, $V_n = Q/A$

$$= \frac{6.33\times10^{-4}}{7.854\times10^{-5}}$$

$$= \mathbf{8.0596\ ms^{-1}}$$

Impact Velocity, $V_i = \sqrt{V_n^2 - 2gh}$

$$= \sqrt{8.0596^2 - 2 \times 9.81 \times 0.045}$$

$$= \mathbf{8.0046\ ms^{-1}}$$

Experimental Force, $F = \rho Q V_i (1 - \cos\theta)$

$$= 1000 \times 6.33 \times 10^{-4} \times 8.0046 \times (1 - \cos 40°)$$

$$= \mathbf{1.1854\ N}$$

Theoretical Force, $F_n = mg$

$$= (150/1000) \times 9.81$$

$$= \mathbf{1.4715\ N}$$

Error (%) = $\left| \frac{F_n - F}{F_n} \right| \times 100$

$$= \left| \frac{1.4715 - 1.1854}{1.4715} \right| \times 100$$

$$= \mathbf{19.44}\ \%$$

For **200** gm weight:

Average Time, t = $\mathbf{60\ sec}$

2.011 sec time needed for 1.5 liters

So, Volume = $\left(\frac{1.5\times60}{2.011}\right)$

$= \mathbf{44.76\ litre/min}$

Flow Rate, Q = V/t

$= \left(\frac{44.76\times0.001}{60}\right)$

$= \mathbf{7.46\times10^{-4}\ m^3/s}$

Nozzle Diameter, D = $\mathbf{10\times10^{-3}\ m}$

Area, A = $\pi D^2/4$

$= \frac{\pi\times(10\times10^{-3})^2}{4}$

$= \mathbf{7.854\times10^{-5}\ m^2}$

Exit Velocity, V_n = Q/A

$= \frac{7.46\times10^{-4}}{7.854\times10^{-5}}$

$= \mathbf{9.4983\ ms^{-1}}$

Impact Velocity, $V_i = \sqrt{V_n^2 - 2gh}$

$= \sqrt{9.4983^2 - 2\times9.81\times0.045}$

$= \mathbf{9.4517\ ms^{-1}}$

Experimental Force, F = $\rho Q V_i(1-\cos\theta)$

$= 1000\times7.46\times10^{-4}\times9.4517\times(1-\cos40°)$

$= \mathbf{1.6496\ N}$

Theoretical Force, F_n = mg

$$= (200/1000) \times 9.81$$

$$= \mathbf{1.962\ N}$$

Error (%) = $\left|\frac{F_n - F}{F_n}\right| \times 100$

$$= \left|\frac{1.962 - 1.6496}{1.962}\right| \times 100$$

$$= \mathbf{15.92}\ \%$$

For **250** gm weight:

Average Time, t = $\mathbf{60\ sec}$

1.82 sec time needed for 1.5 liters

So, Volume = $\left(\frac{1.5 \times 60}{1.82}\right)$

$$= \mathbf{49.5\ litre/min}$$

Flow Rate, Q = V/t

$$= \left(\frac{49.5 \times 0.001}{60}\right)$$

$$= \mathbf{8.25 \times 10^{-4}\ m^3/s}$$

Nozzle Diameter, D = $\mathbf{10 \times 10^{-3}\ m}$

Area, A = $\pi D^2/4$

$$= \frac{\pi \times (10 \times 10^{-3})^2}{4}$$

$$= \mathbf{7.854 \times 10^{-5}\ m^2}$$

Exit Velocity, $V_n = Q/A$

$$= \frac{8.25\times10^{-4}}{7.854\times10^{-5}}$$

$$= \mathbf{10.5042\ ms^{-1}}$$

Impact Velocity, $V_i = \sqrt{V_n^2 - 2gh}$

$$= \sqrt{10.5042^2 - 2 \times 9.81 \times 0.045}$$

$$= \mathbf{10.462\ ms^{-1}}$$

Experimental Force, $F = \rho Q V_i (1 - \cos\theta)$

$$= 1000 \times 8.25 \times 10^{-4} \times 10.462 \times (1 - \cos 40°)$$

$$= \mathbf{2.0193\ N}$$

Theoretical Force, $F_n = mg$

$$= (250/1000) \times 9.81$$

$$= \mathbf{2.4525\ N}$$

Error (%) = $\left| \frac{F_n - F}{F_n} \right| \times 100$

$$= \left| \frac{2.4525 - 2.0193}{2.4525} \right| \times 100$$

$$= \mathbf{17.66}\ \%$$

Calculation Keeping Flow Rate Fixed:

When Q = $\mathbf{3.7 \times 10^{-4} m^3/s}$ (Fixed)

Flat Vane:

Mass, m $= \mathbf{200\ gm}$

Nozzle Diameter, D = $\mathbf{10 \times 10^{-3}\ m}$

Area, A = $\pi D^2/4$

$$= \frac{\pi \times (10 \times 10^{-3})^2}{4}$$

$$= \mathbf{7.854 \times 10^{-5}\ m^2}$$

Exit Velocity, $V_n = Q/A$

$$= \frac{3.7 \times 10^{-4}}{7.854 \times 10^{-5}}$$

$$= \mathbf{4.711\ ms^{-1}}$$

Impact Velocity, $V_i = \sqrt{V_n^2 - 2gh}$

$$= \sqrt{4.711^2 - 2 \times 9.81 \times 0.05}$$

$$= \mathbf{4.604\ ms^{-1}}$$

Experimental Force, F = $\rho Q V_i (1 - \cos\theta)$

$$= 1000 \times 3.7 \times 10^{-4} \times 4.604 \times (1 - \cos 90°)$$

$$= \mathbf{1.7035\ N}$$

Theoretical Force, F_n = mg

$$= (200/1000) \times 9.81$$

$$= \mathbf{1.962\ N}$$

Error (%) = $\left|\frac{F_n - F}{F_n}\right| \times 100$

$= \left|\frac{1.962 - 1.7035}{1.962}\right| \times 100$

$= \mathbf{13.18}$ %

Inclined Vane:

Mass, m $= \mathbf{30\ gm}$

Nozzle Diameter, D = $\mathbf{10 \times 10^{-3}\ m}$

Area, A = $\pi D^2/4$

$= \frac{\pi \times (10 \times 10^{-3})^2}{4}$

$= \mathbf{7.854 \times 10^{-5}\ m^2}$

Exit Velocity, $V_n = Q/A$

$= \frac{3.7 \times 10^{-4}}{7.854 \times 10^{-5}}$

$= \mathbf{4.711\ ms^{-1}}$

Impact Velocity, $V_i = \sqrt{V_n^2 - 2gh}$

$= \sqrt{4.711^2 - 2 \times 9.81 \times 0.05}$

$= \mathbf{4.604\ ms^{-1}}$

Experimental Force, F = $\rho Q V_i (1 - \cos\theta)$

$= 1000 \times 3.7 \times 10^{-4} \times 4.604 \times (1 - \cos 60°)$

$= \mathbf{0.2282\ N}$

Theoretical Force, F_n = mg

$$= (30/1000) \times 9.81$$

$$= \mathbf{0.2943\ N}$$

$$\text{Error (\%)} = \left| \frac{F_n - F}{F_n} \right| \times 100$$

$$= \left| \frac{0.2943 - 0.2282}{0.2943} \right| \times 100$$

$$= \mathbf{22.46}\ \%$$

Spherical Vane:

Mass, m $= \mathbf{375\ gm}$

Nozzle Diameter, D = $\mathbf{10 \times 10^{-3}\ m}$

Area, A = $\pi D^2/4$

$$= \frac{\pi \times (10 \times 10^{-3})^2}{4}$$

$$= \mathbf{7.854 \times 10^{-5}\ m^2}$$

Exit Velocity, V_n = Q/A

$$= \frac{3.7 \times 10^{-4}}{7.854 \times 10^{-5}}$$

$$= \mathbf{4.711\ ms^{-1}}$$

Impact Velocity, $V_i = \sqrt{V_n^2 - 2gh}$

$$= \sqrt{4.711^2 - 2 \times 9.81 \times 0.0508}$$

$$= \mathbf{4.6039\ ms^{-1}}$$

Experimental Force, $F = \rho Q V_i(1 - \cos\theta)$

$= 1000 \times 3.7 \times 10^{-4} \times 4.6039 \times (1 - \cos 180°)$

$= \mathbf{3.4069\ N}$

Theoretical Force, $F_n = mg$

$= (375/1000) \times 9.81$

$= \mathbf{3.67875\ N}$

Error (%) = $\left| \frac{F_n - F}{F_n} \right| \times 100$

$= \left| \frac{3.67875 - 3.4069}{3.67875} \right| \times 100$

$= \mathbf{7.39}\ \%$

Conical Vane:

Mass, m $= \mathbf{45\ gm}$

Nozzle Diameter, D = $\mathbf{10 \times 10^{-3}\ m}$

Area, $A = \pi D^2/4$

$= \frac{\pi \times (10 \times 10^{-3})^2}{4}$

$= \mathbf{7.854 \times 10^{-5}\ m^2}$

Exit Velocity, $V_n = Q/A$

$= \frac{3.7 \times 10^{-4}}{7.854 \times 10^{-5}}$

$= \mathbf{4.711\ ms^{-1}}$

Impact Velocity, $V_i = \sqrt{V_n^2 - 2gh}$

$= \sqrt{4.711^2 - 2 \times 9.81 \times 0.045}$

$= \mathbf{4.6163\ ms^{-1}}$

Experimental Force, $F = \rho Q V_i (1 - \cos\theta)$

$= 1000 \times 3.7 \times 10^{-4} \times 4.6163 \times (1 - \cos 120°)$

$= \mathbf{0.3996\ N}$

Theoretical Force, $F_n = mg$

$= (45/1000) \times 9.81$

$= \mathbf{0.44145\ N}$

Error (%) $= \left| \frac{F_n - F}{F_n} \right| \times 100$

$= \left| \frac{0.44145 - 0.3996}{0.44145} \right| \times 100$

$= \mathbf{9.48}\ \%$

Appendix B

Table:

Flat vane:

Weight (g)	Flow Rate (LPM)	Flow Rate, Q $(\mathrm{m^3/s})$
100	15.72	2.62×10^{-4}
150	19.08	3.18×10^{-4}
200	22.2	3.7×10^{-4}
250	24.48	4.08×10^{-4}

Flow Rate, Q $(\mathrm{m^3/s})$	Exit Velocity, V_n (m/s)	h, (mm)	Impact Velocity, V_i (m/s)	Experimental Force, F (N)	Theoretical Force, F_n (N)	Error, (%)
2.62×10^{-4}	3.3359	50	3.183	0.834	0.981	14.99
3.18×10^{-4}	4.0489	50	3.9239	1.2478	1.4715	15.20
3.7×10^{-4}	4.711	50	4.604	1.7035	1.962	13.18
4.08×10^{-4}	5.1948	50	5.098	2.0799	2.4525	15.19

Inclined Vane:

Weight (g)	Flow Rate (LPM)	Flow Rate, Q $(\mathrm{m^3/s})$
100	39.72	6.62×10^{-4}
150	48.72	8.12×10^{-4}
200	57.48	9.58×10^{-4}
250	63.78	10.63×10^{-4}

Flow Rate, Q $(\mathrm{m^3/s})$	Exit Velocity, V_n (m/s)	h, (mm)	Impact Velocity, V_i (m/s)	Experimental Force, F (N)	Theoretical Force, F_n (N)	Error, (%)
6.62×10^{-4}	8.4288	50	8.3704	0.7424	0.981	24.32
8.12×10^{-4}	10.3387	50	10.2911	1.1195	1.4715	23.92
9.58×10^{-4}	12.1976	50	12.1573	1.5604	1.962	20.47
10.63×10^{-4}	13.5345	50	13.4982	1.9223	2.4525	21.62

Spherical Vane:

Weight (g)	Flow Rate (LPM)	Flow Rate, Q $(\mathrm{m^3/s})$
100	11.7	1.95×10^{-4}
150	14.1	2.35×10^{-4}
200	16.32	2.72×10^{-4}
250	17.7	2.95×10^{-4}

Flow Rate, Q $(\mathrm{m^3/s})$	Exit Velocity, V_n $(\mathrm{m/s})$	h, (mm)	Impact Velocity, V_i $(\mathrm{m/s})$	Experimental Force, F (N)	Theoretical Force, F_n (N)	Error, (%)
1.95×10^{-4}	2.4828	50.8	2.273	0.8866	0.981	9.63
2.35×10^{-4}	2.9921	50.8	2.82	1.3257	1.4715	9.91
2.72×10^{-4}	3.463	50.8	3.316	1.804	1.962	8.05
2.95×10^{-4}	3.756	50.8	3.621	2.1364	2.4525	12.89

Conical Vane:

Weight (g)	Flow Rate (LPM)	Flow Rate, Q $(\mathrm{m^3/s})$
100	31.08	5.18×10^{-4}
150	37.98	6.33×10^{-4}
200	44.76	7.46×10^{-4}
250	49.5	8.25×10^{-4}

Flow Rate, Q $(\mathrm{m^3/s})$	Exit Velocity, V_n $(\mathrm{m/s})$	h, (mm)	Impact Velocity, V_i $(\mathrm{m/s})$	Experimental Force, F (N)	Theoretical Force, F_n (N)	Error, (%)
5.18×10^{-4}	6.595	45	6.528	0.7911	0.981	19.35
6.33×10^{-4}	8.0596	45	8.0046	1.1854	1.4715	19.44
7.46×10^{-4}	9.4983	45	9.4517	1.6496	1.962	15.92
8.25×10^{-4}	10.5042	45	10.462	2.0193	2.4525	17.66

When Flow Rate Fixed:

When Q = $\mathbf{3.7 \times 10^{-4} m^3/s}$ (Fixed)

Table:

Vane	**Weight (g)**	**Exit Velocity, $\mathbf{V_n}$ $\mathbf{(m/s)}$**	**h, (mm)**	**Impact Velocity, $\mathbf{V_i}$ $\mathbf{(m/s)}$**	**Experimental Force, F $\mathbf{(N)}$**	**Theoretical Force, $\mathbf{F_n}$ $\mathbf{(N)}$**	**Error,** (%)
Flat	200	4,711	50	4.604	1.7035	1.962	13.18
Inclined	30	4.711	50	4.604	0.2282	0.2943	22.46
Spherical	375	4.711	50.8	4.6039	3.4069	3.67875	7.39
Conical	45	4.711	45	4.6163	0.3996	0.44145	9.48