Dr. AMBEDKAR INSTITUTE OF TECHNOLOGY

BENGALURU - 560056

DEPARTMENT OF CIVIL ENGINEERING

Aided By Govt. of Karnataka

HYDRAULICS & HYDRAULIC MACHINERY LABORATORY

(For Internal Use Only)

Lab Manual Compiled by
Naveen Kumar M
Asst. Professor
Dept. of Civil Engineering
Dr.AIT, Bengaluru - 56

Name	
USN	
Section	
Batch	

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Semester: V		
Course Title: Hydraulics and Hydraulic Machinery Laboratory		
Course Code: **18CVL57**	Evaluation Procedure: CIE + Record + SEE = 20 + 30 + 50 = 100	
Credits: **01**		
Teaching Hours: 26 Hrs (L:T:P:S:0:0:2:0)	SEE Duration: 3 Hrs	
Course Learning Objectives:		
1	To study the measurement of flow of fluid in a pipe, notches and weirs.	
2	To calibration of discharge measuring equipments and their applications.	
3	To study the performance of Pumps and Turbines.	
Expt. No.	**Syllabus Contents**	**No. of Hours**
1	Determination of Hydraulic coefficients of a vertical orifice.	02
2	Calibration of Rectangular and 90^0 V-notch.	02
3	Calibration of Broad- crested and Ogee weir.	02
4	Calibration of Venturimeter and Orificemeter.	02
5	Determination of Darcy's friction factor for a straight pipe.	02
6	Determination of vane coefficients for a flat, inclined and semi-circular vane.	02
7	Performance characteristics of a Pelton wheel Turbine.	02
8	Performance characteristics of Francis turbine.	02
9	Performance characteristics of a Kaplan turbine.	02
10	Performance characteristics of a multi-stage Centrifugal Pump.	02
Course Outcomes: The students will be able to		
1	Explain the principles of flow measuring devices by conducting the experiments.	
2	Illustrate the calibration of velocity and discharge measuring equipments.	
3	Demonstrate the performance of Hydraulic machines.	
Question paper pattern:		
The candidate has to conduct two experiment, one from individual experiment and one from group experiment which carries 70 % of the total marks and viva-voce for 30 % of the total marks.		
Reference Books:		
1	Hydraulics and Hydraulic Machines Laboratory Manual – N Balasubramanya.	
2	Experiments in Fluid Mechanics – Sarbjit Singh.	
3	A text book of Fluid Mechanics & Hydraulic Machines by R K Bansal	
4	A text book of Fluid Mechanics & Hydraulic Machines by Modi & Seth	
5	A text book of Fluid Mechanics & Hydraulic Machines by R K Rajputh	

CO - PO Mapping

CO/PO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	✓		✓	✓	✓							
CO2	✓		✓	✓	✓							
CO3		✓	✓		✓							

Experiment No: 1 – Flow through Vertical Orifice.

Objective:

To determine hydraulic orifice coefficients (i.e., C_d, C_v, C_c & C_r).

Theory:

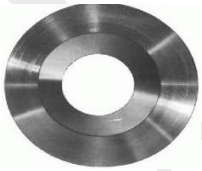
- ✓ An opening in a vessel / tank, through which the liquid flows out is known as an orifice. So as long as the level of the liquid on the upstream side is above the top of the orifice.
- ✓ An orifice may be provided in the vertical side of the vessel / tank or in the base.
- ✓ Jet of water –The continuous stream of a liquid that come out or flows out of an orifice.
- ✓ Vena-contracta –
  - The liquid passes out of an orifice in the form of a jet.
  - The jet goes on contracting from the mouth of the orifice.
  - After a distance of about half the orifice diameter, the jet begins to expand.
  - The least expanded section of the jet is known as vena-contracta.
- ✓ **Hydraulic / orifice co-efficients** – Co-efficient of contraction (C_C), Co-efficient of velocity (C_V), Co-efficient of discharge (C_d), and Co-efficient of resistance (C_r).
  - **Co-efficient of contraction (C_C):** The ratio of the jet at vena-contracta (A_C) to the area of the orifice (A_O). i.e., $C_C = \frac{A_C}{A_O}$
    - The value of C_C varies from 0.613 to 0.69, depending upon the shape, size of orifice and head of liquid under which the flow takes place.
    - In practice, the average value is taken as 0.64.
  - **Co-efficient of velocity (C_V):** The ratio of actual velocity (V_{act}) of the jet at vena-contracta to the theoretical velocity (V_{th}). i.e., $C_V = \frac{V_{act}}{V_{th}} = \frac{V_{act}}{\sqrt{2\,g\,H}}$
    - The value of C_V varies from 0.95 to 0.99, depending upon the shape of orifice and head of liquid under which the flow takes place.
    - For sharp – edged orifices, the value of C_V is taken as 0.98
  - **Co-efficient of discharge (C_d):** The ratio of actual discharge (Q_{act}) through an orifice to the theoretical discharge (Q_{th}). i.e., $C_d = \frac{Q_{act}}{Q_{th}} = C_V \times C_C$

- The value of C_d varies from 0.62 to 0.65, depending upon the shape of orifice and head of liquid under which the flow takes place.

- **Co-efficient of resistance (C_r):** The ratio of loss head, h_f (or loss of kinetic energy) in the orifice to the head of water, H (or actual kinetic energy) available at the exit of the orifice. i.e., $C_r = \frac{h_f}{H}$
- The loss of head in the orifice takes place, because the walls of the orifice offer some resistance to the liquid, as it comes out.

Lab. Setup:







Apparatus:

- ✓ Sump tank – 120 cm x 42 cm x 40 cm.
- ✓ Supply tank -
- ✓ Pump capacity – ½ HP.
- ✓ Measuring tank - 41 cm x 33 cm.
- ✓ Orifice – 12 mm & 16 mm diameter.
- ✓ An arrangement to measure co-ordinate of jet.

Procedure:

- ✓ Note down the dimensions of a given orifice and fix the orifice in position.
- ✓ Note down the cross-sectional area of measuring tank.
- ✓ Note down the initial reading of the supply tank, horizontal scale and vertical scale by adjusting the tip of the pointer to lie at the centre of orifice.
- ✓ Allow the water to flow through the orifice under a constant head 'H'.
- ✓ Select a point on the jet and note down its co-ordinates 'X' and 'Y' from the vena-contracta and centre of the orifice respectively.
- ✓ For the same supply, collect water in the measuring tank for a known interval of time 't' and note down the depth of water collected 'R'.
- ✓ Repeat the procedure for different discharges or different head constants.
- ✓ Tabulate the readings and calculate the co-efficients.

Observations:

- ✓ Diameter of orifice, D_0 = _____= mm = _____ m.
- ✓ C/S area of orifice, $A_0 = \frac{\pi}{4} \times D_0^2$ = _____ m^2.
- ✓ C/S area of measuring tank, A = 0.41 x 0.33 = _____ m^2.
- ✓ Rise of water level in measuring tank, R = _____= mm _____ m.
- ✓ Initial horizontal scale reading at vena-contracta, X_i = _____= mm _____ m.
- ✓ Initial vertical scale reading at centre of orifice, Y_i = _____= mm _____ m.
- ✓ Acceleration due to gravity, g = 9.81 m/s^2.
- ✓ Unit weight of water, γ_ω = 9.81 kN/m^3.

Table 1. Observation tabular column: Vertical Orifice

Trail No.	Head, H (mm)	Scale reading (mm)		Time for which water is collected, t (s)
		X_f	Y_f	
1				
2				
3				
4				
5				

Calculations:

- ✓ Coefficient of Discharge, $C_d = \frac{Q_{act}}{Q_{th}}$

  Here, $Q_{act}\,(m^3/s) = \frac{A\,R}{t}$

  $Q_{th}\,(m^3/s) = A_0\sqrt{2\,g\,H}$

- ✓ Coefficient of Velocity, $C_V = \frac{X}{2\sqrt{Y\,H}}$
- ✓ Coefficient of Contraction, $C_C = \frac{C_d}{C_C}$
- ✓ Coefficient of Resistance, $C_r = 1 - C_V^2$
- ✓ Loss of head in orifice flow, $h_f\,(m) = H\,(1 - C_V^2)$
- ✓ Power lost at the orifice, $P_{LOSS}\,(kW) = \gamma_\omega\,Q_{act}\,h_f$

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Table 1. Calculations tabular column: Vertical Orifice

Trail No.	H (m)	Scale reading (m)		t (s)	Q_{th} (m^3/s)	Q_{act} (m^3/s)	C_d	C_V	C_C	C_r	h_f (m)	P_{LOSS} (kW)
		X	Y									
1												
2												
3												
4												
5												

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Experiment No: 2 – Flow over Notches.

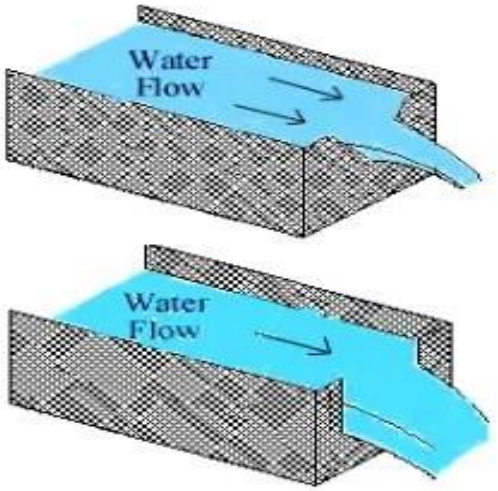
Objective:

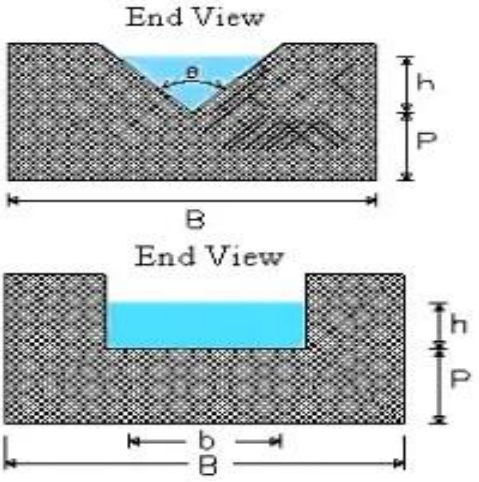
To determine Co-efficient of discharge of a given notch.

Type of Notch based on their shape:

- ✓ Rectangular notch.
- ✓ Triangular notch.
- ✓ Trapezoidal notch.
- ✓ Stepped notch.

Lab. Setup:







Apparatus:

- ✓ Sump tank – 120 cm x 42 cm x 40 cm.
- ✓ Pump capacity – ½ HP.
- ✓ Measuring tank - 41 cm x 33 cm.
- ✓ Notches: Rectangular & Right angled triangular shape.

Procedure:

- ✓ Measure the length of the notch and the cross-sectional area of the measuring tank.
- ✓ Allow the water into the flume provided with notch.
- ✓ Stop the supply of water into the flume when the water level in the flume is at the sill of the notch and note down the initial reading by piezometer.
- ✓ Allow the water to flow over the weir under a constant head.
- ✓ Note down final piezometer reading
- ✓ For the same discharge, collect the water in the measuring tank for a known interval of time 't'.
- ✓ Note down the depth of water collected 'R' in that time.
- ✓ Repeat the steps for different discharges or different constant heads.
- ✓ Tabulate the readings and calculate the co-efficients.
- ✓ Plot a curve between Log Q_{act} and Log H, find the values of K and n from the graph.

Observations:

- ✓ Length of the rectangular notch, B = _____ mm = _____m.
- ✓ Central angle of triangular notch, θ = _____^{0}.
- ✓ C/S area of measuring tank, A = 0.41 x 0.33 = _____ m^2.
- ✓ Rise of water level in measuring tank, R = _____= mm _____ m.
- ✓ Acceleration due to gravity, g = 9.81 m/s^2.
- ✓ Initial head of water at the sill level, H_i = _____ mm = _____m.

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Observation tabular column: Flow over Notches.

Notch	Trail No.	Final Head, H_f (mm)	Time for which water is collected, t (s)
Rectangular Notch	1		
	2		
	3		
	4		
	5		
Triangular Notch	1		
	2		
	3		
	4		
	5		

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Calculations:

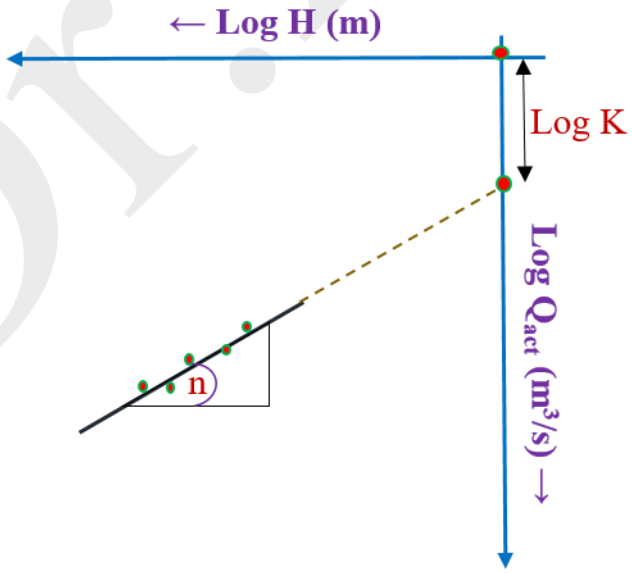
- Head of water over the notch, H (m) = $(H_i \sim H_f) \times 10^{-3}$
- Coefficient of Discharge, $C_d = \frac{Q_{act}}{Q_{th}}$

  Here, $Q_{act}\ (m^3/s) = \frac{A\ R}{t}$

  - For rectangular notch: $Q_{th}\ (m^3/s) = 2/3\ L \sqrt{2\ g}\ H^{3/2}$
  - For triangular notch: $Q_{th}\ (m^3/s) = 8/15\ \tan(\theta/2) \sqrt{2\ g}\ H^{5/2}$
- The above equations is not accurate due to the varied assumptions and approximations made while deriving it, therefore it is necessary to establish experimentally a calibration equations for the notch, having general form, $Q = K\ H^n$
  - Where, K and n are constants for a given notch.
  - This equation can be linearlised by taking logarithm on either side so that,

$$\text{Log } Q = \text{Log } K + n \text{ Log } H$$

- A plot of Log Q v/s Log H will yield a straight line whose intercept on the Log Q axis will be equal to k and whose slope corresponds to the exponent n.



- Notch constant, $K = C_d\ 2/3\ L \sqrt{2\ g}$
- Index value, $n = \frac{\log Q_{act} - \log K}{\log H}$

Results:

- ✓ **Experimental results:**
  - Co-efficient of Discharge, C_d = _____
  - Notch Constant, K = _____
  - Index value, n = _____
- ✓ **Graphical results:**

  (Plot a curve between Log Q_{act} and Log H, compute the values of K and n from the graph)
  - Notch Constant, K = _____
  - Index value, n = _____

Conclusions:

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Table 2. Calculations tabular column: Flow over Notches.

Notch	Trail No.	H (m)	t (s)	Q_{act} (m^3/s)	Q_{th} (m^3/s)	C_d	K	Log Q_{act}	Log K	Log H	n
Rectangular Notch	1										
	2										
	3										
	4										
	5										
Triangular Notch	1										
	2										
	3										
	4										
	5										

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Experiment No: 3 – Flow over weirs.

Objective:

To determine Co-efficient of discharge for a given weir.

Theory:

- ✓ The structure used to dam up a stream or river, over which the water flows, is called a weir.
- ✓ The most popular form is the rectangular weir.
- ✓ The edge of rectangular weir is straight and horizontal and expands over the full width of the channel in which it is placed, then this weir is called weir without end contraction or suppressed weir because the sides of the channel wall will suppress any end effect, neglecting of course the wall friction.
- ✓ If the weir width is less than the width of the channel, it is known as weir with end contraction.
- ✓ The upper surface or edge of the weir over which the water flows is known as crest or sill of the weir.
- ✓ The overflowing sheet of water over the weir is called nappe or vein.
- ✓ If the nappe discharges into air, the weir is said to have a free discharge.
- ✓ If the nappe discharges takes place above sill or weir crest, the weir is said to have a drowned or submerged weir in which case it may totally drowned or partially drowned.
- ✓ If a sharp crested weir is used for long time, its crest will be dulled or damaged, therefore weir with thick crest should be used where discharge is to be measured for long periods. Such a weir is known as Broad-crested weir.

Broad-Crested Weir

- ✓ A weir having a wide crest is called broad-crested weirs.
- ✓ Such weirs generally form a part of a dam and are called spillway or a similar structure for the measurement of water.
- ✓ If the width of crest weir, $0.625\ H < B < 2.5\ H$ is called narrow-crested weir.
- ✓ If the width of crest weir, $2.5\ H \geq B \leq 10H$ is called broad-crested weir.
- ✓ There are two types of broad-crested weirs, namely

- Broad-crested weir with a sharp corner at the upstream end.
- Broad-crested weir with a round corner at the upstream end.
- There may be possibility of cavitations incase of broad-crested weir with a sharp corner at the upstream end and hence it is avoided in most of the cases.

✓ The co-efficient of discharge for a broad-crested weir varies from 0.85 to 1.00.

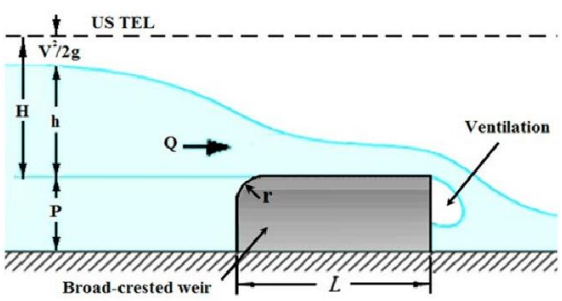
Ogee Weir

✓ It is special type of weir employed as a spillway of a dam.
✓ The discharge flowing over the spillway is measured by making the spillway profile according to the shape of the lower free nappe of a duly ventilated sharp crested weir.
✓ This lower free nappe generally rises slightly as it originates from the crest of a sharp crested weir and then falls making a parabolic form.
✓ Now if the space between the sharp crested weir and lower nappe is filled with concrete or masonry, the weir so formed will be termed an Ogee weir.
✓ Incase of sharp crested rectangular weir, the nappe rises by an amount equal to 0.115H above the crest and then falls.
✓ The major advantage of this weir is that there is no development of negative pressure.

Figures / Lab. Setup:









Procedure:

- ✓ Measure the length of the weir and the cross-sectional area of the measuring tank.
- ✓ Allow the water into the flume provided with weir.
- ✓ Stop the supply of water into the flume when the water level in the flume is at the sill of the weir and note down the initial point gauge reading by adjusting the tip of the point gauge to touch the free surface of water.
- ✓ Allow the water to flow over the weir under a constant head.
- ✓ Note down final point gauge reading by adjusting the tip of the point gauge to touch the surface of water.
- ✓ For the same discharge, collect the water in the measuring tank for a known interval of time 't'.
- ✓ Note down the depth of water collected 'R' in that time.
- ✓ Repeat the steps for different discharges or different constant heads.
- ✓ Tabulate the readings and calculate the co-efficients.
- ✓ Plot a curve between Log Q_{act} and Log H, find the values of K and n from the graph.

Apparatus:

- ✓ Sump tank – 145 cm x 50 cm x 50 cm.
- ✓ Pump capacity – 1 HP.
- ✓ Measuring tank – 0.25 m^2.
- ✓ Weirs: Broad-crested weir & Ogee weir.

Observations:

- ✓ Length of the Broad-crested weir, L = _____ mm = _____m.
- ✓ Length of the Ogee weir, L = _____ mm = _____m.
- ✓ C/S area of measuring tank, A = _____ m^2.
- ✓ Rise of water level in measuring tank, R = _____= cm _____ m.
- ✓ Acceleration due to gravity, g = 9.81 m/s^2.
- ✓ Initial head of water at the crest level, H_i = _____ cm = _____m.

Observation tabular column: Flow over Weirs.

Weir	Trail No.	Final Head, H_f (cm)	Time for which water is collected, t (s)
Broad-Crested Weir	1		
	2		
	3		
	4		
	5		
Ogee Weir	1		
	2		
	3		
	4		
	5		

Calculations:

- Head of water over the weir, H (m) = $(H_i \sim H_f) \times 10^{-2}$
- Coefficient of Discharge, $C_d = \frac{Q_{act}}{Q_{th}}$

  Here, Q_{act} $(m^3/s) = \frac{A\,R}{t}$

  - For broad-crested weir: Q_{th} $(m^3/s) = 1.705\ L\ H^{3/2}$

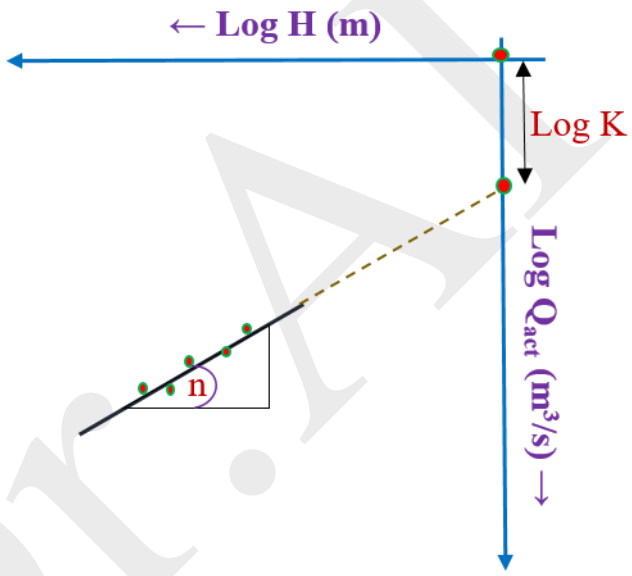
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- For ogee weir: Q_{th} (m^3/s) = 2.204 L $H^{3/2}$

- The above equations is not accurate due to the varied assumptions and approximations made while deriving it, therefore it is necessary to establish experimentally a calibration equations for the weir, having general form, $Q = K H^n$
  - Where, K and n are constants for a given weir.
  - This equation can be linearlised by taking logarithm on either side so that,

$$\text{Log } Q = \text{Log } K + n \text{ Log } H$$

- A plot of Log Q v/s Log H will yield a straight line whose intercept on the Log Q axis will be equal to k and whose slope corresponds to the exponent n.



- Broad-crested weir constant, K = Cd 1.705 L
- Ogee weir constant, K = Cd 2.204 L
- Index value, $n = \frac{\log Q_{act} - \log K}{\log H}$

Results:

✓ **Experimental results:**

- Co-efficient of Discharge, Cd = _____
- Weir Constant, K = _____
- Index value, n = _____

- ✓ **Graphical results:**

  (Plot a curve between Log Q_{act} and Log H, compute the values of K and n from the graph)

  - Weir Constant, K = _____
  - Index value, n = _____

Conclusions:

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Table 1. Calculations tabular column: Flow over Weirs.

Weir	Trail No.	H (m)	t (s)	Q_{act} (m^3/s)	Q_{th} (m^3/s)	C_d	K	Log Q_{act}	Log K	Log H	n
Broad-Crested Weir	1										
	2										
	3										
	4										
	5										
Ogee Weir	1										
	2										
	3										
	4										
	5										

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Experiment No: 4 – Flow measuring devices: Venturimeter and Orificemeter.

Objective:

To determine Co-efficient of discharge for a given flow measuring device.

Theory:

Venturimeter

- ✓ Venturimeter is a device used to measure discharge through pipes.
- ✓ It consists of a convergent cone, a throat and divergent cone.
- ✓ Convergent cone is one which converges from diameter of pipe to diameter of throat.
- ✓ Throat is a small tube in which diameter is kept constant throughout its length.
- ✓ Divergent cone is one which diverges from diameter of throat to diameter of pipe.
- ✓ The length of divergent cone is always kept more than convergent cone to avoid excessive energy loss.
- ✓ There is a restriction on the diameter of the throat in order to avoid the pressure to fall below the vapour pressure and its cavitation effect.
- ✓ Normally the diameter of throat varies from ⅓ to ¾ times the diameter of the pipe.

Orificemeter

- ✓ An orificemeter is simple device used for measuring the discharge through pipes.
- ✓ An orificemeter works on the principle as that of venturimeter (i.e., by reducing the cross-sectional area of the flow passage, a pressure difference between the two sections before and after orifice is developed and the measurement of the pressure difference enables the determination of the discharge measurement of pipes.
- ✓ However, an orificemeter is a cheaper arrangement for discharge measurement through pipes and its installation requires a smaller length as compared with venturimeter.
- ✓ As such where the space is limited, an orificemeter may be used for measurement of discharge through pipes.

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Lab. Setup:







Apparatus:

- ✓ Sump tank – 90 cm x 50 cm x 50 cm.
- ✓ Pump capacity – ½ HP.
- ✓ Measuring tank – 0.12 m^2.
- ✓ Flow rate measuring devices: Venturimeter (25 mm x 12.5 mm) and Orificemeter (25 mm x 12.5 mm).

Procedure:

- ✓ Note down the inlet diameter, throat diameter of the venturimeter and cross-sectional area of the measuring tank.
- ✓ Connect the two ends of the digital manometer to the inlet and throat of the venturimeter.
- ✓ Press 'TARE' switch of the digital manometer and makes the indicator reads '0'.
- ✓ Start the centrifugal pump and open the inlet valve.
- ✓ Open the corresponding ball valve of the venture or orifice meter pipe line.
- ✓ Adjust the outlet valve to give steady reading and note down the differential head reading of the manometer.

- ✓ For the same discharge collect the water in measuring tank and note down depth of water collected in a time interval.
- ✓ Repeat the same procedure for different set of digital manometer readings for different discharges.
- ✓ Tabulate the readings and calculate the co-efficients.
- ✓ Plot a curve between Log Q_{act} and Log H, find the values of K and n from the graph.

Observations:

Horizontal Venturimeter:

- ✓ Inlet diameter of pipe of the venturimeter, D_1 = _____ mm = _____m.
- ✓ C/S area of inlet of pipe of the venturimeter, $A_1 = \frac{\pi}{4} \times D_1^2$ = _____ m^2.
- ✓ Diameter of pipe of the venturimeter at throat, D_2 = _____ mm = _____m.
- ✓ C/S area of pipe of the venturimeter at throat, $A_2 = \frac{\pi}{4} \times D_2^2$ = _____ m^2.

Orificemeter:

- ✓ Inlet diameter of pipe of the orificemeter, D_1 = _____ mm = _____m.
- ✓ C/S area of inlet of pipe of the orificemeter, $A_1 = \frac{\pi}{4} \times D_1^2$ = _____ m^2.
- ✓ Diameter of orificemeter, D_0 = _____ mm = _____m.
- ✓ C/S area of orificemeter, $A_0 = \frac{\pi}{4} \times D_0^2$ = _____ m^2.

- C/S area of measuring tank, A = _____ m^2.
- Rise of water level in measuring tank, R = _____= cm _____ m.
- Acceleration due to gravity, g = 9.81 m/s^2.
- Loss of head, H = _____ m of water, from Digital Manometer.

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Observation tabular column:

Device	Trail No.	Head loss from digital manometer, H (m of water)	Time for which water is collected, t (s)
Venturimrter	1		
	2		
	3		
	4		
	5		
Orificemeter	1		
	2		
	3		
	4		
	5		

Calculations:

- ✓ Coefficient of Discharge, $C_d = \frac{Q_{act}}{Q_{th}}$

  Here, Q_{act} (m^3/s) $= \frac{A\,R}{t}$

- ✓ For venurimeter, Q_{th} (m^3/s) $= \frac{A_1\,A_2}{\sqrt{A_1^2 - A_2^2}}\sqrt{2\,g\,H}$

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- ✓ For orificemeter, Q_{th} (m^3/s) = $\frac{A_1 A_0}{\sqrt{A_1^2 - A_0^2}}\sqrt{2 g H}$
- ✓ Venurimeter constant, K = $C_d \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}}\sqrt{2 g}$
- ✓ Orificemeter constant, K = $C_d \frac{A_1 A_0}{\sqrt{A_1^2 - A_0^2}}\sqrt{2 g}$
- ✓ Index value, n = $\frac{\log Q_{act} - \log K}{\log H}$

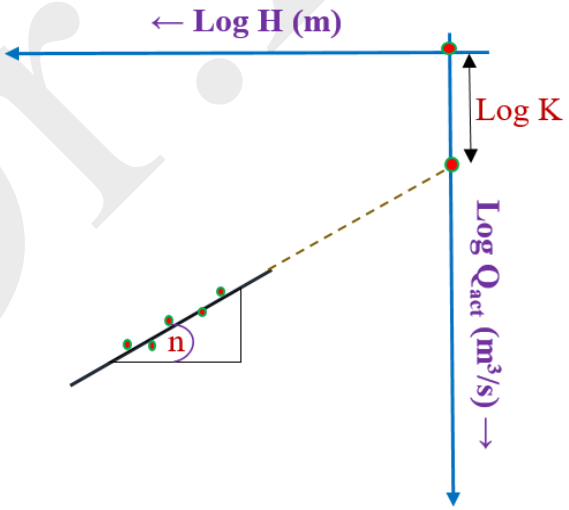
Results:

- ✓ **Experimental results:**

Device	Co-efficient of Discharge, C_d	Constant, K	Index value, n
Venturimeter			
Orificemeter			

- ✓ **Graphical results:**

(Plot a curve between Log Q_{act} and Log H, Compute the values of K and n from the graph)



Device	Constant, K	Index value, n
Venturimeter		
Orificemeter		

Conclusions:

Table 1. Calculations tabular column: Flow measurement by Horizontal Venturimeter & Orificemeter.

Device	Trail No.	H (m)	t (s)	Q_{act} (m^3/s)	Q_{th} (m^3/s)	C_d	K	Log Q_{act}	Log K	Log H	n
Horizontal Venturimrter	1										
	2										
	3										
	4										
	5										
Orificemeter	1										
	2										
	3										
	4										
	5										

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Experiment No: 5 – Head Loss due to Friction in Pipes

Objective:

To determine Co-efficient of friction for the given pipe.

Theory:

- ✓ Whenever liquid flows through a pipe, there will be loss of energy due to force of friction, changes of cross-section, nature of discharge, presence of obstruction, etc.
- ✓ All these losses are measured in terms of kinetic head of liquid.
- ✓ The losses that occur in a pipe flow are broadly classified into two groups.
- ✓ Major loss – It is the loss due to friction. It is measured by Darcy-Weisbach's and Chezy's equation.
- ✓ Minor loss – the following are the minor losses which normally occur in a pipe flow.
    - Loss of head due to entrance of pipe.
    - Loss of head due to exit of pipe.
    - Loss of head due to sudden expansion.
    - Loss of head due to sudden contraction.
    - Loss of head due to a bend.
    - Loss of head due to pipe fittings.
    - Loss of head due to presence of an obstruction.

Lab. Setup:



Apparatus:

- ✓ Sump tank – 75 cm x 50 cm x 45 cm.
- ✓ Pump capacity – 1HP.
- ✓ Measuring tank – 0.12 m^2.
- ✓ Flow head measuring device: Digital differential head manometer.

Procedure:

- ✓ Select the pipe for which the Co-efficient of friction is to be determined and note down its diameter and tapping length.
- ✓ Note down the cross-sectional area of the measuring tank.
- ✓ Connect the digital differential manometer between the gauge points.
- ✓ All the ball valves, except the valves of the pipe for which the Co-efficient of friction is to be determined are kept closed.
- ✓ Start the pump and keep the outlet valve of pump open.
- ✓ Adjust the outlet valve to give steady digital differential manometer reading and note down the readings.
- ✓ For the same discharge collect the water in measuring tank and note down depth of water collected in a time interval.
- ✓ Repeat the same procedure for different set of digital differential manometer reading for different discharges.
- ✓ Tabulate the readings and calculate the co-efficients.

Observations:

- ✓ Length between pressure tapings, L = _____ m.
- ✓ Inner diameter of G.I. pipe, D_1 = _____ mm = _____m.
- ✓ C/S area of G.I. pipe, $A_1 = \frac{\pi}{4} \times D_1^2$ = _____ = _____m^2.
- ✓ Inner diameter of G.I. pipe, D_2 = _____ mm = _____m.
- ✓ C/S area of G.I. pipe, $A_2 = \frac{\pi}{4} \times D_2^2$ = _____ = _____m^2.
- ✓ Inner diameter of G.I. pipe, D_3 = _____ mm = _____m.
- ✓ C/S area of G.I. pipe, $A_3 = \frac{\pi}{4} \times D_3^2$ = _____ = _____m^2.

- ✓ Inner diameter of P.V.C. pipe, D_4 = _____ mm = _____m.
- ✓ C/S area of P.V.C. pipe, $A_4 = \frac{\pi}{4} \times D_4^2$ = _____ = _____m^2.
- ✓ C/S area of measuring tank, A = 0.125 m^2.
- ✓ Rise of water level in measuring tank, R = _____= cm _____ m.
- ✓ Density of water, ρ_ω = 1000 kg/m^3.
- ✓ Acceleration due to gravity, g = 9.81 m/s^2.

Observation tabular column: Head loss due to Friction.

Pipe Material & dia.	Trail No.	Digital Pressure gauge reading, P_i (kg/cm^2)		Time for which water is collected, t (s)
		Section (1) - (1), P_1	Section (2) – (2), P_2	
G.I. Pipe 27 mm dia.	1			
	2			
	3			
	4			
	5			
G.I. Pipe 19 mm dia.	1			
	2			
	3			
	4			
	5			
G.I. Pipe 15 mm dia.	1			
	2			
	3			
	4			
	5			
P.V.C. Pipe 27 mm dia.	1			
	2			
	3			
	4			
	5			

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Calculation tabular column: Head loss due to Friction.

Pipe Material & dia.	Trail No.	h_f (m of water)	t (s)	Q_{act} (m^3/s)	V (m/s)	f	Avg. f
G.I. Pipe 27 mm dia.	1						
	2						
	3						
	4						
	5						
G.I. Pipe 19 mm dia.	1						
	2						
	3						
	4						
	5						
G.I. Pipe 15 mm dia.	1						
	2						
	3						
	4						
	5						
P.V.C. Pipe 27 mm dia.	1						
	2						
	3						
	4						
	5						

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Calculations:

- Head loss due to friction, h_f (m of water) = (P_1~ P_2) x 10
- Actual discharge, Q_{act} (m^3/s) = $\frac{A\ R}{t}$
- Velocity of flow in pipe, V (m/s) = $\frac{Q_{act}}{A_{P_i}}$
- Co-efficient of friction, f = $\frac{2\ h_f\ g\ D}{4\ L\ V^2}$

Results:

- **The Co-efficient of friction (f) for**
  - G.I. Pipe 27 mm diameter = _____
  - G.I. Pipe 19 mm diameter = _____
  - G.I. Pipe 15 mm diameter = _____
  - P.V.C. Pipe 27 mm diameter = _____

Conclusions:

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Experiment No: 6 – Impact of jet on Vanes

Objective:

(i) To determine the force produced by a water jet when it strikes a flat vane, inclined vane and hemi-spherical vane.

(ii) To compare the results measured with the theoretical values calculated from the momentum flux in the jet.

(iii) To determine Co-efficient of impact for different vanes and to compute efficiency of the vane.

Theory:

- ✓ Whenever a jet strikes a vane, it exerts a force on the vane which is hydrodynamic force, exerted by the jet on the vane is called impact of jet on vanes.
- ✓ The amount of hydrodynamic force exerted depends on the diameter of the jet, shape of the vane, fluid density and flow rate of water.
- ✓ The impulse momentum principle based on Newton's second law of motion is used to calculate the hydrodynamic force of jet on the vane.
- ✓ The knowledge of this force is essential for working out the work done by the jet on series of vanes in case of turbines and pumps.

Laboratory setup:

- ✓ It is closed circuit water re-circulating system consisting of sump tank, pumpset, jet / vane chamber, rotameter for flow measurement, direct reading, digital force indicator.
- ✓ The water is drawn from the sump tank by centrifugal pump and delivers vertically to the nozzle through rotameter.
- ✓ The rotameter is a direct indicating flow rate instrument which gives the discharge in LPM which is determined by the top – position of the float.
- ✓ The flow control valve is also provided for controlling the water into the nozzle.
- ✓ The nozzle is issued out of the nozzle as jet.
- ✓ The jet is made to strike the vane, the force of which is transferred directly through the load cell to the force indicator in kgf.
- ✓ The provision is made to change the size of nozzle / jet and the vane of different shapes.

Laboratory setup Operation:

- ✓ Fix the required diameter the jet and the vane of required shape in position.
- ✓ Connect the power cable to single phase, 220 V, 10 Amps with earth connections.
- ✓ Make sure that the digital force indicator is ON.
- ✓ Press 'TARE' switch of the digital force indicator and make the indicator reads '0'.
- ✓ Keep the delivery valve closed and switch ON the pump.
- ✓ Close the front transparent cover tightly.
- ✓ Open the delivery valve and observe the flow rate of water as read on the rotameter.
- ✓ Observe the force as indicated in the force indicator.
- ✓ Note down the diameter of jet, shape of vane, flow rate and force and tabulate the results.
- ✓ Switch OFF the pump after the experiment is over and close the delivery valve.

Lab. Setup and Vanes:





Apparatus:

- ✓ Pump capacity – 1 HP, Single Phase, 230 V with Starter.
- ✓ Flow rate of water by direct reading by Rotameter.
- ✓ Jet force by direct reading digital force indicator through load cell.
- ✓ Vanes: Flat, Inclined and Hemi-spherical vanes.
- ✓ Jet diameter – 4, 5 and 6 mm (interchangeable).
- ✓ Jet pressure by pressure gauge.
- ✓ Jet chamber – fixed with toughened glass windows with leak proof rubber gaskets.

Observations:

- ✓ Diameter of jet, D_j = _____ mm = _____m.
- ✓ C/S area of jet, A = $\frac{\pi}{4}$ x D_j^2 = _____ = _____m^2.
- ✓ Density of water, ρ_ω = 1000 kg/m^3.
- ✓ Acceleration due to gravity, g = 9.81 m/s^2.

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Calculation tabular column: Impact of jet on Vanes

Vane type	Trail No.	Rotameter - Discharge, Q_{act} (LPM)	Jet Pressure gauge (kg/cm^2)	Actual Force, F_{act} (kgf)
Flat Vane	1			
	2			
	3			
	4			
	5			
Inclined Vane	1			
	2			
	3			
	4			
	5			
Hemi-Spherical vane	1			
	2			
	3			
	4			
	5			

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Calculations:

- ✓ Velocity of the jet, V (m/s) = $\frac{Q_{act}}{A_j}$

  Here, Q_{act} (m^3/s) = actual discharge obtained from the Rotameter

- ✓ For flat vane
  - Theoretical force, F_{th} (kg) = $\frac{\rho_\omega A_j V^2}{g}$
- ✓ For inclined vane
  - Theoretical force, F_{th} (kg) = $\frac{\rho_\omega A_j V^2}{g} \sin^2\Theta$

  Here, Θ (^{0}) = angle deflected jet makes with the axis of the jet striking
- ✓ For Hemi-Spherical vane
  - Theoretical force, F_{th} (kg) = $\frac{2\ \rho_\omega A_j V^2}{g}$

- ✓ Co-efficient of impact, Ci = $\frac{F_{act}}{F_{th}}$
- ✓ Efficiency of vane, η (%) = Ci x 100

Results:

- The efficiency of the vane
  - Flat vane, η = _____ %
  - Inclined vane, η = _____ %
  - Hemi-Spherical vane, η = _____ %

Conclusions:

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Table 2Calculation tabular column: Impact of jet on Vanes

Vane type	Trail No.	Q_{act} (m^3/s)	V (m/s)	F_{act} (kgf)	F_{th} (kgf)	C_i	Avg. C_i	η
Flat Vane	1							
	2							
	3							
	4							
	5							
Inclined Vane	1							
	2							
	3							
	4							
	5							
Hemi-Spherical vane	1							
	2							
	3							
	4							
	5							

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Experiment No: 7 - Pelton Wheel Turbine

Objective:

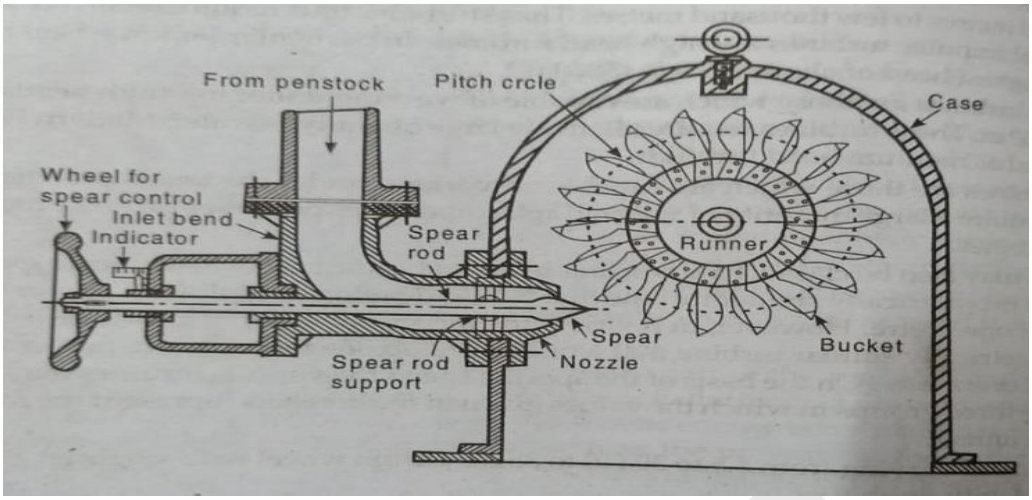
To determine the efficiency of Pelton wheel turbine under constant Speed and constant head and to draw the characteristics curves of Pelton wheel turbine.

Theory:

- ✓ A Pelton wheel is impulse type turbine.
- ✓ It is employed to where very high head of water is available.
- ✓ It converts pressure energy of water into kinetic energy which further rotates the wheel/runner of the turbine.
- ✓ The wheel/runner essentially consists of a disc made of cast-iron or steel fitted to the shaft.
- ✓ On the periphery of the wheel are attached the blades or buckets.
- ✓ The buckets are made of cast-iron or hard bronze and are in the form of a double hemispherical cup.
- ✓ The water to the wheel is delivered by one or more nozzles.
- ✓ The water after passing through the nozzle strikes the bucket at its centre in a tangential direction and flows axially in both directions over the two cups.
- ✓ Due to impulse of water the wheel rotates.

Lab. Setup:





Apparatus:

- ✓ Electrical supply – 3 Ph, 440 V, AC, 30 A with Neutral & Earth.
- ✓ Pump capacity – 12.5 HP, 3Ph, 440 V, 50 Hz, AC
- ✓ Turbine – Mean dia. = 250 mm, No. of buckets = 20, Dia. of jet = 18mm, Runway sped = 2000 rpm, head = 80 m (max.)
- ✓ Loading – Electrical Loading (AC Alternator)
- ✓ Provisions –
    - Supply water control by Butterfly valve.
    - Flow rate measurement by 60^0 V-notch, Cd = 0.62.
    - Head on turbine by pressure gauge (0 – 10 kg/cm^2).
    - Turbine speed by digital rpm indicator.
    - Electrical load, change by loading switches – 10 No. (Max. Load : 2 kW).

Laboratory setup:

- ✓ The experimental setup consists of a centrifugal pumpset supplies the water from the sump tank to the turbine through gate valve and notch tank with 60^0 V-notch and then to the sump tank, the whole unit arranged in such a way that the unit works on recirculating water system.
- ✓ Loading of the turbine is achieved by electrical loading (AC) connected to lamp-bank loading with switches for the measurement of brake power.
- ✓ Measurement of turbine speed (digital rpm indicator), head on turbine (pressure gauge) and head over notch by point gauge are provided.

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Operations:

1. **To obtain runway speed characteristics:**
   - Keep the butterfly valve opening and spear rod setting at maximum.
   - Keep electrical load on the turbine at zero.
2. **To obtain constant speed characteristics:**
   - Keep the butterfly valve opening at maximum.
   - For different electrical load on the turbine, change spear rod setting between maximum and minimum so that the speed is held constant.
   - Tabulate the readings.
   - The above readings are utilised for drawing percentage of full load v/s efficiency.
3. **To obtain constant head characteristics:**
   - Keep the butterfly valve opening and spear rod setting at maximum.
   - For different electrical load on the turbine, note down the speed, head over V-notch.
   - Tabulate the readings.
   - The above readings are utilised for drawing percentage of full load v/s efficiency.
4. **Performance under unit head – unit quantities:**
   - In order to predict the behaviour of a turbine working under varying conditions and to facilitate comparison between the performances of the turbines of the same type but having different outputs, speeds and working under different heads, it is often convenient to express the test results in-terms of certain unit quantities.

Observations:

- ✓ Pressure gauge reading,1 kg/cm^2 = 10 m head of water.
- ✓ Discharge co-efficient of V-notch, C_d = 0.60.
- ✓ Central angle of V-notch, $\theta = 60^0$.
- ✓ Density of water, ρ_ω = 1000 kg/m^3.
- ✓ Acceleration due to gravity, g = 9.81 m/s^2.

Formulae for calculations:

- ✓ Actual discharge by 60^0 V-notch, Q_{act} (m^3/s) = C_d 8/15 tan (θ/2) $\sqrt{2\,g}\,h^{5/2}$
- ✓ Hydraulic input to the turbine, WP (kW) = $\frac{\rho_\omega\, Q_{act}\, H}{75}$

- ✓ Brake horse power of the turbine, SP (kW) = $\frac{n}{E.M.Constant} \times \frac{1000}{736} \times \frac{60 \times 60}{t} \times \frac{1000}{0.75}$

  Here, n = No. of revolutions of Energy meter disc, usually 5 or 10.

  E.M. Constant = 750 revolutions / kWhr

  t = time taken for 'n' revolutions in seconds.

  0.75 = transmission & friction losses.

- ✓ Turbine efficiency, η (%) = $\frac{SP}{WP} \times 100$
- ✓ Unit quantities – under unit head,
  - Unit Speed, $N_U = \frac{N}{\sqrt{H}}$
  - Unit Power, $P_U = \frac{P}{H^{\frac{3}{2}}}$
  - Unit Discharge, $Q_U = \frac{Q}{\sqrt{H}}$
- ✓ Specific Speed, $N_S = \frac{N\sqrt{P}}{H^{\frac{5}{4}}}$
- ✓ **Working Proportions of Pelton wheel turbine:**
  - Velocity of the jet at inlet (m/s), $V_1 = C_V\sqrt{2\,g\,H}$

    Here, C_V → Co-efficient of velocity (0.98 to 0.99)

    H → Net head on the turbine (m) = $(H_g - h_f)$

    H_g → Gross head (m)

    h_f → Head loss due to friction (m) = $\frac{4\,f\,L\,V^2}{2\,g\,d}$

    f→ friction factor depends on pipe material

    L → Length of the penstock (m)

    V → Velocity of flow in the penstock (m/s)

    d → Diameter of penstock (m)

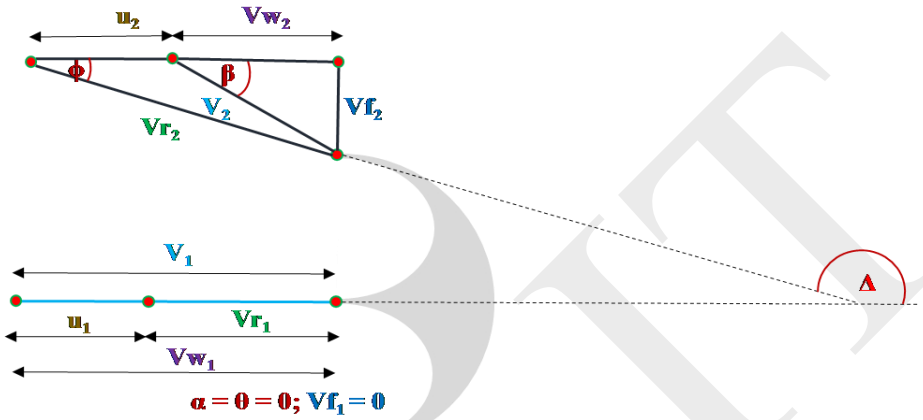
    g → Acceleration due to gravity = 9.81 m/s^2
  - Velocity of the wheel (m/s), $u = C_u\sqrt{2\,g\,H}$

    Here, C_u → Co-efficient of speed (0.43 to 0.48)
  - The deflection angle of the jet through the bucket, $\Delta = 165^0$
  - The mean or pitch diameter of the Pelton wheel turbine (m), $u = \frac{\pi\,D\,N}{60}$

    Here, N → Specific Speed of the turbine (rpm)
  - Jet ratio (m) = $\frac{\text{Pitch Diameter of the turbine, D (m)}}{\text{Diameter of the jet, d (m)}}$ = 12 (for most cases)

- Number of buckets on the runner, Z = 15 + ½ (m)
- Number of jets = $\frac{\text{Total flow rate of water through the turbine, } (\frac{m^3}{s})}{\text{Flow rate of water through a single jet, } (\frac{m^3}{s})}$
- Size of the bucket: Width = 5 d and depth = 1.2 d

Draw velocity triangles at inlet and outlet of vane.



- Velocity of wheel, $u = u_1 = u_2 = \frac{\pi D N}{60}$
- Velocity triangle at inlet will be a straight line.

  $\therefore \quad V_{r1} = V_1 - u_1,\ V_{w1} = V_1,\ \alpha = 0,\ \theta = 0$
- Velocity triangle at outlet,

  $V_{r1} = V_{r2}\ ,\ V_{w2} = V_{r2} \cos \phi - u_2 = (V_1 - u) \cos \phi - u$

✓ Force exerted by the jet of water in the direction of motion,

$F_X = \rho_\omega A_j V_1 (V_{w1} + V_{w2})$ ..... $(\because \beta < 90^0)$

✓ Work done by the jet on the runner per second,

$F_X \times u = \rho_\omega A_j V_1 (V_{w1} + V_{w2}) \times u$ ..... N-m/s (Watts)

✓ Power given to the runner by the jet = $\frac{\rho_\omega A_j V_1 (V_{W_1} + V_{W_2})}{1000}$ ..... kW

✓ Work done/s per unit weight of water striking/s,

$$= \frac{\rho_\omega A_j V_1 (V_{W_1} + V_{W_2}) \times u}{\rho_\omega A_j V_1 g} = \frac{(V_{W_1} + V_{W_2}) \times u}{g}$$

✓ The energy supplied to the jet at inlet in the form of kinetic energy = ½ mV^2

✓ Kinetic energy of the jet /s = ½ $(\rho_\omega A_j V_1) V_1^2$

✓ Hydraulic efficiency, η_H (%) = $\frac{\text{Workdone/sec}}{\text{Kinetic energy/sec}} \times 100 = \frac{2u (V_1 - u) (1 + \cos \phi)}{V_1^2} \times 100$

- For max. Hydraulic efficiency, η_{Hmax} (%) = $\frac{(1 + \cos \phi)}{2}$

1. **To obtain constant speed characteristics:**
   - ✓ Keep the butterfly valve opening at maximum.
   - ✓ For different electrical load on the turbine, change spear rod setting between maximum and minimum so that the speed is held constant.

Table 1: Observations tabular column: ***Constant Speed Characteristics***

Spear rod position	Turbine			Generator		Energy meter reading, n = 5 revolutions	Head over V-notch,
	Electrical Load (Watts)	Speed, N (rpm)	Head, P (kg/cm^2)	Voltage (V)	Current (Amp)	Time, t (sec)	h (cm)
100%	0						
	200						
	400						
	600						
	800						
	1000						
	1200						
	1400						
	1600						
	1800						
	2000						
75%	0						
	200						
	400						
	600						
	800						
	1000						

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	1200						
	1400						
	1600						
	1800						
	2000						
50%	0						
	200						
	400						
	600						
	800						
	1000						
	1200						
	1400						
	1600						
	1800						
	2000						
25%	0						
	200						
	400						
	600						
	800						
	1000						
	1200						
	1400						

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	1600						
	1800						
	2000						

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2. To obtain constant Head characteristics:

- ✓ Keep the butterfly valve opening and spear rod setting at maximum.
- ✓ For different electrical load on the turbine, note down the speed, head over V-notch.

Table 2: Observations tabular column: ***Constant Head Characteristics***

Head, P (kg/cm^2)	Turbine		Generator		Energy meter reading, n = 5 revolutions	Head over V-notch, h (cm)
	Electrical Load (Watts)	Speed, N (rpm)	Voltage (V)	Current (Amp)	Time, t (sec)	
	0					
	200					
	400					
	600					
	800					
	1000					
	1200					
	1400					
	1600					
	1800					
	2000					
	0					
	200					
	400					
	600					
	800					
	1000					

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	1200					
	1400					
	1600					
	1800					
	2000					
	0					
	200					
	400					
	600					
	800					
	1000					
	1200					
	1400					
	1600					
	1800					
	2000					
	0					
	200					
	400					
	600					
	800					
	1000					
	1200					
	1400					

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	1600					
	1800					
	2000					

Formulae for calculations:

- ✓ Actual discharge over 60^0 V-notch, Q_{act} (m^3/s) = C_d 8/15 tan ($\theta/2$) $\sqrt{2\,g}\ h^{5/2}$
- ✓ Hydraulic input to the turbine, WP (kW) = $\frac{\rho_\omega\ Q_{act}\ H}{75}$
- ✓ Brake horse power of the turbine, SP (kW) = $\frac{n}{\text{E.M.Constant}}$ x $\frac{1000}{736}$ x $\frac{60\text{ x }60}{t}$ x $\frac{1000}{0.75}$

  Here, n = No. of revolutions of Energy meter disc, usually 5 or 10.

  E.M. Constant = 750 revolutions / kWhr

  t = time taken for 'n' revolutions in seconds.

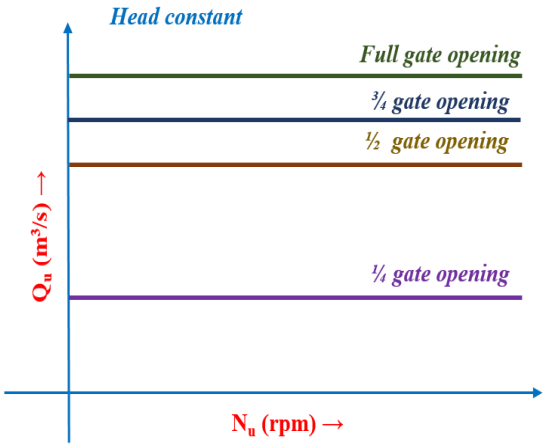
  0.75 = transmission & friction losses.

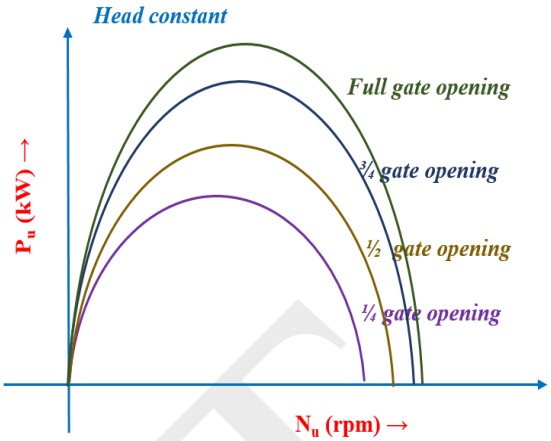
- ✓ Turbine efficiency, η (%) = $\frac{SP}{WP}$ x 100
- ✓ Unit quantities – under unit head,
  - Unit Speed, $N_U = \frac{N}{\sqrt{H}}$
  - Unit Power, $P_U = \frac{P}{H^{\frac{3}{2}}}$
  - Unit Discharge, $Q_U = \frac{Q}{\sqrt{H}}$
- ✓ Specific Speed, $N_S = \frac{N\sqrt{P}}{H^{\frac{5}{4}}}$

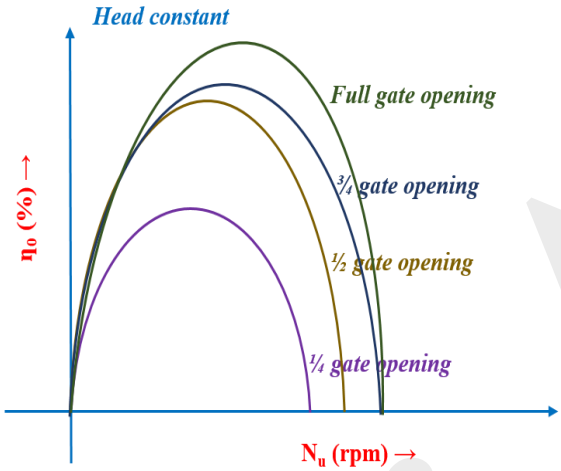
To draw operating characteristics of Pelton wheel turbine:

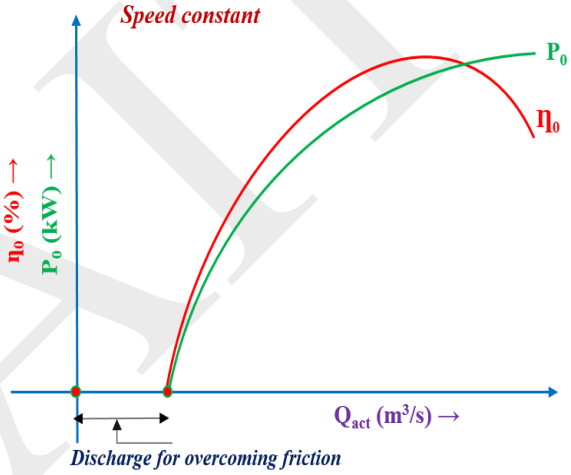
- ✓ A constant speed is maintained by varying the discharge (by changing spear position) as the load changes
- ✓ From the measured discharge (Q_{act}), head (almost constant), power developed (P) and overall efficiency (η_0) are calculated.
- ✓ Curves are plotted between overall efficiency (η_0), power developed (P) and discharge (Q_{act}).
- ✓ The operating characteristic curves are also known as constant speed characteristic curves.
- ✓ Figure shows the variation of overall efficiency (η_0) and power developed (P) with respect to discharge (Q_{act}).

Plot Constant Head & Constant Speed Characteristics:









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Table 3. Calculations tabular column: ***Pelton Wheel Turbine – Constant Speed Characteristics***

Spear rod position	Turbine			Generator		Energy Meter	V-Notch		Turbine	Unit Quantities under Unit Head			
	Electrical Load (Watts)	Speed, N (rpm)	Net Head, H (m)	Voltage (V)	Current (Amp)	SP (kW)	Discharge, Q_{act} (m^3/s)	WP (kW)	η (%)	Unit Speed, N_U (rpm)	Unit Power, P_U (kW)	Unit Discharge, Q_U (m^3/s)	Specific Speed, N_S (rpm)
100%	0												
	200												
	400												
	600												
	800												
	1000												
	1200												
	1400												
	1600												
	1800												
	2000												
75%	0												

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	200												
	400												
	600												
	800												
	1000												
	1200												
	1400												
	1600												
	1800												
	2000												
50%	0												
	200												
	400												
	600												
	800												
	1000												

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	1200												
	1400												
	1600												
	1800												
	2000												
25%	0												
	200												
	400												
	600												
	800												
	1000												
	1200												
	1400												
	1600												
	1800												
	2000												

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Table 4. Calculations tabular column: ***Pelton Wheel Turbine – Constant Head Characteristics***

Turbine			Generator		Energy Meter	V-Notch		Turbine	Unit Quantities under Unit Head			
Net Head, H (m)	**Electrical Load (Watts)**	**Speed, N (rpm)**	**Voltage (V)**	**Current (Amp)**	**SP (kW)**	**Discharge, Q_{act}(m^3/s)**	**WP (kW)**	**η (%)**	**Unit Speed, N_U (rpm)**	**Unit Power, P_U (kW)**	**Unit Discharge, Q_U (m^3/s)**	**Specific Speed, N_S (rpm)**
	0											
	200											
	400											
	600											
	800											
	1000											
	1200											
	1400											
	1600											
	1800											
	2000											
	0											

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	200											
	400											
	600											
	800											
	1000											
	1200											
	1400											
	1600											
	1800											
	2000											
	0											
	200											
	400											
	600											
	800											
	1000											

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	1200											
	1400											
	1600											
	1800											
	2000											
	0											
	200											
	400											
	600											
	800											
	1000											
	1200											
	1400											
	1600											
	1800											
	2000											

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Experiment No: 8 - Francis Wheel Turbine

Objective:

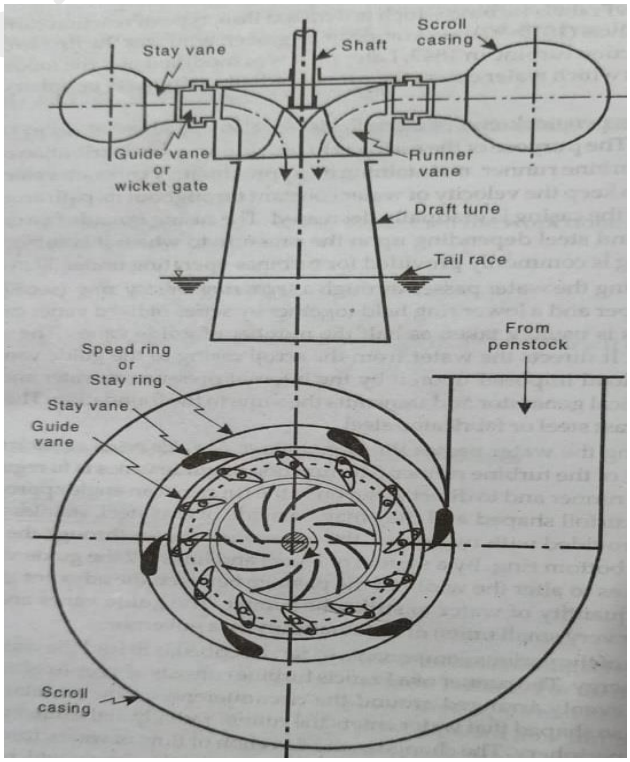
To determine the efficiency of Francis wheel turbine under constant Speed and constant head and to draw the characteristics curves of Francis wheel turbine.

Lab. Setup:









Apparatus:

- ✓ Electrical supply – 3 Ph, 440 V, AC, 30 A with Neutral & Earth.
- ✓ Pump capacity – 10HP, 3Ph, 440 V, 50 Hz, AC
- ✓ Turbine capacity – 2.5 HP
- ✓ Impeller diameter – 150 mm
- ✓ Runway speed – 2000 rpm (max)
- ✓ Venturimeter – Casted, solid body, 100 mm dia. at inlet & 60 mm dia. at throat.
- ✓ Discharge control – Butter fly valve
- ✓ Guide vane opening – Hand wheel with 100%, 75%, 50% & 25% openings
- ✓ No. of guide vanes – 8 (adjustable)
- ✓ Loading – Electrical dynamometer (AC Alternator) belt driven, 2 kW, Single phase, 220 V, 13 amps, 50 Hz at 1500 rpm, transmission efficiency – 85%, Generator efficiency – 70%, Resistance load bank 200 Watts each 10 Nos.
- ✓ Panel mounting & Instrumentations –
    - Pump starter, Main rotary switch, Switches & Indicator lamps.
    - Head on turbine by pressure gauge (Bourdon type) - (0 – 10 kg/cm^2).
    - Turbine speed by digital RPM indicator with sensor.
    - Digital voltmeter, 0 – 750 V, A.C.
    - Digital ammeter, 0 – 20 A, A.C.
    - Electrical load, change by loading switches – 10 No. (Max. Load : 2 kW).

Laboratory setup:

- ✓ The experimental setup consists of a centrifugal pumpset supplies the water from the sump tank to the turbine through gate valve with venturimeter with U tube manometer containing mercury and then to the sump tank through draft tube, the whole unit arranged in such a way that the unit works on recirculating water system.
- ✓ Loading of the turbine is achieved by electrical loading (AC) connected to electrical dynamometer loading with resistance bank (heaters) with switches, fan to dissipate heat for the measurement of brake power.
- ✓ Measurement of turbine speed (digital rpm indicator), head on turbine (pressure gauge) and head over notch by point gauge are provided.

Theory:

- ✓ A Francis turbine is an inward mixed flow reaction turbine (i.e., water under pressure, enters the runner from the guide vanes towards the centre in radial direction and discharges out of the runner axially).
- ✓ The Francis turbine operates under medium heads and also requires medium quantity of water.
- ✓ Water is brought down to the turbine through a penstock and directed to a number of stationary orifices fixed all around the circumference of the runner. These stationary orifices are commonly called as guide vanes or wicket gates.

Observations:

- ✓ Pressure gauge reading, 1 kg/cm^2 = 10 m head of water = 760 mm of mercury.
- ✓ Unit weight of water, γ_ω = 9.81 kN/m^3.
- ✓ Acceleration due to gravity, g = 9.81 m/s^2.
- ✓ Generator efficiency, η_g = 70 % = 0.7
- ✓ Transmission efficiency, η_T = 90 % = 0.9
- ✓ Specific gravity of Heavy liquid in manometer (Mercury), G_H = 13.6
- ✓ Specific gravity of Light liquid in penstock (Water), G_L = 1.00

- **Horizontal Venturimeter:**

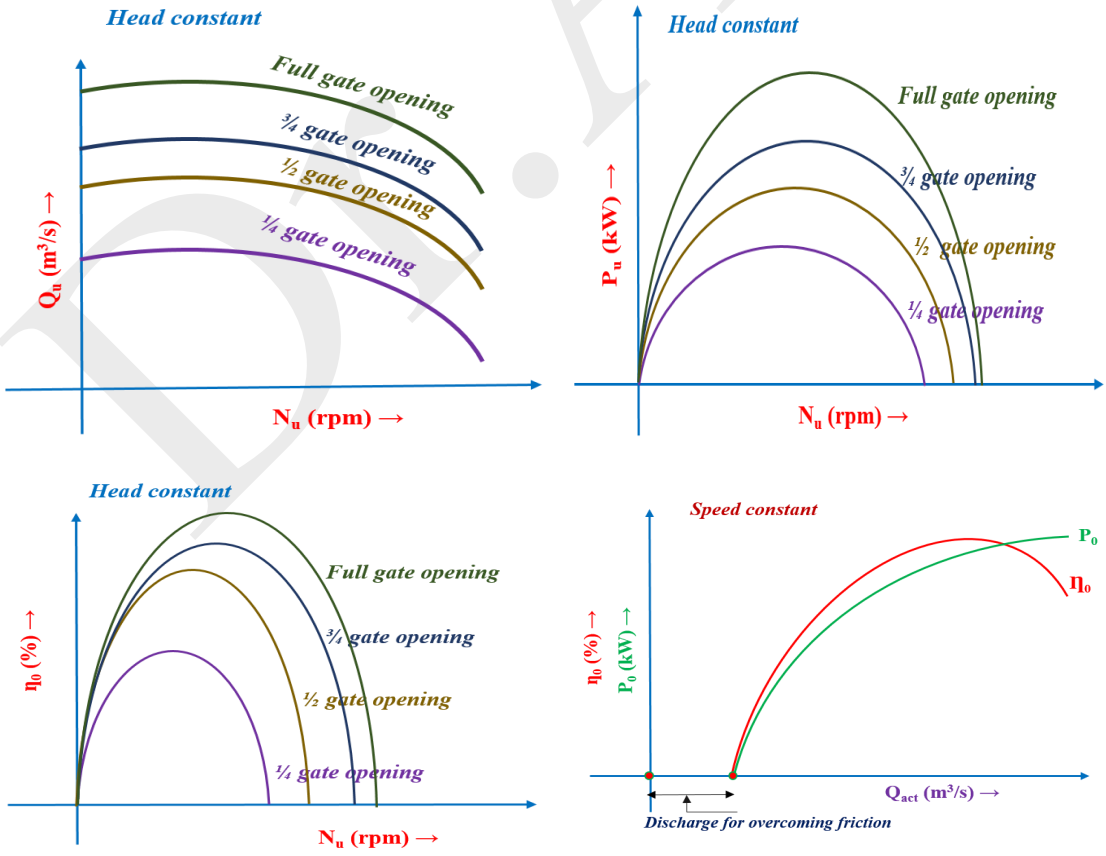
- ✓ Inlet diameter of pipe of the venturimeter, D_1 = 100 mm = 0.1m.
- ✓ C/S area of inlet of pipe of the venturimeter, $A_1 = \frac{\pi}{4} \times D_1^2$ = 0.007855 m^2.
- ✓ Diameter of pipe of the venturimeter at throat, D_2 = 60 mm = 0.06 m.
- ✓ C/S area of pipe of the venturimeter at throat, $A_2 = \frac{\pi}{4} \times D_2^2$ = 0.002826 m^2.
- ✓ Venturimeter Co-efficient of discharge, Cd = 0.98
- ✓ Venturimeter constant, $K = C_d \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2\,g}$ = 0.013144
- ✓ Differential head of water, $h\,(m) = X \left(\frac{G_H}{G_L} - 1\right)$

$$h\,(m) = X \left(\frac{13.6}{1} - 1\right) = 12.6 \times X = _____ \text{ m of water.}$$

Formulae for calculations:

- ✓ Differential head of mercury, X (m of Hg) = $(LL_X - RL_X) \times 10^{-3}$
- ✓ Actual discharge by Venturimeter, Q_{act} (m^3/s) = $K\sqrt{h}$
- ✓ Hydraulic input to the turbine, WP (kW) = $\gamma_\omega Q_{act} H$
- ✓ Brake horse power of the turbine, SP (kW) = $\frac{V \times I}{1000 \times \eta_g \times \eta_T}$
- ✓ Turbine efficiency, η (%) = $\frac{SP}{WP} \times 100$
- ✓ Unit quantities – under unit head,
  - Unit Speed, $N_U = \frac{N}{\sqrt{H}}$
  - Unit Power, $P_U = \frac{P}{H^{\frac{3}{2}}}$
  - Unit Discharge, $Q_U = \frac{Q}{\sqrt{H}}$
- ✓ Specific Speed, $N_S = \frac{N\sqrt{P}}{H^{\frac{5}{4}}}$

Plot Constant Head & Constant Speed Characteristics:



Working Proportions of Francis wheel turbine:

- ✓ The ratio of the width (B) of the runner to the diameter (D) of the runner is represented by n, i.e., $n = \frac{B}{D}$ .... $(0.10 < n < 0.45)$
- ✓ The ratio of the velocity of flow (V_f) at the inlet tip of the vane to the spouting velocity ($\sqrt{2\,g\,H}$) is represented by ψ, i.e., $\psi = \frac{V_f}{\sqrt{2\,g\,H}}$ .... $(0.15 < \psi < 0.30)$
- ✓ The ratio of the velocity of wheel (u) at the inlet tip of the vane to the spouting velocity ($\sqrt{2\,g\,H}$) is represented by ψ, i.e., $K_u = \frac{u}{\sqrt{2\,g\,H}}$ .... $(0.60 < K_u < 0.90)$
- ✓ Discharge of the Francis wheel turbine, $Q = \pi D_1 B_1 V_{f1} = \pi D_2 B_2 V_{f2}$

  Where, D_1, B_1 & V_{f1} are diameter, runner & velocity of flow at inlet and D_2, B_2 & V_{f2} corresponding values at outlet.

  If the thickness of the vanes are taken into consideration, then the area through which flow takes place is given by $Q = (\pi D_1 - n\,t)\, B_1\, V_{f1}$

- ✓ The head on turbine, $H = \frac{P}{\gamma} + \frac{V^2}{2\,g}$
- ✓ Radial discharge at outlet: The angle made by the absolute velocity with the tangent on the wheel is 90^0 and component of whirl velocity is zero.
  (i.e., at outlet: $\beta = 90^0$ & $V_{W2} = 0$, at inlet: $\alpha = 90^0$ & $V_{W1} = 0$)
- ✓ If there is no loss of energy when water flows through the vanes,

  Then, $H - \frac{V_2^2}{2\,g} = \frac{1}{g}(V_{W1}\,u_1 \pm V_{W2}\,u_2)$
- ✓ Workdone / sec on the runner by the jet = $\rho\, A_j\, V_1\, (V_{W1}\,u_1 \pm V_{W2}\,u_2)$

  Here, Velocity of wheel, $u_1 = \frac{\pi D_1 N}{60}$ and $u_2 = \frac{\pi D_2 N}{60}$
- ✓ Work done / sec / unit weight of water / s = $\frac{1}{g}(V_{W1}\,u_1 \pm V_{W2}\,u_2)$
- ✓ Hydraulic efficiency, $\eta_H = \frac{R.\,P.}{W.\,P.} = \frac{1}{g\,H}(V_{W1}\,u_1 \pm V_{W2}\,u_2)$

  For radial discharge at outlet, $\eta_H = \frac{1}{g\,H}(V_{W1}\,u_1)$

Draw Velocity triangles at inlet and outlet of the vane:

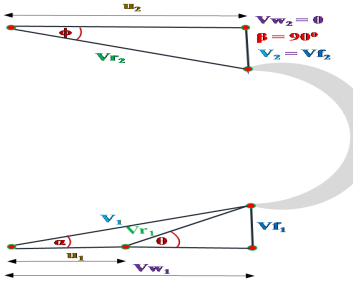


Table 1: Observations tabular column: Francis Wheel turbine

Opening of Guide vanes	Turbine			Generator		Manometer, X (mm)		Draft tube
	Electrical Load (Watts)	Speed, N (rpm)	Head, P (kg/cm^2)	Voltage (V)	Current (Amp)	Left limb, LL_X (mm)	Right limb, RL_X (mm)	Vacuum (mm of Hg)
100%	0							
	200							
	400							
	600							
	800							
	1000							
	1200							
	1400							
	1600							
	1800							
	2000							
75%	0							
	200							
	400							
	600							
	800							
	1000							
	1200							
	1400							
	1600							

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	1800							
	2000							
50%	0							
	200							
	400							
	600							
	800							
	1000							
	1200							
	1400							
	1600							
	1800							
	2000							
25%	0							
	200							
	400							
	600							
	800							
	1000							
	1200							
	1400							
	1600							
	1800							
	2000							

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Formulae for calculations:

- ✓ Differential head of mercury, X (m of Hg) = $(LL_X \sim RL_X) \times 10^{-3}$
- ✓ Actual discharge by Venturimeter, Q_{act} (m^3/s) = $K\sqrt{h}$
- ✓ Hydraulic input to the turbine, WP (kW) = $\gamma_\omega Q_{act} H$
- ✓ Brake horse power of the turbine, SP (kW) = $\frac{V \times I}{1000 \times \eta_g \times \eta_T}$
- ✓ Turbine efficiency, η (%) = $\frac{SP}{WP} \times 100$
- ✓ Unit quantities – under unit head,
  - Unit Speed, $N_U = \frac{N}{\sqrt{H}}$
  - Unit Power, $P_U = \frac{P}{H^{\frac{3}{2}}}$
  - Unit Discharge, $Q_U = \frac{Q}{\sqrt{H}}$
- ✓ Specific Speed, $N_S = \frac{N\sqrt{P}}{H^{\frac{5}{4}}}$

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Table 2. Calculations tabular column: Francis Wheel Turbine

Guide vane opening	Turbine			Generator			Venturimeter			Turbine	Unit Quantities under Unit Head			
	Electrical Load (Watts)	Speed, N (rpm)	Net Head, H (m)	Voltage (V)	Current (Amp)	SP (kW)	Head of water, h (m)	Discharge, $Q_{act}(m^3/s)$	WP (kW)	η (%)	Unit Speed, N_U (rpm)	Unit Power, P_U (kW)	Unit Discharge, Q_U (m^3/s)	Specific Speed, N_S (rpm)
100%	0													
	200													
	400													
	600													
	800													
	1000													
	1200													
	1400													
	1600													
	1800													
	2000													
75%	0													

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	200													
	400													
	600													
	800													
	1000													
	1200													
	1400													
	1600													
	1800													
	2000													
50%	0													
	200													
	400													
	600													
	800													
	1000													

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	1200													
	1400													
	1600													
	1800													
	2000													
25%	0													
	200													
	400													
	600													
	800													
	1000													
	1200													
	1400													
	1600													
	1800													
	2000													

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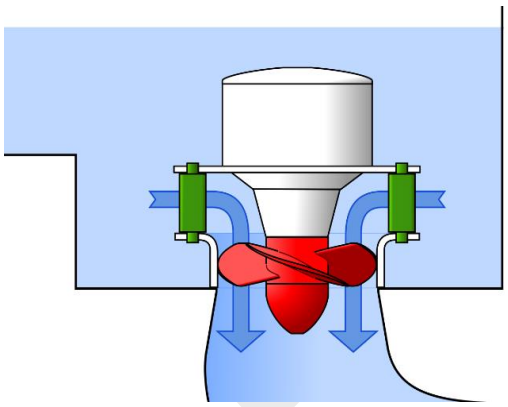
Experiment No: 9 - Kaplan Wheel Turbine

Objective:

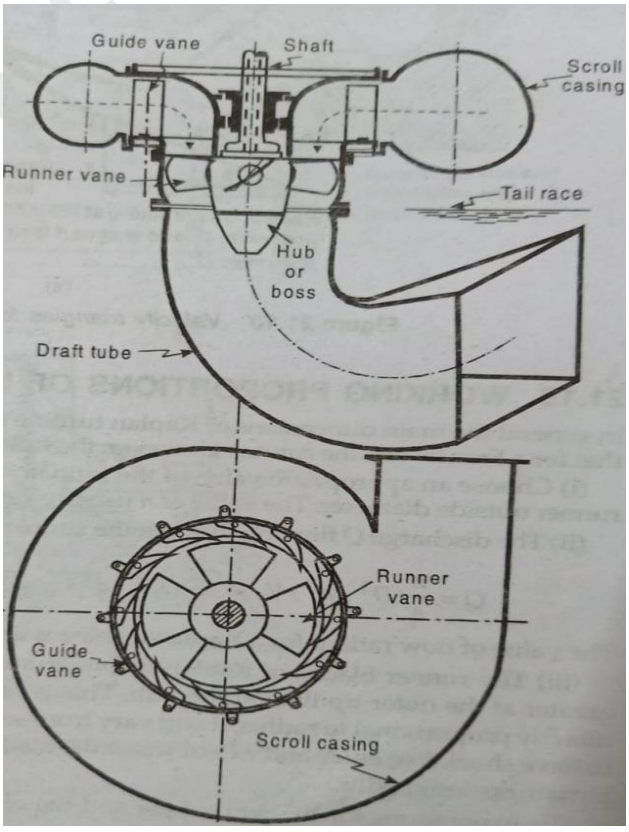
To determine the efficiency of Kaplan wheel turbine under constant Speed and constant head and to draw the characteristics curves of Kaplan wheel turbine.

Lab. Setup:









Apparatus:

- ✓ Electrical supply – 3 Ph, 440 V, AC, 30 A with Neutral & Earth.
- ✓ Pump capacity – 10 HP, 3Ph, 440 V, 50 Hz, AC
- ✓ Turbine capacity – 1 - 2 HP
- ✓ Propeller diameter, D – 150 mm
- ✓ No. of blades – 4
- ✓ Hub diameter, d – 60 mm
- ✓ Runway speed – 2000 rpm (max)
- ✓ Venturimeter – Casted, solid body, 100 mm dia. at inlet & 60 mm dia. at throat.
- ✓ Discharge control – Butter fly valve
- ✓ Guide vane opening – Hand wheel with 100%openings
- ✓ Loading – Electrical dynamometer (AC Alternator) belt driven, 2 kW, Single phase, 220 V, 13 amps, 50 Hz at 1500 rpm, transmission efficiency – 85%, Generator efficiency – 70%, Resistance load bank 200 Watts each 10 Nos.
- ✓ Panel mounting & Instrumentations –
    - Pump starter, Main rotary switch, Switches & Indicator lamps.
    - Head on turbine by pressure gauge (Bourdon type) - (0 – 10 kg/cm^2).
    - Turbine speed by digital RPM indicator with sensor.
    - Digital voltmeter, 0 – 750 V, A.C.
    - Digital ammeter, 0 – 20 A, A.C.
    - Electrical load, change by loading switches – 10 No. (Max. Load: 2 kW).

Laboratory setup:

- ✓ The experimental setup consists of a centrifugal pumpset supplies the water from the sump tank to the turbine through gate valve and discharges water through draft tube and then notch tank with rectangular notch and then to the sump tank, the whole unit arranged in such a way that the unit works on recirculating water system.
- ✓ Loading of the turbine is achieved by electrical loading (AC) connected to electrical dynamometer loading with resistance bank (heaters) with switches, fan to dissipate heat for the measurement of brake power.
- ✓ Measurement of turbine speed (digital rpm indicator), head on turbine (pressure gauge) and head over notch by hook gauge are provided.

Operations:

Performance under unit head – unit quantities:

- In order to predict the behaviour of a turbine working under varying conditions and to facilitate comparison between the performances of the turbines of the same type but having different outputs, speeds and working under different heads, it is often convenient to express the test results in-terms of certain unit quantities.

Theory:

- ✓ If the water flows parallel to the axis of the rotation of the shaft, the turbine is known as axial flow turbine.
- ✓ Head at the inlet of the turbine is the sum of pressure energy and kinetic energy and during the flow of water through the runner a part of pressure energy is converted into kinetic energy, the turbine is known as reaction turbine.
- ✓ For the axial flow reaction turbine, the shaft of the turbine is vertical.
- ✓ The lower end of the shaft is made larger which is known as 'hub' or 'boss'.
- ✓ The vanes are fixed on the hub and hence act as a runner for axial flow turbine.
- ✓ The vanes are fixed to the hub and they are adjustable, the turbine is known as a Kaplan turbine.
- ✓ Kaplan turbine is suitable where a large quantity of water at low head is available.
- ✓ The main parts of Kaplan turbine are:
  - Scroll casing
  - Guide vane mechanism
  - Hub with vanes or runner of the turbine
  - Draft tube
- ✓ The water from penstock enters the scroll casing and then moves to the guide vanes.
- ✓ From the guide vanes, the water runs through 90^0 and flows axially through the runner.
- ✓ The discharge through the runner is given by, $Q = \frac{\pi}{4} (D_O^2 - D_B^2) \times V_{f1}$

  Where, D_O – Outer diameter of the runner

  D_B – Diameter of the boss

  V_{f1} – Velocity of the flow at inlet
- ✓ The inlet and outlet velocity triangles are drawn at the extreme edges of the runner vane.

Observations:

- ✓ Pressure gauge reading, 1 kg/cm^2 = 10 m head of water = 760 mm of mercury.
- ✓ Unit weight of water, γ_ω = 9.81 kN/m^3.
- ✓ Acceleration due to gravity, g = 9.81 m/s^2.
- ✓ Generator efficiency, η_g = 70 % = 0.7
- ✓ Transmission efficiency, η_T = 90 % = 0.9
- ✓ Length of the rectangular notch, L = 0.5 m
- ✓ Coe-efficient of discharge for rectangular notch, C_d = 0.62
- ✓ Rectangular Notch constant, K = C_d 2/3 L $\sqrt{2\,g}$ = 0.915419

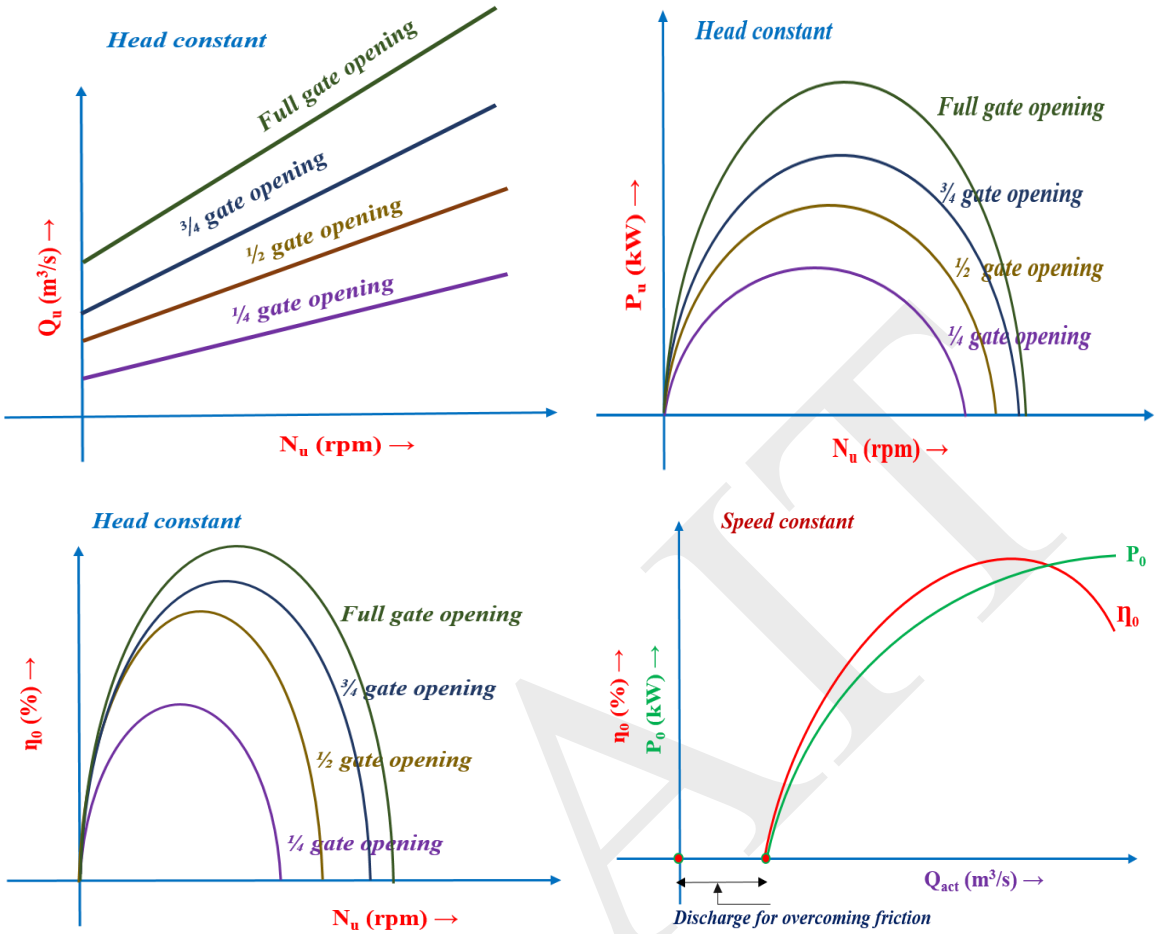
Formulae for calculations:

- ✓ Actual discharge over rectangular notch, Q_{act} (m^3/s) = K $h^{\frac{3}{2}}$
- ✓ Hydraulic input to the turbine, WP (kW) = $\gamma_\omega Q_{act}$ H
- ✓ Brake horse power of the turbine, SP (kW) = $\frac{\text{V x I}}{1000 \text{ x } \eta_g \text{ x } \eta_T}$
- ✓ Turbine efficiency, η (%) = $\frac{SP}{WP}$ x 100
- ✓ Unit quantities – under unit head,
  - Unit Speed, $N_U = \frac{N}{\sqrt{H}}$
  - Unit Power, $P_U = \frac{P}{H^{\frac{3}{2}}}$
  - Unit Discharge, $Q_U = \frac{Q}{\sqrt{H}}$
- ✓ Specific Speed, $N_S = \frac{N\sqrt{P}}{H^{\frac{5}{4}}}$

Working principles of Kaplan turbine:

- ✓ The peripheral velocity at inlet and outlet are equal, $u_1 = u_2 = \frac{\pi D_0 N}{60}$
- ✓ Velocity of flow at inlet and outlet are equal, $V_{f1} = Vf_2$
- ✓ Area of flow at inlet = Area of flow at outlet = $\frac{\pi}{4}$ ($D_O^2 - D_B^2$)

Plot Constant Head & Constant Speed Characteristics:



Draw velocity triangles at inlet and outlet of vane.

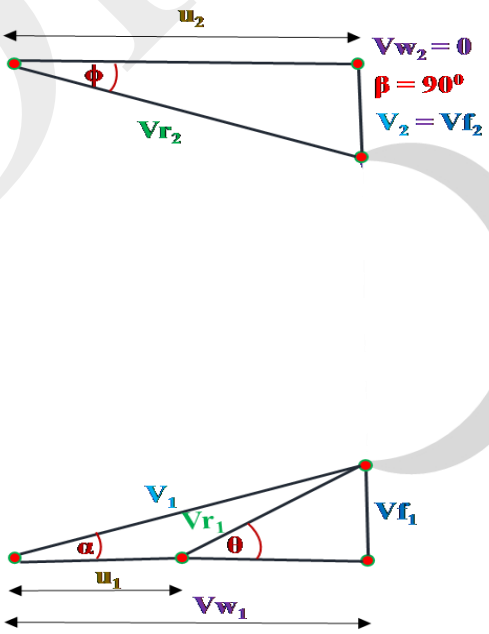


Table 1: Observations tabular column: Kaplan Wheel turbine

Opening of Guide vanes	Turbine			Generator		Rectangle Notch	Draft tube
	Load (kg) / Wattage of bulb (Watts) / Switch	Speed, N (rpm)	Head, P (kg/cm^2)	Voltage (V)	Current (Amp)	Head over notch, h (cm)	Vacuum (mm of Hg)
100%	0						
	200						
	400						
	600						
	800						
	1000						
	1200						
	1400						
	1600						
	1800						
	2000						

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Formulae for calculations:

- ✓ Head over turbine, H (m) = P x 10
- ✓ Actual discharge over rectangular notch, Q_{act} (m^3/s) = K $h^{\frac{3}{2}}$
- ✓ Hydraulic input to the turbine, WP (kW) = $\gamma_\omega Q_{act}$ H
- ✓ Brake horse power of the turbine, SP (kW) = $\frac{V \times I}{1000 \times \eta_g \times \eta_T}$
- ✓ Turbine efficiency, η (%) = $\frac{SP}{WP}$ x 100
- ✓ Unit quantities – under unit head,
  - Unit Speed, $N_U = \frac{N}{\sqrt{H}}$
  - Unit Power, $P_U = \frac{P}{H^{\frac{3}{2}}}$
  - Unit Discharge, $Q_U = \frac{Q}{\sqrt{H}}$
- ✓ Specific Speed, $N_S = \frac{N\sqrt{P}}{H^{\frac{5}{4}}}$

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Table 2. Calculations tabular column: Kaplan Wheel Turbine

Guide vane opening	Turbine			Generator			Rectangular Notch			Turbine	Unit Quantities under Unit Head			
	Electrical Load (Watts)	Speed, N (rpm)	Net Head, H (m)	Voltage (V)	Current (Amp)	SP (kW)	Head of water, h (m)	Discharge, Q_{act} (m^3/s)	WP (kW)	η (%)	Unit Speed, N_U (rpm)	Unit Power, P_U (kW)	Unit Discharge, Q_U (m^3/s)	Specific Speed, N_S (rpm)
100%	0													
	200													
	400													
	600													
	800													
	1000													
	1200													
	1400													
	1600													
	1800													
	2000													

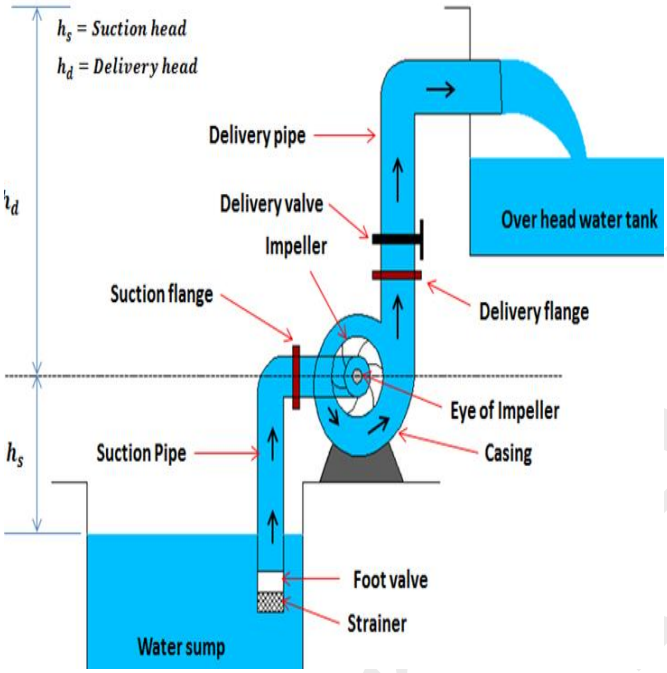
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Experiment No: 10 - Multi Stage Centrifugal Pump Test Rig (4 – Stage)

Objective:

To determine the efficiency, specific speed and to draw the characteristics curves of multi stage centrifugal pump under constant speed.

Lab. Setup:



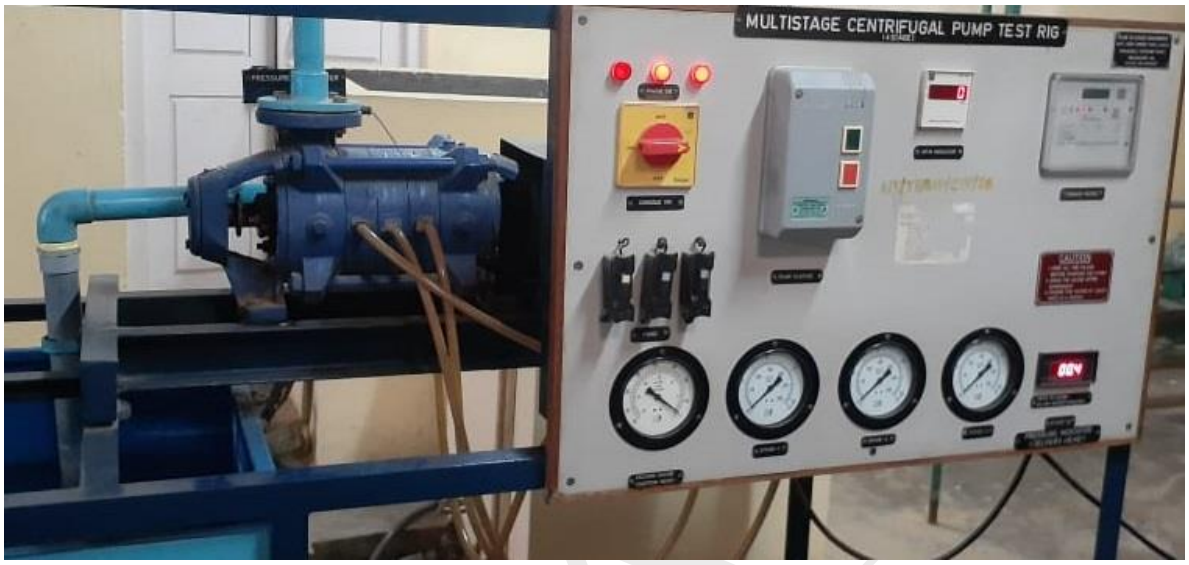


Apparatus:

- ✓ Electrical supply – 3 Ph, 440 V, AC, 30 A with Neutral & Earth.
- ✓ Motor capacity –7.5 kW, 3 Ph, 415 V, 50 Hz, 14 A, 2880 rpm, η = 87 %.
- ✓ Sump tank – Stainless steel, 1000 mm x 850 mm x 600 mm
- ✓ Multi stage Pump (4 stage) capacity –5.5kW, 2875 rpm, suction – 37 mm dia, delivery – 31 mm dia.
- ✓ Discharge control – Butter fly valve
- ✓ Measuring tank – 500 mm x 500 mm x 500 mm, Area of cross-section = 0.25 m^2.
- ✓ Panel mounting & Instrumentations –
    - Pump starter, Main rotary ON/OFF switch, lamps &fuses.
    - Energy meter for measurement of power input to the motor.
    - Digital RPM indicator to indicate the speed of the pump / motor.

- Vacuum gauge to measure suction head.
- Three nos. Pressure gauge – measurement of individual stage delivery head.
- Digital Pressure Transducer – indicating of total delivery head.

Lab. Setup:









Theory:

- ✓ A pump is a device which converts mechanical energy to hydraulic energy.
- ✓ A centrifugal pump is one which converts mechanical energy to hydraulic energy by the centrifugal action of the impeller.
- ✓ Important components of a centrifugal pump are an impeller, suction pipe with a foot valve and strainer, a delivery pipe with a delivery valve and a casing.
- ✓ The purpose of conducting the experiment is to find the design head and design speed of the pump for which the characteristics curves are essential.

- ✓ The selection of pump for any particular application is done by understanding their characteristics.
- ✓ The principle of operation of multi-stage centrifugal pump is covered under rotodynamic pump category.
- ✓ In this pump, the liquid is made to rotate in a closed volute chamber. Thus creating centrifugal action, which gradually builds the pressure gradient towards outlet resulting a continuous flow.
- ✓ These pumps are of simple construction can be directly coupled to electric motor and more suitable for handling clear, semi viscous as well as turbid liquids.
- ✓ The hydraulic head per stage at low flow rates is limited and hence it is not suitable for high heads, in case of single stage centrifugal pumps.
- ✓ But, as the pump in this case in a multi stage construction the pressure gradually builds up in successive stages almost equally in each stage. Thus achieving considerably higher heads.
- ✓ **Main parts of Centrifugal Pump:**
  - Impeller
  - Casing
  - Suction pipe with a foot valve and a strainer
  - Delivery pipe.
- ✓ **Heads of Centrifugal Pump:**
  - Suction head
  - Delivery head
  - Static head
  - Manometric head
- ✓ **Efficiencies of Centrifugal Pump:**
  - Manometric efficiency
  - Mechanical efficiency
  - Overall efficiency

Observations:

- ✓ Cross-sectional area of collecting tank = 0.25 m^2.
- ✓ Pressure gauge reading, 1 kg/cm^2 = 10 m head of water = 760 mm of mercury.
- ✓ Unit weight of water, γ_ω = 9.81 kN/m^3.

- ✓ Acceleration due to gravity, g = 9.81 m/s^2.
- ✓ Motor efficiency, η_M = 87 % = 0.87

Formulae for calculations:

- ✓ Actual discharge, Q_{act} (m^3/s) = $\frac{A\ R}{t}$
- ✓ Manometric head, H_M (m of water) = $H_S + H_D$ = [P_{VG} x 10^{-3} x 13.6 + P_{SG} x10]
- ✓ Input Power to the Motor,

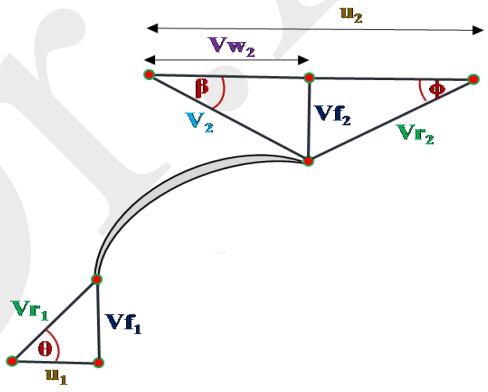
$$P_I\,(kW) = \frac{\text{Energy meter reading (change of decimal digit)}}{\text{Time (T)}} \times 3.6 \times 10^6$$

Here, 3.6 x 10^6 ---- is conversion factor from kWh to Watts

T (sec) – time required to change in decimal digit

- ✓ Output power (delivered by the pump), P_O (kW) =γ_ω Q_{act} H_M
- ✓ Power available at shaft, SP (kW) = Input Power to the Motor, P_I x η_{Motor}
- ✓ Overall efficiency, η_O (%) = $\frac{\text{Out out Power}}{\text{Shaft Power}}$ x 100

Draw velocity triangles at inlet and outlet of vane.



- ✓ As the water enters the impeller radially, which means the absolute velocity of water at inlet is in the radial direction and hence angle $\alpha = 90^0$ and $V_{W1} = 0$.
- ✓ Work done / sec / unit weight of water / s = $\frac{1}{g}(V_{W2}\ u_2)$
- ✓ Discharge, Q = Area x Velocity of flow = $\pi\ D_1\ B_1\ V_{f1} = \pi\ D_2\ B_2\ V_{f2}$

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Table 1: Observations tabular column: Multi-Stage Centrifugal Pump

Control valve Open	Trial No.	Multi-Stage Centrifugal Pump					Measuring tank	Energy meter
		Suction head (mm of Hg)	Delivery head (kg/cm^2)				time t (sec)	Time for change in 0.1 digit T (sec)
			Stage - 1	Stage - 2	Stage - 3	Stage - 4		
	1							
	2							
	3							
	4							
	5							
	6							
	7							
	8							
	9							
	10							

Formulae for calculations:

- ✓ Actual discharge, Q_{act} (m^3/s) = $\frac{A\,R}{t}$
- ✓ Manometric head, H_M (m of water) = $H_S + H_D = [P_{VG} \times 10^{-3} \times 13.6 + P_{SG} \times 10]$
- ✓ Input Power to the Motor,

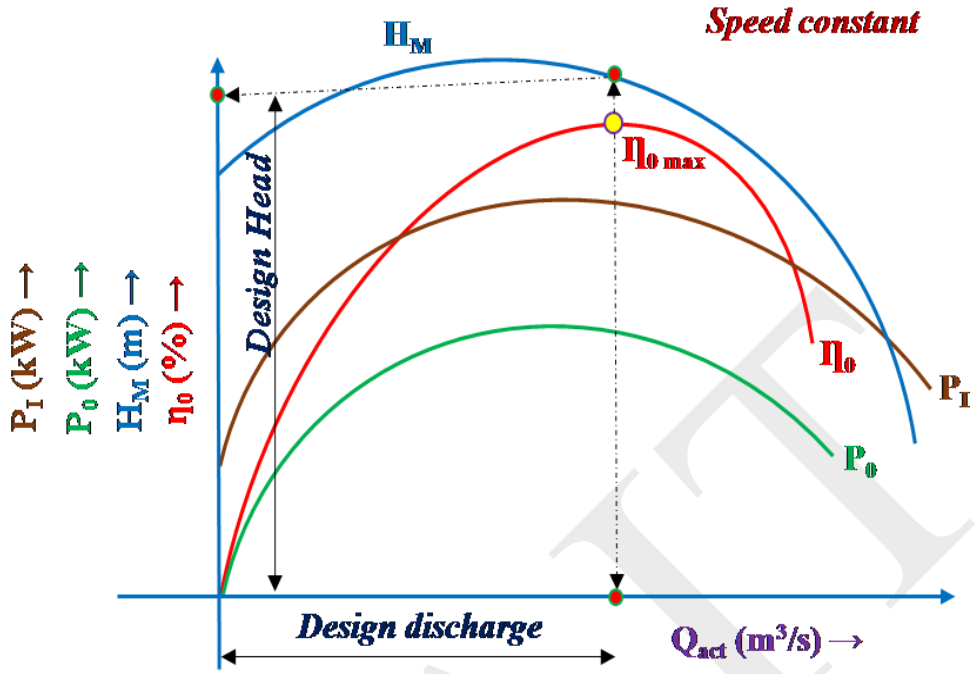
$$P_I\,(kW) = \frac{\text{Energy meter reading (change of decimal digit)}}{\text{Time (T)}} \times 3.6 \times 10^6$$

Here, 3.6×10^6 ---- is conversion factor from kWh to Watts

T (sec) – time required to change in decimal digit

- ✓ Output power (delivered by the pump), P_O (kW) = $\gamma_\omega\ Q_{act}\ H_M$
- ✓ Power available at shaft, SP (kW) = Input Power to the Motor, $P_I \times \eta_{Motor}$
- ✓ Overall efficiency, η_O (%) = $\frac{\text{Out out Power}}{\text{Shaft Power}} \times 100$

Plot: Operating Characteristics Curves of a Centrifugal Pump



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Table 2. Calculations tabular column: Multi-Stage Centrifugal Pump

Control valve Open	Trial No.	`Measuring Tank		Multi-Stage Centrifugal Pump				Energy meter		Pump	
		t (sec)	Q_{act}, (m^3/s)	H_S (m)	H_D (m)	H_M (m)	P_O (kW)	T (sec)	P_I (kW)	SP (kW)	η_O (%)
	1										
	2										
	3										
	4										
	5										
	6										
	7										
	8										
	9										
	10										

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