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# DESIGN AND CONSTRUCTION OF THE IMPACT OF JET APPARATUS FOR THE FLUID MECHANICS LABORATORY

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***Abstract**:* The design and construction of the impact of the jet laboratory apparatus have been completed. The design analysis was carried out for the apparatus's significant components: the pipe, the cylinder, the flat plate, the curved cup, and the spring. The areas of the big elbow PVC and nozzle pipe are 0.0010752 and 0.0004908 $m^2$, respectively. The area and volume of the transparent PVC cylinder are 0.5026 $m^2$ and 0.4021 $m^3$, respectively. The area and volume of the flat plate and the hemispherical cup are 0.000625 $m^2$ and 0.134 $m^3$, respectively. The maximum weight the spring can carry was determined to be 70.1 N, while the highest mass was 7.1 kg. The deflection of the spring was calculated to be 4.3 m. The jet impact efficiency was 92 %. The results from the flat plate experiment with the nozzle at 90° showed that the mass increased from 0.05 to 0.5 kg, with a corresponding increase in discharge from 0.3162 to 0.7257 $m^3/s$. The results from the curve cup for the nozzle at 180 ° showed that the mass increased from 0.05 to 0.2 kg, with the same increase in discharge from 0.156 to 0.1891 $m^3/s$, while the discharge decreased from 0.189 to 0.1766 $m^3/s$, as the mass increased from 0.25 to 0.5 kg.

***Keywords*:** *Design and construction; PVC pipe; nozzle; flat plate and curved cup; spring; straight iron rod.*

## INTRODUCTION

The jet's impact is utilized to rotate the turbine, namely the Pelton wheel, in the generator as noted by [1]. The water jet exerts a tangential force on the wheel. The tangential forces of the water jet produce maximum torque on the wheel, thus enhancing the mechanical energy of the wheel, which is then turned into electrical energy.

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Additionally, another application of water jet technology is the water jet cutter. A water jet cutter can slice through metal and other materials using high-pressure, high-velocity water jets, a process akin to natural water erosion but accelerated and concentrated [3]. This apparatus measures the force produced by a water jet impacting a flat plate or a hemispherical cup and compares the findings with the calculated momentum flow rate of the jet [8,9]. The design and building of the jet laboratory apparatus is intended for demonstration purposes in a laboratory setting. The operation of this apparatus incorporates several geometries (flat plate, curved, and hemispherical). The target is encircled by a rod, a top which is a cup that can accommodate weights, supported by a spring, with the jet impacting the cup to provide force measurement [9-12]. The jet laboratory apparatus facilitates experiments on the vane. The examination of these response forces is a crucial phase in fluid mechanics and applies to hydraulic machinery such as the Pelton wheel and the impulse turbine [10]. Currently, the force of water jets is extensively utilized in many mechanical applications, including surface cleaning and treatment [8]. The primary issue with conventional mechanical cutting tools is their significant wear from direct contact with the workpiece, which rapidly increases cutting temperature. Degraded tools generate elevated cutting forces. This critical issue can be resolved using water-jet force technology, which avoids thermal complications such as recast layers and thermal distortion while exerting minimal stress on the work material [12]. This process is accomplished by generating a high-velocity stream of water, with or without abrasives, that removes material primarily through erosion. The erosive impact of water-jet forces has been used since the early 1930s in the tunnelling and mining sectors. At that time, it was feasible to generate a pump pressure of around 10 MPa [11]. The consistent application of water jet technology commenced circa 1975 for the cutting of newborn nappies using pure water. The essential expansion of potential applications occurred around 180, with the incorporation of abrasives such as sand (garment) or corundum (aluminum oxide), resulting in a notable enhancement in cutting performance [14]. Recent advancements in water jet force technology enable its application across nearly all production processes involving a diverse array of materials. Unlike mechanical cutting processes, the waterjet cutting tool is not a rigid body but rather a stream of fluid. Throughout the process, its geometric dimensions and fluid flow are variable. The system encompasses the intricacies of jet formation and the fluid dynamics in the free air space, where mass and energy are transported [13]. [13] asserted that water exists from a combination of orifices and traverses within the beam stream. It is comparable to a river, where the stream remains constant, although the flowing water displays geographically and temporally varying flow rates. Furthermore, at the orifice of a jet nozzle, the beam width and length may remain constant over time. [13-16] elucidated that a fluid jet consists of a stream of fluid ejected from the nozzle at high velocity, resulting in elevated kinetic energy. A jet striking a plate or vane puts a force on it due to a change in momentum [16]. [8] observed that chondrules may have originated in environments abundant in dust (high dust-to-gas ratio), resembling impact plumes more than conventional depictions of the solar nebula. These concepts employed turbulence to aggregate dust and proposed that shock waves or high-energy collisions supply the energy for melting. [9] approached the issue from an alternative perspective and suggested that the dust was highly concentrated, accumulating into substantial formations, so creating dust piles upon which one can stand. A significant impact disrupts their objectives, as previously discussed.

The initial phase of an effect entails intense pressure and energy, resulting in the total melting of material at the interface between the impactor and the target body, which is then ejected at high velocity. Both theoretical and experimental evidence indicate that in the early phases of a high-velocity impact, a jet of molten material emanates radially from the point of impact and disperses from both bodies [16].

## MATERIALS AND METHODS

**The components listed below were used to design the impact of the jet apparatus.**

(1) A stem or connecting rod; (2) Loading pan or scale or weight pan; (3) Deflectors (vane); (4) PVC Nozzle; (5). Helical Spring; (6). Meter rule; (7). Pointer; (8). Three (3) binding or holding rods; (9). Nuts; (10). Base plate (top and bottom); (11). Supply and inlet connection; (12). Drain connection or discharge; (13). three (3) Iron legs stand [4, 5, 14].

**Tools used for the construction of the project**

(1). A tape; (2). A steel rule; (3). Venier-calliper; (4). Gum; (5). Spanner; (6). Scriber; (7). Spanner (8). Rubber fittings; (9). Washer [6].

**Design considerations**

The following were considered for using the materials [9].

1. A transparent cylinder to see the impact of jets
2. A nozzle designed for producing a jet
3. Spring assisting in compression and supporting the weight pan
4. The apparatus can be positioned on the hydraulic bench.
5. Drainage or discharge part for expelling water post-readings
6. The flow rate and, consequently, the impact force must be modified from the supply.

These were the assumptions made [14].

1. The interaction between water particles and the target surface is free of friction.
2. When water molecules impact the target surface, they will maintain a consistent angle with the water jet, ensuring that the target surface remains stationary.
3. The collision between water molecules and the target surface is fully elastic. The kinetic energy and linear momentum of the water jet are consequently conserved.
4. The size of the water jet's force remains constant as it exits the nozzle and impacts the target.
5. The aircraft is positioned as near as feasible to the water jet's acceleration.

**APPARATUS SET-UP [16]**.

1. Detach the upper plate of the equipment and clear the enclosure.
2. Assess the diameter of the nozzle.
3. Fix the flat target to the bar linked to the weight pan.
4. Reassemble the device and position it in the bench channel.
5. Attach the device hose to the water supply.
6. Adjust the apparatus base to a level position utilizing the black feet.
7. Align the pointer with the datum line on the weight pan, reducing friction in the spring by oscillating the weight pan.

**Description of the apparatus [11].**

Once the apparatus is assembled (see the setup procedure above), connect the feed tube of the hydraulics bench to the rear base of the jet impact apparatus, and install the 0.37m nozzle along with the flat target. Activate the pump or tap to initiate water flow, directing nozzle discharge at the target. Once the target has stabilized, deactivate the pump to halt the supply, pause the stopwatch, and record your measurements before discharging the water for the subsequent experiment.

1. Position a 50g mass on the weighing pan.
2. Activate the electricity at the wall outlet.
3. Activate the pump at the bench control panel and open the red valve to initiate the water delivery. The pump must be deactivated while the water supply is not in use; otherwise, it may overheat and fail.
4. Regulate the flow rate via the red valve until the datum line on the weight pan aligns with the pointer once more (slightly jostle the pan to mitigate friction in the spring).
5. Measure the flow by lowering the ball plug and measuring volume rise with time using the top volume indicator on the side of the bench. Initiate the stopwatch upon the level reaching zero.
6. Persist in adding 50g weight and reiterate the procedure until you obtain ten measurements.
7. Experiment again, utilizing the 1200 and hemispherical targets.

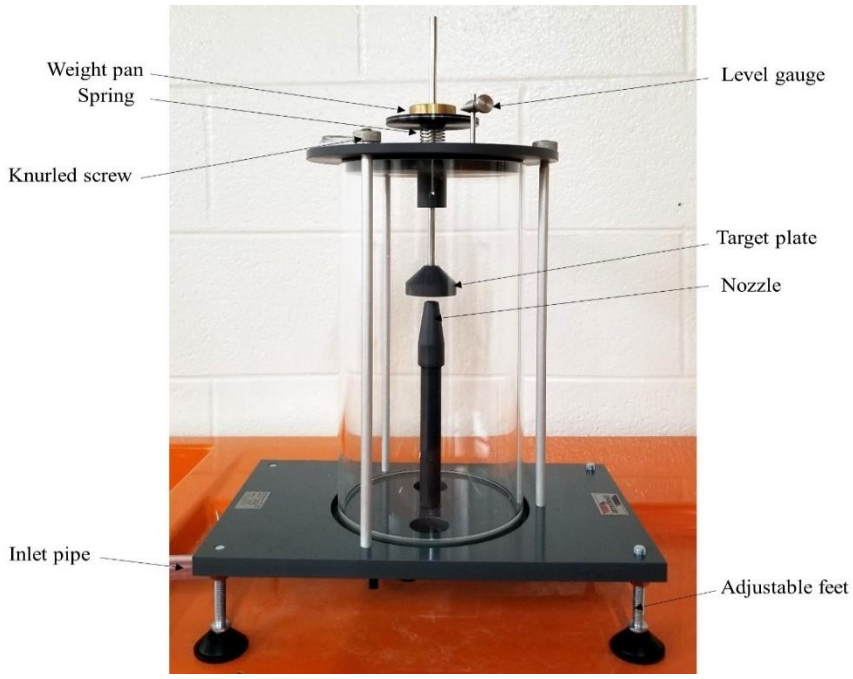



Fig.1. Impacts of jets laboratory apparatus.

**DESIGN EQUATIONS**

**The area of the PVC Nuzzle, according to [3-6], is given by equation (1).**

Diameter of nuzzle $d_1$ = 37mm (0.037m); $d_2$ = 25mm (0.025m)

$$\text{Area}_1 = \frac{\pi d^2}{4} \quad (1)$$

$$\text{Area}_2 = \frac{\pi d^2}{4} \quad (2)$$

**The volume of the transparent cylinder is stated by [10] in equation (3).**

$$\text{Volume, } V = \pi r^2 h \quad (3)$$

Where: D = outer diameter; d = inner diameter; r = radius; h = height

D = 80mm (0.8m), r = 40mm = (0.4m), h = 800mm (0.8m)

$$\text{Area Ac} = \frac{\pi d^2}{4} \quad (4)$$

**The volume of the hemispherical cup,**

$$V_h = \frac{2\pi r^3}{3} \quad (5)$$

**The area of the Flat cup.**

$$Area = lenght \times width \quad (6)$$

**The maximum load the spring can carry, according to [7], is given in equations (7-13).**

The parameters of the Helical Spring:

$D = 60mm\ (0.60m), d = 6mm(0.06m), n = 20mm\ (0.2m), W = 800\text{N}$

Where, D = Outer diameter; d = inner diameter; n = number of springs;

W = Loaded mass

$$\text{Area of the spring, } \frac{\pi D^2}{4} \quad (7)$$

$$\text{C = Spring index} = \frac{D}{d} \quad (8)$$

$$\text{Shear stress factor } k_s = 1 + \frac{1}{2c} \quad (9)$$

$$\text{Maximum shear stress } \tau = k_s \times \frac{8.W.D}{\pi d^3} \quad (10)$$

(neglecting the effect of wire curvature)

The maximum load the spring can carry,

From shear stress $\tau$

$$W = \frac{\tau \times \pi \times d^3}{k_s \times 8 \times D} \quad (11)$$

Therefore, the maximum weight the spring can carry = $7.1k_g$

The modulus of rigidity for the spring material, G (N/mm$^2$)

$$G = \frac{Force}{area} \quad (12)$$

The deflection (δ) of the spring because of an axial load,

$$\delta = \frac{8.W.D^3}{G.d^4} \quad (13)$$

The efficiency of Impact of Jets ($\eta_{Jet}$) as given by [15] is stated in eqn. (14).

The input diameter of a straight iron bar is 55mm; the output diameter of the spring is 60mm.

$$\eta_{Jet} = \frac{Input}{output} \times 100 \quad (14)$$

**Newton's Second Law of Motion**

This law states that "The net forces are equal to the rate at which momentum changes" or

The force acting on an object is equal to the mass of that object times its acceleration.

$$F = ma \quad (15)$$

Where, F = force; M = mass; a = acceleration

**Newton's Third law of motion [12].**

This law states that for every action, there is an equal and opposite reaction."

**MOMENTUM EQUATION**

Newton's second law states that "the sum of forces acting on an element of fluid to its acceleration is equal to the rate of change of momentum [8-10].

$$p = mv \quad (16)$$

Where, P = momentum of the body; m = mass; v = velocity of the body.

Mathematical derivations.

Applying the momentum equation in the y-direction, the force exerted by the vane, $F_y$ is given by [12-16] and is presented in equation (17).

$$F_y = \rho Q(V_{out} - V_{in}) \quad (17)$$

Where Vout is the velocity of the jet before striking the plate, and Vin is the velocity of the plane after striking the plate.

**Force on a flat plate**

$$F_1 = \rho Q(V_{out} - V_{in}) \quad (18)$$

The velocity of the jet after striking the plate is equal to zero ($V_{in}$=0).

$$F_1 = \rho Q(V_{0ut} - 0)$$

$$F_1 = \rho QV$$

**Force on a curved plate**

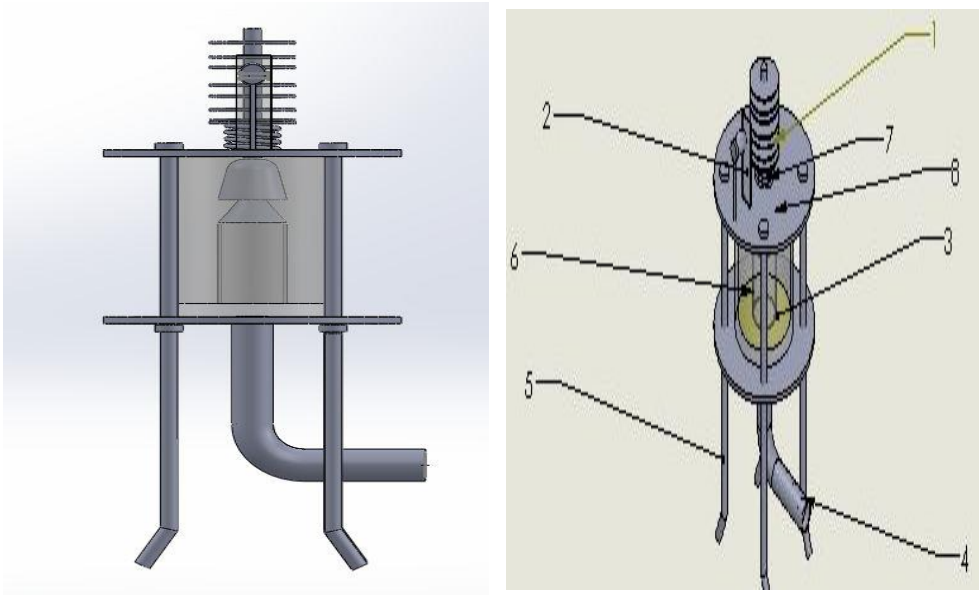
$$F_2 = \rho QV(\cos\theta + 1) \quad (19)$$

$$\theta = (180 - \delta)$$

δ- fluid flow deflection.

Where, Q = Discharge from the nozzle; V = velocity of jet; $A_n$ = area of the nozzle

$$V = \frac{Q}{A_n} \quad (20)$$




(a) Front view (b) 3D-view

Fig. 2. The three 3D Impact of Jet (a) and (b).
(b). 3D-view. 1-the mass (kg); 2- the meter rule (m); 3- the PVC pipe inside the trasparent glass; 4- the PVC elbow pipe; 5- iron stand; 6- transparent PVC glass.

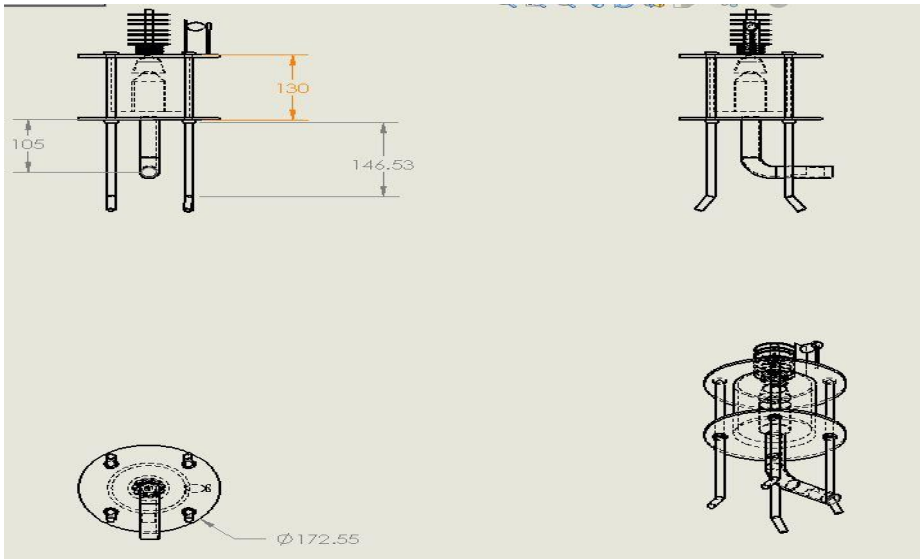



Fig. 3. The autographic drawing of the Impact of Jets.

## CONSTRUCTION PROCEDURES

The construction procedures in this project involve measuring, marking out, cutting, bending, and assembling.

Table 1. Construction Procedures.

| s/n | Operation | Tools used | Description |
|---|---|---|---|
| 1 | Measuring, marking, and cutting out the required length for the binding rods and the legs. | Tape, steel rule vice, hawk saw. | The mild steel rod was placed in the vice and tightened firmly. The required length is measured and marked with the steel rule and scriber, then cut. |
| 2 | Measuring, marking out, cutting off, and bending the base plate | Tape, steel rule, vernier caliper, vice, hawk saw, scriber | The steel plate was placed correctly, measured out, and marked. Then the marked-out part was punched round and gently removed and filed for smoothing, then re-measured |
| 3 | Measuring, marking, and perforating | Vernier caliper, scriber, drilling machine | The top and bottom plates were placed correctly, measured, marked out, and drilled (a hole was made) to the diameter of the binding or holding rod. |
| 4 | Assembling the round steel irons on the base plate, both the top and bottom. | Soldering machine | The steel round iron was soldered on top of the base plate |
| 5. | Fitting the nozzle and the discharge pipe on the bottom plate | | Screw in the nozzle pipe to the base plate, then insert the nozzle, secure it to the discharge pipe, and test the flow rate, etc. |
| 6 | Fitting the metre rule, the steam, spring, weight pan, and pointer. | Plier, welding machine | Place the meter rule on the base plate after bending and tack it up by welding it lightly; screw in the pointer by the side, fit in the weight pan on the stem, put in the spring on the top base plate, push in the stem, and ensure it is free to move up and down. |
| 7 | Fitting in the legs | Hand only | The legs with the fitting rubbers were first fixed at one end, and the other end was screwed into the base plate. |
| 8 | Assembling the components to produce the work | Spanners | Place the above set bottom plate; as it's firm, check it first, gently fit the transparent glass, and check for leaks. Connect the binding rods, place the top plate, and check leakages. If none, then fix in the vanes and go for testing. |
| 9 | Experiment | | |

Table 2. Bill of Quantity of Materials.

| S/N | Material | Part No | Unit cost | Total |
|---|---|---|---|---|
| 1 | Spring | 1 | 400 | 400 |
| 2 | Meter rule | 1 | 300 | 300 |
| 3 | Round plate | 2 | 2000 | 4000 |
| 4 | Weight pan | 1 | 1000 | 1000 |
| 5 | Vanes or target | 2 | 4000 | 4000 |
| 6 | Nozzle | 2 | 1000 | 2000 |
| 7 | Stem | 1 | 1000 | 1000 |
| 8 | Transparent glass | 1 | 65000 | 65000 |
| 9 | Binding rods | 3 | 1200 | 3600 |
| 10 | Legs | 3 | 1000 | 3000 |
| 11 | Rubber | 3 | 200 | 800 |
| 12 | Washer | 6 | 20 | 200 |
| 13 | Nuts | 6 | 200 | 200 |
| 14 | Discharge pipe | 1 | 600 | 600 |

## TESTING APPARATUS

The primary components of the testing apparatus consisted of a hydraulic bench and a 120-gallon tank. The supplies for the testing apparatus comprise a clear cylinder for observing jet impact, a stopwatch, a measuring bucket, a flat plate, a curved plate, and masses of varying kilograms for the experiment. A distinct target plate was secured in the opposite orientation to the nozzle, with the water jetting nozzle affixed to a tank. The tank was opened, and the machine was activated for jet flow to assess performance. After the mass in the spring achieves a stable position, and the fluid jet impacts the flat plate or curved cup, measurements on the meter rule will be recorded, along with time, mass, and water volume. The experiments will persist until ten (10) readings are completed [2, 19].

## RESULTS ANALYSIS AND DISCUSSION

The results from the design and construction of the jet's impact are in Table 3 and Figs. (4-5).

Tab. 3. the Impact of Jet design results

| | Meter (m) | Area (A) $m^2$ | Volume (V) $m^3$ | Ratio | Mass (kg) | Weight (N) | Efficiency (%) |
|---|---|---|---|---|---|---|---|
| Area of the bigger pipe | | 0.0010752 | | | | | |
| Area of the nozzle pipe | | 0.0004908 | | | | | |
| The transparent cylinder | | 0.5026 | 0.4021 | | | | |
| Hemispherical cup | | | 0.134 | | | | |
| Flat plate | | 0.000625 | | | | | |
| Spring weight | | | | | | 70.1 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Contin. Tab.3. Maximum mass the spring can carry | | | | | 7.1 | | |
| Spring deflection | 4.3 | | | | | | |
| Impact of Jet performance | | | | | | | 92 |

Table 3 shows the results of the design analysis of the impact of the jet laboratory apparatus. The areas of the big elbow PVC and nozzle pipe are 0.0010752 and 0.0004908 m2, respectively. The area and volume of the transparent PVC cylinder are 0.5026 $m^2$ and 0.4021$m^{3,}$ respectively. The area and volume of the flat plate and the hemispherical cup are 0.000625 m2 and 0.134 m3, respectively. The maximum weight the spring can carry was determined to be 70.1 N, while the highest mass was 7.1 kg. The deflection of the spring was calculated to be 4.3 m. The jet impact efficiency was 92 %. Most of the results from this design analysis are consistent with or similar to those of [10,21].

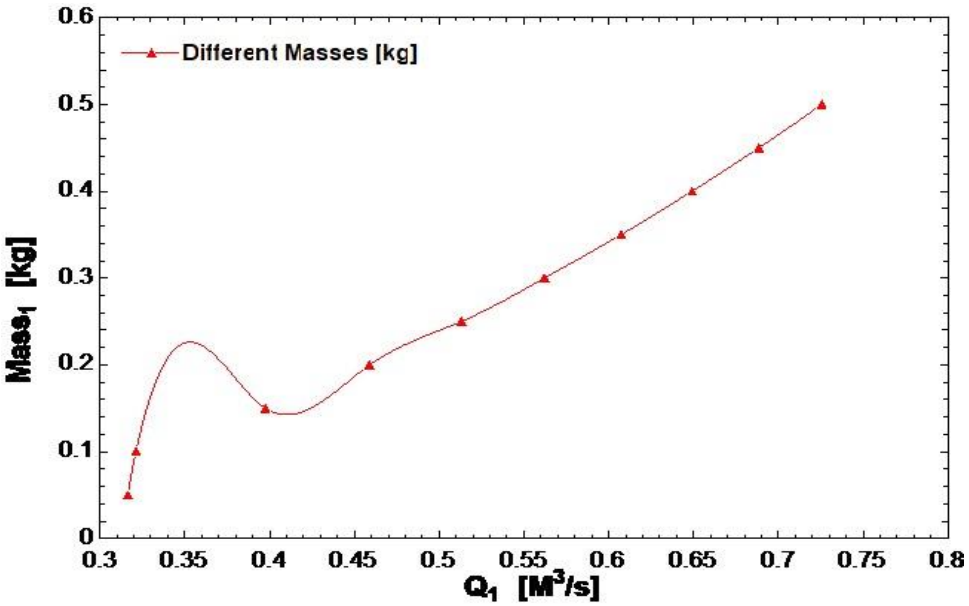



Fig.4. Mass vs. discharge (flat plate for nozzle at 90 °)

Figure 4 is the graph of mass vs. discharge (flat plate for nozzle at 90 °). The mass is directly proportional to the discharge. The increase in mass during the laboratory experiment led to a corresponding increase in discharge. The mass increases from 0.05 to 0.5 kg, while the discharge rises from 0.3162 to 0.7257 $m^3/s$ [4,5].

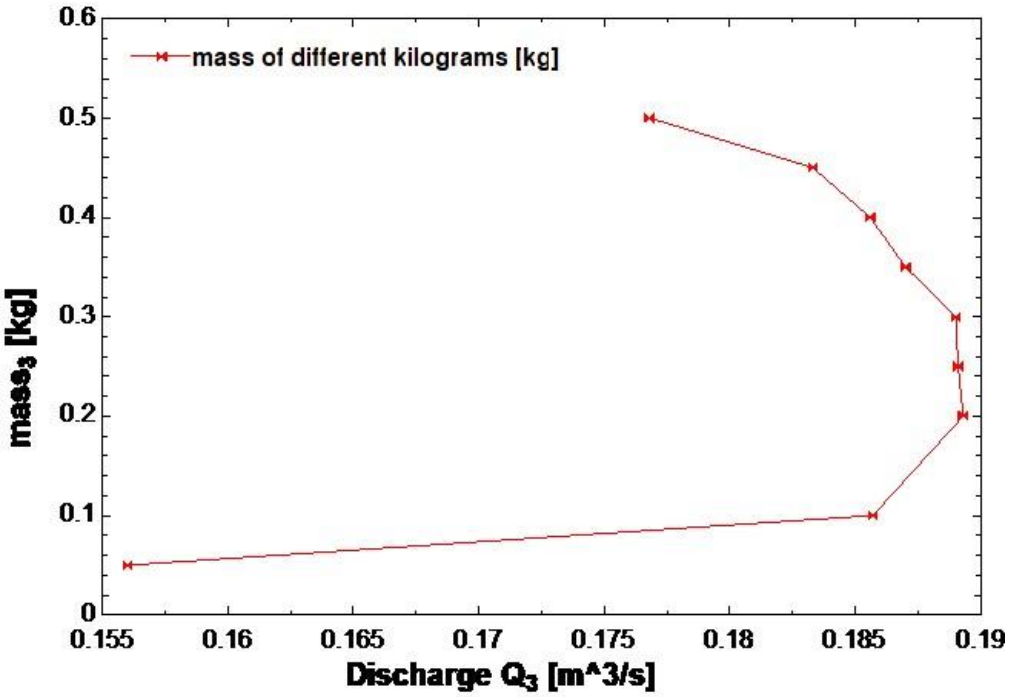



Fig. 5. Mass vs. discharge (curve cup for nozzle at 180 °)

Fig. 5 shows mass vs. discharge (curve cup for the nozzle at 180 °). The graph is curved. This signifies that the experiment conformed to the shape of the curve cup used in the apparatus. At first, as the mass increased, the discharge increased too, but at a certain point in the experiment, the discharge decreased as the mass increased. The mass increased from 0.05 to 0.2 kg, while discharge rose from 0.156 to 0.1891 $m^3/s$ [15]. Conversely, the discharge decreases from 0.189 to 0.1766 m3/s, while the mass increases from 0.25 to 0.5 kg, as seen in Table 4 below.

Tab. 4: Flat Plate for nozzle at 90 ° and curved cup for nozzle at 180

| Flat Plate | | | Hemispherical (curved) cup 180 | |
|---|---|---|---|---|
| mass on pan m (kg) | Velocity (V) (m/s) | Q ($m^3/s$) | Velocity (V) (m/s) | Q ($m^3/s$) |
| 0.050 | 2.208 | 0.3162 | 3.19 | 0.156 |
| 0.100 | 3.128 | 0.3212 | 4.512 | 0.1857 |
| 0.150 | 3.825 | 0.3974 | 6.38 | 0.1893 |
| 0.200 | 4.417 | 0.4590 | 7.14 | 0.1891 |
| 0.250 | 4.938 | 0.5131 | 7.82 | 0.189 |
| 0.300 | 5.410 | 0.5621 | 8.44 | 0.187 |
| 0.350 | 5.843 | 0.6072 | 9.025 | 0.1856 |
| 0.400 | 6.246 | 0.6491 | 9.57 | 0.1833 |
| 0.450 | 6.625 | 0.6885 | 10.09 | 0.1768 |
| 0.500 | 6.984 | 0.7257 | 10.10 | 0.1766 |

## CONCLUSION

The design and construction of the impact of the jet laboratory apparatus have been completed. The areas of the big elbow PVC and nozzle pipe are 0.0010752 and 0.0004908 $m^2$, respectively. The area and volume of the transparent PVC cylinder are 0.5026 $m^2$ and 0.4021$m^{3,}$ respectively. The area and volume of the flat plate and the hemispherical cup are 0.000625 $m^2$ and 0.134 $m^3$, respectively. The maximum weight the spring can carry was determined to be 70.1N, while the highest mass was 7.1 kg. The deflection of the spring was calculated to be 4.3m.

The jet impact efficiency was 92 %. The results from the flat plate experiment with the nozzle at 90° showed that the mass increased from 0.05 to 0.5 kg, while the discharge rose from 0.3162 to 0.7257 $m^3$/s. The results from the curve cup experiment at 180° for the nozzle showed that the mass increased from 0.05 to 0.2kg, with the same increase in discharge from 0.156 to 0.1891 $m^3$/s, while the discharge decreased from 0.189 to 0.1766 $m^3$/s as the mass increased from 0.25 to 0.5 kg.

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## PROJEKTOVANJE I KONSTRUKCIJA APARATA ZA ISPITIVANJE UDARA MLAZA U LABORATORIJI MEHANIKE FLUIDA

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***Apstrakt:*** Projektovanje i izrada laboratorijskog aparata za ispitivanje udara mlaza su uspešno realizovani. Proračunska analiza sprovedena je za ključne komponente – delove ovog aparata: cev, cilindar, ravnu ploču, zakrivljenu (poluloptastu) čašicu i oprugu. Površine velikog PVC kolena i mlaznice iznose 0,0010752 m² i 0,0004908 m², respektivno. Površina i zapremina providnog PVC cilindra iznose 0,5026 m² i 0,4021 m³. Površina i zapremina ravne ploče i hemisferične lopte iznose 0,000625 m² i 0,134 m³. Maksimalna sila koju opruga može da podnese određena je na 70,1 N, dok je maksimalna masa 7,1 kg. Deformacija opruge izračunata je na 4,3 m. Efikasnost udara mlaza iznosila je 92%.

Rezultati ogleda sa ravnom pločom pri uglu mlaznice od 90° pokazali su da se masa povećava od 0,05 kg do 0,5 kg, uz odgovarajuće povećanje protoka sa 0,3162 m³/s na 0,7257 m³/s. Rezultati za poluokruglu diznu pri uglu mlaznice od 180° pokazuju da se masa povećava od 0,05 kg do 0,2 kg, uz povećanje protoka sa 0,156 m³/s na 0,1891 m³/s, dok se protok tečnosti smanjuje sa 0,189 m³/s na 0,1766 m³/s pri porastu mase od 0,25 kg do 0,5 kg.

***Ključne reči:*** *Projektovanje i konstrukcija; PVC cev; mlaznica; ravna ploča i zakrivljena čašica; opruga; prava čelična šipka.*

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