The American University of Iraq- Sulaimaniah

Wet Lab

Impact of a Water Jet

I. **Objective:** To determine the impact force of a water jet on surfaces with different return angles, and to determine the velocity and area of the resultant spray.

II. **Theory:** Refer to Fluid Mechanics, 7th Edition, by Frank M. White, Section 3.4.

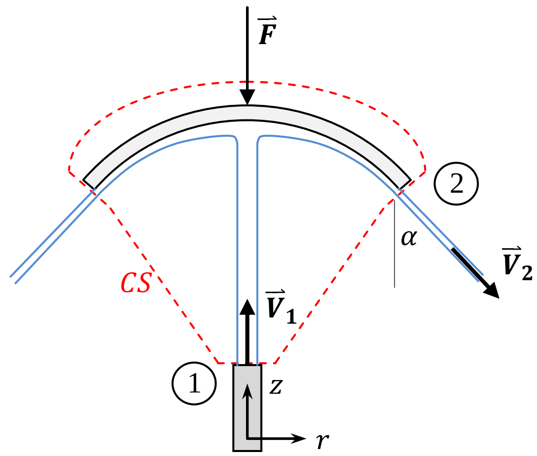

Figure 1 Water Jet Impacting a Curved Surface

The general form of Newton's second law, applied to a control volume using the Reynolds transport theorem is

$$\sum \vec{F} = \frac{d}{dt}(m\vec{V}_{syst}) = \frac{d}{dt}\left(\int_{CV} \vec{V}\rho d\mathcal{V}\right) + \int_{CS} \vec{V}\rho\vec{V}\cdot\hat{n}\, dA$$

where

$\vec{F}$ is any applied force
$m\vec{V}_{syst}$ is the system's linear momentum
$\vec{V}$ is the fluid velocity as a function of time and location
ρ is the fluid density
CV is the control volume containing the location of interest
CS is the control surface surrounding the CV
$\hat{n}$ is the outward normal to the CS at any point.

For a fixed CV and steady flow, the time derivative of the first integral is zero. For inlet and exit flows with constant (1D) velocity and density over the cross-sectional area of each inlet and outlet, the second integral can be simplified to summations as follows.

$$\sum \vec{F} = \sum_i (\dot{m}_i \vec{V}_i)_{out} - \sum_i (\dot{m}_i \vec{V}_i)_{in}$$

where

$\dot{m}_i = \rho_i A_i V_i$ is the mass flow rate at a particular inlet/outlet

Looking at the control volume in Figure 1, there is only one inlet (numbered 1), which is well defined. The cross-sectional area can easily be measured. The mass flow rate can be experimentally measured, and the velocity, $\vec{V_1}$ can be easily calculated.

The outlet (numbered 2) is a conical sheet. Conservation of mass requires that it have the same flow rate as the inlet, but the cross-sectional area and velocity are not known.

There is only one force, due to the mass placed on the curved surface. Putting these details into the above equation gives

$$\vec{F} = \dot{m}\vec{V}_1 - \dot{m}\vec{V}_2$$

where the only unknown is $\vec{V}_2$. Writing the vectors in component form, in cylindrical coordinates,

$$F_z\hat{k} + F_r\hat{r} = \dot{m}V_1\hat{k} - \dot{m}\left(-V_2 \cos\alpha\, \hat{k} + V_2 \sin\alpha\, \hat{r}\right)$$

From the axisymmetric nature of the problem, it should be clear that the forces generated by the horizontal components of V_2 cancel out, and that $F_r = 0$. This means that $F = F_z$ and the vertical components of the equation can be written as

$$F = \dot{m}(V_1 + V_2 \cos\alpha) \qquad \text{Equation 1}$$

This equation can be used in two ways:

1. Assuming that $V_1 = V_2$ (which may not be reasonable), $F = \dot{m}V_1(1 + \cos\alpha)$. Since $\dot{m}$ and V_1 are related by $\dot{m} = \rho A_1 V_1$ and both ρ and A_1 are constants, F can be predicted from a chosen $\dot{m}$ or $\dot{m}$ can be predicted from a chosen F.
2. V_2 can be determined by experiment, when F and $\dot{m}$ are measured, by solving for V_2.

III. Procedure:

1. Verify that the jet diameter =8 mm.
2. Measure the diameter of the impact surface.
3. Disassemble the top that is placed over the transparent water tank and screw the flat surface ($\alpha = 90°$) onto the vertical post which runs through the support on which the weights are placed, as shown in Figure 2. Place the cover back on the tank.

Figure 2 The Flat Surface Attached to the Rod above the Nozzle

4. Verify that the device is on the Hydraulic Bench and that the water inlet is connected to the pump outlet (see Figure 3).

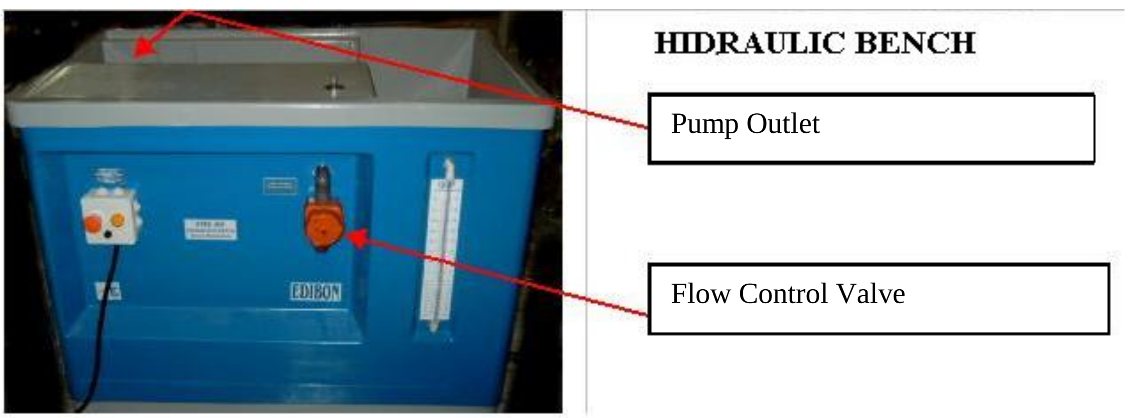

Figure 3 The Hydraulic Bench

5. Balance the equipment using the help of the bubble level placed on the cover of the cylinder by manipulating the adjustable supports until the bubble stabilizes in the center of the gauge.
6. Adjust the reference marker so that it is aligned with the weight platform, *before adding weight* (see Figure 4).

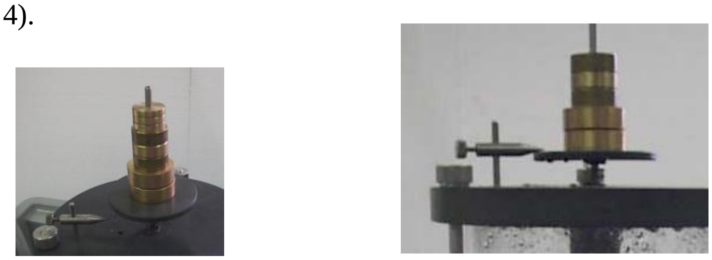

Figure 4 Weight Platform with Weights

7. Place approximately 100 grams on the platform and record the value.
8. Close the flow control valve of the hydraulic bench (see Figure 3) by turning it fully clockwise and then switch on the pump.
9. Using the flow control valve, regulate the flow so that it impacts against the surface. Adjust the flow rate until the platform returns to its initial position (see Figure 4).
10. While monitoring that the platform remains in its initial position, measure the mass flow rate through the nozzle. To do this, close the drain of the hydraulic bench and use a stopwatch to measure the time between two volume markings on the sight gage. The data may be recorded in Table 1.
11. Repeat steps 7 through 10 four extra times by increasing weights at 100 gm interval and measure flows, velocities, and jet forces.
12. Repeat the entire procedure with the $120°$ curved surface ($\alpha = 60°$) and the $180°$ hemispherical surface ($\alpha = 0°$).

Table 1 Experimental Data for Jet Impact

α (degrees)	Mass (g)	Vol_1 (Liter)	Vol_2 (Liter)	Time (sec.)
$90°$				
$90°$				
$90°$				
$90°$				
$90°$				
$60°$				
$60°$				
$60°$				
$60°$				
$60°$				
$0°$				
$0°$				
$0°$				
$0°$				
$0°$				

IV. Calculations:

1. Predict the mass flow rate:
   a. Calculate the weight of the mass placed on the weight platform for each data point. (This is F.)
   b. Assuming $V_1 = V_2$, calculate the mass flow rate that should be required to balance this force.
2. Calculate the mass flow rate:
   a. Calculate the volume flow rate for each recorded data point by dividing the volume of water captured by the time taken: $Q = (Vol_2 - Vol_1)/t$.
   b. Convert the volume flow rate to mass flow rate by multiplying by the density of water: $\dot{m} = \rho Q$.
3. Calculate the water velocities:
   a. Find the velocity of the jet by solving the following equation for V_1: $\dot{m} = \rho A_1 V_1$.
   b. Calculate V_2 for each data point with the curved surfaces using Equation 1.
4. Calculate the exit area:
   a. Calculate the cross-sectional area of the outlet, by solving for A_2: $\dot{m} = \rho A_2 V_2$.
   b. Determine the thickness of the spray as it exits the impact surface, noting that A_2 is approximately the circumference of the disk times the thickness of the water spray.
5. Create graphs to display the data:
   a. Create a graph showing both predicted and actual mass flow rate (y-axis) against the force created by the mass placed on the platform (x-axis) for each surface (90°, 120°, and 180°). This may be one graph with six sets of data points, or three graphs, one for each surface.
   b. Create a graph showing both V_1 and V_2 for each surface (excepting V_2 for the flat surface). Again, this may be either one graph with curves for each surface, or a separate graph for each surface.
6. Calculate the % difference between predicted values assuming $V_1 = V_2$:
   a. Calculate the error in the predicted flow rate:

$$\%err = \frac{\dot{m}_{predicted} - \dot{m}_{actual}}{\dot{m}_{actual}}$$

   b. Calculate the difference between V_1 and V_2:

$$\%diff = \frac{V_2 - V_1}{V_1}$$

V. Questions:

1. How reasonable is the assumption that $V_1 = V_2$?
2. Looking at your graphs, what does the relationship appear to be between the force and mass flow rate (e.g. linear, quadratic, exponential, logarithmic, or something else)?
3. Looking at Equation 1, can you explain this behavior?
4. Do you think there was any error in your measurements? If so, what was the cause?