NARASARAOPETA ENGINEERING COLLEGE

NEC

(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

COURSE FILE

Academic year	: 2022-23
Department	: ME
Course Name	: B.Tech
Student's Batch	: 2022-23
Regulation	: R20
Year and Semester	: II B.Tech I Semester
Name of the Subject	: FM&HM
Subject Code	: R20ME2102
Faculty In charge	: M.Venkaiah.

M.Venkai

Signature of Faculty

Head of the Department

NARASARAOPETA
NEC ENGINEERING COLLEGE
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DEPARTMENT OF MECHANICAL ENGINEERING

COURSE FILE CONTENTS

S. NO:	CONTENTS
1	Institute Vision and Mission
2	Department Vision and Mission
3	Program Educational Objectives (PEOs) and Program Specific Outcomes (PSOs)
4	Program Outcomes (POs)
5	Bloom's Taxonomy Levels
6	Course Outcomes (COs)
7	Course Information Sheet
8	Academic Calendar
9	Time Table
10	Syllabus Copy
11	Lesson Plan
12	CO-POs & CO-PSOs Mapping (Course Articulation Matrix)
13	Web References
14	Student's Roll List
15	Hand Written/Printed Lecture Notes
16	Mid & Assignment Examination Question Papers with Scheme and Solutions
17	Unit Wise Important Questions
18	Previous Question Papers
19	CO-POs & CO-PSOs Attainment

NARASARAOPETA
ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

INSTITUTE VISION AND MISSION

NARASARAOPETA ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

INSTITUTE VISION AND MISSION

VISION:

To emerge as a **Centre of excellence** in technical education with a blend of effective **student centric teaching learning** practices as well as **research** for the transformation of **lives and community**.

MISSION:

1. Provide the best class infrastructure to explore the field of engineering and research.
2. Build a passionate and a determined team of faculty with student centric teaching, imbibing experiential and innovative skills.
3. Imbibe lifelong learning skills, entrepreneurial skills and ethical values in students for addressing societal problems.

PRINCIPAL

NARASARAOPETA
NEC ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

DEPARTMENT VISION AND MISSION

NARASARAOPETA ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

DEPARTMENT VISION AND MISSION

VISION:

To strive for making competent **Mechanical Engineering Professionals** to cater the real time needs of Industry and **Research** Organizations of high repute with **Entrepreneurial Skills and Ethical Values.**

MISSION:

M1. To train the students with State of Art Infrastructure to make them industry ready professionals and to promote them for higher studies and research.

M2. To employ committed faculty for developing competent mechanical engineering graduates to deal with complex problems.

M3. To support the students in developing professionalism and make them socially committed mechanical engineers with morals and ethical values.

HOD-ME

NARASARAOPETA
NEC ENGINEERING COLLEGE
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DEPARTMENT OF MECHANICAL ENGINEERING

PROGRAM EDUCATIONAL OBJECTIVES (PEOs)

AND

PROGRAM SPECIFIC OUTCOMES (PSOs)

NARASARAOPETA ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

PROGRAM EDUCATIONAL OBJECTIVES (PEOs)

PEO 1: Excel in profession with sound knowledge in mathematics and applied sciences

PEO 2: Demonstrate leadership qualities and team spirit in achieving goals

PEO 3: Pursue higher studies to ace in research and develop as entrepreneurs.

PROGRAM SPECIFIC OUTCOMES (PSOs)

PSO1. The students will be able to apply knowledge of modern tools in manufacturing enabling to conquer the challenges of Modern Industry.

PSO2. The students will be able to design various thermal engineering systems by applying the principles of thermal sciences.

PSO3. The students will be able to design different mechanisms and machine components of transmission of power and automation in modern industry.

HOD-ME

NARASARAOPETA
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DEPARTMENT OF MECHANICAL ENGINEERING

PROGRAM OUTCOMES
(POs)

NARASARAOPETA
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(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

PROGRAM OUTCOMES (POs):

Engineering Graduates will be able to:

1. Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

2. Problem analysis: Identify, formulate, review research literature, and analyse complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

3. Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

4. Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

5. Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modelling to complex engineering activities with an understanding of the limitations.

6. The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

7. Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

8. Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

9. Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

10. Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11. Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

12. Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

HOD-ME

NEC NARASARAOPETA ENGINEERING COLLEGE
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DEPARTMENT OF MECHANICAL ENGINEERING

BLOOM'S TAXONOMY LEVELS

REVISED Bloom's Taxonomy Action Verbs

Definitions	I. Remembering	II. Understanding	III. Applying	IV. Analyzing	V. Evaluating	VI. Creating
Bloom's Definition	Exhibit memory of previously learned material by recalling facts, terms, basic concepts, and answers.	Demonstrate understanding of facts and ideas by organizing, comparing, translating, interpreting, giving descriptions, and stating main ideas.	Solve problems to new situations by applying acquired knowledge, facts, techniques and rules in a different way.	Examine and break information into parts by identifying motives or causes. Make inferences and find evidence to support generalizations.	Present and defend opinions by making judgments about information, validity of ideas, or quality of work based on a set of criteria.	Compile information together in a different way by combining elements in a new pattern or proposing alternative solutions.
Verbs	• Choose • Define • Find • How • Label • List • Match • Name • Omit • Recall • Relate • Select • Show • Spell • Tell • What • When • Where • Which • Who • Why	• Classify • Compare • Contrast • Demonstrate • Explain • Extend • Illustrate • Infer • Interpret • Outline • Relate • Rephrase • Show • Summarize • Translate	• Apply • Build • Choose • Construct • Develop • Experiment with • Identify • Interview • Make use of • Model • Organize • Plan • Select • Solve • Utilize	• Analyze • Assume • Categorize • Classify • Compare • Conclusion • Contrast • Discover • Dissect • Distinguish • Divide • Examine • Function • Inference • Inspect • List • Motive • Relationships • Simplify • Survey • Take part in • Test for • Theme	• Agree • Appraise • Assess • Award • Choose • Compare • Conclude • Criteria • Criticize • Decide • Deduct • Defend • Determine • Disprove • Estimate • Evaluate • Explain • Importance • Influence • Interpret • Judge • Justify • Mark • Measure • Opinion • Perceive • Prioritize • Prove • Rate • Recommend • Rule on • Select • Support • Value	• Adapt • Build • Change • Choose • Combine • Compile • Compose • Construct • Create • Delete • Design • Develop • Discuss • Elaborate • Estimate • Formulate • Happen • Imagine • Improve • Invent • Make up • Maximize • Minimize • Modify • Original • Originate • Plan • Predict • Propose • Solution • Solve • Suppose • Test • Theory

derson, L. W., & Krathwohl, D. R. (2001). A taxonomy for learning, teaching, and assessing, Abridged Edition. Boston, MA: Allyn and Bacon.

NARASARAOPETA
NEC ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

COURSE OUTCOMES
(COs)

NARASARAOPETA ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING
R20 REGULATION – COURSE OUTCOMES

Course Name: FLUID MECHANICS AND HYDRAULIC MACHINERY		Course Code: C212
CO	**After successful completion of this course, the students will be able to:**	
C212.1	**Explain** about Fluid Properties and hydrostatic forces acting on different surfaces.	
C212.2	**Apply** conversation laws to fluid flow problems in engineering applications.	
C212.3	**Compute** theory of Boundary layer flows, Identifies dimensionless parameters.	
C212.4	**Illustrate** the force required to move the vane using by Jet.	
C212.5	**Demonstrate** the turbines and its functions & Operating conditions of Centrifugal and Reciprocating pumps.	

NARASARAOPETA ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

COURSE INFORMATION SHEET

Narasaraopeta Engineering College
(Autonomous)
Yallmanda(Post), Narasaraopet- 522601

Department of Mechanical Engineering

COURSE INFORMATION SHEET

PROGRAMME: B.Tech Mechanical Engineering	
COURSE: **FLUID MECHANICS AND HYDRAULIC MACHINERY**	Semester : I CREDITS: 3
COURSE CODE: **R20ME2102** REGULATION: **Autonomous**	COURSE TYPE (CORE /ELECTIVE / BREADTH / S&H) : **CORE**
COURSE AREA/DOMAIN: **THERMAL**	PERIODS: 6 Per Week.

COURSE PRE-REQUISITES:

C.CODE	COURSE NAME	DESCRIPTION	SEM
R20CC1107	Engineering Mechanics	An ability to understand the Kinematics and Dynamics	I-I

COURSE OUTCOMES:

SNO	Course Outcome Statement
CO1	Explain about Fluid Properties and hydrostatic forces acting on different surfaces
CO2	Apply conversation laws to fluid flow problems in engineering applications
CO3	Compute theory of Boundary layer flows, Identifies dimensionless parameters
CO4	Illustrate the force required to move the vane using by Jet
CO5	Demonstrate the turbines and its functions & Operating conditions of Centrifugal and Reciprocating pumps

SYLLABUS:

UNIT	DETAILS
I	**PROPERTIES OF FLUIDS AND FLUID STATICS:** Fluid properties: Mass density, specific weight, specific volume, specific gravity, viscosity, vapour pressure, compressibility, surface tension and capillarity. **FLUID STATICS:** Fluid pressure at a point, variation of pressure within a static fluid, hydrostatic law - Pressure head, Pascal's law, Measurement of pressure, U-Tube manometer, Differential U-Tube manometer.
II	**FLUID KINEMATICS:** Lagrangian and Eulerian approach of fluid flow: velocity and acceleration of fluid particles, different types of fluid flow, description of flow pattern: Stream line, streak line, path line. Principle of conservation of mass: Continuity equation, applications of continuity equation. **FLUID DYNAMICS:** Euler's equation of motion along a stream line - Bernoulli's equation, Practical applications of Bernoulli's equation in flow measurement devices like venturimeter, orifice meter and Pitot tube.
III	**BOUNDARY LAYER THEORY:** Boundary layer development on a flat plate and its

	characteristics - Boundary layer thickness, displacement thickness, momentum thickness, energy thickness. **DIMENSIONAL AND MODEL ANALYSIS:** Dimensional analysis: dimensions, dimensional homogeneity, methods of dimensional analysis-Buckingham Pi theorem, Raleigh's method, Model analysis. Similitude, derivations of important dimensionless numbers.
IV	**BASICS OF TURBO MACHINERY:** Hydrodynamic force or jets on stationary and moving flat, inclined, and curved vanes, jet striking centrally and at tip, velocity diagrams, work done and efficiency, flow over radial vanes **HYDRAULIC TURBINES:** Classification of turbines, impulse and reaction turbines, Pelton wheel, Francis turbine and Kaplan turbine-working proportions, work done, efficiencies.
V	**HYDRAULIC PUMPS:** Classification, working, work done - manometric head losses and efficiencies, specific speed- pumps in series and parallel-performance characteristic curves, NPSH; Reciprocating pump, centrifugal pump.

TEXT BOOKS	
T	**BOOK TITLE/AUTHORS/PUBLISHER**
T1	Fluid Mechanics and Hydraulics Machines by R.K.Bansal, Laxmi publications
T2	Fluid Mechanics and Hydraulic Machines by R.K.Rajput, S. Chand Publications
REFERENCE BOOKS	
R	**BOOK TITLE/AUTHORS/PUBLISHER**
R1	Fluid Mechanics by White.F.M, Tata McGraw-Hill, 5th Edition, New Delhi, 2003.
R2	Hydraulics and Fluid Mechanics by P.N.Modi and S.M.Sethi, Standard Book House, New Delhi.

TOPICS BEYOND SYLLABUS/ADVANCED TOPICS:

SNO	DESCRIPTION	Associated PO & PSO
1	Open Channel Flows	PO1, PO2,PO3, PO5 & PSO1
2	Navier stokes Equation	PO1, PO2,PO3, PO5 & PSO1

WEB SOURCE REFERENCES:

1	https://nptel.ac.in/courses/105101082/ Fluid Mechanics by Prof S K Som, Department of Mechanical Engineering
2	https://nptel.ac.in/courses/112/104/112104118/
3	https://nptel.ac.in/courses/112/103/112103249/
4	https://nptel.ac.in/courses/112/104/112104117/

VERY/INSTRUCTIONAL METHODOLOGIES:

✓ Chalk & Talk	✓ PPT	Active Learning
✓ Web Resources	Students Seminars	Case Study
Blended Learning	✓ Quiz	Tutorials
Project based learning	✓ NPTEL/MOOCS	☐Simulation
Flipped Learning	Industrial Visit	Model Demonstration
☐Brain storming	☐Role Play	☐Virtual Labs

MAPPING CO'S WITH PO'S & PSOs

Course Code: C212	Course Name: FLUID MECHANICS AND HYDRAULIC MACHINERY														
COs	POs & PSOs														
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
C212.1	3	3	2	-	-	-	-	-	-	-	-	-	-	-	2
C212.2	3	3	2	-	-	-	-	-	-	-	-	-	-	-	3
C212.3	3	3	3	2	-	-	-	-	-	-	-	-	-	2	3
C212.4	3	3	3	2	-	-	-	-	-	-	-	-	-	-	3
C212.5	3	3	3	2	-	-	-	-	-	-	-	-	-	-	3
C212	3.00	3.00	2.60	2.00	-	-	-	-	-	-	-	-	-	2.00	2.80

Course Outcome Assessment Methods			Weightages		
Direct Assessment	Cumulative Internal Examinations (CIE)	Descriptive Test	30%	90%	Final Course Outcome (100%)
		Objective Test			
		Assignment Test			
	Semester End Examinations (SEE)		70%		
Indirect Assessment	Course End Survey			10%	

Rubrics for overall attainment of course outcomes:
If 50% of the students crossed 50% of the marks: Attainment Level 1
If 60% of the students crossed 50% of the marks: Attainment Level 2
If 70% of the students crossed 50% of the marks: Attainment Level 3

M.Venkat

Course Instructor **Course Coordinator** **Module Coordinator** **Head of the Department**

ANNEXURE I:

(A) PROGRAM OUTCOMES (POs) Engineering Graduates will be able to:

1. Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

2. Problem analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

3. Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

4. Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

5. Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

6. The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

7. Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

8. Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

9. Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

10. Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11. Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

12. Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

(B) PROGRAM SPECIFIC OUTCOMES (PSOs) :

PSO1.The students will be able to understand the modern tools of machining which gives them good expertise on advanced manufacturing methods.

PSO2.The students will be able to design different heat transfer devices with emphasis on combustion and power production.

PSO3.The students are able to design different mechanisms and machine components suitable to automation industry.

Cognitive levels as per Revised Blooms Taxonomy:

Cognitive Domain	LEVEL	Key words
Remember	K1	Defines, describes, identifies, knows, labels, lists, matches, names, outlines, recalls, recognizes, reproduces, selects, states.
Understand	K2	Comprehends, converts, defends, distinguishes, estimates, explains, extends, generalizes, gives an example, infers, interprets, paraphrases, predicts, rewrites, summarizes, translates.
Apply	K3	Applies, changes, computes, constructs, demonstrates, discovers, manipulates, modifies, operates, predicts, prepares, produces, relates, selcts, shows, solves, uses.
Analyse	K4	Analyzes, breaks down, compares, contrasts, diagrams, deconstructs, differentiates, discriminates, distinguishes, identifies, illustrates, infers, outlines, relates, selects, separates.
Evaluate	K5	Appraises, compares, concludes, contrasts, criticizes, critiques, defends, describes, discriminates, evaluates, explains, interprets, justifies, relates, summarizes, supports
Create	K6	Categorizes, combines, compiles, composes, creates, devises, designs, explains, generates, modifies, organizes, plans, rearranges, reconstructs, relates, reorganizes, revises, rewrites, summarizes, tells, write

Unit wise Sample assessment questions

COURSE OUTCOMES: Students are able to

CO1: Explain about Fluid Properties and hydrostatic forces acting on different surfaces

CO2: Apply conversation laws to fluid flow problems in engineering applications

CO3: Compute theory of Boundary layer flows, Identifies dimensionless parameters

CO4: Illustrate the force required to move the vane using by Jet

CO5: Demonstrate the turbines and its functions & Operating conditions of Centrifugal and

S NO	QUESTION	KNOWLEDGE LEVEL	CO
	UNIT I		
1	Explain the terms dynamic viscosity and kinematic viscosity.	K3	CO1
2	A simple manometer is used to measure the pressure of oil (sp.gr=0.8) flowing in pipe line. Its right limb is open to the atmosphere and left limb is connected to the pipe. The centre of the pipe is 9cm below the level of mercury in the right limb. If the difference of mercury level in the two limbs is 15cm, determine the absolute pressure of the oil in the pipe.	K4	CO1
3	Explain the phenomenon of capillarity. Obtain an expression for capillary rise of a liquid.	K3	CO1
4	An oil film of thickness 1.5 mm is used for lubrication between a square plate of size 0.9 m × 0.9 m and an inclined plane having an angle of inclination 20^0. The weight of the square plate is 392.4 N and it slides down the plane with a uniform velocity of 0.2 m/s. Find the dynamic viscosity of the oil.	K3	CO1
	UNIT 2		
1	Explain the terms: (i) Path line (ii) Streak line (iii) Stream line, (iv) Stream tube.	K3	CO2
2	For steady incompressible flow verify whether the following values of u and v are possible: i) $u = 6xy + 2y^2$, $v = 7xy + 5x$ ii) $u = x^2 + y^2$, $v = -4xy$ iii) $u = -2x/(x^2 + y^2)$, $v = -2y/(x^2 + y^2)$.	K3	CO2
3	Derive the continuity equation for one dimensional flow	K4	CO2
	UNIT 3		
1	Explain the development of boundary layer formation over a flat plate.	K3	CO3
2	Find the displacement thickness, the momentum thickness and energy thickness for the velocity distribution in the boundary layer given by $(u/U) = 2(y/\delta) - (y/\delta)^2$.	K3	CO3
3	What do you understand by Boundary Layer ? Explain the development of	K3	CO3

	Boundary layer over a flat plate.		
4	Discuss displacement thickness, energy thickness and momentum thickness	K3	CO3
	UNIT 4		
1	Show that the efficiency of a free jet striking normally on a series of flat plates mounted on the periphery of a wheel can never exceed 50%.	K3	CO4
2	Derive the Equation for impact of jet striking a curved plate when the plate is moving in the direction of the jet?	K3	CO4
3	Differentiate between Francis turbine and Kaplan turbine.	K3	CO4
4	Classify the different types of turbines?	K2	CO4
5	Explain the function of various main components of Pelton Turbine with neat sketches.	K3	
	UNIT 5		
1	What is meant by NPSH (Net Positive Suction Head) ?	K3	CO5
2	Explain about main parts of a centrifugal pump.	K3	CO5
3	A centrifugal pump works against a head of 30 m and discharges 0.25 m3/s while running at 1000 rpm. The velocity of flow at the outlet is 3 m/s and the vane angle at outlet is 300. Determine the diameter and width of impeller at outlet if the hydraulic efficiency is 80 per cent.	K4	CO5
4	Draw and discuss the operating characteristics of a centrifugal pump	K3	CO5

Model Question Paper

Code:II B.Tech I Semester Regular Examinations

Sub Code: R20ME2102

SUBJECT NAME: **FLUID MECHANICS & HYDRAULICS MACHINERY**

(ME)

MODEL PAPER

Time: 3 hours **Max. Marks: 70**

Note: Answer All **FIVE** Questions.
All Questions Carry Equal Marks (5 X 14 = 71M)

Time: 3 Hrs **Max. Marks: 70**

Note: 1.Answer FIVE Questions, choice from each unit.

Execution Plan

Sl. No	Activities	Time (Minutes)
1	To study the Question Paper and choose to attempt	5
3	33 Minutes x 5 Questions	165
4	Quick revision & Winding up	10
	Total	180

Answer any FIVE Questions

Q.No.		Questions	Marks
		Unit-I	
1	a	A simple manometer is used to measure the pressure of oil (sp.gr=0.8) flowing in pipe line. Its right limb is open to the atmosphere and left limb is connected to the pipe. The centre of the pipe is 9cm below the level of mercury in the right limb. If the difference of mercury level in the two limbs is 15cm, determine the absolute pressure of the oil in the pipe.	[14M]
		OR	
	b	An oil film of thickness 1.5 mm is used for lubrication between a square plate of size 0.9 m × 0.9 m and an inclined plane having an angle of inclination 20^0. The weight of the square plate is 392.4 N and it slides down the plane with a uniform velocity of 0.2 m/s. Find the dynamic viscosity of the oil.	[14M]
		Unit-II	

2	a	Explain the terms: (i) Path line (ii) Streak line (iii) Stream line, (iv) Stream tube	[14M]
		OR	
	b	Derive the continuity equation for one dimensional flow	[14M]
		Unit-III	
3	a	Explain the development of boundary layer formation over a flat plate.	[7M]
		Discuss displacement thickness, energy thickness and momentum thickness	[7M]
		OR	
	b	What do you understand by Boundary Layer ? Explain the development of Boundary layer over a flat plate.	[14M]
		Unit-IV	
4	a	Show that the efficiency of a free jet striking normally on a series of flat plates mounted on the periphery of a wheel can never exceed 50%.	[7M]
		Derive the Equation for impact of jet striking a curved plate when the plate is moving in the direction of the jet?	[7M]
		OR	
	b	Explain the function of various main components of Pelton Turbine with neat sketches.	[14M]
		Unit-V	
5	a	What is meant by NPSH (Net Positive Suction Head) ?	[7M]
		Explain about main parts of a centrifugal pump.	[7M]
		OR	
	b	A centrifugal pump works against a head of 30 m and discharges 0.25 m3/s while running at 1000 rpm. The velocity of flow at the outlet is 3 m/s and the vane angle at outlet is 300. Determine the diameter and width of impeller at outlet if the hydraulic efficiency is 80 per cent.	[7M]
		Draw and discuss the operating characteristics of a centrifugal pump	[7M]

NARASARAOPETA
ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

ACADEMIC CALENDAR

Narasaraopeta Engineering College (Autonomous)
Kotappakonda Road, Yellamanda (P.O), Narasaraopet- 522601, Guntur District, AP.

ACADEMIC CALENDAR
(B.Tech. 2022 Admitted batch, Academic Year 2023-24)

2022 Batch 2nd Year 1st Semester

Description	From Date	To Date	Duration
Commencement of Class Work	24-07-2023		
1st Spell of Instructions	24-07-2023	16-09-2023	8 Weeks
I Assignment Test	21-08-2023	26-08-2023	
I Mid examinations	18-09-2023	23-09-2023	1 Week
2nd Spell of Instructions	25-09-2023	18-11-2023	8 Weeks
II Assignment Test	23-10-2023	28-10-2023	
II Mid examinations	20-11-2023	25-11-2023	1 Week
Preparation & Practicals	27-11-2023	02-12-2023	1Week
Semester End Examinations	04-12-2023	16-12-2023	2 Weeks

2022 Batch 2nd Year 2nd Semester

Description	From Date	To Date	Duration
Commencement of Class Work	18-12-2023		
1st Spell of Instructions	18-12-2023	10-02-2024	8 Weeks
I Assignment Test	15-01-2024	20-01-2024	
I Mid examinations	12-02-2024	17-02-2024	1 Week
2nd Spell of Instructions	19-02-2024	13-04-2024	8 Weeks
II Assignment Test	18-03-2024	23-03-2024	
II Mid examinations	15-04-2024	20-04-2024	1 Week
Preparation & Practicals	22-04-2024	27-04-2024	1Week
Semester End Examinations	29-04-2024	11-05-2024	2 Weeks

PRINCIPAL

NARASARAOPETA
NEC ENGINEERING COLLEGE
(AUTONOMOUS)

ACADEMIC CALENDAR
(B.Tech. 2021 Admitted Batch, Academic Year 2022-23)

2021 Batch 2nd Year 1st Semester			
Description	**From Date**	**To Date**	**Duration**
Commencement of Class Work	5-09-2022		7 Weeks
1st Spell of Instructions	5-09-2022	22-10-2022	
Assignment Test-I	26-9-2022	31-09-2022	
I Mid examinations	24-10-2022	29-10-2022	1 Week
2nd Spell of Instructions	31-10-2022	17-12-2022	7 Weeks
Assignment Test-II	21-11-2022	26-11-2022	
II Mid examinations	19-12-2022	24-12-2022	1 Week
Preparation & Practicals	26-12-2022	31-12-2022	1Week
Semester End Examinations	02-01-2023	14-01-2023	2 Weeks
Commencement of Class Work	16-01-2023		

PRINCIPAL

NARASARAOPETA
ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

TIME TABLE

NARASARAOPETA ENGINEERING COLLEGE: NARASARAOPET (AUTONOMOUS)
DEPARTMENT OF MECHANICAL ENGINEERING
II B.TECH I SEM TIME TABLE
Section-A

ROOM NO: 1221

Wef: 24/07/2023

	1	2	BREAK	3	4		5	6	7
TIMINGS	9.10-10.00	10.00-10.50	10.50-11.00	11.00-11.50	11.50-12.40	12.40-1.30	1.30-2.20	2.20-3.10	3.10-4.00
MON	NMT			MOS		LUNCH	FM&HM	M&I	
TUE	TD	SM/ M&I LAB					MOS		FM&HM
WED	TD			FM&HM			NM&T	ES	M&I
THU	MOS			TD			MOS&M/ FM&HM LAB		
FRI	ES	MOS&M/ FM&HM LAB					M&I		TD
SAT	FM&HM			NM&T			SM/ M&I LAB		

CODE	SUBJECT	FACULTY
NM&T	Numerical Methods and Transformations	Mr.MD.Shareef
FM&HM	Fluid Mechanics &Hydraulic Machinery	Mr.M.Venkaiah
M&I	Metrology& Instrumentation	Mr.K.Kiran Chand
TD	Thermodynamics	Dr.M.Naveen Kumar
MOS	Mechanics of Solids	Mr.T.Ashok Kumar
FM&HM LAB	Fluid Mechanics &Hydraulic Machinery Lab	Dr.M.Sreenivasa Kumar/Mr.M.Venkaiah
MOS&M LAB	MOS & Metallurgy Lab	Mr.G.Bhargav/B.Ajay Kumar
M&I LAB	Metrology& Instrumentation Lab	Dr.M.Rama Kotaiah/T.N.V.Mahesh
SM	Solid Modelling	Mr.K.John Babu/R.Chinna Rao
ES	Environmental Studies	Dr.K.Srinivasulu

2nd YEAR INCHARGE& CLASS TEACHER: Dr. M.VENKANNA BABU

MENTORS: A.Pavan Kumar / K.Kiran Chand

Signature of HOD

Signature of Principal

NARASARAOPETA
NEC ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

SYLLABUS COPY

II B.Tech I SEMESTER	L	T	P	INTERNAL MARKS	EXTERNAL MARKS	TOTAL MARKS	CREDITS
	2	1	0	30	70	100	3
Code: R20ME2102	**FLUID MECHANICS AND HYDRAULIC MACHINERY**						

COURSE OBJECTIVES:

- To understand the concept of fluid statics and properties of fluids.
- To understand the fluid kinematics and dynamics.
- Get the knowledge of boundary layer theory to solve the problems.
- To understand velocity diagrams on different vanes.
- Learn the working of different kinds of turbines and pumps.

COURSE OUTCOMES:

After successful completion of this course, the students will be able to:

CO 1: Explain about Fluid Properties and hydrostatic forces acting on different surfaces

CO 2: Apply conversation laws to fluid flow problems in engineering applications

CO 3: Compute theory of Boundary layer flows, Identifies dimensionless parameters

CO 4: Illustrate the force required to move the vane using by Jet

CO 5: Demonstrate the turbines and its functions & Operating conditions of Centrifugal and Reciprocating pumps.

UNIT - I

PROPERTIES OF FLUIDS AND FLUID STATICS: Fluid properties: Mass density, specific weight, specific volume, specific gravity, viscosity, vapour pressure, compressibility, surface tension and capillarity.

FLUID STATICS: Fluid pressure at a point, variation of pressure within a static fluid, hydrostatic law - Pressure head, Pascal's law, Measurement of pressure, U-Tube manometer, Differential U-Tube manometer.

UNIT - II:

FLUID KINEMATICS: Lagrangian and Eulerian approach of fluid flow: velocity and acceleration of fluid particles, different types of fluid flow, description of flow pattern: Stream line, streak line, path line. Principle of conservation of mass: Continuity equation, applications of continuity equation.

FLUID DYNAMICS: Euler's equation of motion along a stream line - Bernoulli's equation, Practical applications of Bernoulli's equation in flow measurement devices like venturimeter, orifice meter and Pitot tube.

UNIT – III:

BOUNDARY LAYER THEORY: Boundary layer development on a flat plate and its characteristics - Boundary layer thickness, displacement thickness, momentum thickness, energy thickness.

DIMENSIONAL AND MODEL ANALYSIS: Dimensional analysis: dimensions, dimensional homogeneity, methods of dimensional analysis-Buckingham Pi theorem, Raleigh's method, Model analysis. Similitude, derivations of important dimensionless numbers.

UNIT – IV:

BASICS OF TURBO MACHINERY: Hydrodynamic force or jets on stationary and moving flat, inclined, and curved vanes, jet striking centrally and at tip, velocity diagrams, work done and efficiency, flow over radial vanes

HYDRAULIC TURBINES: Classification of turbines, impulse and reaction turbines, Pelton wheel, Francis turbine and Kaplan turbine-working proportions, work done, efficiencies.

UNIT - V:

HYDRAULIC PUMPS: Classification, working, work done - manometric head losses and efficiencies, specific speed- pumps in series and parallel-performance characteristic curves, NPSH; Reciprocating pump, centrifugal pump.

TEXT BOOKS:

1. Fluid Mechanics and Hydraulics Machines by R.K.Bansal, Laxmi publications
2. Fluid Mechanics and Hydraulic Machines by R.K.Rajput, S. Chand Publications

REFERENCE BOOKS:

1. Fluid Mechanics by White.F.M, Tata McGraw-Hill, 5th Edition, New Delhi, 2003.
2. Hydraulics and Fluid Mechanics by P.N.Modi and S.M.Sethi, Standard Book House, New Delhi.

WEB REFERENCES:

1. https://nptel.ac.in/courses/105101082/ Fluid Mechanics by Prof S K Som, Department of Mechanical Engineering

NARASARAOPETA ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

LESSON PLAN

NEC	**Narasaraopeta Engineering College** **(Autonomous)** **Yallmanda(Post), Narasaraopet- 522601**

DEPARTMENT OF MECHANICAL ENGINEERING
LESSON PLAN

Course Code	Course Title (Regulation)	Year/ Sem	Branch	Contact Periods/Week	Sections
R20ME2102	FLUID MECHANICS AND HYDRAULIC MACHINERY	II/I	Mechanical Engineering	6	A

Course Name: FLUID MECHANICS AND HYDRAULIC MACHINERY	Course Code: C212
CO	**After successful completion of this course, the students will be able to:**
C212.1	**Explain** about Fluid Properties and hydrostatic forces acting on different surfaces.
C212.2	**Apply** conversation laws to fluid flow problems in engineering applications.
C212.3	**Compute** theory of Boundary layer flows, Identifies dimensionless parameters.
C212.4	**Illustrate** the force required to move the vane using by Jet.
C212.5	**Demonstrate** the turbines and its functions & Operating conditions of Centrifugal and Reciprocating pumps.

Unit No	Outcome		Topics/Activity	Ref Text book	Total Periods	Delivery Method
1	CO1. **Explain** about Fluid Properties and hydrostatic forces acting on different surfaces (K2)		**Unit-1. PROPERTIES OF FLUIDS AND FLUID STATICS & FLUID STATICS**			
		1.1	Fluid properties: Mass density, specific weight, specific volume, specific gravity, viscosity,	T1,R1	2	Chalk & Talk
		1.2	vapour pressure, compressibility, surface tension and capillarity.	T1, R1	2	Chalk & Talk
		1.3	Fluid pressure at a point, variation of pressure within a static fluid,	T1, R1	2	Chalk & Talk, Web Resources
		1.4	hydrostatic law - Pressure head, Pascal's law,	T1, R1	3	Chalk & Talk
		1.5	Measurement of pressure, U-Tube manometer, Differential U-Tube manometer	T1, R1	3	Chalk & Talk, PPT
2	CO2. **Apply** conversation laws to fluid flow		**Unit-2. FLUID KINEMATICS & FLUID DYNAMICS**			
		2.1	Lagrangian and Eulerian approach of fluid flow: velocity and acceleration of fluid particles, different types of fluid flow, description of flow pattern: Stream line, streak line, path line.	T1, R1	3	Chalk & Talk, PPT

	problems in engineering applications. (K2)	2.2	Principle of conservation of mass: Continuity equation, applications of continuity equation.	T1, R1	2	Chalk & Talk, Web Resources
		2.3	Euler's equation of motion along a stream line - Bernoulli's equation,	T1, R1	2	Chalk & Talk, NPTEL
		2.4	Practical applications of Bernoulli's equation in flow measurement devices like venturimeter	T1, R1	2	Chalk & Talk, PPT
		2.5	Practical applications of Bernoulli's equation in flow measurement devices like orifice meter and Pitot tube	T1, R1	3	Chalk & Talk, PPT
3	CO 3. **Compute** theory of Boundary layer flows, Identifies dimensionless parameters. (K2)	**Unit-3. BOUNDARY LAYER THEORY & DIMENSIONAL AND MODEL ANALYSIS**				
		3.1	Boundary layer development on a flat plate and its characteristics	T1, R1	3	Chalk & Talk
		3.2	Boundary layer thickness, displacement thickness, momentum thickness, energy thickness	T1, R1	2	Chalk & Talk, PPT
		3.3	Dimensional analysis: dimensions, dimensional homogeneity,	T1, R1	2	Chalk & Talk, Web Resources
		3.4	methods of dimensional analysis-Buckingham Pi theorem, Raleigh's method, Model analysis. Similitude,	T1, R1	2	Chalk & Talk, NPTEL
		3.5	derivations of important dimensionless numbers.	T1, R1	3	Chalk & Talk, PPT
MID I EXAMINATION DURING SEVENTH WEEK						
4	CO 4. **Illustrate** the force required to move the vane using by Jet.. (K2)	**Unit-4. BASICS OF TURBO MACHINERY & HYDRAULIC TURBINES**				
		4.1	Hydrodynamic force or jets on stationary and moving flat, inclined,	T1, R1	3	Chalk & Talk, PPT
		4.2	curved vanes, jet striking centrally and at tip, velocity diagrams, work done and efficiency, flow over radial vanes	T1, R1	3	Chalk & Talk
		4.3	Classification of turbines, impulse and reaction turbines,	T1, R1	3	Chalk & Talk, PPT
		4.4	Pelton wheel and Francis turbine and Kapla turbine-working proportions, work done, efficiencies.	T1, R1	3	Chalk & Talk, PPT, NPTEL
		4.5	Kaplan turbine-working proportions, work done, efficiencies.	T1, R1	2	Chalk & Talk, Web Resources
5	CO 5. **Demonstrate** the turbines and its functions & Operating conditions of Centrifugal and Reciprocating pumps. (K2)	**Unit 5. HYDRAULIC PUMPS**				
		5.1	Classification, working, work done - manometric -	T2, R2	2	Chalk & Talk, NPTEL
		5.3	head losses and efficiencies, specific speed-pumps in series and parallel	T21, R1	3	Chalk & Talk, Web Resources
		5.4	performance characteristic curves, NPSH;	T1, R1	3	Chalk & Talk, PPT
		5.5	Reciprocating pump, centrifugal pump.	T2, R1	3	Chalk & Talk, PPT
MID II EXAMINATION DURING FOURTEENTH WEEK						
END EXAMINATIONS						

TEXT BOOKS	
T	BOOK TITLE/AUTHORS/PUBLISHER
T1	Fluid Mechanics and Hydraulics Machines by R.K.Bansal, Laxmi publications
T2	Fluid Mechanics and Hydraulic Machines by R.K.Rajput, S. Chand Publications
REFERENCE BOOKS	
R	BOOK TITLE/AUTHORS/PUBLISHER
R1	Fluid Mechanics by White.F.M, Tata McGraw-Hill, 5th Edition, New Delhi, 2003.
R2	Hydraulics and Fluid Mechanics by P.N.Modi and S.M.Sethi, Standard Book House, New Delhi.

WEB SOURCE REFERENCES:

1	https://nptel.ac.in/courses/105101082/ Fluid Mechanics by Prof S K Som, Department of Mechanical Engineering
2	https://nptel.ac.in/courses/112/104/112104118/
3	https://nptel.ac.in/courses/112/103/112103249/
4	https://nptel.ac.in/courses/112/104/112104117/

M. Venkai

Faculty

HOD

Principal

NARASARAOPETA
NEC ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

CO-POs & CO-PSOs MAPPING (COURSE ARTICULATION MATRIX)

NEC NARASARAOPETA ENGINEERING COLLEGE

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DEPARTMENT OF MECHANICAL ENGINEERING
COURSE ARTICULATION MATRIX

R20-REGULATION

FLUID MECHANICS AND HYDRAULIC MACHINERY

Explanation of Course Articulation Matrix Table to be ascertained:

- Course Articulation Matrix correlates the individual COs of a course with POs and PSOs.
- The Course Outcomes are mapped with POs and PSOs in the scale of 1 to 3.
- The strength of correlation is indicated as **3** for **Substantial (High)** correlation, **2** for **Moderate (Medium)** correlation, and 1 for **Slight (Low)** correlation.

II B.Tech I SEMESTER

Course Code: C212	Course Name: FLUID MECHANICS AND HYDRAULIC MACHINERY														
COs	POs & PSOs														
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
C212.1	3	3	2	-	-	-	-	-	-	-	-	-	-	-	2
C212.2	3	3	2	-	-	-	-	-	-	-	-	-	-	-	3
C212.3	3	3	3	2	-	-	-	-	-	-	-	-	-	2	3
C212.4	3	3	3	2	-	-	-	-	-	-	-	-	-	-	3
C212.5	3	3	3	2	-	-	-	-	-	-	-	-	-	-	3
C212	3.00	3.00	2.60	2.00	-	-	-	-	-	-	-	-	-	2.00	2.80

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WEB REFERENCES

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1	https://nptel.ac.in/courses/105101082/ Fluid Mechanics by Prof S K Som, Department of Mechanical Engineering
2	https://nptel.ac.in/courses/112/104/112104118/
3	https://nptel.ac.in/courses/112/103/112103249/
4	https://nptel.ac.in/courses/112/104/112104117/

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DEPARTMENT OF MECHANICAL ENGINEERING

STUDENT'S ROLL LIST

NARASARAOPETA ENGINEERING COLLEGE (AUTONOMOUS)

DEPARTMET OF MECHANICAL ENGINEERING

II Year I Semester

Serial No.	Admission No.	First Name	Last Name
1	21471A0301	ANGIREKULA	VEERANJANEYULU
2	21471A0302	BATTULA	YUVA RAJU
3	21471A0303	BOMMIREDDY	VENU
4	21471A0304	JEEDIMALLA	SRI LAKSHMI NILENDRA
5	21471A0305	KONATHAM VENKATA	NARAYANA
6	21471A0306	KUNCHALA	ANKA RAO
7	21471A0307	PATHAN	RIYAZ
8	21471A0309	SASAPU	SAI SANTOSH
9	21471A0310	SOUBHAGYAPU	SAI RAM
10	21471A0311	MUNAGA	RAMANJANEYULU
11	21471A0312	YELCHURI	HEMALATHA MEGHANA
12	21471A0314	ALLAM	TIRUMALA RAJU
13	22475A0301	LUKALAPU	RAMBABU
14	22475A0302	THUNUGUNTLA	NAGA THARUN
15	22475A0303	MAILAVARAPU	PAVAN KALYAN
16	22475A0304	KOLLI	GOWRI SANKARA RAO
17	22475A0305	VANTAKU	GANAPATHI LAXMI NAIDU
18	22475A0306	SYED	HUSSAIN
19	22475A0307	BEHERA	SANJAY KUMAR
20	22475A0308	YASAM	MANIKANTA
21	22475A0309	MALLADI	GOPI PURNA
22	22475A0310	UNGATI	LOKESH
23	22475A0311	RAMAVATH	VASU DEVA NAIK
24	22475A0312	PASALA	SYAM KUMAR
25	22475A0313	THURIMELLA	VAMSI GANESH
26	22475A0314	KUKKAMALLA	KARTHIK
27	22475A0315	VUTLA	KISHORE
28	22475A0316	DHARMANA	APPALA NAIDU
29	22475A0317	NIKKU	SURESH
30	22475A0318	GORANTLA	SIVA KOTESWARA RAO
31	22475A0319	POGUNOLLA	KARUN KUMAR
32	22475A0321	BANDLAMUDI	NAGA RAJU
33	22475A0322	BOJJA	SYAM BABU
34	22475A0323	ATHULURI	PURNA VENKATA RAMARAO
35	22475A0324	BATTULA	LAKSHMI NARAYANA
36	22475A0325	GUDIKANDULA	ANJANEYULU
37	22475A0326	AYINAMPUDI	KISHORE BABU
38	22475A0327	KETHABOYINA	MAHESH
39	22475A0328	SHAIK	BABULAL

40	22475A0329	BANDARU	VENU GOPAL
41	22475A0330	YADAVALLI	LOKESH
42	22475A0331	CHOUDAM	VENKATESH
43	22475A0332	CHATTI	MURALI KRISHNA
44	22475A0333	DARAM	PRUDHVI KRISHNA
45	22475A0334	SHAIK	NAGUR BASHA
46	22475A0335	GOLLAPUDI	SARATH KUMAR
47	22475A0336	ADAKA	VINOD
48	22475A0337	JANNI	ARUN
49	22475A0338	NOWPADA	MEGHANADH
50	22475A0339	BALAGA	YUGANDHAR
51	22475A0340	NEYYELA	KUMAR BEHERA
52	22475A0341	KUNITI	PAVAN KUMAR
53	22475A0342	BHUKYA	DIWAKAR NAIK
54	22475A0343	VOONA	NARENDRA
55	22475A0344	CHANDARLAPATI	GANESH
56	22475A0345	BALAGA	MOHAN
57	22475A0346	BOMMALI	MAHESH
58	22475A0347	DUDDETI	NAGA SAI
59	22475A0348	BASWA	DILLESWARA RAO
60	22475A0349	KORRAPATI	MOHAN KRISHNA
61	22475A0350	NAKKANABOINA	NAGA SRIDHAR
62	22475A0351	GONDU	GANESH PAVAN
63	22475A0352	LINGA	SRINIVAS

NEC NARASARAOPETA ENGINEERING COLLEGE
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DEPARTMENT OF MECHANICAL ENGINEERING

HAND WRITTEN/PRINTED LECTURE NOTES

UNIT-I

Properties of Fluids and Fluid statics:

Fluid properties: Mass density, Specific weight, Specific volume, specific gravity, viscosity, vapour pressure, compressibility, surface tension and Capillarity.

Fluid statics: Fluid pressure at a point, variation of pressure within a static fluid, Hydrostatic law - pressure head, Pascal's law, measurement of pressure: U-Tube Manometer, Differential U-Tube manometer.

A substance which flows is called as fluid. (or) A substance which deforms Continuously when subjected to external shearing force is called fluid.

Ideal fluid: A fluid, assuming to be having no viscosity, surface tension and Incompressible is treated as Ideal fluid.

Real fluid: A fluid which has viscosity, surface tension, density and also compressible is called real fluid.

Fluid properties

Mass density: Mass per unit volume of a liquid is called mass density.

$$\therefore \text{Mass density } (\rho) = \frac{m}{V} \ kg/m^3$$

This is also called as specific mass (or) simply density.

Weight density: The weight of a liquid per unit volume is called weight density.

$$\therefore \text{weight density } (w) = \rho g \ kgf/m^3$$

This is also called as specific weight.

Specific weight of water $w = 9.81 \ KN/m^3$ (SI unit)

$= 1000 \ kgf/m^3$ (MKS)

PTO

Specific volume: This is defined as the volume per unit mass of the fluid.

$\therefore$ Specific volume (υ) = $\frac{V}{m} = \frac{1}{\rho}$ m^3/kg

Specific gravity: The ratio of specific weight of a fluid to the specific weight of a standard fluid is called specific gravity.

$\therefore$ Specific gravity = $\frac{\text{specific weight of the liquid}}{\text{specific weight of pure water}}$

For liquids, standard fluid is pure water at 4°C.

Viscosity: The resistance for the flow of a fluid is termed as viscosity. This is because of the cohesive forces and molecular momentum exchange causing the fluid flows in the form of fluid layers.

— An ideal fluid has no viscosity.

The shear stress (τ) causing viscosity between two layers of a fluid flow is directly proportional to the difference between the velocities of the layers and the distance from the datum (reference line).

$\therefore \tau \propto \frac{du}{dy} \Rightarrow \tau = \mu \frac{du}{dy}$, where μ is coe. of dynamic viscosity.

SI units of viscosity $N\text{-}s/m^2$

MKS " " $kgf\text{-}s/m^2$

CGS " " $\frac{dyne\text{-}s}{cm^2}$

$\frac{dyne\text{-}s}{cm^2}$ is called "poise".

$\therefore$ 1 poise = $\frac{1}{10} \frac{N\text{-}s}{m^2}$

$$\mu = \frac{\tau}{\left(\frac{du}{dy}\right)} = \frac{\frac{N}{m^2}}{\frac{\left(\frac{m}{s}\right)}{m}} = \frac{\frac{N}{m^2}}{\frac{m}{s} \times \frac{1}{m}} = \frac{N\text{-}s}{m^2}$$

Viscosity is also defined as shear stress required to produce unit rate of shear strain.

PTO

Kinematic viscosity: The ratio between dynamic viscosity and density of the fluid is called kinematic viscosity.

$\therefore$ Kinematic viscosity $(\nu) = \frac{\mu}{\rho}$

$\nu = \frac{\mu}{\rho} = \frac{NS/m^2}{(Kg/m^3)}$

$= \left(\frac{Kg \times m}{s^2}\right) \times \frac{s}{m^2} \times \frac{m^3}{Kg}$

$= m^2/s$

SI units = m^2/s

MKS units = m^2/s

CGS units = cm^2/s

$\frac{1\,cm^2}{s}$ is called "Stoke"

1 stoke = $10^{-4}\,\frac{m^2}{s}$

- **Newton's law of viscosity:** This law states that the shear stress on a fluid element layer is directly proportional to the rate of shear strain.

$$\therefore \tau \propto \frac{du}{dy} \Rightarrow \tau = \mu \frac{du}{dy}$$

where μ is called Coefficient of viscosity, $\frac{du}{dy}$ is rate of shear strain.

Fluids obey Newton's law are called Newtonian fluids and donot obey are called Non-Newtonian fluids.

- **Viscosity variation with temperature:**

The viscosity of the liquids decreases with Increase of temperature and that of gases Increases with Increase of temperature.

Worked examples

1. If the velocity distribution over a plate is given by $u = \frac{2}{3}y - y^2$, where 'u' is velocity in m/sec and y is distance in metres from the plate. Determine the shear stress at y=0 and y=0.15m, take dynamic viscosity of the fluid as 8.63 poises.

Solution: $u = \frac{2}{3}y - y^2$; $\mu = 8.63$ poise $= \frac{8.63}{10}\,NS/m^2$; $y=0$; $y=0.15\,m$

PTO

$$\frac{du}{dy} = \frac{2}{3} - 2y \quad \therefore \left(\frac{du}{dy}\right)_{y=0} = \frac{2}{3} = 0.667$$

$$\left(\frac{du}{dy}\right)_{y=0.15} = \frac{2}{3} - 2(0.15) = 0.367$$

$\therefore$ Shear stress at $y=0$ is $\tau = \mu\left(\frac{du}{dy}\right)_{y=0} = 0.867 \times 0.667 = 0.5756 N/$

" $y=0.15$ $\tau = \mu\left(\frac{du}{dy}\right)_{y=0.15} = 0.867 \times 0.367 = 0.3167\ N/m^2$

2. A plate 0.025 mm distant from a fixed plate moves at a speed of 60 cm/sec. To maintain this speed, a force of $2 N/m^2$ is required. Determine the viscosity of the fluid between the plates.

Solution: $dy = 0.025\ mm = 0.025 \times 10^{-3}\ m$; $u = 60\ cm\ s^{-1} = 60 \times 10^{-2}\ m\ s^{-1}$;

$F = 2\ N/m^2$

Let μ be the viscosity of the fluid between the plates

shear stress required$(\tau) = \mu\left(\frac{du}{dy}\right)$

$$\therefore 2 = \mu\left(\frac{60 \times 10^{-2}}{0.025 \times 10^{-3}}\right) \Rightarrow \mu = \frac{2 \times 0.025 \times 10^{-3}}{60 \times 10^{-2}} = 8.33 \times 10^{-5} \frac{N}{m^2}$$

$\therefore$ viscosity (coefficient of viscosity) of the fluid between the plates is

$$\mu = 8.33 \times 10^{-5} \frac{Ns}{m^2} = 8.33 \times 10^{-5} \times 10\ \text{poise} = 8.33 \times 10^{-4}\ \text{poise}.$$

3. Two horizontal plates are 1.25 cm apart. The space between them is filled with an oil of viscosity 14 poises. Calculate shear stress in the oil, if the upper plate moves with a velocity of 2.5 m/sec.

Solution: $dy = 1.25\ cm = 1.25 \times 10^{-2}\ m$; $\mu = 14$ poises $= 1.4\ Ns/m^2$;

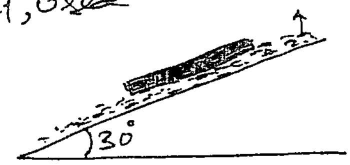
$du = 2.5\ m\ s^{-1}$;

$$\therefore \text{Shear stress}(\tau) = \mu \frac{du}{dy}$$

$$= 1.4 \times \frac{2.5}{1.25 \times 10^{-2}} = 280\ N/m^2$$

PTO

4. Calculate the dynamic viscosity of the oil, used as a lubricant between a square plate of size 0.8 m × 0.8 m and an Inclined plane with Inclination 30° as shown in the figure. weight of the plate is 300 N, thickness of the oil film is 1.5 mm and the plate slides down with a uniform velocity of 0.3 m s^{-1}.



Solution: $A = 0.8 \times 0.8\,m = 0.64\,m^2$; $W = 300\,N$; $\theta = 30°$; $dy = 1.5\,mm = 1.5 \times 10^{-3}\,m$, $du = 0.3\,m s^{-1}$;

Component of the weight along the plane $= W\sin\theta = 300 \sin 30° = 150\,N$

$\therefore$ Stress on the oil $= \frac{F}{A} = \frac{150}{0.64} = 234.375\,N/m^2$

But stress(or) shear stress $\tau = \mu \frac{du}{dy}$

$$\therefore \frac{150}{0.64} = \mu \frac{0.3}{1.5 \times 10^{-3}}$$

$$\Rightarrow \mu = \frac{150 \times 1.5 \times 10^{-3}}{0.64 \times 0.3} = 1.17\,\frac{NS}{m^2} = 11.7 \text{ poise.}$$

5. Find the kinematic viscosity of an oil having density 981 kg/m³. The shear stress at a point in oil is 0.2452 N/m² and velocity gradient at that point is 0.2 per second.

Solution: $\rho = 981\,kg/m^3$; $\tau = 0.2452\,N/m^2$; $\frac{du}{dy} = 0.2/sec$;

we know that $\tau = \mu \frac{du}{dy} \Rightarrow \mu = \tau \times \frac{1}{\left(\frac{du}{dy}\right)}$

$$\therefore \mu = \frac{0.2452}{0.2} = 1.226\,NS/m^2$$

$\therefore$ Kinematic viscosity $(\nu) = \frac{\mu}{\rho} = \frac{1.226}{981} = 0.125 \times 10^{-2}\,m^2/sec = 12.5\,cm^2/s$
$= 12.5$ stokes

6. A gas weighs 16 N/m³ at 25°C and at an absolute pressure 0.25 N/mm². Determine gas constant and density of the gas.

Solution: $W = 16\,N/m^3$; $t = 25°C$; $T = 273 + 25 = 298\,K$;

$P = 0.25\,N/mm^2 = 0.25 \times 10^6\,N/m^2$

PTO

we know that $w = \rho g$

$$\Rightarrow \rho = \frac{w}{g} = \frac{16}{9.81} = 1.63\ kg/m^3$$

Gas equation is $P\forall = RT$, where $\forall$ = specific volume = $\frac{1}{\rho}$

$$\therefore \frac{P}{\rho} = RT \Rightarrow R = \frac{P}{\rho T} = \frac{0.25 \times 10^6}{1.63 \times 298} = 532.55\ \frac{Nm}{kg\,K}$$

7. A cylinder of $0.6\ m^3$ volume contains air at $50°C$ and $0.3\ N/mm^2$ absolute pressure. The air is compressed to $0.3\ m^3$. Find pressure inside the cylinder assuming (i) Isothermal process (ii) Adiabatic process, take $k = 1.4$

Solution: $\forall_1 = 0.6\ m^3$; $T_1 = 50 + 273 = 323\ K$; $P_1 = 0.3\ N/mm^2 = 0.3 \times 10^6\ N/m^2$
$\forall_2 = 0.3\ m^3$; $k = 1.4$; $P_2 = ?$

(i) Isothermal process:

we know that $P_1\forall_1 = P_2\forall_2$

$$\therefore 0.3 \times 10^6 \times 0.6 = P_2 \times 0.3$$

$$\Rightarrow P_2 = \frac{0.3 \times 10^6 \times 0.6}{0.3} = 0.6\ N/mm^2$$

(ii) Adiabatic process:

we know that $P_1\forall_1^k = P_2\forall_2^k$

$$(0.3 \times 10^6) \times (0.6)^{1.4} = P_2 (0.3)^{1.4}$$

$$\Rightarrow P_2 = 0.3 \times 10^6 \times \left(\frac{0.6}{0.3}\right)^{1.4} = 0.791\ N/mm^2$$

Compressibility and Bulk modulus: Elasticity of fluids is measured by Bulk modulus of elasticity. Bulk modulus is defined as the ratio of compressive stress to the volumetric strain.

Let P and V be the pressure and volume of a gas enclosed in a cylinder. Let P+dP is increase in pressure and V−dV is decrease in the volume.

$\therefore$ Increase in pressure $= dP\ kgf/m^2$

PTO

Decrease in the volume = dv m^3

$\therefore$ Volumetric strain $= -\frac{dv}{v}$

$\therefore$ Bulk modulus (K) = $\frac{\text{Increase in pressure}}{\text{volumetric strain}}$

$$\Rightarrow K = -\frac{dp}{\left(\frac{dv}{v}\right)} = -\frac{dp}{dv} \times v$$

Compressibility is the reciprocal of Bulk modulus, hence

$$\text{Compressibility} = \frac{1}{K}$$

NOTE: Relation between Bulk modulus (K) and pressure (P) of a gas is (i) for Isothermal process $K = P$
(ii) for Adiabatic process $K = P\gamma$

Compressibility: The property by virtue of which fluids undergo a change in volume under the action of external pressure is known as compressibility.

Vapour pressure: Molecules are continuously projected from the free surface of the liquid into the atmosphere. These ejected molecules are in the gaseous state and exert their own partial pressure on the liquid surface. This pressure is known as vapour pressure of the liquid.

Saturation vapour pressure: If the free surface of a liquid is confined, the partial vapour pressure exerted by the molecules increases till the rate at which they reentered the liquid is equal to the rate at which they leave the surface. When equilibrium condition is reached, the vapour pressure is called saturation vapour pressure.

NOTE: 1. If the pressure on the liquid surface is lower than (or) equal to the saturation pressure, boiling takes place.
2. Vapour pressure increases with increase of temperature

3. Mercury has a very low vapour pressure, and hence it is used in Barometer.

Surface Tension: The free surface of a liquid behaves like stretched membrane, this property is called surface tension.
(or)
The tensile force acting on the surface of a liquid in contact with a gas (or) on the surface between two immiscible liquids is called surface tension.

Surface tension is the force acting per unit length of the free surface of the liquid. units are N/m

$$\text{Surface tension} (\sigma) = \text{Force/unit length} \quad N/m$$

Ex:- spherical shape of rain drops, Capillary rise, Rise of sap in trees

pressure inside a liquid drop $(P) = \frac{4\sigma}{d}$, d = dia. of the liquid drop

pressure inside a soap bubble $(P) = \frac{8\sigma}{d}$

pressure inside a liquid jet $(P) = \frac{\sigma 2L}{d}$, L = length of the jet, d = dia. " "

Capillarity: the phenomenon of rise (or) fall of a liquid surface in a small tube, when it is held vertically in the liquid.
Capillarity depends upon the specific weight of the fluid, diameter of the tube and surface tension of the liquid.

$$\text{Capillary rise} (h) = \frac{4\sigma \cos\theta}{\rho g d}, \quad \theta = \text{angle of contact}$$

$$\text{Capillary depression} (h) = \frac{4\sigma \cos\theta}{\rho g d}$$

NOTE: 'θ' for mercury and Glass is 128°

PTO

Cavitation: Consider a liquid flowing in a pipe. If pressure at any point equals (or) less than vapour pressure, vaporization starts. The bubbles of these vapour when reaches high pressure region, they collapse and gives high impact pressure. This pressure erodes the material from the adjoining boundaries and hence cavities are formed. This phenomenon is called Cavitation.

Fluid statics

- Fluid pressure at a point: If a force F is uniformly distributed over an area A of a static fluid, then pressure at any point is given by $p = \frac{F}{A}$

units: MKS system $\frac{N}{m^2}$, CGS system Dyne/cm^2

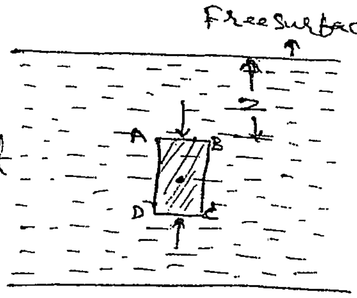
N/m^2 is also called as "Pascal"

$\therefore$ 1 pascal = $\frac{N}{m^2}$ (1 bar = 100 kPa = $10^5 N/m^2$)

Pascal's law: pressure at a point in a static fluid is equal in all directions.

pressure variation in a static fluid: The rate of increase of pressure in vertically downward direction in a static fluid at a point equals to the specific weight of the fluid at that point.

proof: Consider a small element ABCD in a static fluid as shown in the figure.



Let ΔA is cross-sectional area of the element

Δz " height "

z is distance of the element from the free surface.

'p' is the pressure acting on the face AB.

Forces acting on the element are

a) (pressure) force on AB = pressure × Area = $P \times \Delta A$

b) (pressure) force on CD = pressure × Area = $\left(P + \frac{\partial P}{\partial z}\Delta z\right) \times \Delta A$

c) weight of the element = mg = (density × volume) × g = $\rho \times \Delta A \times \Delta z$

d) pressure forces on surfaces BC and AD. These two force are equal in magnitude and opposite in direction.

∴ For the equilibrium of the element, algebraic sum of the forces is zero, hence

$$P\Delta A - \left(P + \frac{\partial P}{\partial z}\Delta z\right)\Delta A + \rho \times \Delta A \times \Delta z \times g = 0$$

$$\Rightarrow -\frac{\partial P}{\partial z}\Delta z + \rho \Delta z g = 0$$

$$\Rightarrow \frac{\partial P}{\partial z} = \rho g = \text{weight density}$$

∴ Rate of increase of pressure in vertical direction is equal to the weight density of the fluid at that point.

Total pressure (or) pressure above the atmospheric pressure is given by $\int \partial P = \int \rho g \partial z$

$$\Rightarrow P = \rho g z,$$

$$\Rightarrow z = \frac{P}{\rho g}, \text{ this is called pressure Head.}$$

(Bramah press)

Worked examples

1. A hydraulic press has a ram of 30 cm diameter and a plunger of 4.5 cm diameter. Find the weight lifted by the hydraulic press when the force applied at the plunger is 500 N

Solution: $D = 30\,cm = 30 \times 10^{-2}\,m$; $d = 4.5\,cm = 4.5 \times 10^{-2}\,m$; $F = 500\,N$

Area of the ram $A = \frac{\pi}{4}(D)^2 = \frac{\pi}{4} \times (30 \times 10^{-2})^2 = 0.07068\,m^2$

" plunger $a = \frac{\pi}{4}(d)^2 = \frac{\pi}{4} \times (4.5 \times 10^{-2})^2 = 0.00159\,m^2$

Let 'W' be the weight lifted by the ram.

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Pressure Intensity due to plunger $(P_1) = \frac{F}{a} = \frac{500}{0.00159} = 314465.4\,N/$

By the pascal's Law, this pressure Intensity is equally distributed In all the directions.

$\therefore$ pressure Intensity at the Ram $= 314465.4\ N/m^2$

But pressure Intensity at the Ram is $P_2 = \frac{W}{A}$

$$\therefore \frac{W}{0.07068} = 314465.4$$

$$\Rightarrow W = 314465.4 \times 0.07068 = 22222\,N = 22.222\,KN$$

2. A hydraulic press has a ram of 20 cm diameter and a plunger of 3 cm diameter. This is used to lift a weight of 30K. find the force required at the plunger.

Solution: $D = 20\,cm = 20 \times 10^{-2}\,m$; $d = 3\,cm = 3 \times 10^{-2}\,m$; $W = 30\,KN$;

Area of the ram $(A) = \frac{\pi}{4}(D)^2 = \frac{\pi}{4}(20 \times 10^{-2})^2 = 0.0314\,m^2$

" plunger $(a) = \frac{\pi}{4}(d^2) = \frac{\pi}{4}(3 \times 10^{-2})^2 = 7.068 \times 10^{-4}\,m^2$

Let F be the force applied at the plunger

$\therefore$ pressure Intensity at the plunger $= \frac{F}{a} = \frac{F}{7.068 \times 10^{-4}}$

By pascal's law this pressure is distributed In all direction

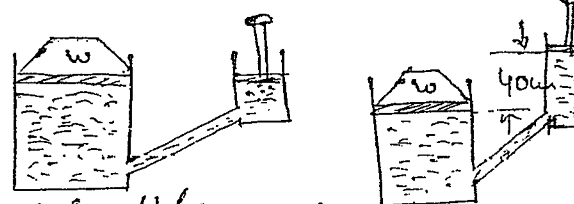
$\therefore$ pressure at ram $= \frac{F}{a}$

But pressure at ram is $\frac{W}{A} = \frac{30 \times 10^3}{0.0314}$

$$\therefore \frac{F}{7.068 \times 10^{-4}} = \frac{30 \times 10^3}{0.0314}$$

$$\Rightarrow F = \frac{30 \times 10^3 \times 7.068 \times 10^{-4}}{0.0314} = 675.20\,N$$

3. For a hydraulic Jack the diameter of small piston is 3 cm and that of large piston is 10 cm. A force of 80 N is applied at the small piston.



Find the load lifted by the large piston, when (i) the pistons are at same level and (ii) small piston is 40 cm above the large piston. Take density of the liquid in the hydraulic jack as 1000 kg/m3.

Solution: $D = 10\text{cm} = 10\times10^{-2}\text{m}$; $d = 3\text{cm} = 3\times10^{-2}\text{m}$; $h = 40\text{cm} = 40\times10^{-2}\text{m}$

$\rho = 1000\text{ kg/m}^3$; $F = 80N$

(i) when two pistons are at same level

$$A = \frac{\pi}{4}(D)^2 = \frac{\pi}{4}(10\times10^{-2})^2 = 78.54\times10^{-4}\text{m}^2$$

$$a = \frac{\pi}{4}(d)^2 = \frac{\pi}{4}(3\times10^{-2})^2 = 7.068\times10^{-4}\text{m}^2$$

Let 'W' be the weight lifted

$$\therefore \frac{W}{A} = \frac{F}{a} \Rightarrow W = \frac{FA}{a} = \frac{80\times78.54\times10^{-4}}{7.068\times10^{-4}} = 888.96N$$

(ii) when small piston is 40 cm above the large piston

pressure intensity at the bottom of the small cylinder is

$$P = \frac{F}{a} + \text{pressure density}$$

$$= \frac{F}{a} + \rho gh = \frac{80}{7.068\times10^{-4}} + 1000\times9.81\times40\times10^{-2} = 11.71\times10^{4}$$

$$\therefore \frac{W}{A} = P \Rightarrow W = PA = 11.71\times10^{4}\times78.54\times10^{-4} = 919.70N$$

4. Calculate the pressure due to a column of 0.3m of (i) water (ii) an oil of sp. gravity 0.8 and (iii) mercury of sp. gr. 13.6. Take density of water as 1000 kg/m3

Solution: $Z = 0.3\text{m}$; $\rho = 1000\text{ kg/m}^3$;

pressure head due to liquid column $(P) = \rho gz$

(i) For water $\quad P = \rho gz = 1000\times9.81\times0.3 = 2943\text{ N/m}^2$

(ii) For oil $\quad$ density (ρ_o) = sp. gr. × density of water

$= 0.8\times1000 = 800\text{ kg/m}^3$

PTO

$\therefore$ pressure head $= \rho g z = 800 \times 9.81 \times 0.3 = 2354.4\, N/m^2$

(iii) For mercury density(ρ) = sp.gr. × density of water

$= 13.6 \times 1000 = 13600\, kg/m^3$

$\therefore$ pressure head $= \rho g z = 13600 \times 9.81 \times 0.3 = 40025\, N/m^2$

Absolute pressure: pressure of a fluid above the absolute zero (or) complete vacuume is called absolute pressure.

Gauge pressure: pressure measured by an Instrument in which atmospheric pressure is taken as datum i.e. reference point.

Vaccum pressure: The pressure below the atmospheric press is called vaccum pressure.

NOTE: Absolute pressure = Atmospheric pressure + Gauge pressure
Vaccum pressure = Atmospheric pressure − Absolute pressure

Measurement of Pressure

The pressure of a fluid can be measured by mechanical gauges (or) by manometers.

In mechanical gauges the fluid pressure is measured by balancing the fluid column by the spring (or) dead load.

Ex: Diaphragm gauge, Bourdon tube pressure gauge
Dead weight pressure gauge, Bellows pressure gauge

Manometers: In this, the pressure of a fluid can be measured by balancing the fluid column by the same (or) another fluid column at the atmospheric pressure.

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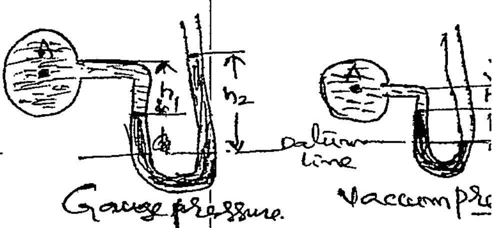
Manometers are classified into (a) Simple manometers (b) Differential manometers.

<u>Simple Manometers</u>: A simple manometer consists of a glass tube one end is connected to a point where pressure is to be measured and the other end opens to the atmosphere.

Ex: piezometer, U-tube manometer, Single Column manom

<u>piezometer</u>: This is the simplest form of the manometer. As shown in the figure, one end is connected to the point where pressure is measured and the other is open to the atmosphere. The rise of the liquid gives the pressure head at the point A. If 'h' is the height of the liquid rised in the tube, then pressure at A is $P = \rho g h \ N/m^2$.

<u>U-Tube Manometer</u>: In this, a glass tube is bent in U-sha. Its one end is connected the point where pressure is to be measu and the other end is opened to the atmosphere. The tube contains a liquid whose specific gravity is greater than that of the liquid whose pressure is to be measured.



<u>Gauge pressure</u>: Let 'P' be the pressure tobe measured at point A

pressure in the right Column $= \rho_2 g h_2$

" " left " $= P + \rho_1 g h_1$

These two pressures must equal for the equilibrium condition.

$\therefore P + \rho_1 g h_1 = \rho_2 g h_2$

$\Rightarrow P = (\rho_2 g h_2 - \rho_1 g h_1)$

<u>Vaccum pressure</u>: pressure in the left Column $= P + \rho_2 g h_2 + \rho_1 g h_1$

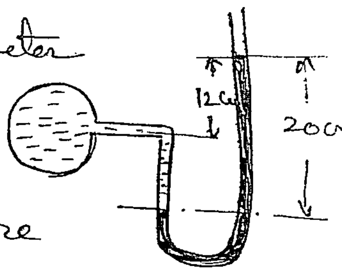
" " right " $= 0$

$\therefore P + \rho_2 g h_2 + \rho_1 g h_1 = 0 \Rightarrow P = -[\rho_2 g h_2 + \rho_1 g h_1]$

PTO

worked examples

1. The right limb of a simple U-tube manometer containing mercury open to the atmosphere and left limb is connected to a pipe in which a fluid of sp.gr. 0.9 is flowing. The centre of the pipe is 12 cm below the mercury level of the right limb, find the pressure of the fluid in the pipe, if difference of mercury level in the two limbs is 20 cm.



Solution: $S_l = 0.9$; $S_m = 13.6$; Difference of the mercury level (h_2) = 20cm = 20×10^{-2}

Height of the fluid $(h_1) = 20 - 12 = 8\,cm = 8\times10^{-2}\,m$;

pressures above the datum are equal, hence

$$P + \rho_1 g h_1 = \rho_2 g h_2,$$ where P is pressure head of the fluid

ρ_1 and ρ_2 are the densities

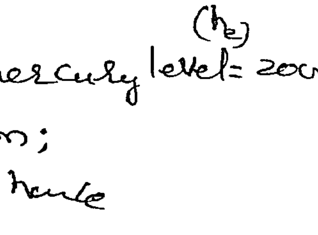
$\therefore \rho_1 = S_l \times 1000 = 0.9\times1000 = 900\ kg/m^3$

$\rho_2 = S_m \times 1000 = 13.6\times1000 = 13600\ kg/m^3$

$$\therefore P + 900\times9.81\times8\times10^{-2} = 13600\times9.81\times20\times10^{-2}$$

$$\Rightarrow P = 9.81\times10^{-2}(13600\times20 - 900\times8) = 25977\ N/m^2$$

2. A U-tube manometer having mercury is connected to a pipe in which a fluid is flowing at vaccum pressure. Sp.gr. of the fluid is 0.8. other end of the manometer is opened to atmosphere. Find the vaccum pressure in the pipe, if the difference in the two mercury levels is 40cm and height of the fluid column is 15cm.



Solution: $S_f = 0.8$; $S_m = 13.6$; $h_1 = 15\,cm = 15\times10^{-2}\,m$; $h_2 = 40\,cm = 40\times10^{-2}\,m$,

$\rho_f = 0.8\times1000 = 800\ kg/m^3$; $\rho_m = 13.6\times1000 = 13600\ kg/m^3$

Let P be the pressure head of the fluid.

$$\therefore P + \rho_1 g h_1 + \rho_2 g h_2 = 0$$

$$\Rightarrow P = -[\rho_2 g h_2 + \rho_1 g h_1]$$

$$= -[13.6\times9.81\times40\times10^{-2} + 800\times9.81\times15\times10^{-2}]$$

$$= -54543.6\ N/m^2$$

Differential Manometer

Differential manometer is used for measuring difference of pressure between two points in a pipe (or) in two different pipe. Most commonly used differential manometers are

(i) U-tube differential manometer and
(ii) Inverted U-tube differential manometer.

For U-tube differential manometer, two pipes are at different levels, the difference of the pressure is

$$P_1 - P_2 = hg(\rho_m - \rho_1) + \rho_2 g y - \rho_1 g x,$$

where h = difference of mercury levels in U-tube
x = distance of centre of pipe 1 from the mercury level in the right limb
y = distance of centre of pipe 2 from the mercury level in the right limb

If the two pipes are at same height, then

$$P_1 - P_2 = hg(\rho_m - \rho_1)$$

For Inverted U-tube manometer

$$P_1 - P_2 = \rho_1 g h_1 - \rho_2 g h_2 - \rho_l g h,$$ where ρ_l = density of liquid

UNIT – II

Fluid kinematics: Lagrangian and Eulerian description of fluid flow, velocity and Acceleration of fluid particles, different types of fluid flow, description of flow pattern: stream line, streak line, path line; principle of Conservat of mass; Continuity equation, application of Continuity equation.

Fluid Dynamics: Euler's equation of motion along a strea line - Bernoulli's equation, practical application of Bernoulli's equation In flow measurement devices like venturimeter, orifice meter and pitot tube.

Fluid motion Can be described by two methods, they are (a) Lagrangian method (b) Eulerian method.

Lagrangian method: In this method, a single fluid particle is Considered for the study of motion of the flui and Its velocity, Acceleration and Density are treated as the respective characteristics of the fluid.

Eulerian method: In this method, the velocity, accelerati pressure, Density etc are described (or) studied at a point In the flow. (This method is Commonly used In FM)

Velocity and Acceleration:

Let V be the resultant velocity at any point In a fluid flow. Let "u, v and w" are its Components In the three Coordinate axes directions

$\therefore \; u = f_1(x, y, z, t)$; $v = f_2(x, y, z, t)$; $w = f_3(x, y, z, t)$

Resultant velocity $(V) = u\bar{i} + v\bar{j} + w\bar{k} = \sqrt{u^2+v^2+w^2}$

PTO

Let a_x, a_y and a_z be the accelerations of the flow at any point in the flow along the Coordinate axes. Then

$$a_x = \frac{du}{dt}; \quad a_y = \frac{dv}{dt}; \quad a_z = \frac{dw}{dt}$$

But by the Chain rule of the differentiation, we have

$$a_x = \frac{du}{dt} = \frac{\partial u}{\partial x}\cdot\frac{dx}{dt} + \frac{\partial u}{\partial y}\cdot\frac{dy}{dt} + \frac{\partial u}{\partial z}\cdot\frac{dz}{dt} + \frac{\partial u}{\partial t}$$

But $\frac{dx}{dt} = u$; $\frac{dy}{dt} = v$: $\frac{dz}{dt} = w$

$$\therefore \quad a_x = u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} + \frac{\partial u}{\partial t}$$

lllly

$$a_y = u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} + \frac{\partial v}{\partial t}$$

$$a_z = u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} + \frac{\partial w}{\partial t}$$

Corollary: For steady flow $\frac{\partial V}{\partial t} = 0$, hence

$$\frac{\partial u}{\partial t} = \frac{\partial v}{\partial t} = \frac{\partial w}{\partial t} = 0$$

$$\therefore \quad a_x = u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}$$

$$a_y = u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}$$

$$a_z = u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}$$

Resultant Acceleration $(A) = a_x\bar{i} + a_y\bar{j} + a_z\bar{k}$

$$= \sqrt{a_x^2 + a_y^2 + a_z^2}$$

PTO

Solved problems

1. The velocity vector in a fluid flow is given by $\bar{V} = 4x^3\bar{i} - 10x^2y\bar{j} + 2t$. Find the velocity and acceleration of a fluid particle at (2, 1, 3) at time t = 1

Solution: Velocity vector $V = 4x^3\bar{i} - 10x^2y\,\bar{j} + 2t\bar{k}$

point $P = (2,1,3) \Rightarrow x = 2;\ y = 1;\ z = 3;\quad t = 1$

velocity components of the particle are $u = 4x^3;\ v = -10x^2y;\ w = 2t$

$\therefore\ u = 4(2)^3 = 32;\quad v = -10(2)^2(1) = -40;\ w = 2\times1 = 2$

$\therefore$ velocity of the particle at the point 'p' is

$$V_{(P)} = 32\bar{i} - 40\bar{j} + 2\bar{k}$$

Resultant velocity $= \sqrt{u^2+v^2+w^2} = \sqrt{(32)^2+(-40)^2+(2)^2} = 51.21$ units/s

Accelerations in the coordinate axes directions are

$$a_x = u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} + \frac{\partial u}{\partial t}$$

$$a_y = u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} + \frac{\partial v}{\partial t}$$

$$a_z = u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} + \frac{\partial w}{\partial t}$$

But $\frac{\partial u}{\partial x} = 12x^2;\quad \frac{\partial u}{\partial y} = \frac{\partial u}{\partial z} = \frac{\partial u}{\partial t} = 0$

$\frac{\partial v}{\partial x} = -20xy;\quad \frac{\partial v}{\partial y} = -10x^2;\quad \frac{\partial v}{\partial z} = \frac{\partial v}{\partial t} = 0$

$\frac{\partial w}{\partial x} = \frac{\partial w}{\partial y} = \frac{\partial w}{\partial z} = 0;\quad \frac{\partial w}{\partial t} = 2$

$\therefore\ a_x = 4x^3(12x^2) + (-10x^2y)(0) + 2t(0) + 0 = 48x^5$

PTO

$\therefore$ At point 'p' acceleration a_x is given by

$$a_x = 48(2)^5 = 1536 \text{ units/sec}^2.$$

$|||^{ly}$ $\quad a_y = 320 \text{ units/sec}^2; \quad a_z = 2 \text{ units/sec}^2$

$\therefore$ Acceleration $A = 1536\bar{i} + 320\bar{j} + 2\bar{k}$

Resultant Acceleration $= \sqrt{(1536)^2 + (320)^2 + (2)^2} = 1568.90 \text{ units/sec}^2$

2. The following cases represent two velocity components, determine the third velocity component satisfying the continuity equation

(i) $u = x^2 + y^2 + z^2$; $v = xy^2 - yz^2 + xy$ (ii) $v = 2y^2$; $w = 2xyz$

<u>Solution:</u> (i) $u = x^2 + y^2 + z^2$; $v = xy^2 - yz^2 + xy$

Continuity equation is given by $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$

$$\therefore \frac{\partial u}{\partial x} = 2x \, ; \quad \frac{\partial v}{\partial y} = 2xy \; z^2 + x$$

From continuity equation we have

$$(2x) + (2xy \; z^2 + x) + \frac{\partial w}{\partial z} = 0$$

$$\Rightarrow \frac{\partial w}{\partial z} = -3x - 2xy + z^2$$

$$\Rightarrow \partial w = (-3x - 2xy + z^2)\,\partial z$$

Integration on both sides

$$\int \partial w = \int (-3x - 2xy + z^2)\,\partial z$$

$$\Rightarrow w = -3xz - 2xyz + \frac{z^3}{3} + c$$

(ii) $v = 2y^2$; $w = 2xyz$ Solve in the same manner above.

PTO

TYPES OF FLUID FLOW

Fluid flow may be classified as the following.

(i) Steady and unsteady flows (ii) Uniform and Non-uniform flows (iii) Laminar and Turbulent flows (iv) Compressible and Incompressible flows (v) Rotational and Irrotational flows and (vi) 1-D, 2-D and 3-D flows.

- Steady and unsteady flows: In a flow, If the fluid characteristics velocity, pressure, Density etc at a point does not change w.r.t. time, then It is called " Steady state flow" otherwise " unsteady state flow".

∴ For a steady state flow

$$\left(\frac{\partial v}{\partial t}\right)_{(x,y,z)} = \left(\frac{\partial P}{\partial t}\right)_{(x,y,z)} = \left(\frac{\partial \rho}{\partial t}\right)_{(x,y,z)} = 0$$

For unsteady state flow

$$\frac{\partial v}{\partial t} = \frac{\partial P}{\partial t} = \frac{\partial \rho}{\partial t} \neq 0$$

- Uniform and Non uniform flows: In a flow, If the velocity of the flow does change w.r.t. time at a given point, then It is called uniform flow, otherwise It is a nonuniform flow.

For uniform flow

$$\left(\frac{\partial v}{\partial s}\right)_{t=c} = 0$$

∂v = Change In velocity
∂s = Length of the flow

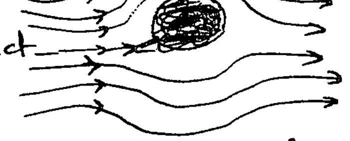
For Non uniform flow

$$\left(\frac{\partial v}{\partial s}\right)_{t=c} \neq 0$$

PTO

Laminar and Turbulent flows: In a flow, If the fluid particles move along a well defined paths called "stream lines" and all the stream lines are straight and parallel to one another, then It is called "Laminar flow".

Thus, particles move In laminas (or) layers one over another, hence this is also called as "stream line flow" (or) "viscous flow".



In a flow, If the particles move In a Zig-zag manner, It is called "Turbulent flow".

Compressible and InCompressible flows: In a flow, If the density of the fluid changes from point to point In the flow, then It is called Compressible flow, otherwise It is InCompressible flow.

For compressible flow density(ρ) $\neq$ Constant

For InCompressible flow Density (ρ) = Constant

Rotational and Irrotational flows: In a flow, the fluid particles are having rotatory motion about their own axis along with the stream line flow, then It is Rotational flow, otherwise It is Irrotational.

1-D, 2-D and 3-D flows: In a flow, If the fluid particles moves In one (or) two (or) three Coordinate axes directions then they are 1-D, 2-D, and 3-D flows respectively.

∴ For 1-D flow $u = f(x);\ v = w = 0$, For 2-D flow $u = f_1(x,y)\ v = f_2(x,y)$ $w=0$

For 3-D flow $u = f_1(x,y,z);\ v = f_2(x,y,z);\ w = f_3(x,y,z)$

Rate of Flow (or) Discharge (Q): In general, the quantity of the fluid flowing per second through a section of a pipe (or) channel is termed as rate of flow (or) discharge.

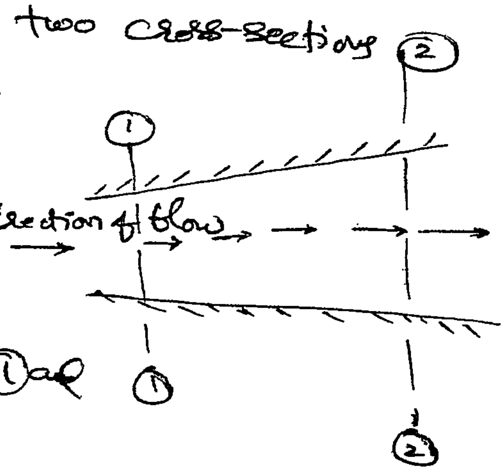
Mathematically discharge $(Q) = A \times V \ m^3/sec$,

where A = area of cross-section of the pipe (or) channel

V = average velocity of the fluid.

For incompressible fluids, the rate of flow (or) discharge is volume of the fluid flowing per second and whereas for compressible fluids, weight of the fluid per second.

Continuity equation: Consider two cross-sections of a pipe at ①-① and ②-② as shown in the figure.



Let V_1, ρ_1, A_1 and V_2, ρ_2, A_2 are the average velocity, density and area of cross-section at sections ①-① and ②-② respectively.

$\therefore$ The rate of flow at ①-① $(Q_1) = \rho_1 A_1 V_1$

The rate of flow at ②-② $(Q_2) = \rho_2 A_2 V_2$

According to the law of conservation of mass,

rate of flow at ①-① = rate of flow at ②-②

$$\Rightarrow \rho_1 A_1 V_1 = \rho_2 A_2 V_2$$

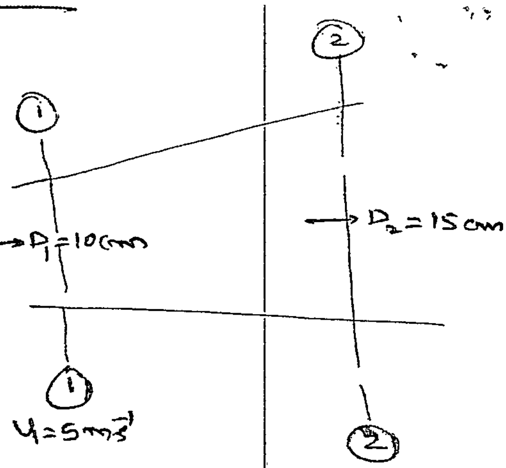
This is called continuity equation which is applicable for both compressible and incompressible fluids.

NOTE: If the fluid is incompressible, then $\rho_1 = \rho_2$

$\therefore$ Continuity equation is $A_1 V_1 = A_2 V_2$

Worked examples

1. The diameters of a pipe at sections ①-① and ②-② are 10cm and 15cm respectively as shown in the figure. If the velocity of the water flowing in the pipe at ①-① is $5\ ms^{-1}$ find the velocity of the water at section ②-②. Also find the discharge.



Solution: $D_1 = 10\ cm = 10 \times 10^{-2}\ m$; $V_1 = 5\ m/sec$;

$D_2 = 15cm = 15 \times 10^{-2}\ m$; $V_2 = ?$; $Q = ?$

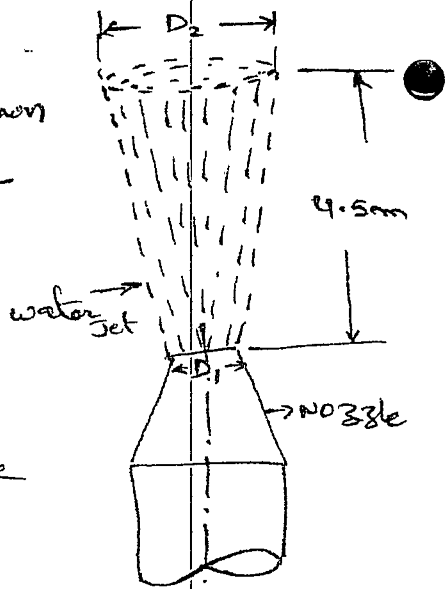
From the Continuity equation $A_1V_1 = A_2V_2$

$$\therefore \frac{\pi}{4}(D_1)^2 \times V_1 = \frac{\pi}{4}(D_2)^2 \times V_2$$

$$\Rightarrow V_2 = \frac{(10 \times 10^{-2})^2 \times 5}{(15 \times 10^{-2})^2} = 2.2\ m/sec$$

Discharge $(Q) = A_2V_2 = \frac{\pi}{4}(15 \times 10^{-2})^2 \times 2.2 = 0.0392\ m^3/sec$

2. A jet of water from 25mm diameter nozzle is directed vertically upwards as shown in the figure. The jet remains circular at a height 4.5m above the nozzle. Neglecting the loss of energy what will be the diameter of the water jet, if the velocity of jet leaving the nozzle is 12 m/sec.



Solution: $D_1 = 25\ mm = 25 \times 10^{-3}\ m$; $V_1 = 12\ m/sec$

$h = 4.5m$; $D_2 = ?$

For the jet Initial velocity $(u) = V_1 = 12$ m/sec

Final velocity $(v) = V_2$

∴ From the relation $v^2 - u^2 = 2gh$, we have

$$V_2^2 - V_1^2 = 2(-9.81) \times 4.5$$

$$\Rightarrow V_2 = \sqrt{(12)^2 - 2 \times 9.81 \times 4.5} = 7.46 \text{ m/sec.}$$

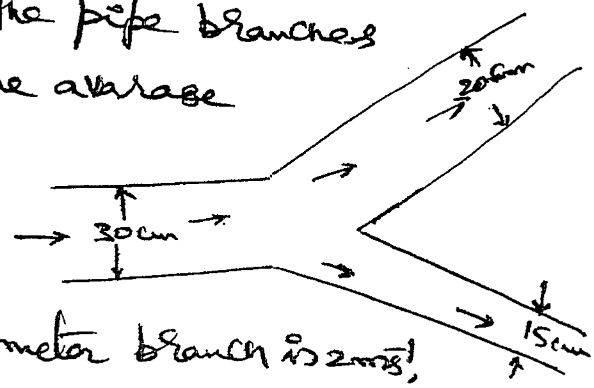
From the Continuity equation $A_1V_1 = A_2V_2$, we have

$$\frac{\pi}{4}(D_1)^2 V_1 = \frac{\pi}{4}(D_2)^2 V_2$$

$$\Rightarrow (25 \times 10^{-3})^2 \times 12 = (D_2)^2 \times 7.46$$

$$\Rightarrow D_2 = \sqrt{\frac{(25 \times 10^{-3})^2 \times 12}{7.46}} = 0.0317 \text{ m} = 31.7 \text{ mm.}$$

3. A 30 cm diameter pipe branches into two as shown in the figure. The diameters of the pipe branches are 20 cm and 15 cm. If the average velocity in the main pipe is 2.5 ms^{-1}, find the discharge. If the average velocity in the larger diameter branch is 2 ms^{-1}, find the velocity in the smaller diameter branch.



Solution: $D_1 = 30$ cm $= 30 \times 10^{-2}$ m; $V_1 = 2.5$ m/sec

$D_2 = 20$ cm $= 20 \times 10^{-2}$ m; $V_2 = 2$ m/sec²

$D_3 = 15$ cm $= 15 \times 10^{-2}$ m; $V_3 = ?$; $Q_1 = ?$

Let Q_1, Q_2, Q_3 be the discharges in the pipes, according to Continuity equation

$$Q_1 = Q_2 + Q_3$$

$Q_1 = A_1V_1 = \frac{\pi}{4}(D_1)^2 V_1 = \frac{\pi}{4}(30\times10^{-2})^2 \times 2.5 = 0.1767\ m^3/sec.$

$Q_2 = A_2V_2 = \frac{\pi}{4}(D_2)^2 V_2 = \frac{\pi}{4}(20\times10^{-2})^2 \times 2 = 0.0628\ m^3/sec$

$\therefore$ From $Q_1 = Q_2 + Q_3$

$\Rightarrow Q_3 = Q_1 - Q_2 = 0.1767 - 0.0628 = 0.1139\ m^3/sec$

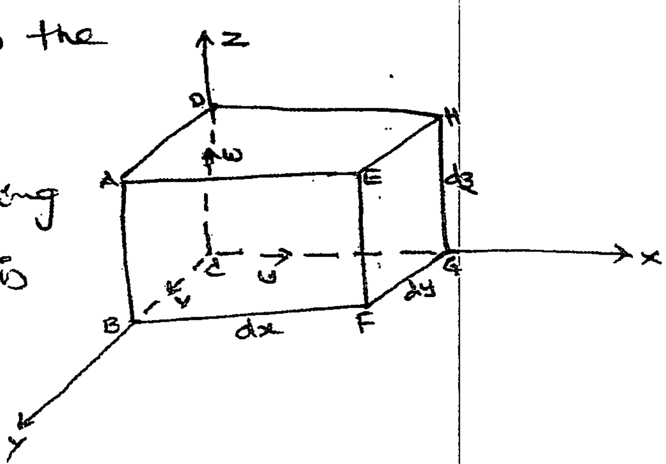
But $Q_3 = A_3 V_3$

$\Rightarrow 0.1139 = \frac{\pi}{4}(D_3)^2 \times V_3$

$$\Rightarrow V_3 = \frac{0.1139\times4}{\pi\times15\times10^{-2}} = 6.44\ m/sec.$$

Continuity equation in Cartesian Coordinates

Consider a fluid element with sides dx, dy and dz along the three coordinate axes, whose velocities are u, v and w respectively in the three directions.



$\therefore$ Mass of the fluid entering the face ABCD per second is

m = Density × Velocity in x-direction × Area of ABCD

$\Rightarrow m = \rho \times u \times (dy\,dz)$

Mass of the fluid leaving the face EFGH $= m + \frac{\partial m}{\partial x}dx$

$\therefore$ Mass leaving $= \rho u\,dy\,dz + \frac{\partial}{\partial x}(\rho u\,dy\,dz)\,dx$

$\therefore$ Gain of mass in x-direction = Mass through ABCD − Mass thro EFGH

$\therefore$ dm In x-direction $= \rho u\, dy\, dz - \left(\rho u\, dy\, dz + \frac{\partial}{\partial x}(\rho u\, dy\, dz)\, dx\right)$

$= -\frac{\partial}{\partial x}(\rho u)\, dx\, dy\, dz$

IIIly dm In y-direction $= -\frac{\partial}{\partial y}(\rho v)\, dx\, dy\, dz$

dm In z-direction $= -\frac{\partial}{\partial z}(\rho w)\, dx\, dy\, dz$

$\therefore$ Net gain of mass $(dm)_{Net} = -\left[\frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w)\right] dx\, dy\, dz$

But mass of the fluid In the element is the product of density and volume of the element.

$\therefore$ Mass of the fluid In the element $= \rho . dx\, dy\, dz$

The rate of Increase of mass In the element is given by $\frac{\partial}{\partial t}(\rho\, dx\, dy\, dz)$ (or) $\frac{\partial \rho}{\partial t} . dx\, dy\, dz$

$\therefore$ According to the Law of Conservation of mass, the net Increase (or) gain of mass In the element must be equal to rate of Increase of mass In the element.

$$\therefore -\left[\frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w)\right] dx\, dy\, dz = \frac{\partial \rho}{\partial t}\, dx\, dy\, dz$$

$$\Rightarrow \frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0$$

This is the Continuity equation In Cartesian Coordinates.

This equation is applicable to steady and unsteady flows, uniform and non-uniform flows and Compressible and Incompressible flows.

For Steady flow density is constant, hence $\frac{\partial \rho}{\partial t} = 0$,

∴ Continuity equation becomes

$$\frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0$$

For Incompressible flows 'ρ' is constant, hence

Continuity is $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$

Velocity potential and Stream functions

Velocity potential function: A function, whose negative derivative w.r.t. any direction gives the fluid velocity, is called velocity potential function. This is a scalar function. If $\phi = f(x, y, z)$ is a velocity potential function, then $u = -\frac{\partial \phi}{\partial x}$; $v = -\frac{\partial \phi}{\partial y}$; $w = -\frac{\partial \phi}{\partial z}$

Continuity equation for Incompressible, steady flow is

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

By substituting the values of u, v and w in continuity equation we have

$$\frac{\partial}{\partial x}\left(-\frac{\partial \phi}{\partial x}\right) + \frac{\partial}{\partial y}\left(-\frac{\partial \phi}{\partial y}\right) + \frac{\partial}{\partial z}\left(-\frac{\partial \phi}{\partial z}\right) = 0$$

$$\Rightarrow \frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \phi}{\partial z^2} = 0$$

This is called Laplace equation.

properties of potential function are (i) If velocity potential 'φ' exists, the flow should be Irrotational (ii) If velocity potential 'φ' satisfies Laplace equation, it represents steady Incompressible and Irrotational flow.

PTO

Stream function: A function, whose partial derivative w.r.t any direction gives the velocity component at right angles to that direction, is called stream function. This is defined only for 2-D flow.

If ψ (psi) is a stream function, then

$$\frac{\partial \psi}{\partial x} = v \; ; \quad \frac{\partial \psi}{\partial y} = -u$$

By substituting these values in continuity equation, we ha

$$\frac{\partial}{\partial x}\left(-\frac{\partial \psi}{\partial y}\right) + \frac{\partial}{\partial y}\left(\frac{\partial \psi}{\partial x}\right) = 0$$

$$\Rightarrow -\frac{\partial^2 \psi}{\partial x \partial y} + \frac{\partial^2 \psi}{\partial x \partial y} = 0$$

If stream function 'ψ' exists, the flow may be rotational (or) Irrotational. If stream function satisfies Laplace equation, the flow is Irrotational.

Worked examples

1. The velocity potential function is given by $\phi = \frac{-xy^3}{3} - x^2 + \frac{x^3 y}{3} + y^2$, find velocity components in x and y-directions. Show that 'ϕ' represents possible case of flow.

Solution: $\phi = -\frac{xy^3}{3} - x^2 + \frac{x^3 y}{3} + y^2$

Velocity component in x-direction $(u) = -\frac{\partial \phi}{\partial x}$

$$\therefore u = -\frac{\partial}{\partial x}\left[-\frac{xy^3}{3} - x^2 + \frac{x^3 y}{3} + y^2\right]$$

$$= \frac{y^3}{3} + 2x - x^2 y$$

IIIly $v = -\frac{\partial \phi}{\partial y} = -\frac{\partial}{\partial y}\left[-\frac{xy^3}{3} - x^2 + \frac{x^3 y}{3} + y^2\right] = xy^2 - \frac{x^3}{3} - 2y$

Laplace equation for 2-D flow is $\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}=0$

$$\therefore \frac{\partial^2\phi}{\partial x^2}=\frac{\partial}{\partial x}\left[\frac{\partial\phi}{\partial x}\right]=\frac{\partial}{\partial x}\left[-\frac{y^3}{3}-2x+x^2y\right]=-2+2xy \quad -(1)$$

$$\frac{\partial^2\phi}{\partial y^2}=\frac{\partial}{\partial y}\left[\frac{\partial\phi}{\partial y}\right]=\frac{\partial}{\partial y}\left[-xy^2+\frac{x^3}{3}+2y\right]=-2xy+2 \quad -(2)$$

From (1) and (2) Laplace equation is satisfied i.e

$\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}=0$, hence '$\phi$' represents a flow.

2. The velocity potential function is given by $\phi=5(x^2-y^2)$. Calculate the velocity components at a point (4,5)

Solution: Velocity potential function $(\phi)=5(x^2-y^2)$; $P=(4,5)$

velocity component in x-direction is

$$u=-\frac{\partial\phi}{\partial x}=-\frac{\partial}{\partial x}(5x^2-5y^2)=-10x$$

At P, the value of $u=-10(4)=-40$ units/sec

velocity component in y-direction is

$$v=-\frac{\partial\phi}{\partial y}=-\frac{\partial}{\partial y}\left[5x^2-5y^2\right]=10y$$

v at P $=10(5)=50$ units/sec.

3. A stream function is given by $\psi=5x-6y$, Calculate velocity components and magnitude and direction of the resultant velocity.

Solution: Stream function $(\psi)=5x-6y$

velocity component $(u)=-\frac{\partial\psi}{\partial y}=-(-6)=6$ units/sec

" $(v)=+\frac{\partial\psi}{\partial x}=+(5)=5$ units/sec

PTO

∴ Resultant velocity magnitude $= \sqrt{u^2+v^2} = \sqrt{(6)^2+(5)^2} = 7.81$ units/s

" direction $(\theta) = \tan^{-1}\left(\frac{v}{u}\right) = \tan^{-1}\left(\frac{5}{6}\right) = 39°48'$

4. The stream function for a 2-D flow is given by $\psi = 2xy$. Calculate velocity at the point P(2,3), also find velocity potential function ϕ

Solution: stream function $(\psi) = 2xy$; $P = (2,3)$

velocity Component $(u) = -\frac{\partial\psi}{\partial y} = -2x$

" $(v) = \frac{\partial\psi}{\partial x} = 2y$

At point P(2,3), $u = -2\times2 = -4$ units/sec

$v = 2\times3 = 6$ units/sec

Resultant velocity $V = \sqrt{u^2+v^2} = \sqrt{4^2+6^2} = 7.21$ units/sec

Let 'ϕ' be the velocity potential function, then

$$\frac{\partial\phi}{\partial x} = -u = -(-2x) = 2x \quad \text{(1)}$$

$$\frac{\partial\phi}{\partial y} = -v = -2y \quad \text{(2)}$$

From (1) $\frac{\partial\phi}{\partial x} = 2x \rightarrow \partial\phi = 2x\partial x$ Integrating on both sides,

$\int d\phi = \int 2x\,dx$

$\Rightarrow \phi = x^2 + c$, where c is Constant of Integration and is Independent of x, but function of y

∴ $\frac{\partial\phi}{\partial y} = \frac{\partial c}{\partial y}$

But $\frac{\partial\phi}{\partial y} = -2y$

∴ $\frac{\partial c}{\partial y} = -2y \Rightarrow \partial c = -2y\,dy \Rightarrow c = -y^2$

$$\therefore \boxed{\phi = x^2 - y^2}$$

FLOW PATTERN

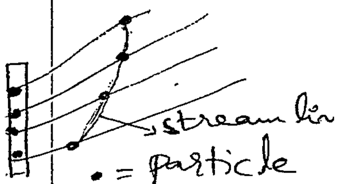
The flow of a fluid may be well described by the pattern of the path followed by the fluid particles In the flow. These pattern may be stream lines, streaklines (or) pathli

Stream lines: A stream line is a line that is tangentia to the Instantaneous velocity direction of a massless Imaginary fluid particle.

(or)

A stream line is an Imaginary line drawn through a flowing fluid such that the tangent to It at any point gives the direction of velocity of the flow at that point.

Streak lines: The Instantaneous picture of the position of the all fluid particles which have passed through a given point at some previous time are called streak lines.



(or)

streak lines are curved lines formed by a string of fluid particles which have passed through a certain poi These lines concentrates on fluid particles that have gon through a fixed station (or) point.

Ex: Smoke from a Chimney.

path lines: A path line is the line traced by a single fluid particle as It moves over a period of time. The path line is detected by Introducing a dye In the fluid. A path line Indicates the direction of velocity of the same fluid particle at successive Instants of time where as a stream line shows the direction of velocity of a number of fluid particles at the same Instant of time.

Fluid Dynamics

Equations of motion: According to Newton's second law of motion the net force acting on a fluid element is equal to the product of mass of the element and acceleration produced in it.

$$\therefore \quad F = ma$$

But in a fluid flow, the following forces are present, they are

(i) gravity force (F_g), (ii) pressure force (F_p)

(iii) force due to viscosity (F_v) (iv) force due to turbulance (F_t) (v) force due to compressibility (F_c)

$$\therefore \quad F = F_g + F_p + F_v + F_t + F_c$$

If force due to compressibility is negligible, the net force is

$$F = F_g + F_p + F_v + F_t$$

If in the equations of motion, above net force is used, then it is called "Reynold's equations" of motion.

If the force due to turbulance (F_t) is negligible, then

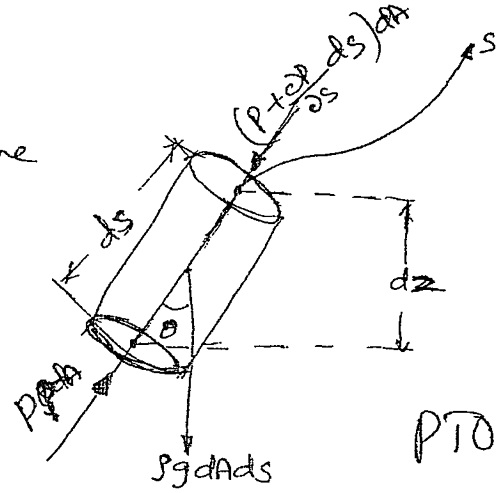
$$F = F_g + F_p + F_v,$$ this force equations are called as "Navier - Stokes" equations of motion.

If the flow is assumed to be Ideal, viscous force F_v is zero then the equations of motion are called as Euler's equations of motion.

$$\therefore \quad F = F_g + F_p$$

Euler's equation of motion:

Consider a stream line in which flow is taking place in S-direction as shown in the figure.



PTO

Consider a cylindrical element of cross-section dA and length ds. The forces acting on the cylindrical element are (a) pressure force $p\,dA$ in the direction of flow and

(b) pressure force $\left[p+\frac{\partial p}{\partial s}ds\right]dA$ opposite to the direction of flow and

(c) weight of the element $\rho g\,dA\,ds$.

Let 'θ' be the angle between the direction of flow and the line of action of the weight of the element.

∴ the resultant force on the element in the direction of 's'

is $F_s = p\,dA - \left(p+\frac{\partial p}{\partial s}ds\right)dA - \rho g\,dA\,ds\cos\theta$ — (1)

But F_s = resultant force is given by the product of mass of the element and acceleration in the direction of s

$$\therefore F_s = \rho\,dA\,ds \times a_s \quad \text{— (2)}$$

But $a_s = \frac{dv}{dt} = \frac{\partial v}{\partial s}\times\frac{ds}{dt} + \frac{\partial v}{\partial t} = v\frac{\partial v}{\partial s} + \frac{\partial v}{\partial t}$ ($\because \frac{ds}{dt}=v$ and v is a function of s, t)

For the steady flow $\frac{\partial v}{\partial t}=0$

$$\therefore a_s = v\frac{\partial v}{\partial s}$$

∴ From (1) and (2) we have

$$-\frac{\partial p}{\partial s}ds\,dA - \rho g\,dA\,ds\cos\theta = \rho\,dA\,ds \times v\frac{\partial v}{\partial s}$$

Dividing by $\rho\,dA\,ds$, we have

$$\frac{-\partial p}{\rho\,\partial s} - g\cos\theta = v\frac{\partial v}{\partial s}$$

$$\Rightarrow \frac{\partial p}{\rho\,\partial s} + g\cos\theta + v\frac{\partial v}{\partial s} = 0 \quad \text{— (3)}$$

PTO

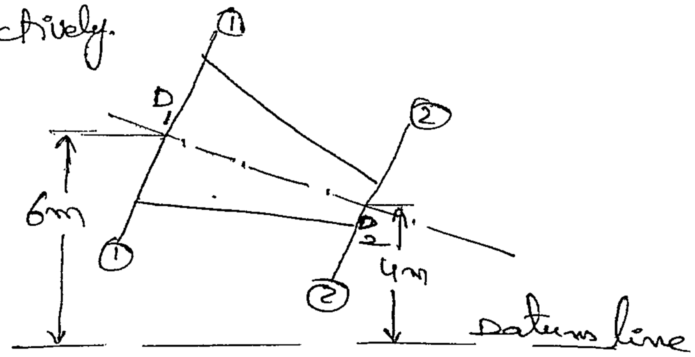
$\therefore$ pressure head $= \dfrac{P}{\rho g} = \dfrac{29.43\times10^4}{1000\times9.81} = 30m$

Kinetic head $= \dfrac{V^2}{2g} = \dfrac{2\times2}{2\times9.81} = 0.204m$

potential head = datum = 5m

$\therefore$ Total head $= 30+0.204+5 = 35.204m$

2. water is flowing through a pipe having diameters 20 cm and 10cm at sections (1) and (2) respectively. The rate of flow through pipe is 35 litres/sec. The section (1) is 6m above the datum line and that of (2) is 4m above the datum line as shown in the figure. If the pressure at (1) is 39.24N/cm², find pressure Intensity at (2).



Solution: $D_1 = 20cm = 20\times10^{-2}m$; $Z_1 = 6m$; $P_1 = 39.24N/cm^2 = 39.24\times10^4 N/m^2$

$D_2 = 10cm = 10\times10^{-2}m$; $Z_2 = 4m$; $P_2 = ?$

Rate of flow $(Q) = 35\ lit/sec = \dfrac{35}{1000}m^3/sec = 0.035 m^3/sec.$

But Rate of flow (or) Discharge $(Q) = A_1V_1 = A_2V_2$

$\therefore V_1 = \dfrac{Q}{A_1} = \dfrac{0.035}{\frac{\pi}{4}(20\times10^{-2})^2} = 1.114\ m/sec$

$V_2 = \dfrac{Q}{A_2} = \dfrac{0.035}{\frac{\pi}{4}(10\times10^{-2})^2} = 4.456\ m/sec$

By applying Bernoulli equation for the sections (1) & (2), we have

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

PTO

$$\Rightarrow \frac{39.24\times10^4}{1000\times9.81}+\frac{(1.114)^2}{2\times9.81}+6=\frac{P_2}{1000\times9.81}+\frac{(4.456)^2}{2\times9.81}+4$$

$$\Rightarrow P_2 = 41.051\times9810\ N/m^2$$

$$= \frac{41.051\times9810}{10^4}\ N/cm^2$$

$$= 40.27\ N/cm^2$$

3. water is flowing through a pipe having diameters 300 cm and 200 cm at the bottom and top ends respectively. the Intensity of pressures at bottom and and top ends are 24.525 N/cm² and 9.81 N/cm² respectively. Determine the difference of datum head If the rate of flow through the pipe is 40 litres/sec.

Solution: $D_1 = 300\,cm = 300\times10^{-2}\,m$; $P_1 = 24.525\,N/cm^2 = 24.525\times10^4\,N/m^2$

$D_2 = 200\,cm = 200\times10^{-2}\,m$; $P_2 = 9.81\,N/cm^2 = 9.81\times10^4\,N/m^2$

Rate of flow (Q) $= 40\,lit/sec = \frac{40}{1000} = 0.04\,m^3/sec$

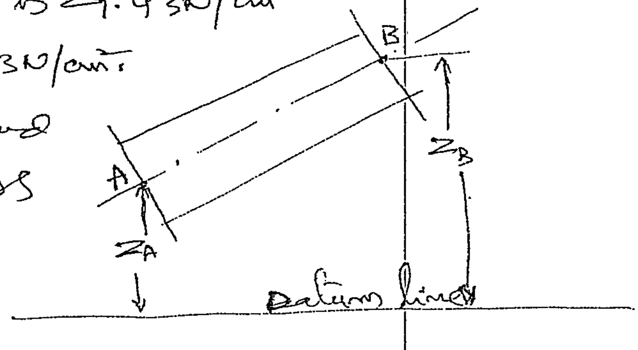
$\therefore Q = A_1V_1 = A_2V_2$

$Z_2 - Z_1 = ?$

By applying Bernoulli's equation $Z_2 - Z_1 = 13.70\,m$.

(Solve the problem as above problem)

4. A pipe of diameter 400 mm Carries water at a velocity of 25 m/sec. The pressure at point A is 29.43 N/cm² and pressure at point B is 22.563 N/cm². The datum head at A is at 28 m and that at B is at 30 m. Find the loss of head between A and B.



Solution: $D = 400\,mm = 400\times10^{-3}\,m$;

$V = 25\,m/sec$; $P_A = 29.43\,N/cm^2 = 29.43\times10^4\,N/m^2$; $Z_A = 28\,m$

also $V_A = 25\,m/sec$; $P_B = 22.563\,N/cm^2 = 22.563\times10^4\,N/m^2$; $Z_B = 30\,m$

also $V_B = 25\,m/sec$;

PTO

∴ Total energy at A is $E_A = \frac{P_A}{\rho g} + \frac{V_A^2}{2g} + Z_A$

$$= \frac{29.43 \times 10^4}{1000 \times 9.81} + \frac{(25)^2}{2 \times 9.81} + 28$$

$$= 89.85 \text{ m}$$

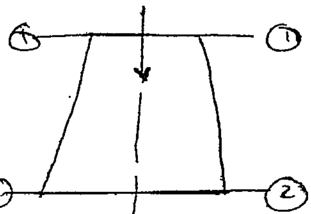
Total energy at B is $E_B = \frac{P_B}{\rho g} + \frac{V_B^2}{2g} + Z_B$

$$= \frac{22.563 \times 10^4}{1000 \times 9.81} + \frac{(25)^2}{2 \times 9.81} + 30$$

$$= 84.85 \text{ m}$$

∴ Loss of energy $= E_A - E_B = 89.85 - 84.85 = 5 \text{ m}$

5. A conical tube of length 2m is fixed vertically with its smaller end upwards. The velocity of flow at smaller end is 5 ms^{-1} and that at larger end is 2 ms^{-1}. The pressure head at the smaller end is 2.5m of liquid, the loss of head in the tube is $\frac{0.35[V_1 - V_2]^2}{2g}$, where V_1 and V_2 are the velocities at upper and lower ends of the tube respectively. Determine the pressure head at the lower end. The flow is in the downward direction.



Solution: Length of the tube (L) = 2m; $V_1 = 5$ m/sec; $\frac{P_1}{\rho g} = 2.5$ m of liquid

$V_2 = 2$ m/sec; Loss of head $(h_L) = \frac{0.35(V_1 - V_2)^2}{2g}$; $\frac{P_2}{\rho g} = ?$

∴ Loss head $(h_L) = \frac{0.35(V_1 - V_2)^2}{2g} = \frac{0.35[5-2]^2}{2 \times 9.81} = 0.16 \text{ m}$

Consider the datum line at section ②-②, hence

$Z_1 = L = 2\text{m}$; $Z_2 = 0$

PTO

From the Bernoulli's equation, we have

$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}+Z_1=\frac{P_2}{\rho g}+\frac{V_2^2}{2g}+Z_2+h_L$$

$$\Rightarrow 2.5+\frac{(5)^2}{2\times 9.81}+2=\frac{P_2}{\rho g}+\frac{(2)^2}{2\times 9.81}+0+0.16$$

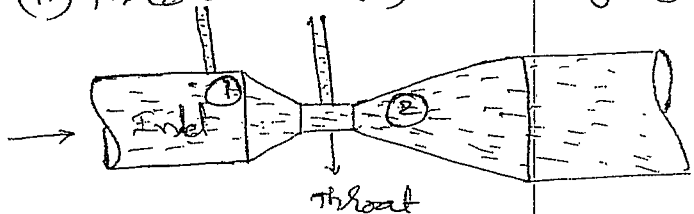
$$\Rightarrow \frac{P_2}{\rho g}=5.407\text{ m of liquid.}$$

Practical applications of Bernoulli's equation:

For the following measuring devices, Bernoulli's equation Can be applied. But generally Bernoulli's equation Can be applied to all problems of Incompressible fluid flow where energy Considerations are Involved.

Measuring devices are (i) Venturimeter (ii) Orifice meter (iii) pitot - tube.

Venturimeter: A Venturimeter is a device used for measuring the rate of flow of a fluid through it. It Consists of (i) a short Converging part (ii) throat and (iii) a diverging part, as shown In the figure.



Expression for Rate of flow (or) Discharge:

Consider a venturimeter fitted In a horizontal pipe through which a fluid is flowing. Let d_1, V_1, P_1 and d_2, V_2, P_2 are the diameters, velocities and pressures of the fluid at sections (1) and (2) respectively.

Applying the Bernoulli's equation at

Sections (1) and (2), we have

$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}+Z_1=\frac{P_2}{\rho g}+\frac{V_2^2}{2g}+Z_2$$

Since the pipe is horizontal $Z_1=Z_2$

$$\therefore \quad \frac{P_1}{\rho g}+\frac{V_1^2}{2g}=\frac{P_2}{\rho g}+\frac{V_2^2}{2g}$$

$$\Rightarrow \quad \frac{P_1-P_2}{\rho g}=\frac{1}{2g}\left[V_2^2-V_1^2\right]$$

But $\frac{P_1-P_2}{\rho g}$ is the difference of the pressure heads, h

$$\therefore \quad h=\frac{1}{2g}\left[V_2^2-V_1^2\right]$$

From the Continuity equation $A_1V_1=A_2V_2$, we have

$$V_1=\frac{A_2V_2}{A_1}$$

$$\therefore \quad h=\frac{1}{2g}\left[V_2^2-\frac{A_2^2V_2^2}{A_1^2}\right]=\frac{V_2^2}{2g}\left[\frac{A_1^2-A_2^2}{A_1^2}\right]$$

$$\Rightarrow \quad V_2=\frac{A_1}{\sqrt{A_1^2-A_2^2}}\sqrt{2gh}$$

$\therefore$ Discharge (or) Rate of flow (Q) = A_2V_2

$$\Rightarrow \boxed{Q=\frac{A_2A_1}{\sqrt{A_1^2-A_2^2}}\sqrt{2gh}}$$

The above discharge is under Ideal Conditions and is called theoritical discharge. Actual discharge is less than theoritical discharge.

$\therefore$ Actual discharge (Q_{act}) = $C_d \times Q_{theo}$, where C_d is called Coefficient of discharge and is less than unity.

PTO

Value of $h = \frac{P_1 - P_2}{\rho g}$: This will be given by Differential U-tube manometer.

NOTE:

Case I: If the density of the liquid in the manometer is more than that of the liquid in the pipe, then

S_m = specific gravity of the liquid in the manometer

S_v = specific gravity of the liquid in the pipe

x = difference of the liquid levels in the manometer, then

$$h = x\left[\frac{S_m}{S_v} - 1\right]$$

If the venturimeter is in incline position, then

$$h = x\left[\frac{S_m}{S_v} - 1\right] = \left(\frac{P_1 - P_2}{\rho g}\right) + [Z_1 - Z_2]$$

Case II: If the density of the liquid in the manometer is less than the density of the liquid in the pipe, then

$$h = x\left[1 - \frac{S_m}{S_v}\right]$$

In the case of inclined venturimeter position

$$h = \left(\frac{P_1 - P_2}{\rho g}\right) + (Z_1 - Z_2) = x\left[1 - \frac{S_m}{S_v}\right]$$

Worked examples

1. A horizontal venturimeter has inlet diameter 30 cm and throat diameter 15 cm. This is used to measure flow of water. The reading of the Differential Manometer connected to the inlet and throat is 20 cm of mercury column. Determine rate of flow, take coefficient of discharge 0.98

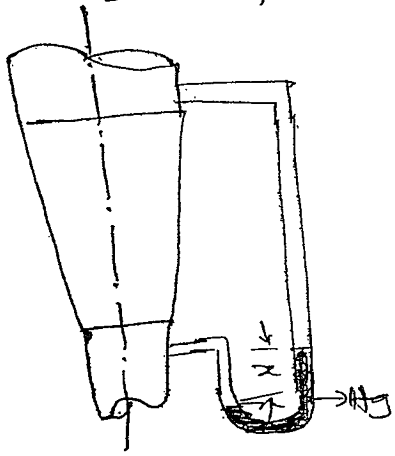
containing mercury, calculate the difference of level of mercury in the two limbs of the U-tube.

Solution: specific gravity of the oil $S_o = 0.8$; $Z_A - Z_B = 2\,m$;

Density of the oil $= 0.8 \times 1000$
$= 800\ kg/m^3$

Diameter at A is $D_A = 16\,cm = 16 \times 10^{-2}\,m$

" B is $D_B = 8\,cm = 8 \times 10^{-2}\,m$



Difference in the pressures at A & B is

$P_B - P_A = 0.981\ N/cm^2$
$= 0.981 \times 10^4\ N/m^2$

Applying Bernoulli's theorem for the points A and B, we have

$$\frac{P_A}{\rho g} + \frac{V_A^2}{2g} + Z_A = \frac{P_B}{\rho g} + \frac{V_B^2}{2g} + Z_B$$

$$\Rightarrow \left(\frac{P_A - P_B}{\rho g}\right) + (Z_A - Z_B) = \frac{1}{2g}\left[V_B^2 - V_A^2\right]$$

$$\Rightarrow \frac{-0.981 \times 10^4}{800 \times 9.81} + 2 = \frac{1}{2 \times 9.81}\left[V_B^2 - V_A^2\right]$$

$$\Rightarrow V_B^2 - V_A^2 = \left(2 - \frac{9810}{800 \times 9.81}\right) \times 2 \times 9.81 = 14.715 \quad \text{---} (1)$$

From the continuity equation, we have

$$V_A \times A_A = V_B \times A_B$$

$$\Rightarrow V_B = \frac{V_A \times A_A}{A_B} = \frac{V_A \times \frac{\pi}{4}(16 \times 10^{-2})^2}{\frac{\pi}{4}(8 \times 10^{-2})^2} = 4 V_A$$

From (1) $(4V_A)^2 - V_A^2 = 14.715$

$$\Rightarrow V_A = \sqrt{\frac{14.715}{15}} = 0.990\ m/sec$$

PTO

Solution: Inlet Diameter (d_1) = 30 Cm = 30×10^{-2} m;
Throat diameter (d_2) = 15 cm = 15×10^{-2} m;
Differential Manometer reading (x) = 20 cm of Hg
Coefficient of Discharge (C_d) = 0.98

Inlet area $(a_1) = \frac{\pi}{4}(d_1)^2 = \frac{\pi}{4}(30)^2 = 706.85\ \text{Cm}^2$

Throat area $(a_2) = \frac{\pi}{4}(d_2)^2 = \frac{\pi}{4}(15)^2 = 176.70\ \text{Cm}^2$

Difference of the pressure head $h = x\left[\frac{S_M}{S_L} - 1\right]$

$\therefore h = 20\left[\frac{13.6}{1} - 1\right] = 252.00$ Cm of water

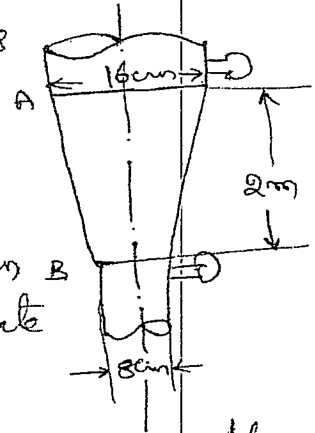
$\therefore$ Rate of flow (or) Discharge through venturimeter is

$$Q = C_d \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}}\sqrt{2gh}$$

$$= 0.98 \times \frac{706.85 \times 176.70}{\sqrt{(706.85)^2 - (176.70)^2}} \times \sqrt{2 \times 98.1 \times 252}$$

$$= 125756\ \text{Cm}^3/\text{sec} = \frac{125756}{1000}\ \text{lit/sec} = 125.756\ \text{lit/sec.}$$

2. A venturimeter is inserted to a vertical pipe conveying oil of specific gravity 0.8. Two pressure gauges are installed at Inlet A and throat B where diameters are 16cm and 8cm respectively. The point A is 2m above the point B. The pressure at B is 0.981 N/cm² is greater than that at A. Neglecting all losses, Calculate the flow rate.



If the gauges at A and B are replaced by tubes filled with same liquid and connected to U-tube

Rate of flow (Q) = $V_A \times A_A = 0.99 \times 0.0201 = 0.0199$ m^3/sec

For U- tube

Let 'h' be the difference In the mercury levels, then

$$h = x\left[\frac{S_g}{S_o} - 1\right]$$

But $h = \frac{P_A - P_B}{\rho g} + (Z_A - Z_B)$

$= -1.25 + 2.00$

$= 0.75$

$\therefore \quad 0.75 = x\left[\frac{13.6}{0.8} - 1\right]$

$\Rightarrow x = 0.04687 m = 4.687 cm.$

3. In a 100mm diameter horizontal pipe a venturimeter of 0.5 contraction ratio has been fixed. The head of water on the meter when there no flow is 3m (gauge). Find the rate of flow for which the throat pressure will be 2m of water. The coefficient of discharge is 0.97, take atmospheric pressure head as 10.3m of water.

Solution: $d_1 = 100mm = 10 cm$; throat diameter $(d_2) = 0.5 d_1 = 5 cm$;

$a_1 = 78.54 cm^2$; $C_d = 0.97$; $a_2 = 19.63 cm^2$

Pressure head for no flow $= \frac{P_1}{\rho g} = 3m$ (gauge) $= 3 + 10.3 = 13.3m$

pressure head at throat $= \frac{P_2}{\rho g} = 2m$ of water

Difference of pressure head (h) $= \frac{P_1}{\rho g} - \frac{P_2}{\rho g} = 13.3 - 2 = 11.3m = 1130 cm$

$$\text{Rate of flow } (Q) = \frac{C_d a_1 a_2}{\sqrt{a_1^2 - a_2^2}}\sqrt{2gh}$$

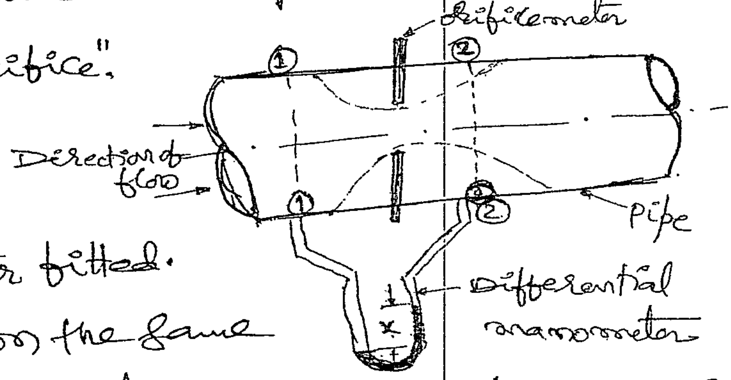
$$= \frac{0.97 \times 78.54 \times 19.63}{\sqrt{(78.54)^2 - (19.63)^2}} \times \sqrt{2 \times 981 \times 1130}$$

$= 29306.8 cm^3/sec = 29.306$ lit/sec

PTO

Orifice meter (or) Orifice plate

Orifice meter is a flat Circular plate has a Circular sharp edged hole Called "orifice". The hole (or) orifice is Concentric with the pipe to which this orifice meter fitted.



Description: This also works on the same principle as that of Venturimeter and is used for measur the rate of flow of a fluid through a pipe.

A differential manometer is Connected at section ①-① at a distance of about 1.5 to 2.0 times the pipe diameter upstream (Inlet) from the orifice meter. And section ②-② is at a distance of half of the diameter of the ~~pipe~~ orifice on the down stream (outlet) from the orifice plate.

Expression for Rate of flow (or) Discharge (Q):

Let P_1, V_1, a_1 and P_2, V_2, a_2 are the pressure, velocity and area of pipe at sections ①-① and ②-② respectively. ($a_1 = a_2 = a$, since pipe is uniform)

Applying Bernoulli's equations for the sections, we have

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

$$\Rightarrow \left(\frac{P_1}{\rho g} + Z_1\right) - \left(\frac{P_2}{\rho g} + Z_2\right) = \frac{V_2^2}{2g} - \frac{V_1^2}{2g}$$

But $\left(\frac{P_1}{\rho g} + Z_1\right) - \left(\frac{P_2}{\rho g} + Z_2\right)$ is Called Differential head 'h'.

$$\therefore h = \frac{V_2^2}{2g} - \frac{V_1^2}{2g} \qquad \boxed{\Rightarrow V_2 = \sqrt{2gh + V_1^2} \quad —①}$$

$$\Rightarrow V_2^2 = 2gh + V_1^2 \quad ①$$

PTO

At the section ②-②, let a_2 represents the area at "Vena-Contracta". If a_0 is the area of the orifice, then the Coefficient of Contraction (C_c) is given by,

$$C_c = \frac{a_2}{a_0}$$

By Continuity equation, we have

$$a_1 V_1 = a_2 V_2$$

$$\Rightarrow V_1 = \frac{a_2}{a_1} V_2 = \frac{C_c a_0 V_2}{a_1}$$

From ①,

$$V_2^2 = 2gh + V_1^2$$

$$= 2gh + \frac{C_c^2 a_0^2 V_2^2}{a_1^2}$$

$$\Rightarrow V_2^2 \left[1 - \left(\frac{a_0}{a_1}\right)^2 C_c^2\right] = 2gh$$

$$\Rightarrow V_2 = \frac{\sqrt{2gh}}{\sqrt{1 - \left(\frac{a_0}{a_1}\right)^2 C_c^2}}$$

$$\therefore \text{Discharge } (Q) = a_2 V_2 = \frac{a_0 C_c \sqrt{2gh}}{\sqrt{1 - \left(\frac{a_0}{a_1}\right)^2 C_c^2}}$$

But Coefficient of discharge (C_d) is the ratio of actual discharge (Q_{act}) to the theoretical discharge (Q_{th})

$$\therefore C_d = \frac{C_c \sqrt{1 - \left(\frac{a_0}{a_1}\right)^2}}{\sqrt{1 - \left(\frac{a_0}{a_1}\right)^2 C_c^2}}$$

$$\Rightarrow C_c = \frac{C_d \sqrt{1 - \left(\frac{a_0}{a_1}\right)^2 C_c^2}}{\sqrt{1 - \left(\frac{a_0}{a_1}\right)^2}}$$

$$\therefore Q = \frac{a_0 C_d \sqrt{1-\left(\frac{a_0}{a_1}\right)^2 C_c^2}}{\sqrt{1-\left(\frac{a_0}{a_1}\right)^2}} \times \frac{\sqrt{2gh}}{\sqrt{1-\left(\frac{a_0}{a_1}\right)^2 C_c^2}}$$

$$= \frac{a_0 C_d a_1 \sqrt{2gh}}{\sqrt{a_1^2 - a_0^2}}$$

worked examples

1. An orifice meter with orifice diameter 10cm is inserted in pipe of 20cm diameter. The readings of the pressure gauges at upstream and downstream are 19.62 N/cm² and 9.81 N/cm² respectively. Coefficient of discharge for the orifice meter is 0.6. Find the discharge of water through the pipe.

Solution: Diameter of the orifice $(d_0) = 10\text{cm} = 10 \times 10^{-2}\text{m}$

Area of the orifice $(a_0) = \frac{\pi}{4}(d_0)^2 = \frac{\pi}{4}(10)^2 = 78.54\text{cm}^2$

Diameter of the pipe $(d_1) = 20\text{cm} = 20 \times 10^{-2}\text{m}$

Area of the pipe $(a_1) = \frac{\pi}{4}(d_1)^2 = \frac{\pi}{4}(20)^2 = 314.16\text{cm}^2$

$P_1 = 19.62\,N/\text{cm}^2 = 19.62 \times 10^4\,N/m^2$; $C_d = 0.6$

$P_2 = 9.81\,N/\text{cm}^2 = 9.81 \times 10^4\,N/m^2$

Differential pressure head $(h) = \frac{P_1}{\rho g} - \frac{P_2}{\rho g}$

$$= \frac{19.62\times10^4}{1000\times9.81} - \frac{9.81\times10^4}{1000\times9.81}$$

$= 10\text{m}$ of water

$= 1000\text{cm}$ of water

P.T.O

$\therefore$ Discharge $(Q) = \dfrac{C_d\, a_0 a_1 \sqrt{2gh}}{\sqrt{a_1^2 - a_0^2}}$

$= \dfrac{0.6 \times 78.54 \times 314.16 \sqrt{2 \times 981 \times 1000}}{\sqrt{(314.16)^2 - (78.54)^2}}$

$= 68213.28\ cm^3/sec$

$= 68.21$ lit/sec.

2. An orifice meter with orifice diameter 15cm is inserted in a pipe of 30 cm diameter. The pressure difference measured by a mercury oil differential manometer on the two sides of the orifice meter gives a reading of 50 cm of Hg. Find the rate of flow of oil of specific gravity 0.9 when the coefficient of discharge of the orifice meter is 0.64.

Solution: Diameter of the orifice $(d_0) = 15cm = 15 \times 10^{-2} m$

Area " " $(a_0) = \frac{\pi}{4}(d_0)^2 = \frac{\pi}{4}(15)^2 = 176.70\ cm^2$

Diameter of the pipe $(d_p) = 30cm$

Area " " $(a_p) = \frac{\pi}{4}(30)^2 = 706.85\ cm^2$

Specific gravity of the oil $(S_o) = 0.9$

Differential manometer reading = 50 cm of Hg.

Coefficient of discharge $(C_d) = 0.64$

$\therefore$ Differential head $(h) = x\left[\dfrac{S_g}{S_o} - 1\right]$

$= 50\left[\dfrac{13.6}{0.9} - 1\right]$

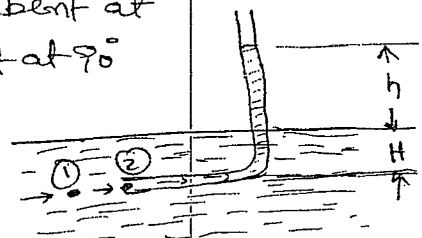
$= 705.50$ cm of oil

$\therefore$ Rate of flow of oil (or) Discharge of the oil is

$Q = \dfrac{C_d\, a_0 a_p \sqrt{2gh}}{\sqrt{a_p^2 - a_0^2}} = \dfrac{0.64 \times 176.70 \times 706.85 \sqrt{2 \times 981 \times 705.5}}{\sqrt{(706.85)^2 - (176.70)^2}}$

$= 137414.25\ cm^3/sec = 137.414$ lit/sec

PTO



<u>Pitot tube:</u> pitot tube is a glass tube, bent at right angles. The lower end which is bent at 90° is directed in the upstream direction as shown in the figure. The liquid rises up in the tube and the velocity is determined by measuring the rise of the liquid in the t[ube]
pitot tube works on the principle that the pressure increase due to conversion kinetic energy into pressure energy.

<u>working:</u> Consider two points ① and ② at the same level such that the point ② is just at the inlet of the pitot tube and point ① is far away from the tube.

Let P_1, V_1 are the pressure and velocity of flow at point ①
P_2 is pressure at point ② and V_2 is velocity at point ② which is zero.
'H' is the depth of the tube in the liquid
'h' is the rise of the liquid in the tube

Applying Bernoulli's equation at points ① and ②, we have

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2$$

But $z_1 = z_2$ and $V_2 = 0$, $\frac{P_1}{\rho g}$ = pressure head = H at ①

$\frac{P_2}{\rho g} = (h+H)$ pressure head at ②

$$\therefore H + \frac{V_1^2}{2g} = h + H$$

$$\Rightarrow V_1 = \sqrt{2gh}$$

This is called theoritical velocity.

PTO

∴ Actual velocity is $(V_1)_{act} = C_v\sqrt{2gh}$, where C_v is coefficient of pitot tube.

worked examples

1. A pitot static tube placed in the centre of a 300mm diameter pipe. The mean velocity in the pipe is 0.8 of the central velocity. Find the discharge through the pipe if the pressure difference is 60mm of water. Take the coefficient of pitot tube as 0.98.

Solution: Diameter of the pipe = 300mm = 300×10^{-3} m;

Mean velocity (V_1) = 0.8 × Central velocity (V) = 0.8V

Difference of pressure head = h = 60mm of water = 60×10^{-3} m of water

~~Coefficient of pitot tube (C_v)~~ = 0.98

∴ Central velocity $(V) = C_v\sqrt{2gh} = 0.98\times\sqrt{2\times9.81\times60\times10^{-3}} = 1.063$ m/sec.

∴ Mean velocity $(V_1) = 0.8\times1.063 = 0.8504$ m/sec.

∴ Discharge through pipe (Q) = Area of the pipe × mean velocity

$= \frac{\pi}{4}(300\times10^{-3})^2\times0.8504$

$= 0.06$ m³/sec.

UNIT-III

Boundary layer theory: Boundary layer development on a flat plate and its characteristics - Boundary layer thickness, displacement thickness, momentum thickness, energy thickness.

Dimensional and model analysis: Dimensional analysis; dimensions, dimensional homogeneity, methods of dimensional analysis; Buckingham's Pi - theorem, Rayleigh's method analysis. Similitude, derivations of Important dimensionless numbers.

When a real fluid flows over a solid body the fluid particles adhere to the solid surface and velocity of the fluid particles will be same as that of solid surface (or) boundary. If the boundary is stationary, the velocity of the fluid at the boundary is zero.

The velocity of the fluid increases from zero to the free stream velocity in the direction normal to the boundary. This variation of velocity takes place in a narrow region in the vicinity of the solid boundary called "boundary layer". The theory dealing with boundary layer flow is called boundary layer theory.

According to boundary layer theory, the flow of fluid is divided into two regions, they are

(i) A very thin layer of the fluid, called boundary layer, where variation of velocity takes place, fluid exerts a shear stress on the wall in the direction of motion.

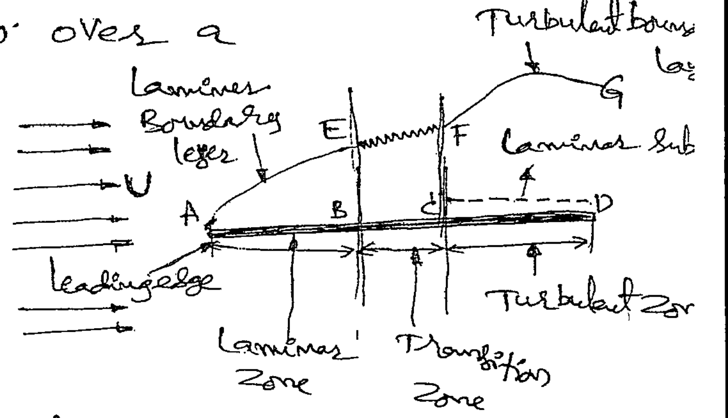
The shear stress is given by $\tau = \mu \frac{du}{dy}$

(ii) The velocity outside the boundary layer is constant and equal to free stream velocity (as there is no variation of velocity in this region, the velocity gradient and shear stress are zero.)

P.T.O.

Boundary layer development on a flat plate:

Consider the flow of a fluid with free stream velocity 'U' over a smooth thin plate, which is flat and placed parallel to the direction of flow.



Let us consider the flow with zero pressure gradient on one side of the plate. The velocity of the fluid on the surface of the plate is zero because the plate is stationary. But at a distance away from the plate, the fluid has certain velocity. Thus a velocity gradient is set in the fluid (near the surface of the plate) which develops shear resistance. This shear resistance retards the fluid so boundary layer region begins at the sharp leading edge and increases at the subsequent points downstream the leading edge. This is called growth of boundary layer.

Near the leading edge, the flow in the boundary layer is laminar though the main flow is turbulent. This layer of the fluid is said to be laminar boundary layer (AE). The length of the plate from the leading edge ~~is called~~ upto the laminar boundary layer exists is called laminar zone (AB). The distance of point B from the leading edge is obtained from Reynold number equal to 5×10^5 for a plate. The Reynold number is given by

$$(R_e)_x = \frac{U \times x}{\nu},$$

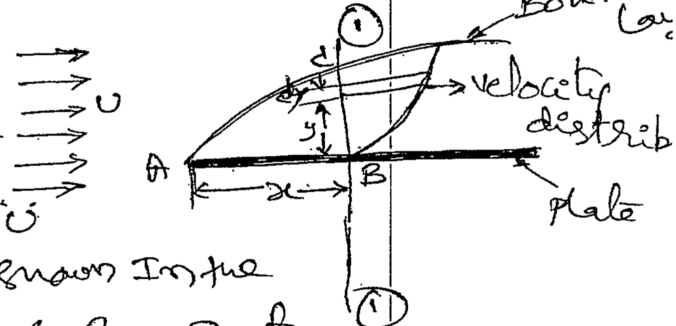
where U = free stream velocity of the fluid
ν = Kinematic viscosity of the fluid
x = distance from the leading edge

PTO

Hence for Laminar boundary layer $5\times10^5 = \frac{U\times x}{\nu}$, If 'U and ν' are known, distance from the leading edge 'x' can be calculated.

<u>Boundary layer thickness (δ)</u>: This is defined as the distance from the boundary (layer) of the solid body measured in y-direction to the point where the velocity of the fluid is approximately equals to 0.99 times the free stream velocity (U) of the fluid.

<u>Displacement thickness</u>: the distance perpendicular to the boundary, by which the free stream is displaced due to the formation of the boundary layer is defined as displacement thickness.



Consider the flow of a fluid with free stream velocity U over a thin smooth plate as shown in the figure. A Section 1-1 is considered at a distance x from the leading edge. Let B and C are points on the section on the plate and on the boundary layer respectively. velocity of the fluid at B is zero and that at C equals to 'U' i.e. free stream velocity. hence BC = δ, boundary layer thickness.

Consider an elemental strip at 1-1

let y = distance of the strip from the plate
dy = thickness of the elemental strip
v = velocity of the fluid at the elemental strip
b = width of the plate

∴ Mass of the fluid flowing per second through the elemental strip is dm = density × velocity × area of the strip

$$\therefore dm = \rho \times v \times dA = \rho v b dy$$

If there is no plate, then mass the fluid flowing per secon at ①-① is $dM = \rho U b dy$.

Hence because of the presence of the plate and form of boundary layer, there is reduction in the mass flow per second.

∴ Reduction in the mass flow through the elemental st is $\Delta m = dM - dm = \rho b[U - v] dy$

$$\therefore \text{Total reduction of mass } (m) = \int_0^\delta \Delta m = \int_0^\delta \rho b (U - v) dy \quad — ①$$

Let the plate is displaced by a distance δ_1 and velocity of the fluid at this distance is equals to free strea velocity U, then Loss of mass at δ_1 is

$$dm_1 = \rho U \delta_1 b \quad — ②$$

From ① and ②, $\int_0^\delta \rho b (U - v) dy = \rho U \delta_1 b$

$$\Rightarrow \delta_1 = \frac{1}{U} \int_0^\delta (U - v) dy$$

This is the ~~distan~~ displacement thickness.

(δ)

$$\delta_1 = \int_0^\delta \left(1 - \frac{v}{U}\right) dy$$

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Momentum thickness (θ): momentum thickness is defined as the distance measured perpendicular to the boundary of the solid, by which the boundary should be displaced to compensate for the reduction in momentum of the fluid on account of boundary layer formation.

$\therefore$ Momentum of the fluid in the strip is

$$dp = \text{mass} \times \text{velocity}$$
$$= (\rho v b\,dy) \times v$$

Momentum of the fluid in the absence of the boundary layer

$$dP = (\rho v b\,dy) U$$

$\therefore$ Loss of momentum $\Delta P = \rho b v (U - v) dy$

$$\text{Total loss of momentum } (P) = \int_0^\delta \rho b v (U - v) dy \quad (1)$$

Let 'θ' be the distance displaced by the plate by the flow of the fluid, then loss of momentum/sec is

$$P_1 = \text{mass of the fluid through } \theta \times \text{velocity}$$
$$= (\rho \times \theta \times b \times U) \times U$$
$$= \rho \theta b U^2 \quad (2)$$

From (1) and (2) $\rho \theta b U^2 = \int_0^\delta \rho b v (U - v) dy$

$$\Rightarrow \theta = \int_0^\delta \frac{v}{U}\left[1 - \frac{v}{U}\right] dy$$

This is momentum thickness

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Energy thickness (δ_2): This is defined as the distance measu... perpendicular to the boundary of the solid, by which boundar... should be displaced to compensate for the reduction in KE of the fluid on account of boundary layer formation.

KE of the fluid in the elemental strip is

$$KE = \frac{1}{2} m v^2 = \frac{1}{2}(\rho v b\,dy) v^2$$

KE of the fluid in the absence of the boundary layer is

$$KE = \frac{1}{2}(\rho v b\,dy) U^2$$

$$\therefore \text{Loss of } KE = \frac{1}{2}\rho v b (U^2 - v^2) dy$$

$$\text{Total loss of } KE = \frac{1}{2}\rho b \int_0^\delta v(U^2 - v^2) dy \quad \text{--- (1)}$$

Let δ_2 be the distance by which the plate is displaced to compensate for the reduction in KE, then total loss of KE is

$$\text{Total Loss of } KE = \frac{1}{2} m V^2 = \frac{1}{2}\times(\rho \times \text{area} \times \text{velocity}) \times \text{velocity}^2$$

$$= \frac{1}{2}(\rho b \delta_2 U) \times U^2$$

$$= \frac{1}{2}\rho b \delta_2 U^3 \quad \text{--- (2)}$$

From (1) & (2) $\frac{1}{2}\rho b \delta_2 U^3 = \frac{1}{2}\rho b \int_0^\delta v(U^2 - v^2) dy$

$$\Rightarrow \delta_2 = \int_0^\delta \frac{v}{U}\left(1 - \frac{v^2}{U^2}\right) dy$$

This is the energy thickness

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worked examples

1. Find the displacement thickness, the momentum thickness and energy thickness for the velocity distribution in the boundary layer given by $\frac{v}{U} = \frac{y}{\delta}$, where v is the velocity at a distance y from the plate and $v = U$ at $y = \delta$, where δ is boundary layer thickness. Also calculate value of δ_1/θ.

Solution: $\frac{v}{U} = \frac{y}{\delta}$ — (1) is velocity distribution function.

(i) Displacement thickness δ_1 is given by

$$\delta_1 = \int_0^{\delta} \left(1 - \frac{v}{U}\right) dy = \int_0^{\delta} \left(1 - \frac{y}{\delta}\right) dy \quad \text{from (1)}$$

$$= \left(y - \frac{y^2}{2\delta}\right)_0^{\delta} = \delta - \frac{\delta}{2} = \delta/2$$

(ii) momentum thickness is

$$\theta = \int_0^{\delta} \frac{v}{U}\left(1 - \frac{v}{U}\right) dy$$

$$= \int_0^{\delta} \frac{y}{\delta}\left(1 - \frac{y}{\delta}\right) dy$$

$$= \int_0^{\delta} \left(\frac{y}{\delta} - \frac{y^2}{\delta^2}\right) dy$$

$$= \left(\frac{y^2}{2\delta} - \frac{y^3}{3\delta^2}\right)_0^{\delta} = \frac{\delta}{2} - \frac{\delta}{3} = \frac{\delta}{6}$$

(iii) Energy thickness is $\delta_2 = \int_0^{\delta} \frac{v}{U}\left(1 - \frac{v^2}{U^2}\right) dy$

$$= \int_0^{\delta} \frac{y}{\delta}\left(1 - \frac{y^2}{\delta^2}\right) dy$$

(8)

$$= \int_0^{\delta} \left(\frac{y}{\delta} - \frac{y^3}{\delta^3}\right) dy$$

$$= \left(\frac{y^2}{2\delta} - \frac{y^4}{4\delta^3}\right)_0^{\delta} = \frac{\delta}{2} - \frac{\delta}{4} = \frac{\delta}{4}$$

(iv) $$\frac{\delta_1}{\theta} = \frac{\left(\frac{\delta}{2}\right)}{\left(\delta/6\right)} = 3$$

Dimensional and Model analysis

A mathematical technique that deals with the dimensions of the physical quantities is called dimensional analysis. This involves fundamental quantities.

Dimensional homogeneity: An equation must be dimensionally correct means dimensions of each term on one side must be equal to the dimensions of another side, this is called principle of homogeneity.

ex: Consider $S = ut + \frac{1}{2}at^2$

Dimensions of $S = L$

Dimensions of $ut = \frac{L}{T} \times T = L$

Dimensions of $at^2 = \frac{L}{T^2} \times T^2 = L$

$\frac{1}{2}$ is number has no dimensions

$\therefore$ Dimensions of LHS = Dimension of RHS, hence the equation is dimensionally correct.

Dimensional analysis methods: The following methods are used for the dimensional analysis, they are

(i) Rayleigh's method and (ii) Buckingham's π-theorem

Rayleigh's method: Let x is a variable (or) physical quantity which depends on fundamental quantities x_1, x_2, x_3, then according to Rayleigh's method x can be expressed as

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$x = f[x_1, x_2, x_3]$, this can also be written as $x = K x_1^a \cdot x_2^b \cdot x_3^c$ where K is constant and a, b, c are arbitrary powers. By equating the power of the fundamental quantities on both sides we can determine the values of a, b, c.

Worked examples

1. The time period (T) of a pendulum, depends on its length (L) and acceleration due to gravity 'g' at that place. Derive an expression for the time period of the pendulum.

Solution: Time period = T ; Length of the pendulum = L

Acceleration due to gravity $= g = \frac{L}{T^2} = LT^{-2}$

T is a function of L and g and hence

$$[T] = K[L]^a[g]^b = K[L]^a[LT^{-2}]^b$$

$$\Rightarrow [M^0 L^0 T^1] = K[M^0 L^1 T^0]^a [M^0 L T^{-2}]^b$$

$$\Rightarrow 0 = a + b \; ; \; 1 = -2b \Rightarrow b = -\frac{1}{2}$$

$$\Rightarrow a = \frac{1}{2}$$

$\therefore T = K(L)^{\frac{1}{2}}(g)^{-\frac{1}{2}} = K\sqrt{\frac{L}{g}}$, the value of K is determined experimentally as 2π

$$\boxed{\therefore T = 2\pi\sqrt{\frac{L}{g}}}$$

2. Find the expression for the power P, developed by a pump when P depends upon the head H, discharge Q and specific weight w of the fluid.

<u>Solution</u>: Power P of a pump is a function of head H, discharge and specific weight ω.

$$\therefore \quad P = K[H\, Q\, \omega]$$

$$\Rightarrow [M L^2 T^{-3}] = K [L]^a [L^3 T^{-1}]^b [M L^{-2} T^{-2}]^c$$

$$\Rightarrow 1 = c \quad ; \quad 2 = a + 3b - 2c \; ; \; -3 = -b - 2c$$

$$\therefore a = 1 ; b = 1 ; c = 1$$

$$\therefore \text{power}(P) = K H Q \omega$$

<u>Buckingham's π-theorem</u>: If there are 'n' variables either independent (or) dependent, in a physical phenomenon, and if these variables contain 'm' fundamental dimensions (M, L, T), then the variables are arranged into (n−m) dimensionless terms. Each term is called "π-term".

Let $x_1, x_2, x_3, \ldots x_n$ are the variables involved in a physical problem, let x_1 be the dependent variable and all the remaining are independent, then x_1 is function of $x_2, x_3, x_4, \ldots x_n$.

$$\therefore \quad x_1 = f(x_2, x_3, x_4, \ldots x_n)$$

$\Rightarrow f(x_1, x_2, x_3, \ldots x_n) = 0$ is dimensionally homogeneous equation, containing 'n' variables. If there are 'm' fundamental dimensions, according to Buckingham's π-theorem, the equation can be written as $f_1(\pi_1, \pi_2, \pi_3, \ldots \pi_{n-m}) = 0$, where each π-term is a dimensionless and is independent of the system.

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Each π-terms contains (m+1) variables, where m fundamental dimensions and called repeating variables.

Let X_2, X_3, X_4 are the repeating variables, the each π-terms is written as

$$\pi_1 = X_2^{a_1} \cdot X_3^{b_1} \cdot X_4^{c_1} \cdot X_1$$

$$\pi_2 = X_2^{a_2} \cdot X_3^{b_2} \cdot X_4^{c_2} \cdot X_5$$

$$\pi_3 = X_2^{a_3} \cdot X_3^{b_3} \cdot X_4^{c_3} \cdot X_6$$

$$\vdots$$

$$\pi_{n-m} = X_2^{a_{n-m}} \cdot X_3^{b_{n-m}} \cdot X_4^{c_{n-m}} \cdot X_n$$

By solving the each equation using principle of Homogenity, the value $a_1, b_1, c_1, \ldots$ can be obtained.

<u>worked examples</u>

1. The efficiency 'η' of a fan depends on density ρ, dynamic viscosity μ of the fluid, angular velocity 'ω', diameter 'D' of the rotor and discharge Q. Express 'η' in terms of dimensionless parameters.

<u>Solution</u>: Efficiency η is a function of ρ, μ, ω, D, Q

$$\therefore \quad \eta = f(\rho, \mu, \omega, D, Q)$$

$$\Rightarrow \quad f_1(\eta, \rho, \mu, \omega, D, Q) = 0$$

Total no. of variables $n = 6$

no. of fundamental dimensions $= m = 3$

$\therefore$ no. of π-terms $= n - m = 6 - 3 = 3$

$$\therefore \quad f_1(\pi_1, \pi_2, \pi_3) = 0$$

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Choosing D, ω, ρ as repeating variables, we have

$$\pi_1 = D^{a_1} \cdot \omega^{b_1} \cdot \rho^{c_1} \cdot \eta$$

$$\pi_2 = D^{a_2} \cdot \omega^{b_2} \cdot \rho^{c_2} \cdot \mu$$

$$\pi_3 = D^{a_3} \cdot \omega^{b_3} \cdot \rho^{c_3} \cdot Q$$

$$\therefore \left[M^0 L^0 T^0\right] = \{L\}^{a_1} \left[T^{-1}\right]^{b_1} \left[M L^{-3}\right]^{c_1} \cdot M^0 L^0 T^0$$

$$\Rightarrow c_1 = 0 ; \; a_1 - 3c_1 = 0 ; \; -b_1 = 0$$

$$\Rightarrow a_1 = b_1 = c_1 = 0$$

$$\therefore \pi_1 = D^0 \cdot \omega^0 \cdot \rho^0 \cdot \eta = \eta$$

$$\left[M^0 L^0 T^0\right] = [L]^{a_2} \left[T^{-1}\right]^{b_2} \left[M L^{-3}\right]^{c_2} \left(M L^{-1} T^{-1}\right)$$

$$\Rightarrow c_2 + 1 = 0 ; \; a_2 - 3c_2 - 1 = 0 ; \; -b_2 - 1 = 0$$

$$\Rightarrow c_2 = -1 ; \; \Rightarrow a_2 = 2 ; \; \Rightarrow b_2 = -1$$

$$\therefore \pi_2 = D^{+2} \omega^{-1} \rho^{-1} \cdot \mu = \frac{\mu D^2}{\omega \rho}$$

$$\left[M^0 L^0 T^0\right] = [L]^{a_3} \left[T^{-1}\right]^{b_3} \left[M L^{-3}\right]^{c_3} \left[L^3 T^{-1}\right]$$

$$\Rightarrow c_3 = 0 ; \; a_3 - 3c_3 + 3 = 0 ; \; -b_3 - 1 = 0$$

$$\Rightarrow c_3 = 0 ; \; a_3 = -3 \quad \Rightarrow b_3 = -1$$

$$\therefore \pi_3 = D^{-3} \omega^{-1} \rho^0 \cdot Q = \frac{Q}{D^3 \omega}$$

$$\therefore \eta = \phi\left[\frac{\mu D^2}{\omega \rho}, \frac{Q}{D^3 \omega}\right]$$

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Similitude

The similarity between the model and its prototype in every respect is defined as "Similitude".

Three types of similarities must exist between model and prototype, they are (i) Geometric similarity, (ii) Kinematic similarity and (iii) Dynamic similarity.

Geometric Similarity: In this, the ratio of all corresponding linear dimensions in model and prototype are equal.

$$\frac{L_p}{L_m} = \frac{b_p}{b_m} = \frac{D_p}{D_m} = L_r,$$

where L_m = length of the model
b_m = breadth of the model
D_m = diameter of the model

Similarly L_p, b_p, D_p are corresponding values of prototype
L_r = Scale ratio

For area $\frac{A_p}{A_m} = \frac{L_p \times b_p}{L_m \times b_m} = L_r \times L_r = (L_r)^2$

For volume $\frac{V_p}{V_m} = \left(\frac{L_p}{L_m}\right)^3 = \left(\frac{b_p}{b_m}\right)^3 = \left(\frac{D_p}{D_m}\right)^3 = (L_r)^3$

Kinematic Similarity: If the ratios of the velocity and acceleration at the points in the model and at the corresponding points in the prototype are same, then kinematic similarity is said to be exist between the model and the prototype.

∴ For kinematic similarity,

$$\frac{V_{P_1}}{V_{m_1}} = \frac{V_{P_2}}{V_{m_2}} = V_r,$$

$$\frac{a_{P_1}}{a_{m_1}} = \frac{a_{P_2}}{a_{m_2}} = a_r, \quad \text{where}$$

V_{P_1}; V_{P_2} are the velocities at points 1 and 2 In prototype
Similarly V_{m_1}, V_{m_2} are the velocities at points 1 and 2 I
the model.
Similarly a_{P_1}, a_{P_2}, a_{m_1}, a_{m_2} are the accelerations.

<u>Dynamic Similarity</u>: If the ratios of the forces at the points In the model and at the corresponding points In the prototype are same, then Dynamic Similarity exists between the model and prototype. Also the directions of the forces In the corresponding points should be same.

∴ For dynamic similarity

$$\frac{(F_i)_p}{(F_i)_m} = \frac{(F_v)_p}{(F_v)_m} = \frac{(F_g)_p}{(F_g)_m} = F_r, \quad \text{where } F_i = \text{Inertia force}$$

F_v = viscous force, F_g = gravity force, F_r = Force ratio

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Dimensionless Numbers

The ratio of one force to another force leads to Dimensionless numbers. Dynamic similarity is a Dimensionless number.

The following are the Important Dimensionless numbers, they are (i) Reynold's number (ii) Froud's number (iii) Euler's number (iv) weber's number and (v) Mach's number.

Reynold's number (R_e): The ratio of Inertia force to the viscous force of a flowing fluid is called "Reynold number".

Inertia force (F_i) = Mass × Acceleration

$= (\text{Density} \times \text{Volume}) \times \text{Velocity}/\text{Time}$

$= \text{Density} \times \dfrac{\text{Volume}}{\text{Time}} \times \text{Velocity}$

$= \rho \times AV \times V \quad \left(\because \dfrac{Vol}{T} = \text{Area} \times \text{velocity}\right)$

$= \rho AV^2$

Viscous force = Shear stress × Area

$= \tau \times A$

$= \mu\left(\dfrac{du}{dy}\right) \times A = \mu \dfrac{V}{L} \times A \quad \left(\because \dfrac{du}{dy} = \dfrac{V}{L}\right)$

$$\therefore \text{Reynold's number } (R_e) = \frac{F_i}{F_v} = \frac{\rho AV^2}{\frac{\mu VA}{L}} = \frac{\rho VL}{\mu}$$

$$= \frac{VL}{\left(\frac{\mu}{\rho}\right)} = \frac{VL}{\nu}$$

(ν = Kinematic viscosity)

$\therefore$ Reynold's number $(R_e) = \frac{\rho V L}{\mu} = \frac{VL}{\nu}$

In Case of pipe flow, 'L' Can be replaced by the diameter (d) of the pipe.

$$\therefore R_e = \frac{\rho V d}{\mu} = \frac{Vd}{\nu}$$

Froud's number (F_e): the Square root of the ratio of Inertia force to the Gravity force of the flowing fluid.

$$\therefore \text{Froud's number } (F_e) = \sqrt{\frac{F_i}{F_g}}$$

Inertia force $(F_i) = \rho A V^2$

Gravity force (F_g) = Mass × Acceleration due to gravity

$= m \times g$

$= \rho V \times g$

$= \rho \times L^3 \times g$

$= \rho \times A \times L \times g$

$$\therefore \text{Froud's number } (F_e) = \sqrt{\frac{F_i}{F_g}} = \sqrt{\frac{\rho A V^2}{\rho A L g}} = \frac{V}{\sqrt{Lg}}$$

Euler's number (E_e): This is defined as the Square root of the ratio of the Inertia force to the pressure force of the flowing fluid.

$$\therefore \text{Euler's number } (E_e) = \sqrt{\frac{F_i}{F_p}}$$

Inertia force $(F_i) = \rho A V^2$

pressure force (F_p) = pressure Intensity × Area

$= P \times A$

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$\therefore$ Euler's number $(E_u) = \sqrt{\frac{F_i}{F_p}} = \sqrt{\frac{\rho A V^2}{p \times A}} = \frac{V}{\sqrt{p/\rho}}$

Weber's number (W_e): This is defined as the square root of the ratio of the Inertia force to the surface tension force of the flowing fluid.

$\therefore$ Weber's number $(W_e) = \sqrt{\frac{F_i}{F_s}}$

Inertia force $(F_i) = \rho A V^2$

Surface tension force (F_s) = Surface tension per unit length $\times L$

$= \sigma \times L$

$\therefore$ Weber's number $(W_e) = \sqrt{\frac{F_i}{F_s}} = \sqrt{\frac{\rho A V^2}{\sigma L}}$

$= \sqrt{\frac{\rho \times L^2 \times V^2}{\sigma \times L}}$

$= V / \sqrt{\sigma / \rho L}$

Mach's number (M_e): This is defined as the square root of the Inertia force to the elastic force of the flowing fluid.

$\therefore$ Mach's number $(M_e) = \sqrt{\frac{F_i}{F_e}}$

Inertia force $(F_i) = \rho A V^2$

Elastic force (F_e) = Elastic stress $\times$ Area

$= K \times A$

$= K \times L^2$

$\therefore$ Mach's number $(M_e) = \sqrt{\frac{F_i}{F_e}} = \sqrt{\frac{\rho A V^2}{K \times L^2}} = \sqrt{\frac{\rho \times L^2 \times V^2}{K \times L^2}}$

$= \frac{V}{\sqrt{K/\rho}} = \frac{V}{C}$

where $\sqrt{\frac{K}{\rho}}$ = velocity of sound in the fluid.

$= C$

UNIT-4

HYDRAULIC TURBINES

1. GENERAL LAYOUT OF A HYDROELECTRIC POWER PLANT

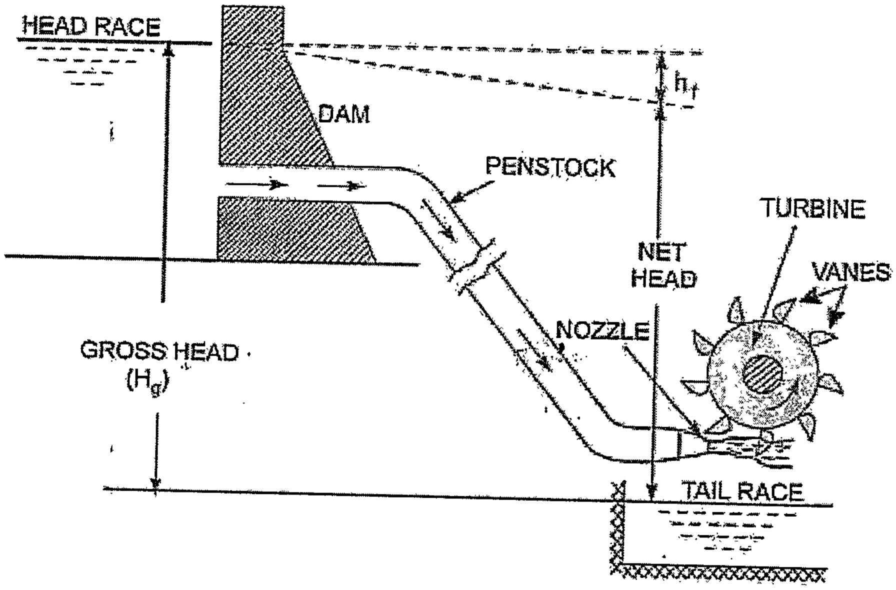


Fig. shows a general layout of a hydroelectric power plant which consists of :

(i) A dam constructed across a river to store water.

(ii) Pipes of large diameters called penstocks, which carry water under pressure from the storage reservoir to the turbines. These pipes are made of steel or reinforced concrete.

(iii) Turbines having different types of vanes fitted to the wheels.

(iv) Tail race, which is a channel which carries water away from the turbines after the water has worked on the turbines. The surface of water in the tail race channel is also known as tail race.

2. DEFINITIONS OF HEADS AND EFFICIENCIES OF A TURBINE :

1. **Gross Head.** The difference between the head race level and tail race level when no water is flowing is known as Gross Head. It is denoted by 'H_g' in Fig.

2. **Net Head.** It is also called effective head and is defined as the head available at the inlet of the turbine.

$$H = H_g - h_f$$

where H_g = Gross head, $h_f = \dfrac{4 \times f \times L \times V^2}{D \times 2g}$

Efficiencies of a Turbine. The following are the important efficiencies of a turbine.

(*a*) Hydraulic Efficiency, η_h (*b*) Mechanical Efficiency, η_m
(*c*) Volumetric Efficiency, η_v and (*d*) Overall Efficiency, η_o

(*a*) Hydraulic Efficiency (η_h).

$$\eta_h = \frac{\text{Power delivered to runner}}{\text{Power supplied at inlet}} = \frac{\text{R.P.}}{\text{W.P.}}$$

where R.P. = Power delivered to runner *i.e.*, runner power

$$= \frac{W}{g} \frac{\left[V_{w_1}u_1 \pm V_{w_2}u_2\right]}{1000} \text{ kW}$$

W.P. = Power supplied at inlet of turbine and also called water power

$$= \frac{W \times H}{1000} \text{ kW}$$

(*b*) Mechanical Efficiency (η_m).

$$\eta_m = \frac{\text{Power at the shaft of the turbine}}{\text{Power delivered by water to the runner}} = \frac{\text{S.P.}}{\text{R.P.}}$$

(*c*) Volumetric Efficiency (η_v).

$$\eta_v = \frac{\text{Volume of water actually striking the runner}}{\text{Volume of water supplied to the turbine}}$$

(*d*) Overall Efficiency (η_o).

$$\eta_o = \frac{\text{Volume available at the shaft of the turbine}}{\text{Power supplied at the inlet of the turbine}} = \frac{\text{Shaft power}}{\text{Water power}}$$

$$= \frac{\text{S.P.}}{\text{W.P.}} = \eta_m \times \eta_h$$

3. CLASSIFICATION OF HYDRAULIC TURBINES :

1. According to the type of energy at inlet :
   (*a*) Impulse turbine, and (*b*) Reaction turbine.
2. According to the direction of flow through runner :
   (*a*) Tangential flow turbine, (*b*) Radial flow turbine,
   (*c*) Axial flow turbine, and (*d*) Mixed flow turbine.
3. According to the head at the inlet of turbine :
   (*a*) High head turbine, (*b*) Medium head turbine, and
   (*c*) Low head turbine.
4. According to the specific speed of the turbine :
   (*a*) Low specific speed turbine, (*b*) Medium specific speed turbine, and
   (*c*) High specific speed turbine.

If at the inlet of the turbine, the energy available is only kinetic energy, the turbine is known as **impulse turbine.**

If at the inlet of the turbine, the water possesses kinetic energy as well as pressure energy, the turbine is known as **reaction turbine.**

If the water flows along the tangent of the runner, the turbine is known as **tangential flow turbine.**

If the water flows in the radial direction through the runner, the turbine is called **radial flow turbine.**

If the water flows through the runner along the direction parallel to the axis of rotation of the runner, the turbine is called **axial flow** turbine.

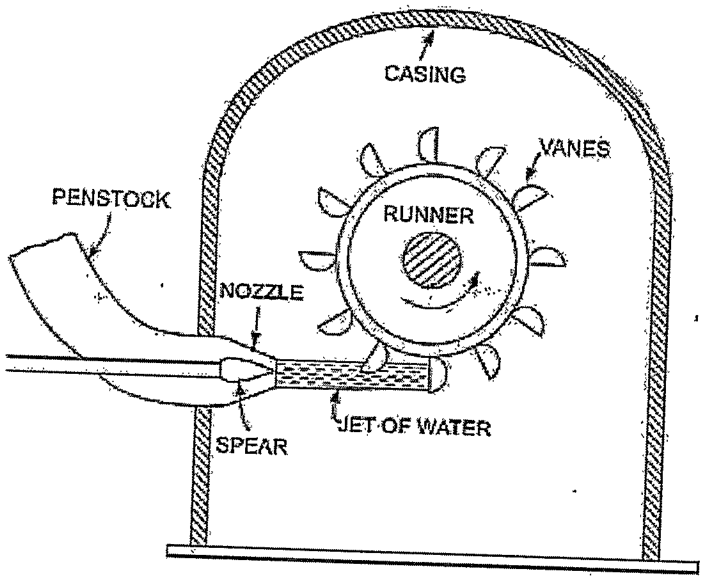
If the water flows through the runner in the radial direction but leaves in the direction parallel to axis of rotation of the runner, the turbine is called **mixed flow** turbine.

4. Difference between Impulse and Reaction Turbines:

Impulse Turbine	Reaction Turbine
1. In impulse turbine only kinetic energy is used to rotate the turbine.	1. In reaction turbine both kinetic and pressure energy is used to rotate the turbine.
2. In this turbine water flow through the nozzle and strike the blades of turbine.	2. In this turbine water is guided by the guide blades to flow over the turbine.
3. All pressure energy of water converted into kinetic energy before striking the vanes.	3. In reaction turbine, there is no change in pressure energy of water before striking.
4. The pressure of the water remains unchanged and is equal to atmospheric pressure during process.	4. The pressure of water is reducing after passing through vanes.
5. Water may admitted over a part of circumference or over the whole circumference of the wheel of turbine.	5. Water, may admitted over a part of circumference or over the whole circumference of the wheel of turbine.
6. In impulse turbine casing has no hydraulic function to perform because the jet is at atmospheric pressure. This casing serves only to prevent splashing of water.	6. Casing is absolutely necessary because the pressure at inlet of the turbine is much higher than the pressure at outlet. It is sealed from atmospheric pressure.
7. This turbine is most suitable for large head and lower flow rate. Pelton wheel is the example of this turbine.	7. This turbine is best suited for higher flow rate and lower head situation.

5. PELTON WHEEL (OR TURBINE) :

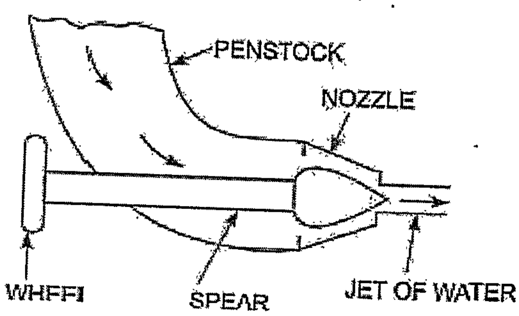
The Pelton wheel or Pelton turbine is a tangential flow impulse turbine. The water strikes the bucket along the tangent of the runner. The energy available at the inlet of the turbine is only kinetic energy. The pressure at the inlet and outlet of the turbine is atmospheric. This turbine is used for high heads . and is named after L.A. Pelton, an American Engineer.



The main parts of the Pelton turbine are :

1. Nozzle and flow regulating arrangement (spear),
2. Runner and buckets,
3. Casing, and
4. Breaking jet.

1. Nozzle and Flow Regulating Arrangement. The amount of water striking the buckets (vanes) of the runner is controlled by providing a spear in the nozzle as shown in Fig. The spear is a conical needle which is operated either by a hand wheel, or automatically in an axial direction depending upon the size of the unit.



2. Runner with Buckets.

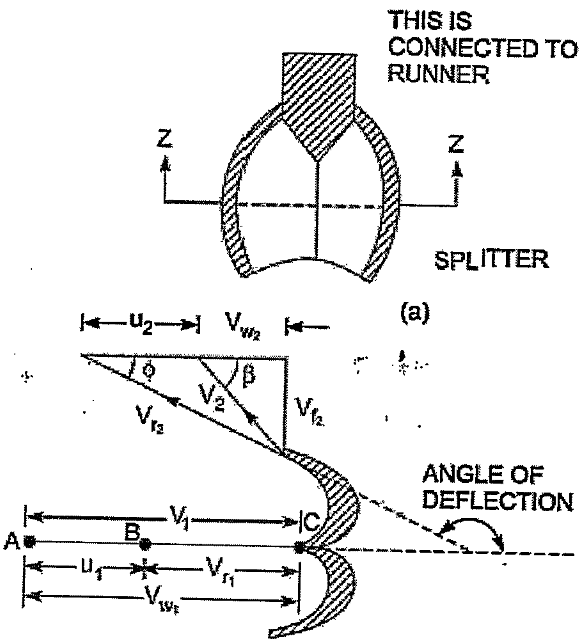
It consists of a circular disc on the periphery of which a number of buckets evenly spaced are fixed. The shape of the buckets is of a double hemispherical cup or bowl. Each bucket is divided into two symmetrical parts by a dividing wall which is known as splitter.

3. Casing.

The function of the casing is to prevent the splashing of the water and to discharge water to tail race. It is made of cast iron or fabricated steel plates. The casing of the Pelton wheel does not perform any hydraulic function.

4. Breaking Jet. When the nozzle is completely closed by moving the spear in the forward direction, the amount of water striking the runner reduces to zero. But the runner due to inertia goes on revolving for a long time. To stop the runner in a short time, a small nozzle is provided which directs the jet of water on the back of the vanes. This jet of water is called breaking jet.

Velocity Triangles and Work done for Pelton Wheel. :



Let $\quad H$ = Net head acting on the Pelton wheel

$$= H_g - h_f$$

where $\quad H_g$ = Gross head and $h_f = \dfrac{4fLV^2}{D^* \times 2g}$

where $\quad D^*$ = Dia. of Penstock, $\quad N$ = Speed of the wheel in r.p.m.,

D = Diameter of the wheel, $\quad d$ = Diameter of the jet.

Then $\quad V_1$ = Velocity of jet at inlet $= \sqrt{2gH}$

$$u = u_1 = u_2 = \frac{\pi DN}{60}.$$

The velocity triangle at inlet will be a straight line where

$$V_{r_1} = V_1 - u_1 = V_1 - u$$

$$V_{w_1} = V_1$$

$$\alpha = 0^\circ \text{ and } \theta = 0^\circ$$

From the velocity triangle at outlet, we have

$$V_{r_2} = V_{r_1} \text{ and } V_{w_2} = V_{r_2} \cos\phi - u_2.$$

Now work done by the jet on the runner per second

$$= F_x \times u = \rho a V_1 [V_{w_1} + V_{w_2}] \times u \text{ Nm/s}$$

Power given to the runner by the jet

$$= \frac{\rho a V_1 \left[V_{w_1} + V_{w_2}\right] \times u}{1000} \text{ kW}$$

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

$$= \frac{1}{g}\left[V_{w_1} + V_{w_2}\right] \times u$$

$\therefore$ K.E. of jet per second $= \frac{1}{2} (\rho a V_1) \times V_1^2$

$\therefore$ **Hydraulic efficiency,** $\eta_h = \frac{\text{Work done per second}}{\text{K.E. of jet per second}}$

$$\eta_h = \frac{2(V_1 - u)\,[1 + \cos\phi]\,u}{V_1^2}$$

The efficiency will be maximum for a given value of V_1 when

$$\frac{d}{du}(\eta_h) = 0 \quad \text{or} \quad \frac{d}{du}\left[\frac{2u(V_1 - u)(1 + \cos\phi)}{V_1^2}\right] = 0$$

or $$\frac{(1 + \cos\phi)}{V_1^2} \frac{d}{du}(2uV_1 - 2u^2) = 0 \quad \text{or} \quad \frac{d}{du}[2uV_1 - 2u^2] = 0 \quad \left(\because \frac{1 + \cos\phi}{V_1^2} \neq 0\right)$$

or $$2V_1 - 4u = 0 \quad \text{or} \quad u = \frac{V_1}{2} \qquad \text{...(18.14)}$$

Equation (18.14) states that hydraulic efficiency of a Pelton wheel will be maximum when the velocity of the wheel is half the velocity of the jet of water at inlet. The expression for maximum efficiency will be obtained by substituting the value of $u = \frac{V_1}{2}$.

$\therefore$ $$\text{Max. } \eta_h = \frac{(1 + \cos\phi)}{2}.$$

(*i*) The velocity of the jet at inlet is given by $V_1 = C_v\sqrt{2gH}$
where C_v = Co-efficient of velocity = 0.98 or 0.99
H = Net head on turbine

(*ii*) The velocity of wheel (u) is given by $u = \phi\sqrt{2gH}$
where ϕ = Speed ratio. The value of speed ratio varies from 0.43 to 0.48.

(*iii*) The angle of deflection of the jet through buckets is taken at 165° if no angle of deflection is given.

(*iv*) The mean diameter or the pitch diameter D of the Pelton wheel is given by

$$u = \frac{\pi DN}{60}$$

(*v*) **Jet Ratio.** It is defined as the ratio of the pitch diameter (D) of the Pelton wheel to the diameter of the jet (d). It is denoted by 'm' and is given as

$$m = \frac{D}{d} \; (= 12 \text{ for most cases})$$

(*vi*) Number of buckets on a runner is given by

$$Z = 15 + \frac{D}{2d} = 15 + 0.5\,m \qquad \text{where } m = \text{Jet ratio}$$

(*vii*) **Number of Jets.** It is obtained by dividing the total rate of flow through the turbine by the rate of flow of water through a single jet.

Problem 18.1 *A Pelton wheel has a mean bucket speed of 10 metres per second with a jet of water flowing at the rate of 700 litres/s under a head of 30 metres. The buckets deflect the jet through an angle of 160°. Calculate the power given by water to the runner and the hydraulic efficiency of the turbine. Assume co-efficient of velocity as 0.98.*

Solution. Given :

Speed of bucket, $u = u_1 = u_2 = 10$ m/s

Discharge, $Q = 700$ litres/s $= 0.7$ m³/s, Head of water, $H = 30$ m

Angle of deflection $= 160°$

∴ Angle, $\phi = 180° - 160° = 20°$

Co-efficient of velocity, $C_v = 0.98$.

The velocity of jet, $V_1 = C_v\sqrt{2gH} = 0.98\sqrt{2 \times 9.81 \times 30} = 23.77$ m/s

∴ $V_{r_1} = V_1 - u_1 = 23.77 - 10$

$= 13.77$ m/s

$V_{w_1} = V_1 = 23.77$ m/s

From outlet velocity triangle,

$V_{r_2} = V_{r_1} = 13.77$ m/s

$V_{w_2} = V_{r_2}\cos\phi - u_2$

$= 13.77\cos 20° - 10.0 = 2.94$ m/s

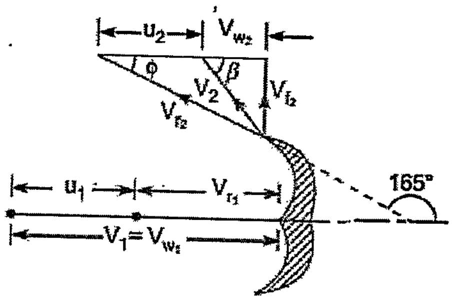


Fig. 18.6

Work done by the jet per second on the runner is given by equation (18.9) as

$= \rho a V_1 \left[V_{w_1} + V_{w_2}\right] \times u$

$= 1000 \times 0.7 \times [23.77 + 2.94] \times 10 \qquad (\because \; aV_1 = Q = 0.7 \text{ m}^3/\text{s})$

$= 186970$ Nm/s

∴ Power given to turbine $= \dfrac{186970}{1000} =$ **186.97 kW. Ans.**

The hydraulic efficiency of the turbine is given by equation (18.12) as

$$\eta_h = \frac{2\left[V_{w_1} + V_{w_2}\right] \times u}{V_1^2} = \frac{2[23.77 + 2.94] \times 10}{23.77 \times 23.77}$$

$=$ **0.9454** or **94.54%. Ans.**

Problem 18.2 *A Pelton wheel is to be designed for the following specifications : Shaft power = 11,772 kW ; Head = 380 metres ; Speed = 750 r.p.m. ; Overall efficiency = 86% ; Je diameter is not to exceed one-sixth of the wheel diameter. Determine :*

(i) The wheel diameter, *(ii) The number of jets required, and*

(iii) Diameter of the jet.

Take $K_{v_1} = 0.985$ *and* $K_{u_1} = 0.45$

Solution. Given :

Shaft power, S.P. = 11,772 kW

Head, $H = 380$ m

Speed, $N = 750$ r.p.m.

Overall efficiency, $\eta_0 = 86\%$ or 0.86

Ratio of jet dia. to wheel dia. $= \frac{d}{D} = \frac{1}{6}$

Co-efficient of velocity, $K_{v_1} = C_v = 0.985$

Speed ratio, $K_{u_1} = 0.45$

Velocity of jet, $V_1 = C_v\sqrt{2gH} = 0.985\sqrt{2\times 9.81\times 380} = 85.05$ m/s

The velocity of wheel, $u = u_1 = u_2$

$= \text{Speed ratio} \times \sqrt{2gH} = 0.45\times\sqrt{2\times 9.81\times 380} = 38.85$ m/s

But $u = \frac{\pi DN}{60} \quad \therefore \quad 38.85 = \frac{\pi DN}{60}$

or $D = \frac{60\times 38.85}{\pi\times N} = \frac{60\times 38.85}{\pi\times 750} =$ **0.989 m. Ans.**

But $\frac{d}{D} = \frac{1}{6}$

$\therefore$ Dia. of jet, $d = \frac{1}{6}\times D = \frac{0.989}{6} =$ **0.165 m. Ans.**

Discharge of one jet, q = Area of jet × Velocity of jet

$= \frac{\pi}{4}d^2\times V_1 = \frac{\pi}{4}(.165)\times 85.05 \text{ m}^3/\text{s} = 1.818 \text{ m}^3/\text{s}$ ...(*i*)

Now $\eta_o = \frac{\text{S.P.}}{\text{W.P.}} = \frac{11772}{\frac{\rho g\times Q\times H}{1000}}$

$$0.86 = \frac{11772\times 1000}{1000\times 9.81\times Q\times 380}, \text{ where } Q = \text{Total discharge}$$

$\therefore$ Total discharge, $Q = \frac{11772\times 1000}{1000\times 9.81\times 380\times 0.86} = 3.672 \text{ m}^3/\text{s}$

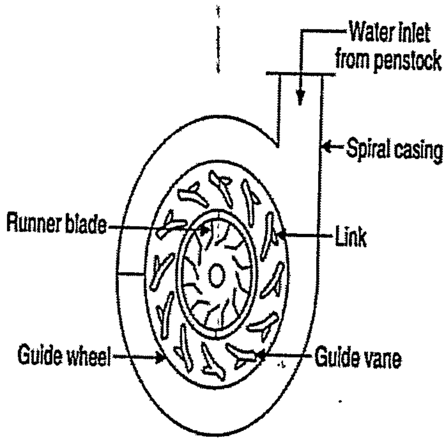
$\therefore$ Number of jets $= \frac{\text{Total discharge}}{\text{Discharge of one jet}} = \frac{Q}{q} = \frac{3.672}{1.818} =$ **2 jets. Ans.**

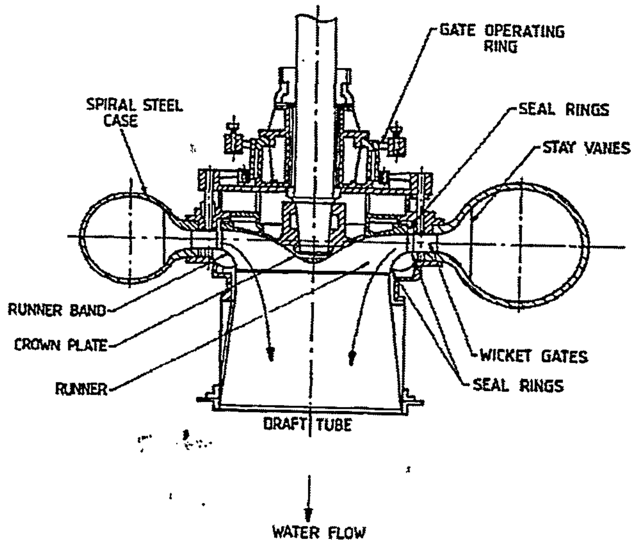
6. RADIAL FLOW REACTION TURBINES :

Radial flow turbines are those tubines in which the water flows in the radial direction. The water may flow radially from outwards to inwards (*i.e.*, towards the axis of rotation) or from inwards to outwards. If the water flows from outwards to inwards through the runner, the turbine is known as inward radial flow turbine. And if the water flows from inwards to outwards, the turbine is known as outward radial flow turbine.

7. FRANCIS TURBINE:

The inward flow reaction turbine having radial discharge at outlet is known as Francis Turbine, after the name of J.B. Francis, an American engineer who in the beginning designed inward radial flow reaction type of turbine. In the modern Francis turbine, the water enters the runner of the turbine in the radial direction at outlet and leaves in the axial direction at the inlet of the runner. Thus the modern Francis Turbine is a mixed flow type turbine.





The velocity triangle at inlet and outlet of the Francis turbine are drawn in the same way as in case of inward flow reaction turbine. As in case of Francis turbine, the discharge is radial at outlet, the velocity of whirl at outlet (*i.e.*, V_{w_2}) will be zero. Hence the work done by water on the runner per second will be

$$= \rho Q[V_{w_1} u_1]$$

And work done per second per unit weight of water striking/s $= \frac{1}{g}[V_{w_1} u_1]$

Hydraulic efficiency will be given by, $\eta_h = \frac{V_{w_1} u_1}{gH}$.

1. The ratio of width of the wheel to its diameter is given as $n = \frac{B_1}{D_1}$. The value of n varies from 0.10 to .40.

2. The flow ratio is given as, Flow ratio $= \frac{V_{f_1}}{\sqrt{2gH}}$ and varies from 0.15 to 0.30.

3. The speed ratio $= \frac{u_1}{\sqrt{2gH}}$ varies from 0.6 to 0.9.

Problem 18.24 *The following data is given for a Francis Turbine. Net head H = 60 m ; Speed N = 700 r.p.m.; shaft power = 294.3 kW ; η_o = 84% ; η_h = 93%; flow ratio = 0.20 ; breadth ratio n = 0.1; Outer diameter of the runner = 2 × inner diameter of runner. The thickness of vanes occupy 5% of circumferential area of the runner, velocity of flow is constant at inlet and outlet and discharge is radial at outlet. Determine :*

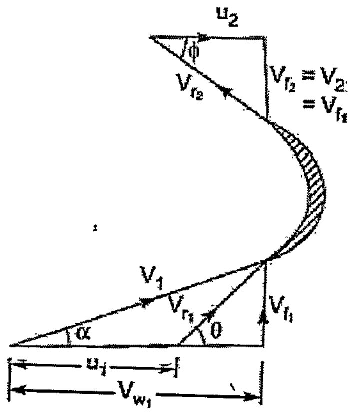
(i) Guide blade angle,

(ii) Runner vane angles at inlet and outlet,

(iii) Diameters of runner at inlet and outlet, and

(iv) Width of wheel at inlet.

Solution. Given :



Net head, $H = 60$ m

Speed, $N = 700$ r.p.m.

Shaft power $= 294.3$ kW

Overall efficiency, $\eta_o = 84\% = 0.84$

Hydraulic efficiency, $\eta_h = 93\% = 0.93$

Flow ratio, $\frac{V_{f_1}}{\sqrt{2gH}} = 0.20$

∴ $V_{f_1} = 0.20 \times \sqrt{2gH} = 6.862$ m/s

Breadth ratio, $\frac{B_1}{D_1} = 0.1$

Outer diameter, $D_1 = 2 \times$ Inner diameter $= 2 \times D_2$

Velocity of flow, $V_{f_1} = V_{f_2} = 6.862$ m/s.

Thickness of vanes = 5% of circumferential area of runner

∴ Actual area of flow $= 0.95\ \pi D_1 \times B_1$

Discharge at outlet = Radial

∴ $V_{w_2} = 0$ and $V_{f_2} = V_2$

Using relation, $\eta_o = \frac{\text{S.P.}}{\text{W.P.}}$

$$0.84 = \frac{294.3}{\text{W.P.}}$$

∴ $$\text{W.P.} = \frac{294.3}{0.84} = 350.357 \text{ kW.}$$

But $$\text{W.P.} = \frac{WH}{1000} = \frac{\rho \times g \times Q \times H}{1000} = \frac{1000 \times 9.81 \times Q \times 60}{1000} = 350.357$$

∴ $$Q = \frac{350.357 \times 1000}{60 \times 1000 \times 9.81} = 0.5952 \text{ m}^3\text{/s.}$$

Using equation (18.21), Q = Actual area of flow × Velocity of flow

$= 0.95\ \pi D_1 \times B_1 \times V_{f_1}$

$= 0.95 \times \pi \times D_1 \times 0.1 D_1 \times V_{f_1}$ $\quad (\because B_1 = 0.1\ D_1)$

or $$0.5952 = 0.95 \times \pi \times D_1 \times 0.1 \times D_1 \times 6.862 = 2.048\ D_1^2$$

$$\therefore \quad D_1 = \sqrt{\frac{0.5952}{2.048}} = 0.54 \text{ m}$$

But $$\frac{B_1}{D_1} = 0.1$$

$$\therefore \quad B_1 = 0.1 \times D_1 = 0.1 \times .54 = .054 \text{ m} = 54 \text{ mm}$$

Tangential speed of the runner at inlet,

$$u_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.54 \times 700}{60} = 19.79 \text{ m/s.}$$

Using relation for hydraulic efficiency,

$$\eta_h = \frac{V_{w_1} u_1}{gH} \text{ or } 0.93 = \frac{V_{w_1} \times 19.79}{9.81 \times 60}$$

$$\therefore \quad V_{w_1} = \frac{0.93 \times 9.81 \times 60}{19.79} = 27.66 \text{ m/s.}$$

(i) Guide blade angle (α)

From inlet velocity triangle, $\tan \alpha = \frac{V_{f_1}}{V_{w_1}} = \frac{6.862}{27.66} = 0.248$

$$\therefore \quad \alpha = \tan^{-1} 0.248 = 13.928° \text{ or } \mathbf{13° \ 55.7'. \ Ans.}$$

(ii) Runner vane angles at inlet and outlet $(\theta$ *and* $\phi)$

$$\tan \theta = \frac{V_{f_1}}{V_{w_1} - u_1} = \frac{6.862}{27.66 - 19.79} = 0.872$$

$$\therefore \quad \theta = \tan^{-1} 0.872 = 41.09° \text{ or } \mathbf{41° \ 5.4'. \ Ans.}$$

From outlet velocity triangle, $\tan \phi = \frac{V_{f_2}}{u_2} = \frac{V_{f_1}}{u_2} = \frac{6.862}{u_2}$ ...(*i*)

But $$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times D_1}{2} \times \frac{N}{60} \qquad \left(\because D_2 = \frac{D_1}{2} \text{ given}\right)$$

$$= \pi \times \frac{.54}{2} \times \frac{700}{60} = 9.896 \text{ m/s.}$$

Substituting the value of u_2 in equation (*i*),

$$\tan \phi = \frac{6.862}{9.896} = 0.6934$$

$$\therefore \quad \phi = \tan^{-1} .6934° = 34.74 \text{ or } \mathbf{34° \ 44.4'. \ Ans.}$$

(iii) Diameters of runner at inlet and outlet

$D_1 = 0.54$ m, $D_2 =$ **0.27 m. Ans.**

(iv) Width of wheel at inlet $B_1 =$ **54 mm. Ans.**

8. AXIAL FLOW REACTION TURBINE (KAPLAN):

If the water flows parallel to the axis of the rotation of the shaft, the turbine is known as axial flow turbine. And if the head at the inlet of the turbine is the sum of pressure energy and kinetic energy and during the flow of water through runner a part of pressure energy is converted into kinetic energy, the turbine is known as reaction turbine.

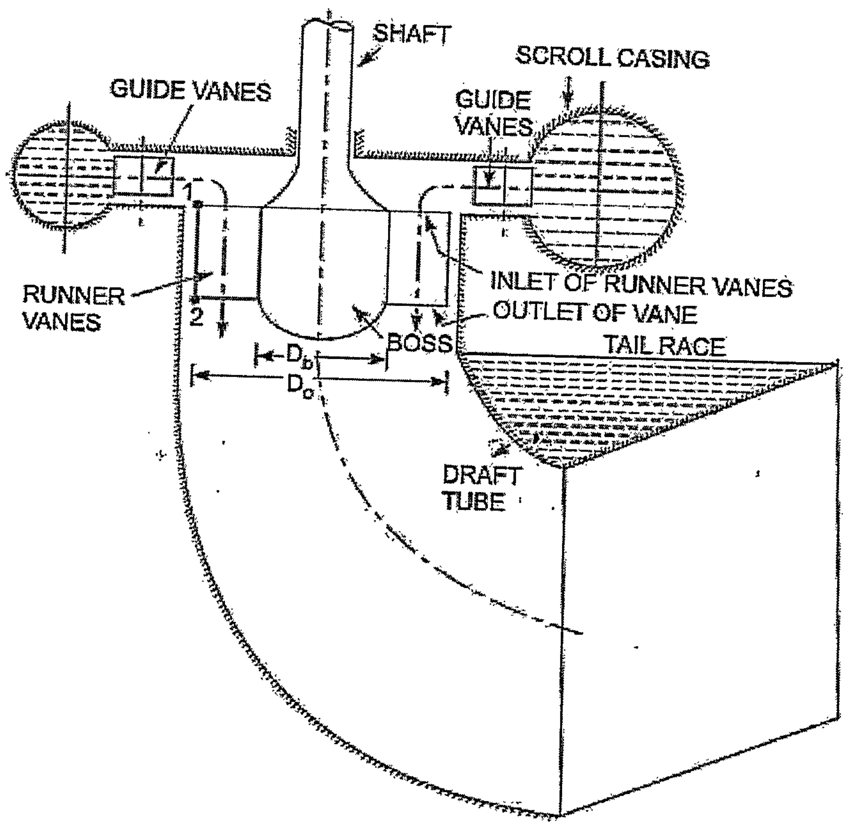
For the axial flow reaction turbine, the shaft of the turbine is vertical. The lower end of the shaft is made larger which is known as 'hub' or 'boss'. The vanes are fixed on the hub and hence hub acts as a runner for axial flow reaction turbine. The following are the important type of axial flow reaction turbines :

1. Propeller Turbine, and 2. Kaplan Turbine.

When the vanes are fixed to the hub and they are not adjust- able, the turbine is known as propeller turbine. But if the vanes on the hub are adjustable, the turbine is known as a *Kaplan*

The main parts of a Kaplan turbine are :

1. Scroll casing,
2. Guide vanes mechanism,
3. Hub with vanes or runner of the turbine, and
4. Draft tube.



The discharge through the runner is obtained as $Q = \frac{\pi}{4}\left(D_o^2 - D_b^3\right) \times V_{f_1}$

where D_o = Outer diameter of the runner, D_b = Diameter of hub, and V_{f_1} = Velocity of flow at inlet.

1. The peripheral velocity at inlet and outlet are equal

$$\therefore \quad u_1 = u_2 = \frac{\pi D_o N}{60}, \text{ where } D_o = \text{Outer dia. of runner}$$

2. Velocity of flow at inlet and outlet are equal

$$\therefore \quad V_{f_1} = V_{f_2}.$$

3. Area of flow at inlet = Area of flow at outlet

$$= \frac{\pi}{4}\left(D_o^2 - D_b^2\right).$$

Problem 18.27 *A Kaplan turbine working under a head of 20 m develops 11772 kW shaft power. The outer diameter of the runner is 3.5 m and hub diameter is 1.75 m. The guide blade angle at the extreme edge of the runner is 35°. The hydraulic and overall efficiencies of the turbines are 88% and 84% respectively. If the velocity of whirl is zero at outlet, determine :*

(i) Runner vane angles at inlet and outlet at the extreme edge of the runner, and

(ii) Speed of the turbine.

Solution. Given :

Head, $H = 20$ m

Shaft power, S.P. = 11772 kW

Outer dia. of runner, $D_o = 3.5$ m

Hub diameter, $D_b = 1.75$ m

Guide blade angle, $\alpha = 35°$

Hydraulic efficiency, $\eta_h = 88\%$

Overall efficiency, $\eta_o = 84\%$

Velocity of whirl at outlet = 0.

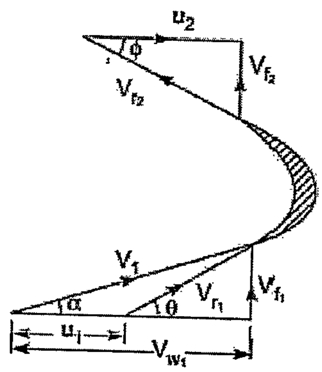


Fig. 18.27

Using the relation, $\eta_o = \dfrac{\text{S.P.}}{\text{W.P.}}$

where $\text{W.P.} = \dfrac{\text{W.P.}}{1000} = \dfrac{\rho \times g \times Q \times H}{1000}$, we get

$$0.84 = \frac{11772}{\dfrac{\rho \times g \times Q \times H}{1000}}$$

$$= \frac{11772 \times 1000}{1000 \times 9.81 \times Q \times 20} \qquad (\because \rho = 1000)$$

$$\therefore \quad Q = \frac{11772 \times 1000}{0.84 \times 1000 \times 9.81 \times 20} = 71.428 \text{ m}^3/\text{s}.$$

Using equation $Q = \dfrac{\pi}{4}\left(D_o^2 - D_b^2\right) \times V_{f_1}$

or $71.428 = \dfrac{\pi}{4}(3.5^2 - 1.75^2) \times V_{f_1} = \dfrac{\pi}{4}(12.25 - 3.0625)\, V_{f_1} = 7.216\, V_{f_1}$

$$\therefore \quad V_{f_1} = \frac{71.428}{7.216} = 9.9 \text{ m/s}.$$

From inlet velocity triangle, $\tan\alpha = \dfrac{V_{f_2}}{V_{w_1}}$

∴ $$V_{w_1} = \frac{V_{f_1}}{\tan\alpha} = \frac{9.9}{\tan 35^\circ} = \frac{9.9}{.7} = 14.14 \text{ m/s}$$

Using the relation for hydraulic efficiency,

$$\eta_h = \frac{V_{w_1} u_1}{gH} \qquad (\because V_{w_2} = 0)$$

$$0.88 = \frac{14.14 \times u_1}{9.81 \times 20}$$

∴ $$u_1 = \frac{0.88 \times 9.81 \times 20}{14.14} = 12.21 \text{ m/s.}$$

(*i*) Runner vane angles at inlet and outlet at the extreme edge of the runner are given as :

$$\tan\theta = \frac{V_{f_1}}{V_{w_1} - u_1} = \frac{9.9}{(14.14 - 12.21)} = 5.13$$

∴ $$\theta = \tan^{-1} 5.13 = \mathbf{78.97^\circ \text{ or } 78^\circ 58'}. \textbf{ Ans.}$$

For Kaplan turbine, $u_1 = u_2 = 12.21$ m/s and $V_{f_1} = V_{f_2} = 9.9$ m/s

∴ From outlet velocity triangle, $\tan\phi = \dfrac{V_{f_2}}{u_2} = \dfrac{9.9}{12.21} = 0.811$

∴ $$\phi = \tan^{-1} .811 = \mathbf{39.035^\circ \text{ or } 39^\circ 2'}. \textbf{ Ans.}$$

(*ii*) Speed of turbine is given by $u_1 = u_2 = \dfrac{\pi D_o N}{60}$

$$12.21 = \frac{\pi \times 3.5 \times N}{60}$$

∴ $$N = \frac{60 \times 12.21}{\pi \times 3.50} = \mathbf{66.63 \text{ r.p.m.}} \textbf{ Ans.}$$

9. DRAFT-TUBE :

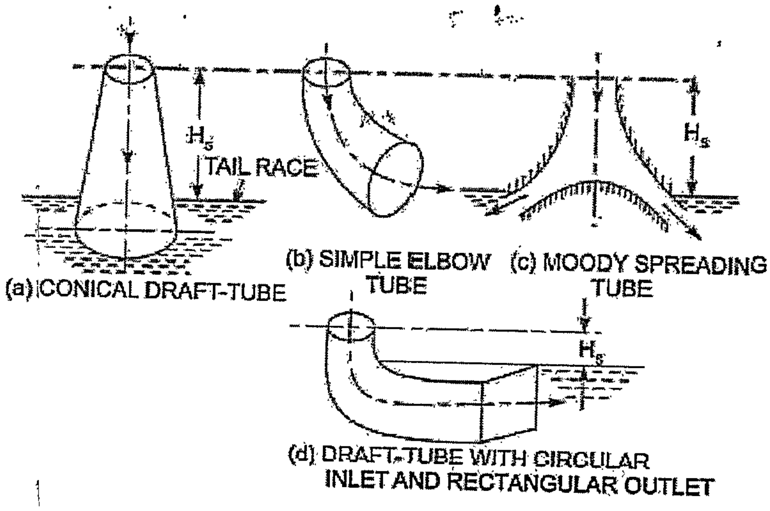
The draft-tube is a pipe of gradually increasing area which connects the outlet of the runner to the tail race. It is used for discharging water from the exit of the turbine to the tail race. This pipe of gradually increasing area is called a draft-tube. One end of the draft-tube is connected to the outlet of the runnner while the other end is sub-merged below the level of water in the tail race. The draft-tube, in addition to serve a passage for water discharge, has the following two purposes also :

1. It permits a negative head to be established at the outlet of the runner and thereby increase the net head on the turbine. The turbine may be placed above the tail race without any loss of net head and hence turbine may be inspected properly.

2. It converts a large proportion of the kinetic energy ($V_2^2/2g$) rejected at the outlet of the turbine into useful pressure energy. Without the draft tube, the kinetic energy rejected at the outlet of the turbine will go waste to the tail race.

Types of Draft-Tubes. The following are the important types of draft-tubes which are commonly used :

1. Conical draft-tubes,
2. Simple elbow tubes,
3. Moody spreading tubes, and
4. Elbow draft-tubes with circular inlet and rectangular outlet.



Draft-Tube Theory. Consider a capital draft-tube as shown in Fig.

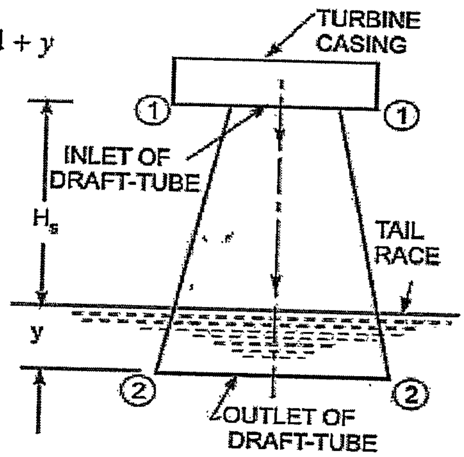
Let H_s = Vertical height of draft-tube above the tail race,

y = Distance of bottom of draft-tube from tail race.

Applying Bernoulli's equation to inlet (section 1-1) and outlet (section 2-2) of the draft-tube and taking section 2-2 as the datum line,we get

$$\frac{p_1}{\rho g}+\frac{V_1^2}{2g}+(H_s+y)=\frac{p_2}{\rho g}+\frac{V_2^2}{2g}+0+h_f \qquad \text{...}(i)$$

where h_f = loss of energy between sections 1-1 and 2-2.



But $\frac{p_2}{\rho g}$ = Atmospheric pressure head + y

$$=\frac{p_a}{\rho g}+y.$$

Substituting this value of $\frac{p_2}{\rho g}$ in equation (i), we get

$$\frac{p_1}{\rho g}+\frac{V_1^2}{2g}+(H_s+y)=\frac{p_a}{\rho g}+y+\frac{V_2^2}{2g}+h_f$$

or

$$\frac{p_1}{\rho g}+\frac{V_1^2}{2g}+H_s=\frac{p_a}{\rho g}+\frac{V_2^2}{2g}+h_f$$

$$\therefore \quad \frac{p_1}{\rho g}=\frac{p_a}{\rho g}+\frac{V_2^2}{2g}+h_f-\frac{V_1^2}{2g}-H_s$$

$$=\frac{p_a}{\rho g}-H_s-\left(\frac{V_1^2}{2g}-\frac{V_2^2}{2g}-h_f\right)$$

Efficiency of Draft-Tube. The efficiency of a draft-tube is defined as the ratio of actual conversion of kinetic head into pressure head in the draft-tube to the kinetic head at the inlet of the draft-tube. Mathematically, it is written as

$$\eta_d = \frac{\text{Actual conversion of kinetic head into pressure head}}{\text{Kinetic head at the inlet of draft-tube}}$$

Let V_1 = Velocity of water at inlet of draft-tube,

V_2 = Velocity of water at outlet of draft-tube, and

h_f = Loss of head in the draft-tube.

Theoretical conversion of kinetic head into pressure head in draft-tube = $\left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right)$.

Actual conversion of kinetic head into pressure head = $\left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right) - h_f$

$$\therefore \quad \eta_d = \frac{\left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right) - h_f}{\left(\frac{V_1^2}{2g}\right)}$$

IMPACT OF JET ON VANES

FLUID JET:

A fluid jet is a stream of fluid issuing from a nozzle with high velocity and hence a high kinetic energy.

IMPULSE MOMENTUM PRINCIPLE (Newton's Second Law):

"The sum of forces on the body equals the rate of change of momentum of the body in the direction of the force. In equation from (F and V are in the same direction).

$$\Sigma F\,dt = d\,(mV) \quad \text{(or)} \quad \Sigma F = \rho Q\,(\Delta V)$$

Force exerted by the jet on the plate:

F = rate of change of momentum

= [mass of jet /sec] [velocity of jet before striking the plate – velocity of jet after striking the plate]

= $\rho Q\,(\Delta V)$

- **Kinetic Energy / Sec = K.E. = $m^{\cdot}\, v^2/2 = \rho\, a\, v^3/2$**
- **Work Done / Sec = Power = $F_x\;u$**
- **Efficiency = η = W/ K.E**

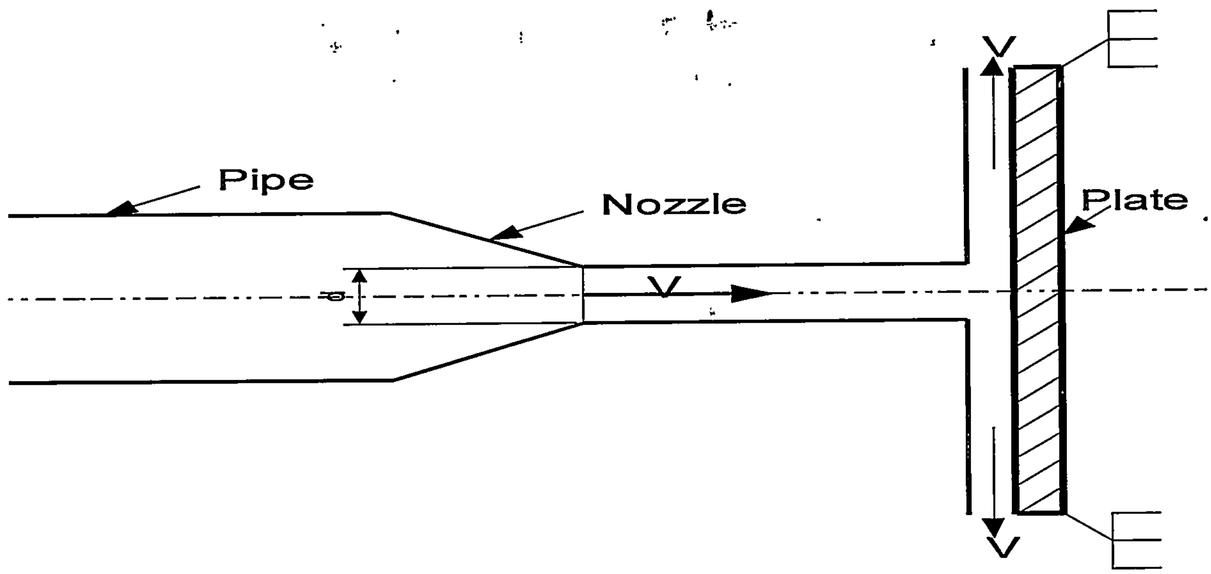
NOTE: The plate is stationary; therefore, the work done on the plate is zero.

CASES:

1. **When the flat plate/vane is held normal to the jet:**
   (a) Stationary vane
   (b) Moving vane
   (c) Series moving vanes
2. **When the flat plate is held inclined to the jet:**
   (a) Stationary vane
   (b) Moving vane
   (c) Series moving vanes
3. **When the plate is curved :jet strikes at the center:**
   (a) Stationary vane
   (b) Moving vane
   (c) Series moving vanes
4. **When the plate is curved :Jet strikes the plate at one end tangentially:**
   (a) Stationary vane
   (b) Moving vane
   (c) Series of moving vanes

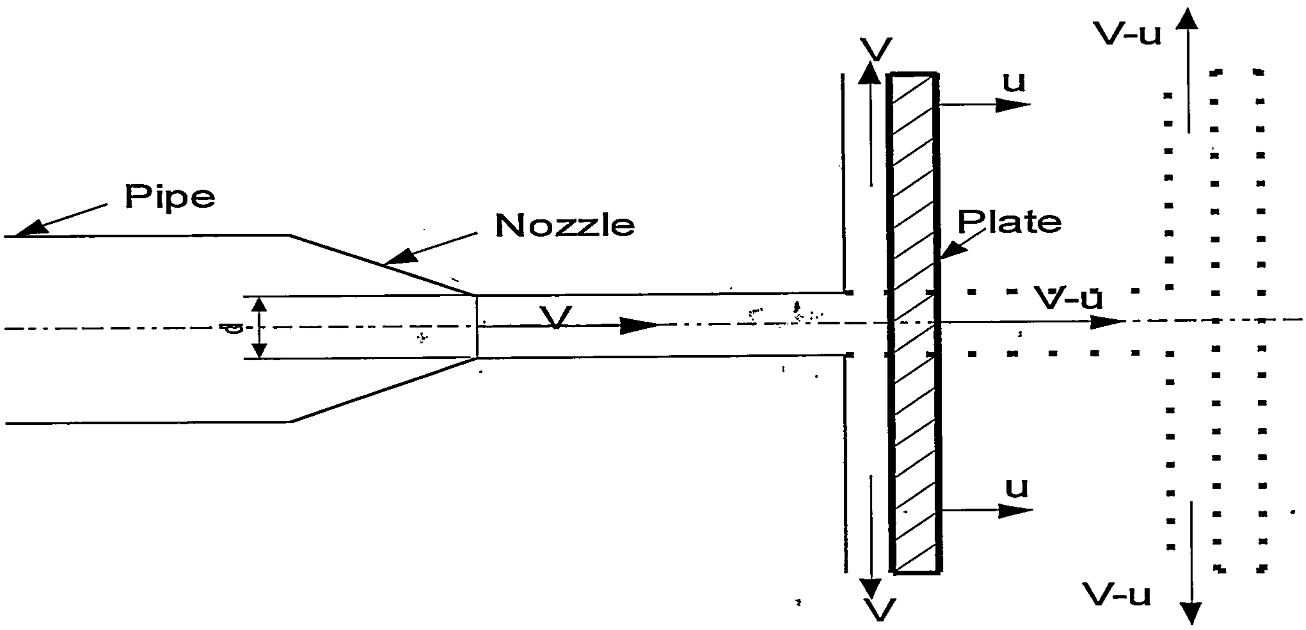
1. When the flat plate/vane is held normal to the jet:

(a) Stationary vane:



1. **Force exerted by jet on vane in x- direction= $F_x = \rho\, a\, v\, [\, v - 0] = \rho\, a\, v^2$**
2. **Plate Velocity = u = 0**
3. **Efficiency = η = W /** Error! Bookmark not defined.**K.E = 0**

(b) Moving vane:



1. **$F_x = \rho\, a\, (v\text{-}u)\, [(v\text{-}u) - 0] = \rho\, a\, (v\text{-}u)^2$**
2. **$\eta = W/\, K.E = 2\,(v\text{-}u)^2\, u\, /\, v^3$**
3. **$d\eta/du = 0 \Rightarrow$ at $v = 3u$; $\eta_{max} = 8/27$**

NARASARAOPET ENGINEERING COLLEGE (AUTONOMOUS)

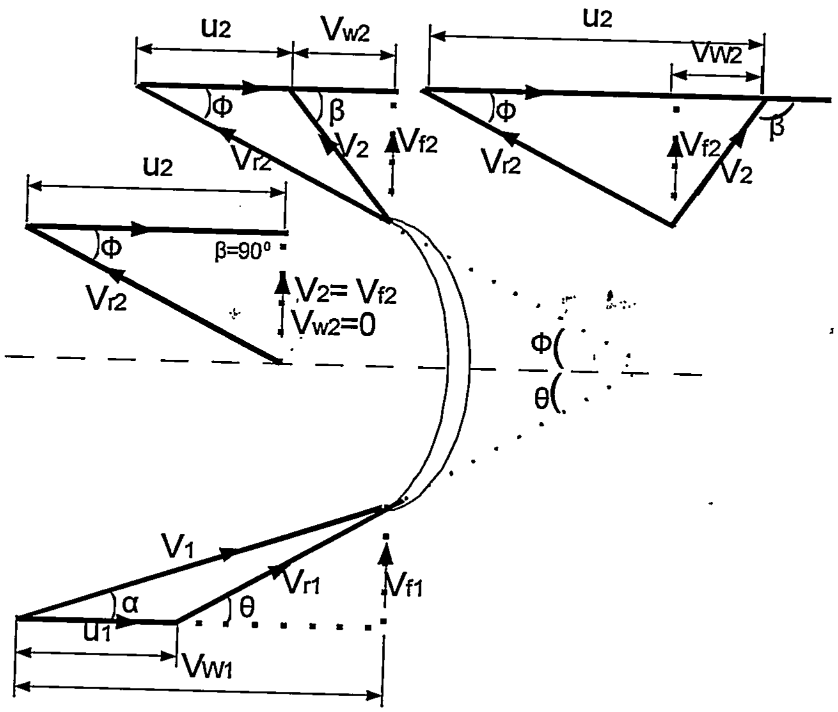
IMPACT OF JET ON VANES

- **FLUID JET:** A fluid jet is a stream of fluid issuing from a nozzle with high velocity and hence a high kinetic energy.
- **Force exerted by the jet on the plate=** F = rate of change of momentum = **ρQ (ΔV)**
- **Kinetic Energy / Sec = K.E. =** $m^{\cdot} v^2/2 = \rho a v^3 / 2$
- **Work Done / Sec = Power =** $F_x \cdot u$

NOTE: The plate is stationary; therefore, the work done on the plate is zero.

S. No:	CASES		Force exerted by the jet on the plate = F_x	Efficiency = η = W/ K.E	Maximum Efficiency = η_{max}
1	When the flat plate is held normal to the jet (Vertical Plate)	(a) Stationary vane	$\rho a v^2$	0	0
		(b) Moving vane	$\rho a (v-u)^2$	$2 (v-u)^2 u / v^3$	8/27 (29.63%) at v = 3u
		(c) Series moving vanes	$\rho a v (v-u)$	$2 (v-u) u / v^2$	½ (50%) at v = 2u
2	When the flat plate is held inclined to the jet	(a) Stationary vane	$\rho a v^2 \sin^2\theta$	0	0
		(b) Moving vane	$\rho a (v-u)^2 \sin^2\theta$	$2 (v-u)^2 u \sin^2\theta / v^3$	8/27 $\sin^2\theta$ at v = 3u
		(c) Series moving vanes	$\rho a v (v-u) \sin^2\theta$	$2 (v-u) u \sin^2\theta / v^2$	½ $\sin^2\theta$ at v = 2u
3	When the plate is curved and Jet strikes at the center	(a) Stationary vane	$\rho a v^2 (1+\cos\theta)$	0	0
		(b) Moving vane	$\rho a (v-u)^2 (1+\cos\theta)$	$2 (v-u)^2 u (1+\cos\theta) / v^3$	8/27 (1+cosθ) at v = 3u
		(c) Series moving vanes	$\rho a v (v-u) (1+\cos\theta)$	$2 (v-u) u (1+\cos\theta) / v^2$	½ (1+cosθ) at v = 2u
4	When the plate is curved and Jet strikes the plate at one end tangentially:	(a) Stationary vane	$\rho a v^2 (\cos\theta + \cos\Phi)$	0	0
		(b) Moving vane	$\rho a v_{r1} [v_{w1} +/- v_{w2}]$	$2 [v_{w1} +/- v_{w2}] u / v_{r1}^2$	----------
		(c) Series moving vanes **(Radial Vanes)**	$\rho a v_1 [v_{w1} R_1 +/- v_{w2} R_2]$.	$2 [v_{w1} u_1 +/- v_{w2} u_2] / v_1^2$	----------

(b) **Moving vane:**



1. $F_x = \rho\ a\ v_{r1}\ [v_{w1} +/- v_{w2}]$
2. $K.E = m v_{r1}^2/2,\ m = \rho\ a\ v_{r1}$
3. $\eta = W/\ K.E = 2\ [v_{w1} +/- v_{w2}]u\ /\ v_{r1}^2$

(C) **Series moving vanes:**

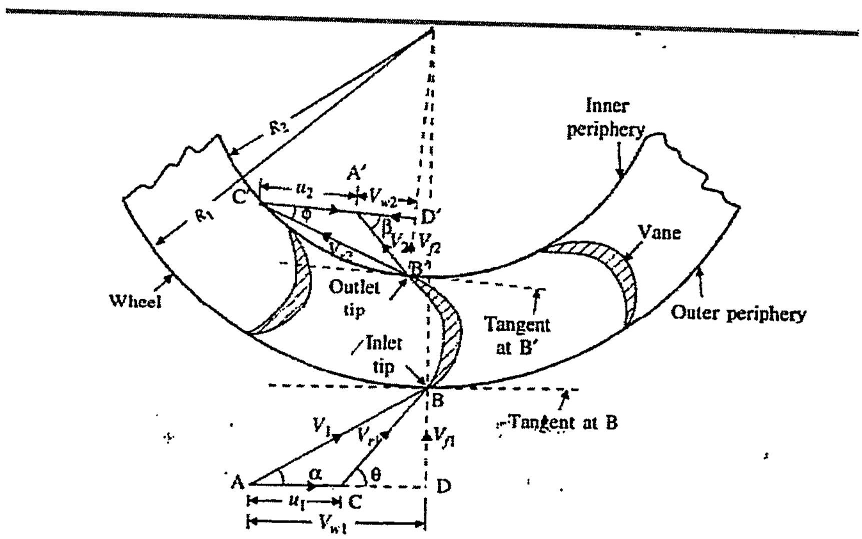


Fig. 18·12. Velocity diagrams for an inward flow reaction turbine.

1. Torque Exerted by water on the wheel = $T = \rho\ a\ v_1\ [v_{w1} R_1 +/- v_{w2} R_2]$
2. Work Done/sec = $W = T\omega = \rho\ a\ v_1\ [v_{w1}\ u_1 +/- v_{w2}\ u_2]$
3. $u_1 = \omega R_1,\ u_2 = \omega R_2;$
4. $K.E = m v_1^2/2\ ,\ m = \ \rho\ a\ v_1$
5. $\eta = W/\ K.E = 2\ [v_{w1}\ u_1 +/- v_{w2}\ u_2]\ /\ v_1^2$

Important Problems

1. **CASE- 1 (a) : When the Stationary flat plate/vane is held normal to the jet:**

Problem 17.2 *Water is flowing through a pipe at the end of which a nozzle is fitted. The diameter of the nozzle is 100 mm and the head of water at the centre nozzle is 100 m. Find the force exerted by the jet of water on a fixed vertical plate. The co-efficient of velocity is given as 0.95.*

Solution. Given :

Diameter of nozzle, $d = 100$ mm $= 0.1$ m

Head of water, $H = 100$ m

Co-efficient of velocity, $C_v = 0.95$

Area of nozzle, $a = \frac{\pi}{4}(.1)^2 = .007854 \text{ m}^2$

Theoretical velocity of jet of water is given as

$$V_{th} = \sqrt{2gH} = \sqrt{2 \times 9.81 \times 100} = 44.294 \text{ m/s}$$

But $$C_v = \frac{\text{Actual velocity}}{\text{Theoretical velocity}}$$

∴ Actual velocity of jet of water, $V = C_v \times V_{th} = 0.95 \times 44.294 = 42.08$ m/s.

Force on a fixed vertical plate is given by equation (17.1) as

$$F = \rho a V^2 = 1000 \times .007854 \times 42.08^2 \quad (\because \text{ In S.I. units } \rho \text{ for water} = 1000 \text{ kg/m}^3)$$

$= 13907.2$ N $=$ **13.9 kN. Ans.**

2. **CASE-3 (a): Stationary Curved Plate and Jet Strikes at center.**

Problem 17.5 *A jet of water of diameter 50 mm moving with a velocity of 40 m/s, strikes a curved fixed symmetrical plate at the centre. Find the force exerted by the jet of water in the direction of the jet, if the jet is deflected through an angle of 120° at the outlet of the curved plate.*

Solution. Given :

Diameter of the jet, $d = 50$ mm $= 0.05$ m

∴ Area, $a = \frac{\pi}{4}(.05)^2 = 0.001963 \text{ m}^2$

Velocity of jet, $V = 40$ m/s

Angle of deflection $= 120°$

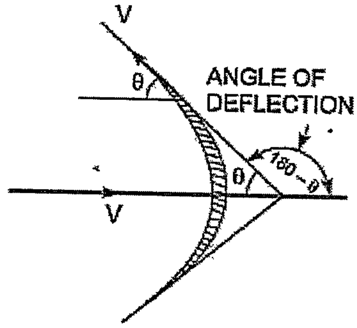


Fig. 17.5

From equation [17.6 (*A*)], the angle of deflection $= 180° - \theta$

∴ $180° - \theta = 120°$ or $\theta = 180° - 120° = 60°$

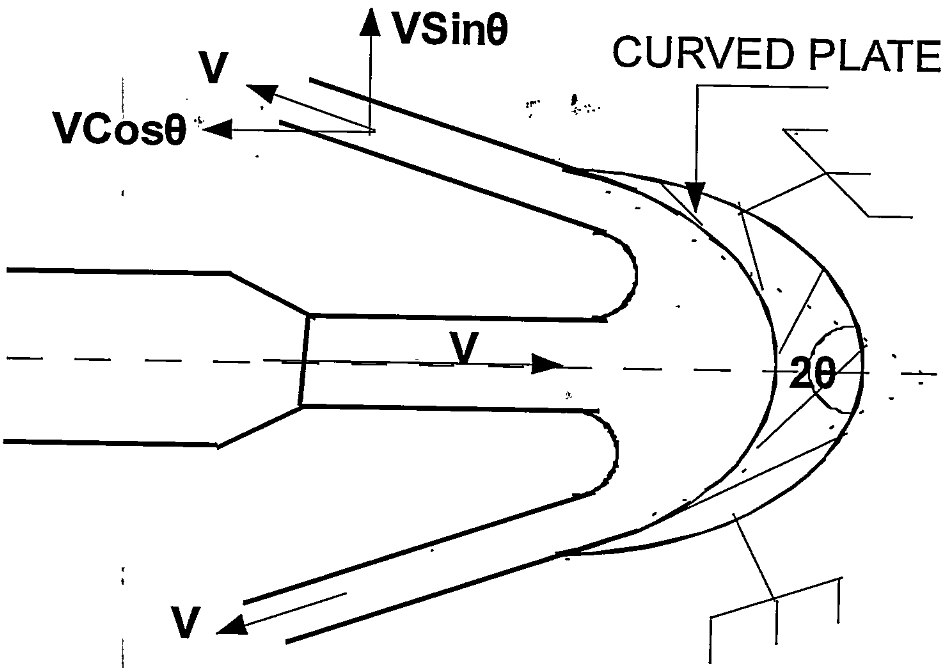
Force exerted by the jet on the curved plate in the direction of the jet is given by equation (17.5) as

$$F_x = \rho a V^2 [1 + \cos\theta]$$

$= 1000 \times .001963 \times 40^2 \times [1 + \cos 60°] =$ **4711.15 N. Ans.**

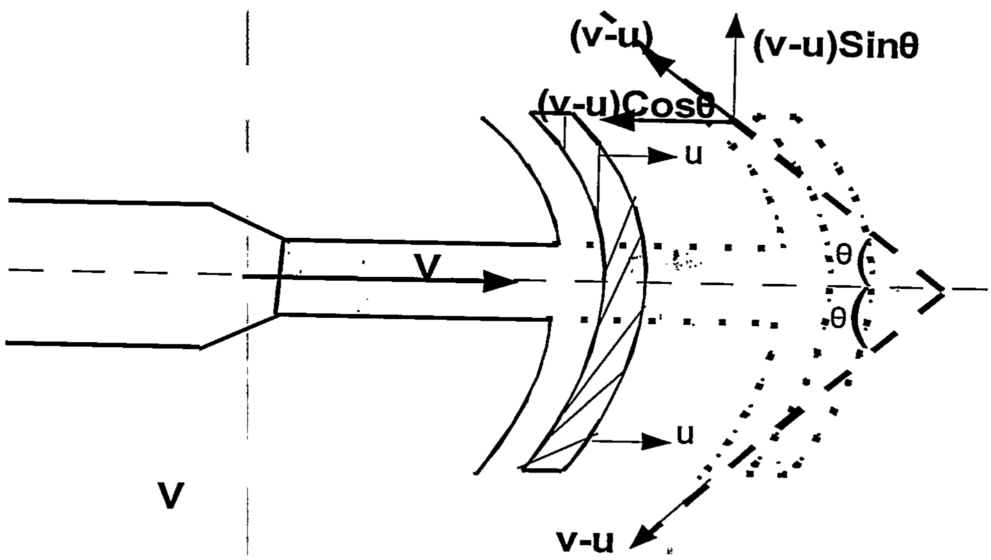
3. **When the plate is curved jet strikes at the center:**

(a) **Stationary vane:**



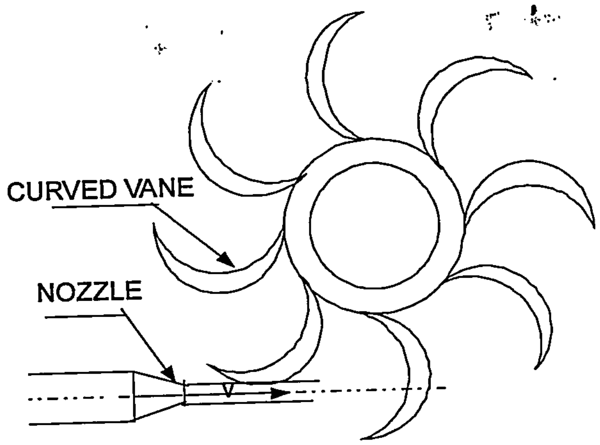
1. $F_x = \rho\ a\ v[v - (-v\cos\theta)] = \rho\ a\ v^2 (1+\cos\theta)$
2. $F_y = \rho\ a\ v[0 - (v\sin\theta)] = -\rho\ a\ v^2 \sin\theta$
3. $u = 0$, $\eta = W/K.E = 0$

(b) **Moving vane:**



1. $F_x = \rho\ a\ (v-u)\ [(v-u) - (-(v-u)\cos\theta)] = \rho\ a\ (v-u)^2 (1+\cos\theta)$,
2. $F_y = \rho\ a\ (v-u)\ [0 - ((v-u)\sin\theta)] = -\rho\ a\ (v-u)^2 \sin\theta$
3. $\eta = W/K.E = 2\ (v-u)^2\ (1+\cos\theta)u / v^3$
4. $d\eta/du = 0 \Rightarrow$ at $v = 3u$; $\eta_{max} = 8/27\ (1+\cos\theta)$

(c) Series moving vanes:



1 $F_x = \rho\ a\ v\ [(v-u) - (-(v-u)\cos\theta)] = \rho\ a\ v\ (v-u)\ (1+\cos\theta)$

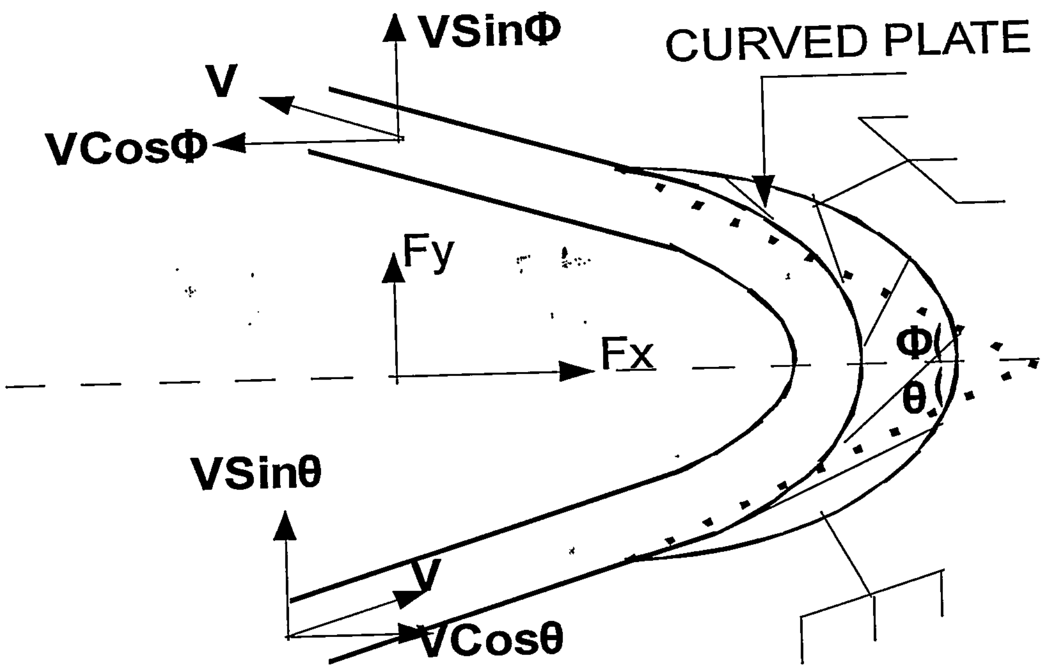
2 $F_y = \rho\ a\ v\ [0 - ((v-u)\sin\theta)] = -\ \rho\ a\ v\ (v-u)\sin\theta$

3 $\eta = W/\ K.E = 2\ v\ (v-u)\ (1+\cos\theta)\ u\ /\ v^3$

4 $d\eta/du = 0 \Rightarrow$ at $v=2u$; $\eta_{max} = ½\ (1+\cos\theta)$

4. **When the plate is curved : Jet strikes the plate at one end tangentially:**

(a) **Stationary vane:**



1 $F_x = \rho\ a\ v[v\cos\theta - (-v\cos\Phi)] = \rho\ a\ v^2 (\cos\theta + \cos\Phi)$

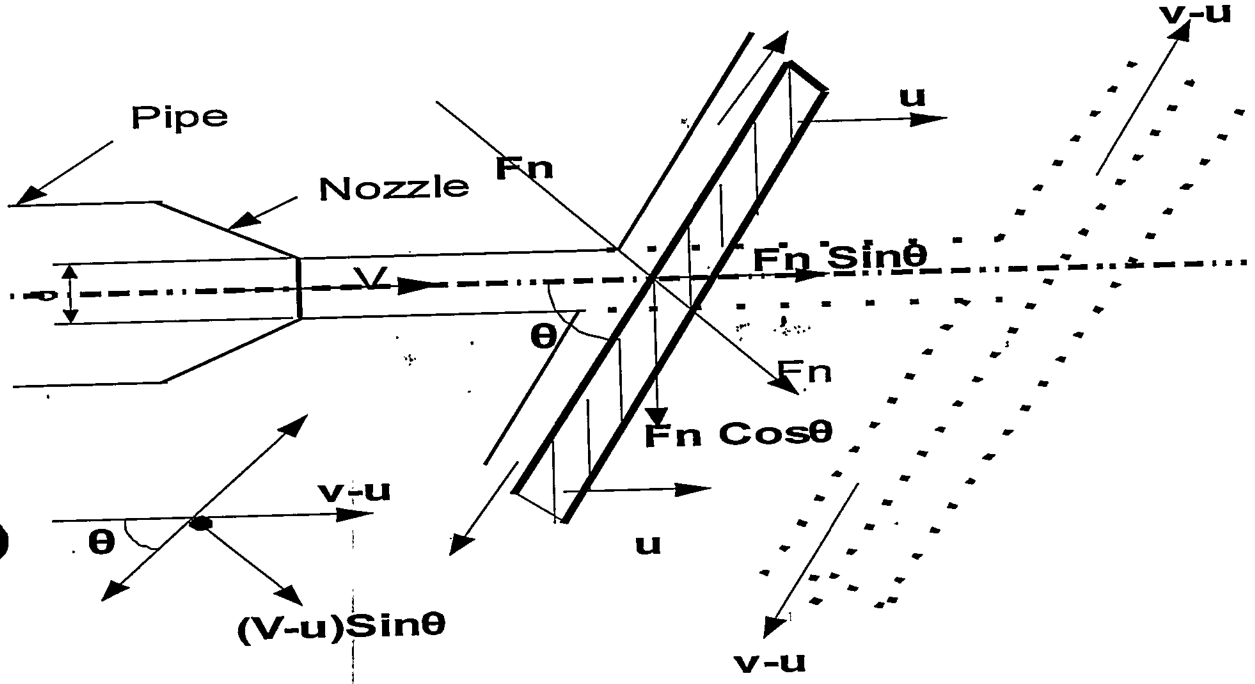
2 $F_y = \rho\ a\ v[v\sin\theta - v\sin\Phi\ ] = \rho\ a\ v^2\ (\sin\theta - \sin\Phi)$

3 plate is symmetrical........$\theta = \Phi$

4 $F_x = 2\rho\ a\ v^2 \cos\theta$, $F_y = 0$

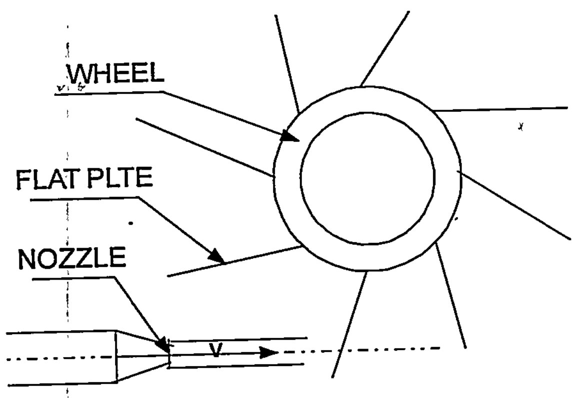
5 $u = 0$, $\eta = W/K.E = 0$

(b) **Moving vane:**



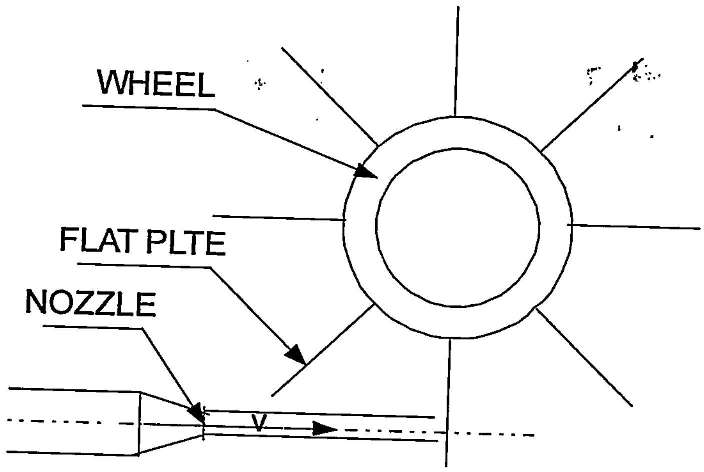
1. $F_n = \rho\ a\ (v\text{-}u)\ [(v\text{-}u)\ \sin\theta - 0] = \rho\ a\ (v\text{-}u)^2\ \sin\theta$
2. $F_x = F_n \sin\theta = \rho\ a\ (v\text{-}u)^2\ \sin^2\theta$
3. $F_y = F_n \cos\theta = \rho\ a\ (v\text{-}u)^2\ \sin\theta \cos\theta$
4. $\eta = W/\ K.E = 2\ u\ (v\text{-}u)^2\ \sin^2\theta/\ v^3$
5. $d\eta/du = 0 \Rightarrow$ at $v = 3u$; $\eta_{max} = 8/27\ \sin^2\theta$

(c) **Series moving vanes:**



1. $F_n = \rho\ a\ v\ [(v\text{-}u)\ \sin\theta - 0] = \rho\ a\ v\ (v\text{-}u)\ \sin\theta$
2. $F_x = F_n \sin\theta = \rho\ a\ v\ (v\text{-}u)\ \sin^2\theta$,
3. $F_y = F_n \cos\theta = \rho\ a\ v\ (v\text{-}u)\ \sin\theta \cos\theta$
4. $\eta = W/\ K.E = 2\ (v\text{-}u)\ u\ \sin^2\theta\ /\ v^2$
5. $d\eta/du = 0 \Rightarrow$ at $v=2u$; $\eta_{max} = ½\ \sin^2\theta$

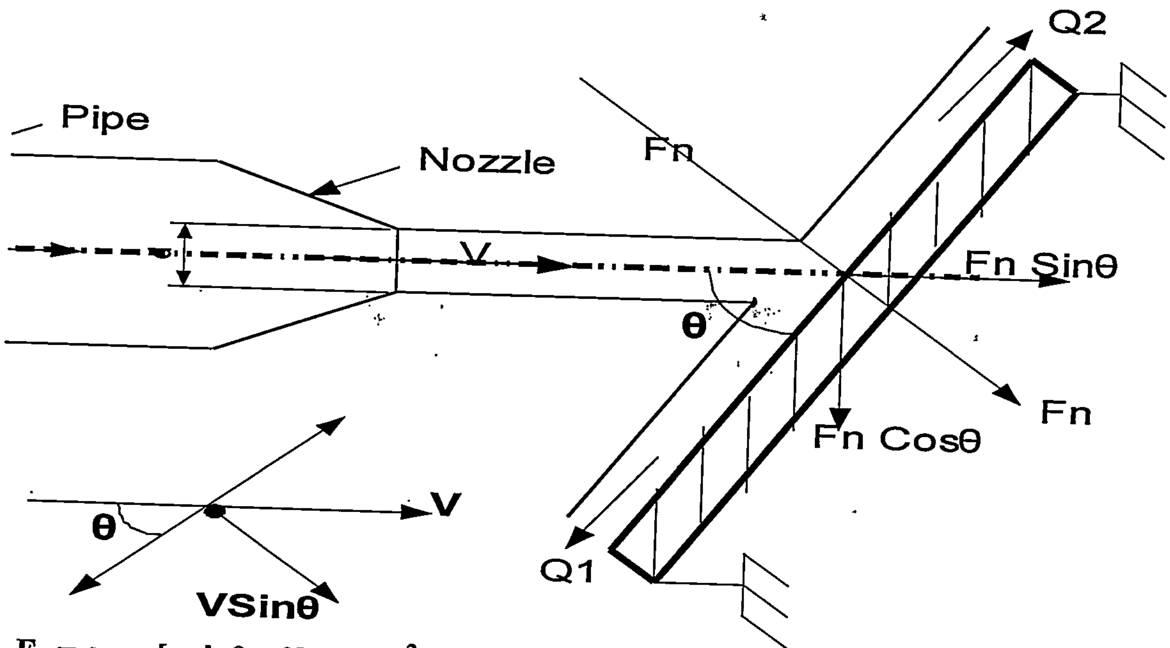
(c) **Series moving vanes:**



1. $F_x = \rho\, a\, v\, [(v-u) - 0] = \rho\, a\, v\, (v-u)$
2. $\eta = W/K.E = 2\,(v-u)\,u / v^2$
3. $d\eta/du = 0 \Rightarrow$ at $v=2u$; $\eta_{max} = ½ = 50\%$

2. **When the flat plate is held inclined to the jet:**

(a) **Stationary vane:**



1. $F_n = \rho\, a\, v\, [v \sin\theta - 0] = \rho\, a\, v^2 \sin\theta$
2. $F_x = F_n \sin\theta = \rho\, a\, v^2 \sin^2\theta$
3. $F_y = F_n \cos\theta = \rho\, a\, v^2 \sin\theta \cos\theta$
4. Ratio of discharges = $Q1/Q2 = (1+\cos\theta)/(1-\cos\theta)$
5. $u = 0$, $\eta = W/K.E = 0$

3. CASE-3 (b): Moving Curved Plate and Jet Strikes at center.

Problem 17.14 *A jet of water of diameter 7.5 cm strikes a curved plate at its centre with a velocity of 20 m/s. The curved plate is moving with a velocity of 8 m/s in the direction of the jet. The jet is deflected through an angle of 165°. Assuming the plate smooth find :*

(i) Force exerted on the plate in the direction of jet, (ii) Power of the jet, and (iii) Efficiency of the jet.

Solution. Given :

Diameter of the jet, $d = 7.5 \text{ cm} = 0.075 \text{ m}$

$\therefore$ Area, $a = \dfrac{\pi}{4} (.075)^2 = 0.004417$

Velocity of the jet, $V = 20$ m/s

Velocity of the plate, $u = 8$ m/s

Angle of deflection of the jet, $= 165°$

$\therefore$ Angle made by the relative velocity at the outlet of the plate,

$$\theta = 180° - 165° = 15°.$$

(*i*) Force exerted by the jet on the plate in the direction of the jet is given by equation (17.17) as

$$= F_x = \rho a(V - u)^2 (1 + \cos \theta)$$
$$= 1000 \times .004417 \times (20 - 8)^2 [1 + \cos 15°] = \textbf{1250.38 N. Ans.}$$

(*ii*) Work done by the jet on the plate per second

$$= F_x \times u = 1250.38 \times 8 = 10003.04 \text{ N m/s}$$

$\therefore$ Power of the jet $= \dfrac{10003.04}{1000} = \textbf{10 kW. Ans.}$

(*iii*) Efficiency of the jet $= \dfrac{\text{Output}}{\text{Input}} = \dfrac{\text{Work done by jet/sec}}{\text{Kinetic energy of jet/sec}}$

$$= \frac{1250.38 \times 8}{\frac{1}{2}(\rho a V) \times V^2} = \frac{1250.38 \times 8}{\frac{1}{2} \times 1000 \times .004417 \times V^3}$$

$$= \frac{1250.38 \times 8}{\frac{1}{2} \times 1000 \times .004417 \times 20^3} = 0.564 = \textbf{56.4\%. Ans}$$

4. Case IV (a) : Stationary Curved Vane… Jet Strikes Tangentially at one end:

Problem 17.15 *A jet of water from a nozzle is deflected through 60° from its original direction by a curved plate which it enters tangentially without shock with a velocity of 30 m/s and leaves with a mean velocity of 25 m/s. If the discharge from the nozzle is 0.8 kg/s, calculate the magnitude and direction of the resultant force on the vane, if the vane is stationary.*

Solution. Given :

Velocity at inlet, $V_1 = 30$ m/s

Velocity at outlet, $V_2 = 25$ m/s

Mass per second $= 0.8$ kg/s

Force in the direction of jet,

$$F_x = \text{Mass per second} \times (V_{1x} - V_{2x})$$

where V_{1x} = Initial velocity in the direction of x

$= 30$ m/s

V_{2x} = Final velocity in the direction of x

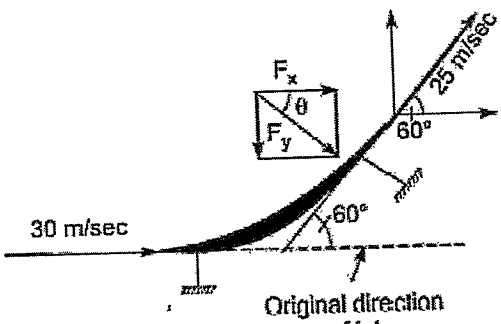


Fig. 17.13 (*d*)

$$= 25 \cos 60^\circ = 25 \times \frac{1}{2} = 12.5 \text{ m/s}$$

$$\therefore \quad F_x = 0.8[30 - 12.5] = 0.8 \times 17.5 = 14.0 \text{ N}$$

Similarly, force normal to the jet,

$$F_y = \text{Mass per second} \times (V_{1y} - V_{2y})$$
$$= 0.8\,[0 - 25 \sin 60^\circ] = -17.32 \text{ N}$$

–ve sign means the force, F_y, is acting in the vertically downward direction.

$\therefore$ Resultant force on the vane $= \sqrt{F_x^2 + F_y^2} = \sqrt{14^2 + (-17.32)^2} = $ **22.27 N. Ans.**

The angle made by the resultant with x-axis

$$\tan\theta = \frac{F_y}{F_x} = \frac{-17.32}{14.0} = -1.237$$

–ve sign means the angle θ is in the clockwise direction with x- axis as shown in Fig. 17.13 (*a*)

$$\therefore \quad \theta = \tan^{-1} 1.237 = \mathbf{51^\circ\ 2.86'}. \text{ Ans.}$$

5. CASE IV (b): Moving Curved Vane... Jet Strikes Tangentially at one end: $\beta < 90^0$

Problem 17.18 *A jet of water having a velocity of 20 m/s strikes a curved vane, which is moving with a velocity of 10 m/s. The jet makes an angle of 20° with the direction of motion of vane at inlet and leaves at an angle of 130° to the direction of motion of vane an outlet. Calculate :*

(i) Vane angles, so that the water enters and leaves the vane without shock.

(ii) Work done per second per unit weight of water striking (or work done per unit weight of water striking) the vane per second.

Solution. Given :

Velocity of jet, $V_1 = 20$ m/s

Velocity of vane, $u_1 = 10$ m/s

Angle made by jet at inlet, with direction of motion of vane,

$\alpha = 20^\circ$

Angle made by the leaving jet, with the direction of motion $= 130^\circ$

$\therefore \quad \beta = 180^\circ - 130^\circ = 50^\circ.$

In this problem, $u_1 = u_2 = 10$ m/s

$V_{r_1} = V_{r_2}$

(*i*) **Vane Angle** means angle made by the relative velocities at inlet and outlet, *i.e.*, θ and ϕ.

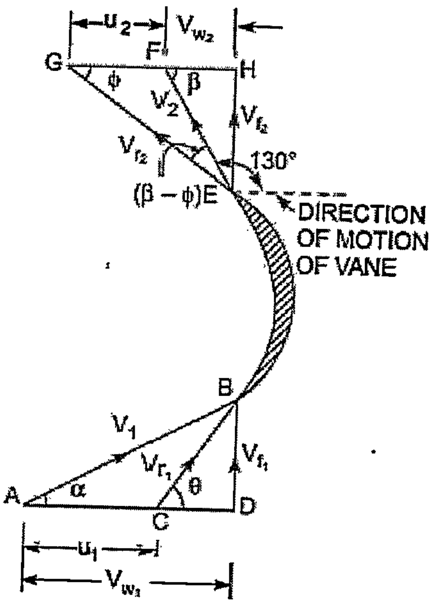


Fig. 17.16

From Fig. 17.16, in ΔABD, we have $\tan\theta = \dfrac{BD}{CD}$

$$= \frac{V_{f_1}}{AD - AC} = \frac{V_{f_1}}{V_{w_1} - u_1} \quad ...(i)$$

where $V_{f_1} = V_1 \sin\alpha = 20 \times \sin 20^\circ = 6.84$ m/s

$V_{w_1} = V_1 \cos\alpha = 20 \times \cos 20^\circ = 18.794$ m/s.

$u_1 = 10$ m/s

$$\therefore \quad \tan\theta = \frac{6.84}{18.794 - 10} = .7778 \text{ or } \theta = 37.875^\circ$$

$$\therefore \quad \theta = \mathbf{37^\circ\ 52.5'}. \text{ Ans.}$$

From, ΔABC, $\sin\theta = \frac{V_{f_1}}{V_{r_1}}$ or $V_{r_1} = \frac{V_{f_1}}{\sin\theta} = \frac{6.84}{\sin 37.875^\circ} = 11.14$

$\therefore$ $V_{r_2} = V_{r_1} = 11.14$ m/s.

From, ΔEFG, applying sine rule, we have

$$\frac{V_{r_2}}{\sin(180^\circ - \beta)} = \frac{u_2}{\sin(\beta - \phi)}$$

or $$\frac{11.14}{\sin\beta} = \frac{10}{\sin[\beta - \phi]} \quad \text{or} \quad \frac{11.14}{\sin 50^\circ} = \frac{10}{\sin[50^\circ - \phi]} \qquad (\because \beta = 50^\circ)$$

$\therefore$ $$\sin(50^\circ - \phi) = \frac{10 \times \sin 50^\circ}{11.14} = 0.6876 = \sin 43.44^\circ$$

$\therefore$ $50^\circ - \phi = 43.44^\circ$ or $\phi = 50^\circ - 43.44^\circ = 6.56^\circ$

$\therefore$ $\phi = 6^\circ\ 33.6'$. **Ans.**

(*ii*) Work done per second per unit weight of the water striking the vane per second is given by equation (17.21) as

$$= \frac{1}{g}[V_{w_1} + V_{w_2}] \times u \text{ Nm/N } (+\text{ ve sign is taken as } \beta \text{ is an acute angle})$$

where $V_{w_1} = 18.794$ m/s, $V_{w_2} = GH - GF = V_{r_2}\cos\phi - u_2 = 11.14 \times \cos 6.56^\circ - 10 = 1.067$ m/s

$u = u_1 = u_2 = 10$ m/s

$\therefore$ Work done per unit weight of water

$$= \frac{1}{9.81}[18.794 + 1.067] \times 10 \text{ Nm/N} = \mathbf{20.24\ Nm/N.\ Ans.}$$

6. CASE IV (b): Moving Curved Vane… Jet Strikes Tangentially at one end: $\beta = 90^0$

Problem 17.19 *A jet of water having a velocity of 40 m/s strikes a curved vane, which is moving with a velocity of 20 m/s. The jet makes an angle of 30° with the direction of motion of vane at inlet and leaves at an angle of 90° to the direction of motion of vane at outlet. Draw the velocity triangles at inlet and outlet and determine the vane angles at inlet and outlet so that the water enters and leaves the vane without shock.*

Solution. Given :

Velocity of jet, $V_1 = 40$ m/s

Velocity of vane, $u_1 = 20$ m/s

Angle made by jet at inlet, $\alpha = 30^\circ$

Angle made by leaving jet $= 90^\circ$

$\therefore$ $\beta = 180^\circ - 90^\circ = 90^\circ$

For this problem, we have

$u_1 = u_2 = u = 20$ m/s

Vane angles at inlet and outlet are θ and ϕ respectively.

From ΔBCD, we have

$$\tan\theta = \frac{BD}{CD} = \frac{BD}{AD - AC} = \frac{V_{f_1}}{V_{w_1} - u_1}$$

where $V_{f_1} = V_1 \sin\alpha = 40 \times \sin 30° = 20$ m/s

$V_{w_1} = V_1 \cos\alpha = 40 \times \cos 30° = 34.64$ m/s

$u_1 = 20$ m/s

$\therefore \quad \tan\theta = \frac{20}{34.64 - 20} = \frac{20}{14.64} = 1.366 = \tan 53.79°$

$\therefore \quad \theta = 53.79°$ or **53° 47.4′. Ans.**

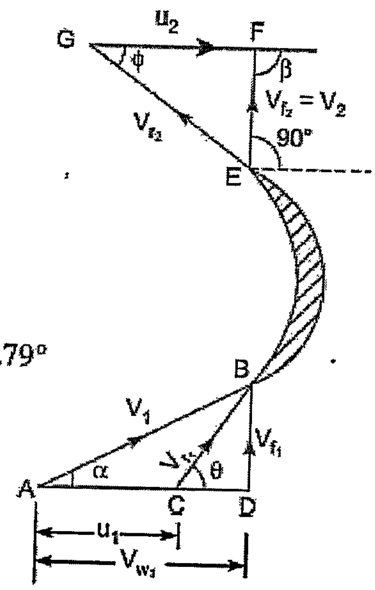


Fig. 17.17

Also from ΔBCD,

$$\sin\theta = \frac{V_{f_1}}{V_{r_1}} \quad \text{or} \quad V_{r_1} = \frac{V_{f_1}}{\sin\theta} = \frac{20}{\sin 53.79°}$$

$\therefore \quad V_{r_1} = 24.78$

But $\quad V_{r_2} = V_{r_1} = 24.78$

Hence, from ΔEFG, $\cos\phi = \frac{u_2}{V_{r_2}} = \frac{20}{24.78} = 0.8071 = \cos 36.18°$

$\therefore \quad \phi = 36.18°$ or **36° 10.8′. Ans.**

7. CASE IV (b): Moving Curved Vane... Jet Strikes Tangentially at one end: $\beta > 90^0$

Problem 17.20 *A jet of water of diameter 50 mm, having a velocity of 20 m/s strikes a curved vane which is moving with a velocity of 10 m/s in the direction of the jet. The jet leaves the vane at an angle of 60° to the direction of motion of vane at outlet. Determine :*

(i) The force exerted by the jet on the vane in the direction of motion.

(ii) Work done per second by the jet.

Solution. Given :

Diameter of the jet, $d = 50$ mm $= 0.05$ m

$\therefore$ Area, $a = \frac{\pi}{4}(.05)^2 = .001963$ m^2

Velocity of jet, $V_1 = 20$ m/s

Velocity of vane, $u_1 = 10$ m/s

As jet and vane are moving in the same direction,

$\therefore \quad \alpha = 0$

Angle made by the leaving jet, with the direction of motion = 60°

$\therefore \quad \beta = 180° - 60° = 120°$

For this problem, we have

$u_1 = u_2 = u = 10$ m/s

$V_{r_1} = V_{r_2}$

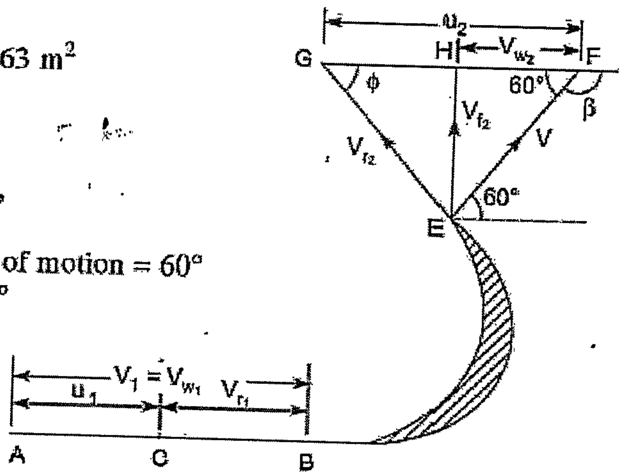


Fig. 17.18

From Fig. 17.18, we have

$V_{r_1} = AB - AC = V_1 - u_1$

$= 20 - 10 = 10$ m/s

$V_{w_1} = V_1 = 20$ m/s

$\therefore \quad V_{r_2} = V_{r_1} = 10$ m/s

Now in ΔEFG, $EG = V_{r_2} = 10$ m/s,

$GF = u_2 = 10$ m/s

$\angle GEF = 180° - (60° + \phi) = (120° - \phi)$

From sine rule, we have

$$\frac{EG}{\sin 60°} = \frac{GF}{\sin(120° - \phi)} \quad \text{or} \quad \frac{10}{\sin 60°} = \frac{10}{\sin(120° - \phi)}$$

or $\sin 60° = \sin(120° - \phi)$

∴ $60° = 120° - \phi$ or $\phi = 120° - 60° = 60°$

Now $V_{w_2} = HF = GF - GH$

$= u_2 - V_{r_2} \cos\phi = 10 - 10 \times \cos 60° = 10 - 5 = 5$ m/s.

(*i*) The force exerted by the jet on the vane in the direction of motion is given by equation (17.19) as

$F_x = \rho a V_{r_1} [V_{w_1} - V_{w_2}]$ (–ve sign is taken as β is an obtuse angle)

$= 1000 \times .001963 \times 10 [20 - 5]$ N = **294.45 N. Ans.**

(*ii*) Work done per second by the jet

$= F_x \times u = 294.45 \times 10 = 2944.5$ N m/s

= **2944.5 W. Ans.** [∵ Nm/s = W (watt)]

8. CASE IV (b): Moving Curved Vane... Jet Strikes Tangentially at one end: Symmetrical :

Problem 17.21 *A jet of water having a velocity of 15 m/s strikes a curved vane which is moving with a velocity of 5 m/s. The vane is symmetrical and is so shaped that the jet is deflected through 120°. Find the angle of the jet at inlet of the vane so that there is no shock. What is the absolute velocity of the jet at outlet in magnitude and direction and the work done per unit weight of water. Assume the vane to be smooth.*

Solution. Given :

Velocity of jet, $V_1 = 15$ m/s

Velocity of vane, $u_1 = 5$ m/s

As vane is symmetrical. Hence angle $\theta = \phi$

Angle of deflection of the jet $= 120° = 180° - (\theta + \phi)$

∴ $\theta + \phi = 60°$ or each angle, *i.e.*, $\theta = \phi = 30°$

Let the angle of jet at inlet $= \alpha$

Absolute velocity of jet at outlet $= V_2$

Angle made by V_2 at outlet with direction of motion of vane = β*.

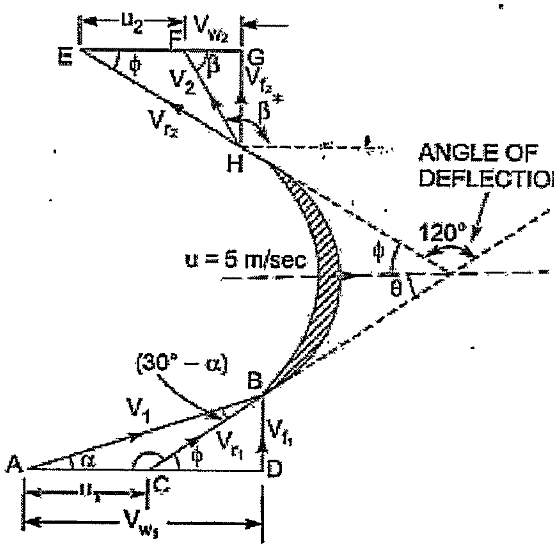


Fig. 17.19

For this problem, $u_1 = u_2 = u = 5$ m/s

$V_{r_1} = V_{r_2}$ (as vane is smooth)

Applying the sine rule to ΔACB,

$$\frac{AB}{\sin(180° - \theta)} = \frac{AC}{\sin(30° - \alpha)} \quad \text{or} \quad \frac{V_1}{\sin(180° - 30°)} = \frac{u_1}{\sin(30° - \alpha)}$$

or

$$\frac{15}{\sin 30°} = \frac{5}{\sin(30° - \alpha)} \quad \text{or} \quad \sin(30° - \alpha) = \frac{5 \sin 30°}{15}$$

$$= \frac{1}{3} \times 0.5 = .1667 = \sin 9.596°$$

$\therefore$ $30° - \alpha = 9.596°$ or $\alpha = 30° - 9.596° = 20.404°$ or **20° 24′. Ans.**

Also from sine rule to ΔACB, we have

$$\frac{AB}{\sin(180° - 30°)} = \frac{CB}{\sin \alpha} \quad \text{or} \quad \frac{V_1}{\sin 30°} = \frac{V_{r_1}}{\sin 20.404°}$$

$$\therefore \quad V_{r_1} = \frac{V_1 \sin 20.404°}{\sin 30°} = 10.46 \text{ m/s}$$

$$\therefore \quad V_{r_2} = V_{r_1} = 10.46 \text{ m/s}$$

From velocity ΔHEG at outlet,

$$V_{r_2} \cos \phi = u_2 + V_{w_2} \quad \text{or} \quad 10.46 \cos 30° = 5.0 + V_{w_2}$$

$$\therefore \quad V_{w_2} = 10.46 \cos 30° - 5.0 = 4.06 \text{ m/s}$$

Also, we have $V_{r_2} \sin \phi = V_{f_2}$ or $V_{f_2} = 10.46 \sin 30° = 5.23$ m/s

In ΔHFG,

$$V_2 = \sqrt{V_{f_2}^2 + V_{w_2}^2} = \sqrt{5.23^2 + 4.06^2}$$

$$= \sqrt{27.353 + 16.483} = \textbf{6.62 m/s. Ans.}$$

$$\tan \beta = \frac{V_{f_2}}{V_{w_2}} = \frac{5.23}{4.06} = 1.288 = \tan 52.17°$$

$\therefore$ $\beta = 52.17°$ or $52° \ 10.2'$

$\therefore$ Angle made by absolute velocity at outlet with the direction of motion β^*

$$= 180° - \beta = 180° - (52° \ 10.2') = 127° \ 49.8'$$

$\therefore$ $\beta^* =$ **127° 49.8. Ans.**

Work done* per unit weight of the water striking

$$= \frac{1}{g} [V_{w_1} + V_{w_2}] \times u \text{ Nm} \quad (\because \text{ +ve sign taken as } \beta \text{ is an acute angle})$$

$$= \frac{1}{9.81} [V_1 \cos \alpha + 4.06] \times 5 \qquad (\because \; V_{w_1} = V_1 \cos \alpha)$$

$$= \frac{5}{9.81} [15 \cos 20.404° + 4.06] = \textbf{9.225 Nm/N. Ans.}$$

9. CASE IV (c): Series of Moving Radial Curved Vanes… Jet Strikes Tangentially at one end:

Problem 17.26 *A jet of water having a velocity of 30 m/s strikes a series of radial curved vanes mounted on a wheel which is rotating at 200 r.p.m. The jet makes an angle of 20° with the tangent to the wheel at inlet and leaves the wheel with a velocity of 5 m/s at an angle of 130° to the tangent to the wheel at outlet. Water is flowing from outward in a radial direction. The outer and inner radii of the wheel are 0.5 m and 0.25 m respectively. Determine :*

(i) Vane angles at inlet and outlet, *(ii) Work done per unit weight of water, and*
(iii) Efficiency of the wheel.

In ΔEFH, $$\tan\phi = \frac{V_{f_2}}{u_2 + V_{w_2}} = \frac{3.83}{5.235 + 3.214} = 0.453 = \tan 24.385^\circ$$

$\therefore$ $\phi = 24.385^\circ$ or **$24^\circ\ 23.1'$. Ans.**

(*ii*) Work done per second by water is given by equation (17.26)

$$= \rho a V_1 \left[V_{w_1} u_1 + V_{w_2} u_2\right]$$

(+ ve sign is taken as β is acute angle in Fig.17.24)

$\therefore$ Work done* per second per unit weight of water striking per second

$$= \frac{\rho a V_1\left[V_{w_1} u_1 + V_{w_2} u_2\right]}{\text{Weight of water/s}} = \frac{\rho a V_1\left[V_{w_1} u_1 + V_{w_2} u_2\right]}{\rho a V_1 \times g}$$

$$= \frac{1}{g}\left[V_{w_1} u_1 + V_{w_2} u_2\right] \text{Nm/N} = \frac{1}{9.81}\,[28.19 \times 10.47 + 3.214 \times 5.235]$$

$$= \frac{1}{9.81}\,[295.15 + 16.82] = \mathbf{31.8\ Nm/N.\ Ans.}$$

(*iii*) Efficiency, η is given by equation (17.28) as

$$\eta = \frac{2\left[V_{w_1} u_1 + V_{w_2} u_2\right]}{V_1^2} = \frac{2[28.19 \times 10.47 + 3.214 \times 5.235]}{30^2}$$

$$= \frac{2[295.15 + 16.82]}{30 \times 30} = 0.6932 \text{ or } \mathbf{69.32\%.\ Ans.}$$

Solution. Given :

Velocity of jet, $V_1 = 30$ m/s

Speed of wheel, $N = 200$ r.p.m.

∴ Angular speed, $\omega = \dfrac{2\pi N}{60} = \dfrac{2\pi \times 200}{60} = 20.94$ rad/s

Angle of jet at inlet, $\alpha = 20°$

Velocity of jet at outlet, $V_2 = 5$ m/s

Angle made by the jet at outlet with the tangent to wheel = 130°

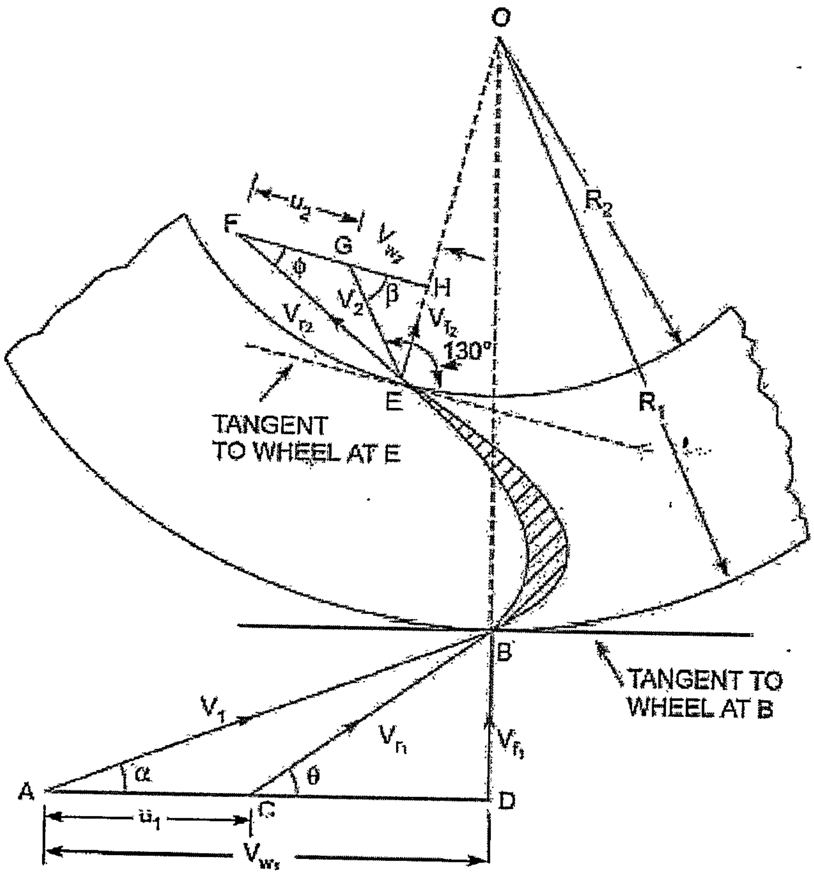
∴ Angle, $\beta = 180° - 130° = 50°$

Outer radius, $R_1 = 0.5$ m

Inner radius, $R_2 = 0.25$ m

∴ Velocity $u_1 = \omega \times R_1 = 20.94 \times 0.5 = 10.47$ m/s

And $u_2 = \omega \times R_2 = 20.94 \times 0.25 = 5.235$ m/s.



(*i*) Vane angles at inlet and outlet means the angle made by the relative velocities V_{r_1} and V_{r_2}, *i.e.*, angle θ and ϕ.

From ΔABD, $V_{w_1} = V_1 \cos\alpha = 30 \times \cos 20° = 28.19$ m/s

$V_{f_1} = V_1 \sin\alpha = 30 \times \sin 20° = 10.26$ m/s

In ΔCBD, $\tan\theta = \dfrac{BD}{CD} = \dfrac{V_{f_1}}{AD - AC} = \dfrac{10.26}{V_{w_1} - u_1} = \dfrac{10.26}{28.19 - 10.47} = 0.579 = \tan 30.07$

∴ $\theta = 30.07°$ or **30° 4.2′. Ans.**

From outlet velocity Δ, $V_{w_2} = V_2 \cos\beta = 5 \times \cos 50° = 3.214$ m/s

$V_{f_2} = V_2 \times \sin\beta = 5 \sin 50° = 3.83$ m/s

CENTRIFUGAL PUMPS UNIT-V

Definition:- A centrifugal Pump is a hydraulic machine used to raise the water (liquid) from lower level to higher level by creating a required Pressure by means of centrifugal action. centrifugal Pumps are the machines which increases the Pressure energy of a fluid. These may either lift the fluid or boost the Pressure in a pipe line.

Classifications

centrifugal Pumps are classified as

i) According to type of casing:-

(a) Volute Pumps b) Vortex Pumps

c) Diffusion Pumps

ii) According to type of impeller:-

a) closed impeller Pump b) semi-closed impeller Pump

c) opened impeller Pump

iii) According to working head

a) low head Pumps : up to 15 m water

b) Medium head Pumps: 15 to 40 m of water

c) high head Pumps : above 40m of water

iv) According to direction of flow through impeller:-

a). Radial flow Pumps b) Axial flow Pumps

c) mixed flow Pumps

v) According to no. of impellers per shaft:-

a) single stage centrifugal Pump

b) Multi stage centrifugal Pump

vi) According to no. of entrances to impeller:-

a) Single entry (or) single suction Pump

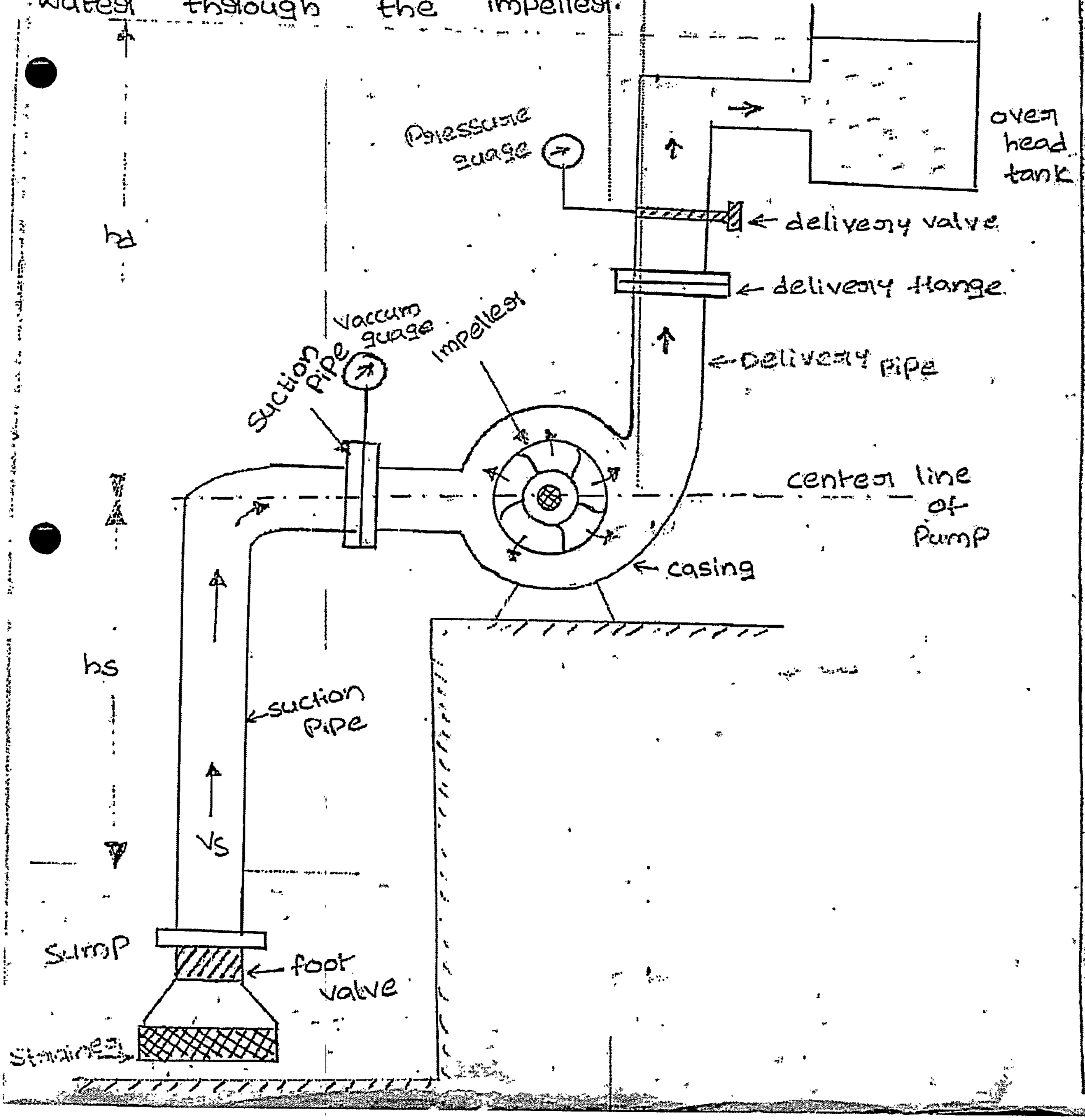
b) Double entry (or) Double suction Pump

COMPONENTS OF CENTRIFOGAL PUMP

A centrifugal pump consists of following components

i) impeller (ii) casing
(iii) suction pipe (iv) Delivery pipe

Impeller :- An impeller is a wheel (or) rotor with a series of backward curved vanes (blades). It is mounted on the shaft which is usually coupled to an electric motor. The function of impeller is to force the water into a rotating motion and the shroud around the impeller is to direct the water through the impeller.



Casing :- The casing is an air-tight chamber surrounding the pump impeller. It contains suction and discharge arrangments, supporting for bearings and facilitates to house the rotor assembley. It has provision to fix stuffing box and house packing materials which prevent external leakage. The essential purpose of casing are

* To Guide the water to and from the impeller
* To convert partially kinetic energy into pressure energy.

Suction Pipe :- The pipe which connects the centrel edge of impeller to sump from which liquid is to be lifted is known as suction pipe. To prevent the entry of solid particles, into the pump, the suction pipe is provided with a strainer at its lower end. the lower end of the pipe is also fitted with a non-return foot valve which does not permit the liquid to drain out of the suction pipe when pump is not working; this also helps in priming.

Delivery Pipe :- The pipe which is connected at its lower end to the outlet of the pump and it delivers the liquid to the required height is known as delivery pipe. A regulating valve is provided on the delivery pipe to regulate the supply of water. The velocity of water in delivery pipe is equal (or) slightly higher than velocity of suction pipe.

Working

A centrifugal pump works on the principle that when a certain mass of fluid is rotated by an external source, it is thrown away from the central axis of rotation and centrifugal head is impressed which enables it to rise to a higher level. The operation/working of centrifugal has the following steps.

(1) The delivery valve is closed and the pump is primed that is, suction pipe, casing and position of the delivery pipe upto delivery valve are completely filled with the liquid so that no air pocket is left.

ii) keeping the delivery valve still closed the electric motor is started to rotate the impeller the rotation of the impeller causes strong suction or vaccum just at the eye of the casing.

3) The speed of the impeller is gradually increased till the impeller rotates at its normal speed and develops normal energy required for pumping the liquid.

4) After the impeller attains the normal speed the delivery valve is opened when the liquid is continuously sucked up the suction pipe. Due to impeller action the pressure head as well as velocity heads of the liquid are increased.

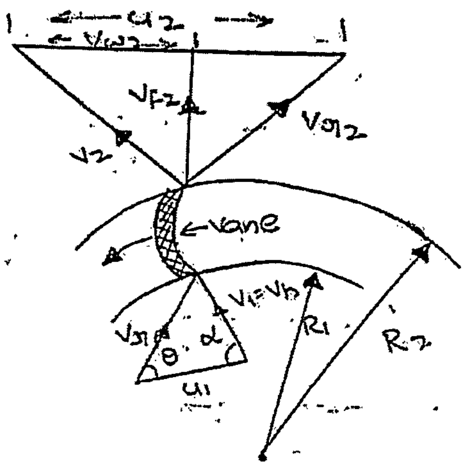
5) From casing, the liquid passes into pipe and is lifted to required height

6) so long as motion is given to the impeller and there is supply of liquid to the lifted the process of lifting the liquid to the required height remains continuous.

7) When pump is to be stopped delivery valve should be closed first, otherwise there may be some back flow from the reservoir.

Work done:- The expression for work done (or) energy supplied by the impeller of a centrifugal pump may be derived in the same way as for turbine. the liquid enters the impeller at its center and leaves at its outer periphery.

Torque on impeller = rate of change of mommentum



Moment of Mommentum of inlet $= 0$

Moment of Mommentum of outlet $= \rho \cdot Q \, (V_{w_2} R_2)$

$\therefore$ Torque $= \rho Q \, (V_{w_2} R_2)$

Work done/sec = Torque × Angular velocity

$\Rightarrow \rho Q \, V_{w_2} R_2 \times \omega \Rightarrow \rho Q \, V_{w_2} R_2 u_2$

Work done/sec unit weight of liquid $= \frac{1}{g} V_{w_2} u_2$

If the flow is not radial at inlet

Work done $= \frac{1}{g} [V_{w_2} u_2 - V_{w_1} u_1] \rightarrow$ It is known as Eulers momentum equation for centrifugal pump.

Volume of liquid $= Q = \pi D_1 B_1 V_{f_1} = \pi D_2 B_2 V_{f_2}$

From outlet velocity triangle

$$V_{f_2}^2 = V_{r_2}^2 - (u_2 - V_{w_2})^2 \text{ and } V_{f_2}^2 = V_2^2 - V_{w_2}^2$$

$$V_2^2 - V_{w_2}^2 = V_{r_2}^2 - u_2^2 - V_{w_2}^2 + 2u_2 V_{w_2}$$

(or)

$$u_2 \cdot V_{w_2} = \frac{1}{2} [V_2^2 + u_2^2 - V_{w_2}^2]$$

Similarly,

from inlet velocity triangle $u_1 V_{w_1} = \frac{1}{2} (V_1^2 + u_1^2 - V_{r_1}^2)$

$$\therefore \text{Work done} = \frac{V_2^2 - V_1^2}{2g} + \frac{u_2^2 - u_1^2}{2g} + \frac{V_{r_1}^2 - V_{r_2}^2}{2g}$$ → This equ. is known as fundemental equation of centrifugal pump.

Heads

i) Static head (H_s):- The sum of suction head (h_s) and delivery head (h_d) is known as static head

$\therefore H_s = h_s + h_d$

Suction head (h_s) :- It is the vertical height of the centre line of the centrifugal pump above the water surface in the tank or pump from which the water is to be lifted.

Delivery head (h_d) :- The vertical distance b/w the centre line of the pump and the water surface in the tank to which water is delivered is known as delivered head.

Manometric head (H_m) :- The head against which a centrifugal pump has to work is known as the manometric head. It is the head measured across the pump inlet and outlet flanges

- H_m = head imparted by the impeller to liquid - loss of head in the pump

$$= \frac{V_{w_2} u_2}{g} - \text{losses}$$

$$H_m = h_s + h_d + h_{fs} + h_{fd} + \frac{V_d^2}{2g}$$

Where,

h_{fs}, h_{fd} : friction head losses in suction and delivery pipes

V_d = velocity in delivery pipe

- H_m = total head at outlet of pump - Total head at inlet

$$= \left[\frac{P_2}{\omega} + \frac{V_2^2}{2g} + Z_2\right] - \left[\frac{P_1}{\omega} + \frac{V_1^2}{2g} + Z_1\right]$$

losses

Various losses occurring in centrifugal pump are

i) Hydraulic losses:-

a) Shock or eddy losses at the entrance and exist from the impeller.

b) losses due to friction in the impeller

c) Friction and eddy losses in the Guide vanes/ diffuser & casing

d) Friction and other minor losses in suction pipe

e) Friction and other minor losses in delivery pipe.

2. Mechanical losses:-

a) losses due to friction b/w the impeller and the liquid which fills the clearence spaces b/w the impeller and casing.

b) losses pertaining to friction of the main bearing and glands.

3. leakage losses:-

The loss of energy due to leakage of liquid is known as leakage loss.

EFFICIENCIES

Various efficiencies of centrifugal pump are

i) Manometric efficiency head (η_{mano}]:- The ratio of the Manometric head developed by the pump to the head imparted by the impeller to the liquid is known as Manometric ~~(head)~~ efficiency

$$\eta_{mano} = \frac{\text{Manometric head}}{\text{Head imparted by impeller to liquid}}$$

$$= \frac{H_m}{\frac{V_{w2}u_2}{g}} \Rightarrow \frac{g \cdot H_m}{V_{w2}u_2}$$

ii) Volumetric efficiency (η_v):- The ratio of quantity liquid discharged / second from pump to quantity passing per second through impeller is known as volumetric efficiency.

$$\eta_v = \frac{Q}{Q+q}$$

Where,

Q = Actual liquid discharge at pump outlet/second

q = leakage of liquid per second.

Mechanical efficiency (η_m):- The ratio of the Power delivered by the impeller to the liquid to the Power input to the pump shaft is known as mechanical efficiency (η_m)

$$\eta_m = \frac{P - P_{mech.losses}}{P} = \frac{w(Q+q) \cdot (V_{w2}u_2/g)}{P}$$

Overall efficiency:- The ratio of output of the Pump to the input of the pump is known as overall efficiency (η_o)

$$\eta_o = \frac{WQ\,H_{mano}}{P} \quad \text{and} \quad \eta_o = \eta_{mano} \times \eta_v \times \eta_m$$

Specific speed:- The specific speed of a centrifugal Pump is defined as the speed of a geometrically similar pump which would deliver unit quantity (1m³/sec) against a unit head (1m). It is denoted by N_s

- discharge

Q = Area × Velocity of flow = $\pi D B V_f$

(or)

$Q \propto D \times B \times V_f \rightarrow (1)$

$Q \propto D^2 \times V_f \quad [B \propto D] \rightarrow (2)$

Tangential Velocity $(u) = \pi D N/60$ (or) $u \propto DN \rightarrow (3)$

also $u \propto V_f \propto \sqrt{H_{mano}} \rightarrow (4)$

from (3) & (4)

$\sqrt{H_{mano}} \propto DN$ [or] $D \propto \frac{\sqrt{H_{mano}}}{N} \rightarrow (5)$

From ② and ⑤

$$Q \propto \frac{H_{mano}}{N^2} \times V_f \propto \frac{H_{mano}}{N^2} \times \sqrt{H_{mano}}$$

(or)

$$Q \propto \frac{[H_{mano}]^{3/2}}{N^2}$$

$$Q = k \cdot \frac{[H_{mano}]^{3/2}}{N^2}$$, where k = constant

When,

$H_m = 1m$ and $Q = 1 m^3/sec$

$$1 = K \cdot \frac{(1)^{3/2}}{N_s^2} \quad (or) \quad k = N_s^2$$

$$\therefore Q = N_s^2 \cdot \frac{[H_{mano}]^{3/2}}{N^2} \quad (or) \quad N_s^2 = \frac{QN^2}{[H_{mano}]^{3/2}}$$

$$\therefore \text{specific ~~head~~ speed } (N_s) = \frac{N\sqrt{Q}}{[H_{mano}]^{3/4}}$$

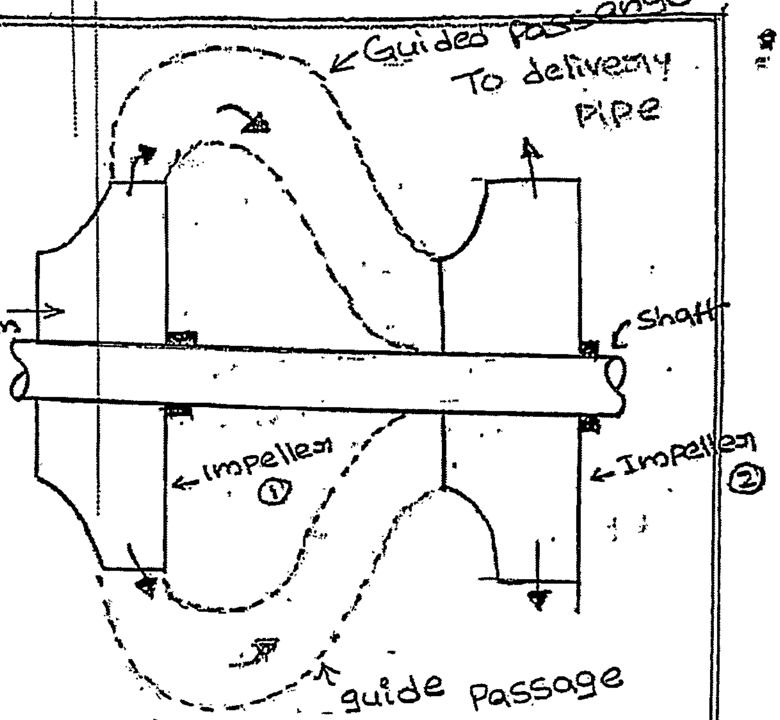
MULTI - STAGE CENTRIFOGAL POMPS:-

A Multi stage centrifugal Pump is one which has two or more identical impellers mounted on the same shaft or different shafts. The important functions performed by these are

(i) To produce heads greater than that permissible with a single impeller discharge remaining constant -series

ii) To discharge a large quantity of liquid, head remaining same- parallel arrangement

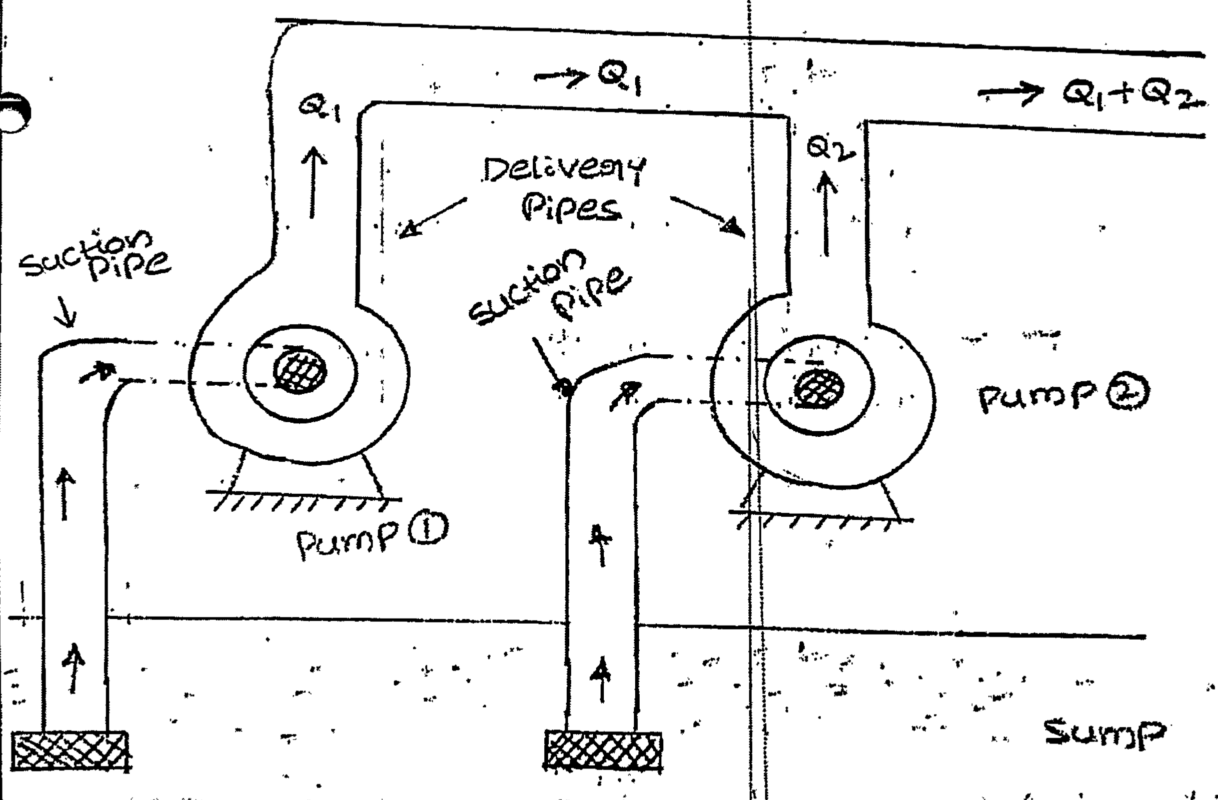
Pumps in series:- For obtaining a high ~~speed~~. head, a no.of impellers are mounted in series or on the same shaft. The below figure shows such an arrangement for a two-stage Pump. The discharge from impeller - ① passes through a guided passage and enters the impeller - ②, At the outlet of impeller-(2), the pressure of water will be more than the pressure of water at outlet of impeller-(1). This if more no. of impellers are mounted on the same shaft the pressure at outlet is increased further.



If in each stage the manometric head imposed on the liquid is H_{mano} then for "n" identical impellers the total head developed will be $H_{total} = nH_{mano}$. however, the discharge passing through each impeller is same.

The series arrangment is employed for delivering a relatively small quantity of liquid against very high heads

PUMPS IN PARALLEL



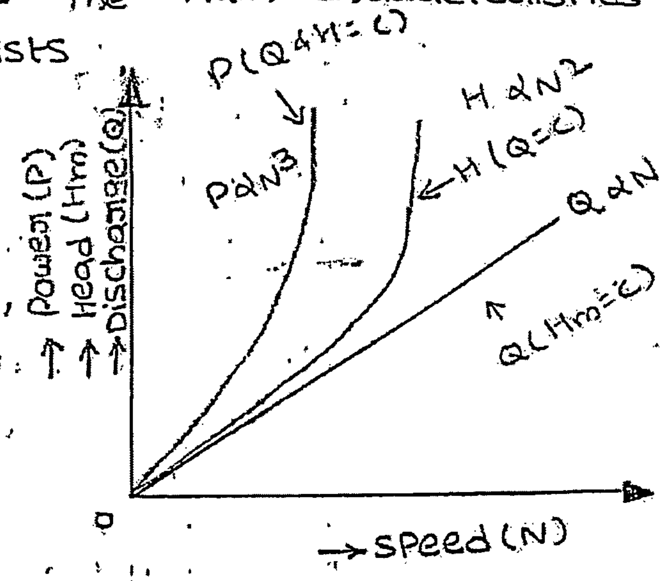
When a large quantity of liquid is required to be pumped against a relatively small head, two or more pumps are empolyed which are so arranged that each of these pumps working separately lifts the liquid from a common sump and delivers to common collecting pipe through which it is created to required height. This arrangment is known as pumps in parallel. If Q is the discharge capacity of the pump and there are n identical pumps then total discharge will be

$$Q_{total} = n \cdot Q$$

Characteristics curves

Ordinarily a centrifugal pump is worked under maximum efficiency conditions. However when the pump run at conditions different from the design conditions, it performs differently. Therefore the predict the behaviour of the pump under varying conditions of speeds, heads discharges (or) powers tests are usually conducted. The results obtained from these tests are plotted in the form of characteristic curves. These are

i) Main characteristic curves:- The main characteristics of a centrifugal pump consists of variation of head (Hm), Power (P), Discharge (Q) w.r.t speed. For plotting curves of manometric head Vs speed, discharge is kept constant. For plotting discharge Vs speed, manometric head (Hm) is kept constant. And for plotting curves of power Vs speed the manometric head and discharge kept constant.



From, head coefficient $\frac{H_m}{D^2N^2}$ = constant (or) $H_m \propto N^2$

This means the head developed by the pump is proportional to N^2. Hence, curve of H_m Vs N is parabolic shape.

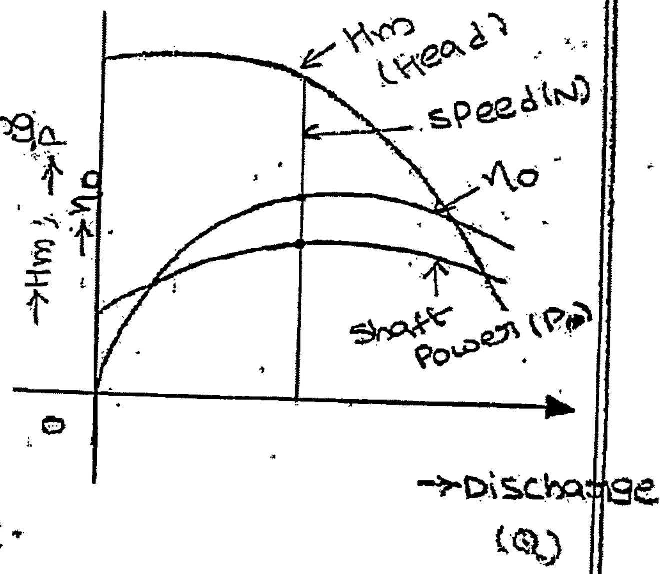
From, flow coefficient $\frac{Q}{D^3N}$ = constant (or) $Q \propto N$

This means discharge is proportional to speed and the curve of Q Vs N is straight line.

From; Power coefficient $\frac{P}{D^5N^3}$ = constant (or) $P \propto N^3$. This curve is P Vs N is cubic curve.

2) Operating characteristics:-

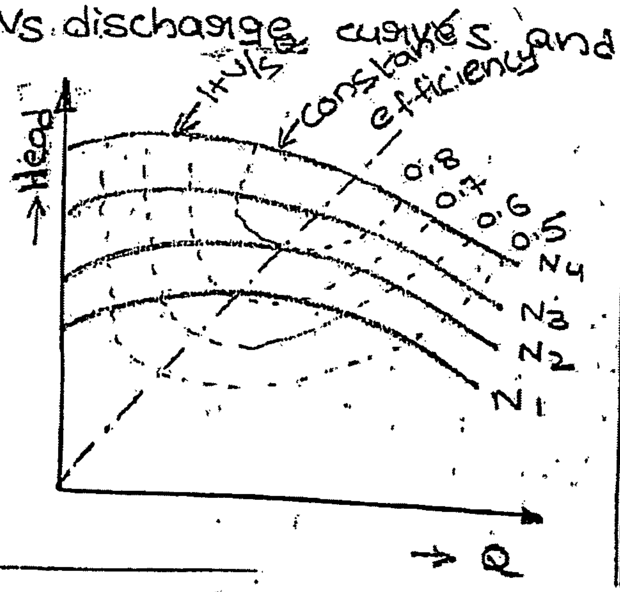
When a centrifugal pump operates at the design speed the maximum efficiency occurs. Evidently for optimum performance, the pump needs to be operated at the design speed. To obtain operating characteristics curves, the pump is run at the design speed and discharge is varied as in the case of main ch's curves.



3) Constant efficiency curves:-

For obtaining constant efficiency curves for a pump, the head Vs discharge curves and efficiency Vs discharge curves for different speed ~~curves~~ are used.

For plotting the constant efficiency curves first η Vs Q curves are drawn. These curves are transferred to the corresponding H Vs Q curves. The points having the



UNIT-V

Hydraulic pumps: Classification, working, workdone, Manometric head losses and Effeciencies, specific speeds - pumps in series and parallel - performance characteristic curves, NSPH: Reciprocating pump working.

A hydraulic machine, which converts mechanical energy into hydraulic energy is called a "pump".

NOTE: Hydraulic energy is in the form of pressure energy.

Classification: on the basis of transfer of mechanical energy, the pumps are broadly classified into two types. they are

1. Rotodynamic pumps
   Ex: Centrifugal pump
2. positive displacement pumps.
   Ex: Reciprocating pump.

Classification of Centrifugal pumps: These are classified on the basis of the following characteristics.

1. Type of Casing: (i) volute pumps (ii) Turbine pump
2. working head: (i) low lift pump (upto 15m)
   (ii) medium lift pump (upto 40m)
   (iii) high lift pump (above 40m)
3. Liquid handled: (i) closed impeller
   (ii) Semi-open impeller
   (iii) open impeller
4. Numbers of Impellers:
   (i) Single ~~Suction (or) Single entry~~ stage
   (ii) ~~Double Suction (or) Double entry~~ multistage
5. Flow through Impeller:
   (i) Radial flow
   (ii) Axial flow
   (iii) Mixed flow

PTO

Classification of Reciprocating pumps:

1. According to the water being in contact with the piston
   - (i) Single acting pump (water contact with one side of the piston)
   - (ii) Double acting pump (water contact with both sides of the piston)

2. According to number of cylinders
   - (i) Single cylinder
   - (ii) Double cylinder
   - (iii) Triple cylinder
   - (iv) Duplex- Double acting (4)
   - (v) Quintuplex(5) cylinder

Head of a pump (centrifugal pump): The head of a centrifugal pump can be expressed as (i) Static head (ii) manometric head and (iii) Total, gross (or) effective head.

Static head: The sum of suction head (h_s) and delivery head (h_d) is called static head (H_s).

$$\therefore H_s = h_s + h_d$$

Manometric head (H_m): The head against which a centrifugal pump has to work is known as the manometric head (H_m) (or) The head measured across inlet and outlet of the pump is called Manometric head

Total, gross head (or) Effective head: The sum of the static head and head losses in the impeller is called effective head.

Losses in Centrifugal pumps: In centrifugal pumps the main losses are hydraulic losses, mechanical losses and leakage loss.

Hydraulic losses: These losses may be
- (i) Shock (or) eddy losses at the entrance to and exit from the Impeller
- (ii) Losses due to friction in the impeller
- (iii) friction and eddy losses in the guide vanes (or) diffuser and casing.

mechanical losses:

(i) losses due to disc friction between the impeller and the liquid in the casing

(ii) losses due to friction in the main bearings

Leakage losses: Loss of energy caused by the leakage of the fluid is called leakage loss.

Efficiencies of Centrifugal pump: The following are the important efficiencies of a centrifugal pump.

(i) Manometric efficiency (η_{man}): The ratio of manometric head developed by the pump to the head imparted by the impeller to the liquid is called manometric efficiency.

$$\therefore \text{Manometric efficiency}(\eta_m) = \frac{H_m}{\left(\frac{V_{w_2}U_2}{g}\right)} = \frac{gH_m}{V_{w_2}U_2},$$

where V_{w_2} = whirl velocity at outlet

U_2 = tangential velocity of impeller at outlet.

(ii) Volumetric efficiency (η_v): The ratio of quantity of liquid discharged per second to the quantity of the liquid passing per second through the impeller is called volumetric efficiency.

$$\therefore \text{volumetric efficiency}(\eta_v) = \frac{Q}{Q+q},$$

where Q = actual liquid discharged per second

q = leakage of liquid from the impeller/second

(iii) mechanical efficiency (η_m): The ratio of the power delivered by the impeller to the liquid to the power input to the pump shaft is called mechanical efficiency.

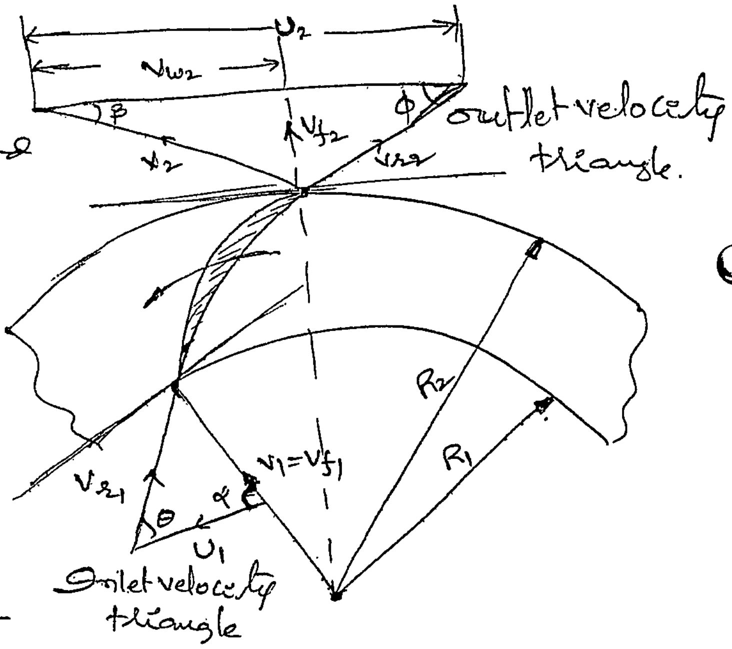
$$\therefore \text{mechanical efficiency}(\eta_m) = \frac{w(Q+q)\left(\frac{V_{w_2}U_2}{g}\right)}{P} = \frac{P - P_{loss}}{P}$$

PTO

(iv) **Over all efficiency (η_o)**: The ratio of power o/p of the pump to the power I/p to the pump is called overall efficiency.

$\therefore$ Over all efficiency $(\eta_o) = \dfrac{w Q H_m}{P} = \eta_{ma} \times \eta_v \times \eta_m$

Workdone by the Centrifugal pump: The liquid enters the impeller radially at the inlet. Let V_1 be the absolute velocity of the liquid at the Inlet. For the best efficiency, its whirl component V_{w1} is zero and its flow velocity component equals to V_1 i.e. $V_{f1} = V_1$ and $V_{w1} = 0$. As the liquid enters the impeller radially hence $\alpha = 90°$.



$\therefore$ workdone by the impeller per second per unit weight of the liquid is

w = negative workdone by an inward flow reaction turbine

$$= -\left[\frac{V_{w1}U_1 - V_{w2}U_2}{g}\right]$$

$$= \frac{1}{g}\left(V_{w2}U_2 - V_{w1}U_1\right)$$

But for Centrifugal pump $V_{w1} = 0$, hence $w = \frac{1}{g}\left(V_{w2}U_2\right)$

If W is the weight of the liquid striking the impeller, then workdone $w = \dfrac{W}{g}\left(V_{w2} \times U_2\right)$

where weight $(W) = \rho \times g \times Q$, Q = volume of the liquid

= Area × velocity of flow

$= \pi D_1 B_1 \times V_{f1}$ (or)

$= \pi D_2 B_2 \times V_{f2}$

D_1, D_2 = Diameters of the impeller at inlet and outlet

B_1, B_2 = width of impeller at inlet and outlet.

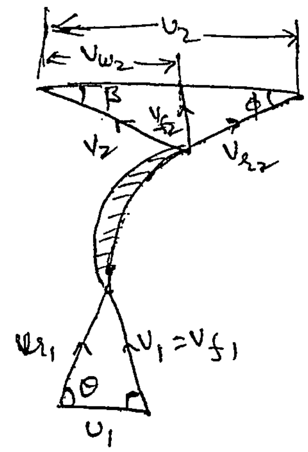
worked examples

1. The internal and external diameters of an impeller of a centrifugal pump are 200 mm and 400 mm respectively. The vane angles at inlet and outlet are 20° and 30° respectively. The pump runs at 1200 rpm and water enters the impeller radially and flow velocity is constant. Determine the workdone by the impeller per unit weight of water.

Solution: $D_1 = 200\ mm = 200 \times 10^{-3}\ m$; $\theta = 20^\circ$

$D_2 = 400\ mm = 400 \times 10^{-3}\ m$; $\phi = 30^\circ$

$N = 1200\ rpm$; $V_{f_1} = V_{f_2}$



Since water enters radially, $\alpha = 90^\circ$, $V_{w_1} = 0$

Tangential velocity of the impeller at inlet $U_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 200 \times 10^{-3} \times 1200}{60}$

$= 12.56\ ms^{-1}$

Tangential velocity at the outlet $U_2 = \frac{\pi D_2 N}{60} = 25.13\ ms^{-1}$

From the inlet velocity triangle,

$$\tan\theta = \frac{V_1}{U_1} = \frac{V_{f1}}{U_1}$$

$$\Rightarrow V_{f1} = U_1 \tan\theta = 12.5 \times \tan 20^\circ = 4.57\ m/sec$$

$$\therefore V_{f_2} = V_{f_1} = 4.57\ m/sec.$$

From outlet velocity triangle,

$$\tan\phi = \frac{V_{f_2}}{U_2 - V_{w_2}} = \frac{4.57}{25.13 - V_{w_2}}$$

$$\Rightarrow V_{w_2} = 25.13 - \frac{4.57}{\tan 30^\circ} = 17.21\ ms^{-1}$$

$\therefore$ workdone per unit weight $(w) = \frac{1}{g}(V_{w_2} U_2) = \frac{1}{9.81}(17.21 \times 25.13)$

$= 44.10\ N\text{-}m$

PTO

Specific speed of a Centrifugal pump (N_s):

The specific speed of a centrifugal is defined as the speed of a geometrically similar pump which would deliver one cubic metre of liquid per second against a head of one metre.

Expression: The discharge for a centrifugal pump is given by

$$Q = \text{Area} \times \text{Velocity of flow}$$

$$= \pi D \times B \times V_f, \quad \text{where } D = \text{dia. of impeller}, \; B = \text{width of impeller}$$

$$\Rightarrow Q \propto D \times B \times V_f \quad \text{--- (1)}$$

But width of the impeller is proportional to the diameter of the impeller.

$$\therefore B \propto D$$

From (1) $$Q \propto D^2 \times V_f \quad \text{--- (2)}$$

But ~~we know that~~ tangential velocity is given by $U = \frac{\pi D N}{60}$

$$\therefore U \propto DN \quad \text{--- (3)}$$

Tangential velocity and flow velocity are related to manometric head (H_m)

$$\therefore U \propto V_f \propto \sqrt{H_m} \quad \text{--- (4)}$$

From (3) $\sqrt{H_m} \propto DN \Rightarrow D \propto \frac{\sqrt{H_m}}{N}$

$\therefore$ From (2) $$Q \propto \frac{H_m}{N^2} \times V_f$$

But from (4) $V_f \propto \sqrt{H_m}$

$$\therefore Q \propto \frac{H_m}{N^2} \sqrt{H_m}$$

$$\Rightarrow Q = K \frac{(H_m)^{3/2}}{N^2}, \quad \text{--- (5)}$$

where K is proportionality constant

By the definition of specific speed (N_s), if $Q = 1\ m^3/sec$ and $H_m = 1m$

then $N = N_s$

$\therefore$ From (5) $\quad 1 = \dfrac{K(1)^{3/2}}{N_s^2} \Rightarrow N_s^2 = K$

$\therefore$ Discharge $(Q) = \dfrac{N_s^2 (H_m)^{3/2}}{N^2}$

$$\Rightarrow N_s = \frac{N\sqrt{Q}}{(H_m)^{3/4}}$$

worked examples

1. A single stage centrifugal pump having an impeller of diameter 30 cm is used to lift 3 m³ of water to a height of 30 m ~~in one~~ per second. pump rotates at 2000 rpm and its efficiency is 75%. If it is replaced by a multistage pump to lift 5 m³ of water per second to a height of 200 m rotating at 1500 rpm, find the no. of stages and diameter of the ~~one~~ impeller of the multistage pump

solution:

Single stage

$D_1 = 30\ cm = 30 \times 10^{-2}\ m$

$N_1 = 2000\ rpm$

$Q_1 = 3\ m^3/sec$

$\eta_{mean} = 0.75$

$H_{m1} = 30\ m$

multistage

$N_2 = 1500\ rpm$

$Q_2 = 5\ m^3/sec$

$H_{m2} =$ ~~200 m~~ height per stage

$D_2 = ?$

Total Head $= 200\ m$

To replace the pumps, their specific speeds should be same

$$\therefore \frac{N_1\sqrt{Q_1}}{(H_{m1})^{3/4}} = \frac{N_2\sqrt{Q_2}}{(H_{m2})^{3/4}}$$

$$\Rightarrow \frac{2000\sqrt{3}}{(30)^{3/4}} = \frac{1500\sqrt{5}}{(H_{m2})^{3/4}} \Rightarrow H_{m2} = 28.71\ m$$

$$\therefore \text{no. of stages} = \frac{\text{Total Head}}{\text{Head per stage}} = \frac{200}{28.71} = 6.96 \simeq 7$$

PTO

we know that $\frac{\sqrt{H_{m1}}}{D_1 N_1} = \frac{\sqrt{H_{m2}}}{D_2 N_2}$

$$\therefore \frac{\sqrt{30}}{30 \times 10^{-2} \times 2000} = \frac{\sqrt{28.71}}{D_2 \times 1500}$$

$$\Rightarrow D_2 = 0.3913\, m = 39.13\, cm$$

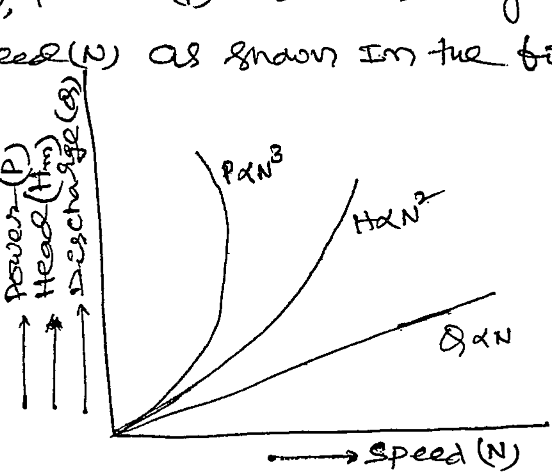
Characteristic Curves of Centrifugal pumps:

The Curves that are plotted from the results of a number of tests, when the pump is working under different Conditions such as flow rate, head and speed are called Characteristic curves.

The following are the important characteristic curves of the Centrifugal pumps.

(i) Main Characteristic curves
(ii) operating characteristic curves and
(iii) Constant efficiency curves.

Main Characteristic Curves: The curves representing the variation of manometric head (H_m), power (P) and discharge (Q) of a Centrifugal pump wrt to speed (N) as shown in the figure.



For plotting curves of manometric head versus speed, discharge is kept Constant.

$\therefore$ From the relation $\frac{\sqrt{H_m}}{DN} =$ Constant

we have $H_m \propto N^2$, hence the curve is a parabola.

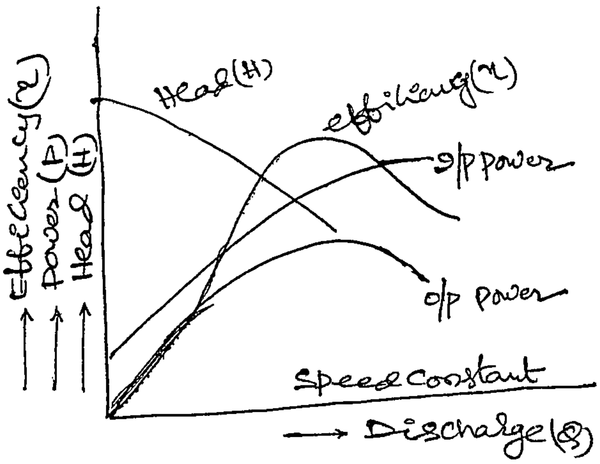
For plotting curves of power versus speed, H_m and Q are kept Constant

$\therefore$ From $\frac{P}{D^5 N^3} =$ Constant, we have $P \propto N^3$. (Cubic curve)

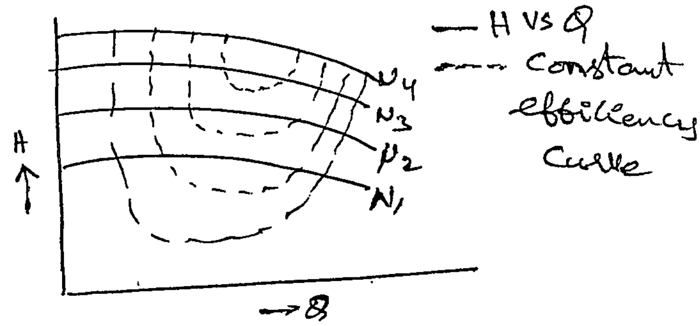
From the relation $\frac{Q}{D^3 N} =$ Constant, we have $Q \propto N$ (straight line)

<u>Operating Characteristic Curves</u>: The curves representing the variation of head, power and efficiency wrt discharge, when the speed of the centrifugal pump is kept constant are called operating curves.

As shown in the figure the o/p power does not pass through the origin because even at zero discharge some power is needed to overcome mechanical losses.



<u>Constant efficiency curves</u>: For plotting these curves, the Head(H) versus discharge(Q) and efficiency (η) versus discharge(Q) curves for different speeds(N) are used. By combining these curves, the constant efficiency curves can be obtained.



<u>Pumps in series</u>: The arrangement of number of impellers mounted in series on the same shaft is called series connection. The connection is used to obtain a high head with relatively small quantity of liquid delivering.

<u>Advantages</u>:
1. less loss due to friction
2. reduced stresses
3. small slip leakage
4. thrust can be eliminated by proper arrangement of impellers
5. high suction lift is possible

PTO

Pumps in parallel: The arrangement of the pumps working separately to lift the liquid from the common sump and deliver it to a common collecting pipe is called "pumps in parallel". This is used to deliver large quantity of liquid against relatively small head.

Cavitation: Vapour bubbles are formed in a flowing fluid where the pressure of the liquid falls below the vapour pressure. These bubbles may collapse suddenly in a higher pressure region causing pitting action on the surfaces. Thus cavities are formed on the metallic surfaces, this is called "Cavitation". ~~(This cavitation causes considerable noise and vibration)~~

Effects of Cavitation:

(i) metallic surfaces are damaged
(ii) considerable noise and vibrations are produced
(iii) efficiency decreases

NOTE: - Reaction turbines and Centrifugal pumps are subjected to Cavitation

Net Positive Suction Head (NSPH): The difference of the vapour pressure head from the sum of absolute pressure head at inlet and velocity head.

∴ Net Positive Suction Head (NSPH) = pressure head at inlet − vapour pressure head + velocity head

$$= \frac{P_i}{\rho g} - \frac{P_v}{\rho g} + \frac{V_s^2}{2g}$$

But pressure head at inlet is given by

$$P_i = \frac{P_a}{\rho g} - \left(\frac{V_s^2}{2g} + h_s + h_{fs}\right),$$ where P_a = atmospheric pressure

h_s = height of inlet pump foundations

h_{fs} = loss of head in the foot valve

$$\therefore NSPH = \frac{P_a}{\rho g} - \left(\frac{V_s^2}{2g} + h_s + h_{fs}\right) - \frac{P_v}{\rho g} + \frac{V_s^2}{2g}$$

$$= \frac{P_a}{\rho g} - \frac{P_v}{\rho g} - h_s - h_{fs}$$

$$= H_a - H_v - h_s - h_{fs} \text{ (Total suction head)}$$

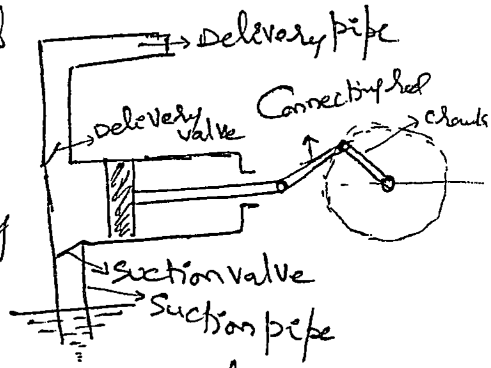
NOTE: NSPH may also defined as the total head required to make the liquid flow through the suction pipe to the impeller.

Priming of Centrifugal pumps: the process of filling the suction pipe, Casing and a portion of the delivery pipe from out side source with the liquid to be raised before starting the pump to remove any air, gas (or) vapour is called ~~pump~~ priming of the pump.

Reciprocating pumps

A pump in which mechanical energy is converted into hydraulic energy by sucking the liquid into a cylinder in which a piston is reciprocating and which exerts thrust on the liquid is called reciprocating pump.

Working: A single acting reciprocating pump is as shown in the figure.



The piston in the cylinder moves with the help of a crank, which is rotated by a motor. when piston moves away from the suction pipe, the suction valve opens and because of the partial vaccum in the cylinder, the liquid is forced into the cylinder from the sump.

when piston moves towards the delivery pipe, pressure on the liquid increases and valve in the delivery pipe opens and liquid is pumped into the delivery pipe.

PTO

Discharge of a reciprocating pump: Discharge of a reciprocating pump is given by the relation

discharge (Q) = discharge in one revolution × No. of revolutions/sec

$$= (A \times L) \times \frac{N}{60} \ m^3/sec.$$

where A = Cross-sectional area of the cylinder

$$= \frac{\pi}{4} D^2$$

D = Diameter of the cylinder

L = Length of the stroke

$= 2r$

r = Radius of the crank

N = RPM of the crank

weight of the liquid delivered (W) $= \rho g \times Q = \frac{\rho g A L N}{60}$ kgf

Coefficient of discharge (C_d): The ratio of actual discharge (Q_{act}) to the theoritical discharge (Q_{the}) is called coefficient of discharge

$$\therefore \text{Coefficient of discharge } (C_d) = \frac{Q_{act}}{Q_{the}}$$

when C_d expressed in percentage, then it is known as volumetric efficiency of the pump.

Slip: The difference between theoritical discharge (Q_{the}) and actual discharge (Q_{act}) is called "slip".

$$\therefore \text{slip} = Q_{the} - Q_{act}$$

But slip must be expressed in terms of percentage

$$\therefore \% \text{ of slip} = \frac{Q_{the} - Q_{act}}{Q_{the}} \times 100 = (1 - C_d) \times 100$$

NOTE: For good condition of the pump, percentage of slip must be 2% (or) less.

Workdone by a Reciprocating pump:

workdone per second = weight of the liquid lifted × height through which the liquid lifted

$$= W \times (h_s + h_d)$$

where h_s = height of the axis of the cylinder from the free surface of the liquid in the sump

h_d = height of delivery outlet above the cylinder axis

$$\text{workdone } (W) = \frac{\rho g A L N}{60}(h_s + h_d)$$

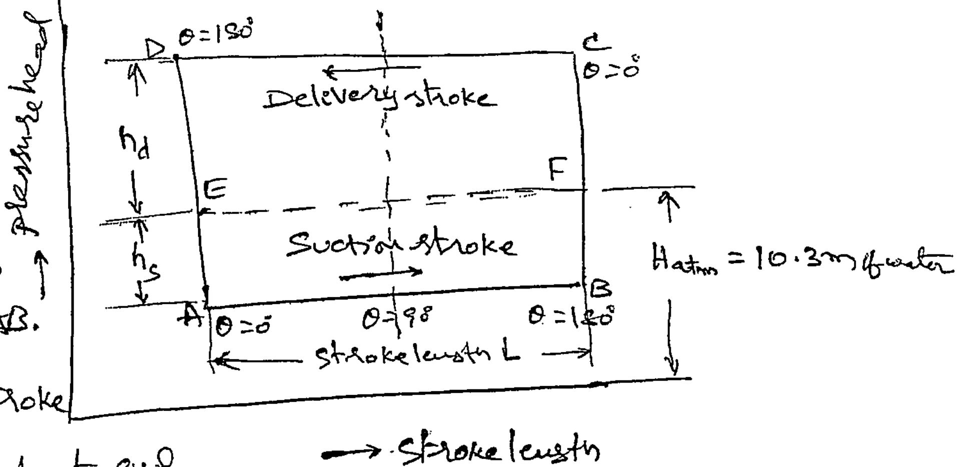
Power required to drive the pump is

$$P = \frac{\text{workdone/second}}{1000} \text{ kW}$$

$$= \frac{\rho g A L N (h_s + h_d)}{60 \times 1000} \text{ kW}$$

Indicator diagram: This is a graph between pressure head and stroke length of the piston for one complete revolution. This gives the pressure head of the liquid in the cylinder corresponding to any position during the suction and delivery strokes. Pressure head is taken as ordinate and stroke length as abscissa.

During suction stroke, pressure head is constant and equal to suction head (h_s). This is represented by the line AB.



During the delivery stroke pressure head is constant and equal to delivery head (h_d). This represented by the line CD.

PTO

thus for one complete revolution of the crank, the pressure head in the cylinder is represented by the diagram A-B-C-D-A, hence this is called indicator diagram.

- workdone by the pump per second $\propto$ Area of the indicator diagram

NARASARAOPETA ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

MID & ASSIGNMENT EXAMINATION QUESTION PAPERS WITH SCHEME AND SOLUTIONS

NARASARAOPET ENGINEERING COLLEGE (AUTONOMOUS): NARASARAOPET
DEPARTMENT OF MECHANICAL ENGINEERING

II B.TECH I - SEMESTER ASSIGNMENT TEST – I, September – 2022

SUBJECT: FLUID MECHANICS AND HYDRAULIC MACHINERY	**DATE:** 27-09-2022
DURATION: 30 MIN	**MAX MARKS:** 10

Q. No	Questions	Course Outcome (CO)	Knowledge Level as Per Bloom's Taxonomy	Marks
1A)	Distinguish the following fluid properties: i. Specific gravity ii. Viscosity iii. Surface tension v. Specific weight	CO1	Analyzing (K4)	5
B)	Calculate the density, density & specific gravity of one liter of liquid which weights 7N	CO1	Analyzing (K4)	5
2A)	Derive & Explain Dynamic viscosity & Kinematic Viscosity	CO1	Analyzing (K4)	5
B)	The space between two square between flat parallel plate is filled with oil,each side of the plate is 60cm.the thichness of the oil film is 12.5mm.the upper plated ,which moves at 2.5 meter per sec requires a force of 98.1 N to maintain the speed. Determine A)the dynamic viscosity of the oil in poise and B)The Kinematic Viscosity Of Oil in stokes if the specific gravity of the oil is 0.95	CO1	Evaluating (K5)	5
3A)	Draw & Explain types of Fluids	CO1	Evaluating (K5)	5
B)	Derive the Pascal's law	CO1	Evaluating (K5)	5
4 A)	Explain surface tension & Capillarity	CO1	Evaluating (K5)	5
B)	Calculate the capillary rise in a glase tube of 2.5 mm diameter when immersed vertically in A) Water B) Mercury, Take the surface tension of water 0.0725 N/m and Surface tension of mercury 0.52 N/m for mercury in contact with air. The specific gravity for mercury is given as 13.6 and angle of contact is 130^0 .	CO1	Analyzing (K4)	5
5 A)	Derive U-Tube manometer of A) Gauge pressure B)Vacuum Pressure	CO1	Evaluating (K5)	5
B)	Derive U-tube Differential Manometer	CO1	Evaluating (K5)	5

NARASARAOPET ENGINEERING COLLEGE (AUTONOMOUS): NARASARAOPET
DEPARTMENT OF MECHANICAL ENGINEERING
II B.TECH I-SEMESTER MID EXAMINATION-I, November-2022

SUBJECT: FLUID MECHANICS AND HYDRAULIC MACHINERY	DATE: 08-11-2022
DURATION: 90 MIN,	MAX MARKS: 25

Answer all the questions

Q. No		Questions	Course Outcome (CO)	Knowledge Level as Per Bloom's Taxonomy	Marks
1.	a.	The space between two square between flat parallel plate is filled with oil,each side of the plate is 60cm.the thickness of the oil film is 12.5mm.the upper plated ,which moves at 2.5 meter per sec requires a force of 98.1 N to maintain the speed. Determine A)the dynamic viscosity of the oil in poise and B)The Kinematic Viscosity Of Oil in stokes if the specific gravity of the oil is 0.95	CO1	Analysing (K4)	5
	b.	Derive U-Tube differential manometer	CO1	Evaluating (K5)	5
2.	a.	Distinguish between: i. Steady and Un-steady Flow ii. Uniform and Non-Uniform Flow iii. Laminar and Turbulent Flow	CO2	Analyzing (K4)	5
	b.	Derive Euler's Equation of Motion? How will you obtain Bernoulli's equation from it?	CO2	Evaluating (K5)	5
3.		A 30cm diameter pipe conveying water, branches into two pipes of diameters 20cm and 15cm respectively. If the average velocity in the 30cm diameter pipe is 2.5m/s, find the discharge in this pipe. Also determine the velocity in 15cm pipe if the average velocity in 20cm diameter pipe is 2m/s	CO3	Evaluating (K5)	5

NARASARAOPET ENGINEERING COLLEGE (AUTONOMOUS): NARASARAOPET
DEPARTMENT OF MECHANICAL ENGINEERING
II B.TECH I-SEMESTER MID EXAMINATION-I, November-2022

SUBJECT: FLUID MECHANICS AND HYDRAULIC MACHINERY	DATE: 08-11-2022
DURATION: 90 MIN,	MAX MARKS: 25

Answer all the questions

Q. No		Questions	Course Outcome (CO)	Knowledge Level as Per Bloom's Taxonomy	Marks
1.	a.	The space between two square between flat parallel plate is filled with oil,each side of the plate is 60cm.the thickness of the oil film is 12.5mm.the upper plated ,which moves at 2.5 meter per sec requires a force of 98.1 N to maintain the speed. Determine A)the dynamic viscosity of the oil in poise and B)The Kinematic Viscosity Of Oil in stokes if the specific gravity of the oil is 0.95	CO1	Analysing (K4)	5
	b.	Derive U-Tube differential manometer	CO1	Evaluating (K5)	5
2.	a.	Distinguish between: i. Steady and Un-steady Flow ii. Uniform and Non-Uniform Flow iii. Laminar and Turbulent Flow	CO2	Analyzing (K4)	5
	b.	Derive Euler's Equation of Motion? How will you obtain Bernoulli's equation from it?	CO2	Evaluating (K5)	5
3.		A 30cm diameter pipe conveying water, branches into two pipes of diameters 20cm and 15cm respectively. If the average velocity in the 30cm diameter pipe is 2.5m/s, find the discharge in this pipe. Also determine the velocity in 15cm pipe if the average velocity in 20cm diameter pipe is 2m/s	CO3	Evaluating (K5)	5

NARASARAOPET ENGINEERING COLLEGE (AUTONOMOUS): NARASARAOPET
DEPARTMENT OF MECHANICAL ENGINEERING

II B.TECH I - SEMESTER ASSIGNMENT TEST – II, November – 2022

SUBJECT: FLUID MECHANICS AND HYDRAULIC MACHINERY	**DATE:** 30-11-2022
DURATION: 30 MIN	**MAX MARKS:** 10

Q. No	Questions	Course Outcome (CO)	Knowledge Level as Per Bloom's Taxonomy	Marks
1A)	Derive Force Excreted by the jet on a stationary vertical plate	CO4	Analyzing (K4)	5
B)	Find the force exerted by the jet of water of diameter 75 mm on a stationary flat plate, when jet strikes the plate normally with a velocity of 20 m/sec	CO4	Analyzing (K4)	5
2A)	Derive Force Excreted by the jet on a stationary inclined flat plate	CO4	Analyzing (K4)	5
B)	A jet of water Diameter 75 mm moving with a velocity of 25 m/s strikes a fixed plate in such a way that the angle between the jet and plate is 60^0. Find the force exerted by the jet on the plate (i) in the direction normal to the plate (ii)in the direction of the jet.	CO4	Evaluating (K5)	5
3A)	Jet strikes the curved plate at one end tangentially and plate is unsymmetrical	CO4	Evaluating (K5)	5
B)	A jet of water diameter 75 mm moving with a velocity of 30m/s,strikes a curved fixed plate tangentially at one end at an angle of 30^0 to the horizontal.the jet leaves the plate at an angle of 20^0 to the horizontal. Find the force exerted by the jet on the plate in the horizontal and vertical direction.	CO4	Evaluating (K5)	5
4 A)	Derive Force Excreted by the jet on a inclined flat moving plate	CO4	Evaluating (K5)	5
B)	A 7.5 cm diameter jet having a velocity of 30 m/s strikes a flat plate, the normal of which is inclined at 45^0 to the axis of the jet. Find the normal pressure on the plate.(i)when the plate is stationary,and (ii)when the plate is moving with a velocity of 15m/s and away from the jet.Also determine the power and efficiency of the jet when the plate is moving.	CO4	Analyzing (K4)	5
5 A)	Explain Boundary Layer development on flat plate	CO3	Evaluating (K5)	5
B)	Explain Boundary Layer Thickness & Displacement Thickness	CO3	Evaluating (K5)	5

NARASARAOPET ENGINEERING COLLEGE(AUTONOMOUS), NARASARAOPET

DEPARTMENT OF MECHANICAL ENGINERRING

II B.TECH I-SEMESTER MID-II, DECEMBER-2022

SUBJECT: **Fluid Mechanics & Hydraulic Machinery** DATE: 20-12-2022

DURATION: 90MIN MAX MARKS: 25 M

Sl. No	Questions	CO	Bloom's Taxanomy	Marks
1	**Derive** the work done, efficiency and specifications of a **Pelton Wheel Turbine** with velocity triangles.	CO4	Analyzing (K4)	5
2	**Draw** and explain the working of **Francis Turbine.**	CO4	Analyzing (K4)	5
3	Following data is given for a Francis Turbine. Net head is 60mts,speed of shaft is 700rpm, shaft power is 294.3kw,overall efficiency is 93%,flow ratio is 0.20,breadth ratio is 0.1,outer diameter of the runner is twice the internal diameter of the runner, thickness of vanes occupy 5% of circumferential area of runner, velocity of flow is constant at inlet and outlet. Discharge is radial at outlet. Determine (i)Guide blade angle (ii)Runner vane angles at inlet and outlet (iii)Diameters of runners at inlet and outlet (iv)Width of wheel at inlet	CO4	Analyzing (K4)	5
4	**Derive** work done and efficiencies of single stage centrifugal pump.	CO4	Analyzing (K4)	5
5	**Draw** and explain the working of reciprocating pump	CO4	Analyzing (K4)	5

NARASARAOPET ENGINEERING COLLEGE(AUTONOMOUS), NARASARAOPET

DEPARTMENT OF MECHANICAL ENGINERRING

II B.TECH I-SEMESTER MID-II, DECEMBER-2022

SUBJECT: Fluid Mechanics & Hydraulic Machinery DATE: 20-12-2022

DURATION: 90MIN MAX MARKS: 25 M

Sl. No	Questions	CO	Bloom's Taxanomy	Marks
1	**Derive** the work done, efficiency and specifications of a **Pelton Wheel Turbine** with velocity triangles.	CO4	Analyzing (K4)	5
2	**Draw** and explain the working of **Francis Turbine.**	CO4	Analyzing (K4)	5
3	Following data is given for a Francis Turbine. Net head is 60mts,speed of shaft is 700rpm, shaft power is 294.3kw,overall efficiency is 93%,flow ratio is 0.20,breadth ratio is 0.1,outer diameter of the runner is twice the internal diameter of the runner, thickness of vanes occupy 5% of circumferential area of runner, velocity of flow is constant at inlet and outlet. Discharge is radial at outlet. Determine (i)Guide blade angle (ii)Runner vane angles at inlet and outlet (iii)Diameters of runners at inlet and outlet (iv)Width of wheel at inlet	CO4	Analyzing (K4)	5
4	**Derive** work done and efficiencies of single stage centrifugal pump.	CO4	Analyzing (K4)	5
5	**Draw** and explain the working of reciprocating pump	CO4	Analyzing (K4)	5

NEC NARASARAOPETA ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

II B.Tech I SEM I - Assignment Examination Scheme

1. a) Definition Fluid Properties - 5 M

   b) Problem Solution, Fluid Properties - 5 M

2. a) Derive and Explanation - 5 M

   b) Problem Solution - 5 M

3. a) Draw and Explain - 5 M

   b) Derive and Explanation - 5 M

4. a) Draw and Explain - 5 M

   b) Problem Solution - 5 M

5. a) Draw and Explain - 5 M

   b) Draw and Explain - 5 M

NEC NARASARAOPETA ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

II B.Tech I SEM I - Mid Examination Scheme

1. a) Problem Solution - 5 M

   b) Derive and Explanation - 5 M

2. a) Definitions - 5 M

   b) Derive and Explanation - 5 M

3. a) Problem Solution - 5 M

NEC NARASARAOPETA ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

II B.Tech I SEM II - Assignment Examination Scheme

1. a) Derive and Explanation - 5 M

   b) Problem Solution - 5 M

2. a) Derive and Explanation - 5 M

   b) Problem Solution - 5 M

3. a) Derive and Explanation - 5 M

   b) Problem Solution - 5 M

4. a) Draw and Explain - 5 M

   b) Problem Solution - 5 M

5. a) Draw and Explain - 5 M

   b) Draw and Explain - 5 M

NEC NARASARAOPETA ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

II B.Tech I SEM II - Mid Examination Scheme

1. a) Derive and Explanation - 5 M
2. a) Draw and Explanation - 5 M

   b) Problem Solution - 5 M
3. a) Derive and Explanation - 5 M
4. b) Draw and Explanation - 5 M

NARASARAOPETA ENGINEERING COLLEGE::NARASARAOPET

(AUTONOMOUS)

(R20) 2021 BATCH II B.TECH I SEMESTER FINAL INTERNAL MARKS 2022-2023

BRANCH - ME			FLUID MECHANICS AND HYDRAULIC MACHINERY(R20ME2102)								
S.NO	H.T.NO.	STUDENT NAME	A1	D1	Q1	CYCLE-1	A2	D2	Q2	CYCLE-2	TOTAL
1	21471A0301	ANGIREKULA VEERANJANEYULU	5	12	9	26	5	14	10	29	29
2	21471A0302	BATTULA YUVA RAJU	5	10	5	20	5	8	6	19	20
3	21471A0303	BOMMIREDDY VENU	5	13	9	27	5	11	9	25	27
4	21471A0304	JEEDIMALLA SRI LAKSHMI NILENDRA	5	11	10	26	5	9	6	20	25
[illegible]	21471A0305	KONATHAM VENKATA NARAYANA	4	5	9	18	5	8	9	22	22
6	21471A0306	KUNCHALA ANKA RAO	5	7	8	20	5	8	10	23	23
7	21471A0307	PATHAN RIYAZ	4	11	7	22	5	10	8	23	23
8	21471A0309	SASAPU SAI SANTOSH	5	14	4	23	5	8	10	23	23
9	21471A0310	SOUBHAGYAPU SAI RAM	A	8	8	16	5	7	6	18	18
10	21471A0311	MUNAGA RAMANJANEYULU	4	5	5	14	5	8	10	23	22
11	21471A0312	YELCHURI HEMALATHA MEGHANA	5	15	10	30	5	15	9	29	30
12	21471A0314	ALLAM TIRUMALA RAJU	4	2	10	16	A	8	7	15	16
13	22475A0301	VANTAKU GANAPATHI LAKSHMI NAIDU	5	14	10	29	5	14	10	29	29
14	22475A0302	SYED HUSSAIN	4	13	9	26	5	8	9	22	26
15	22475A0303	BEHERA SANJAY KUMAR	2	5	4	11	5	9	8	22	20
16	22475A0304	YASAM MANIKANTA	3	4	8	15	5	11	10	26	24
17	22475A0305	MALLADI GOPI PURNA	3	6	10	19	5	11	10	26	25
1[illegible]	22475A0306	UNGATI LOKESH	3	10	10	23	5	13	10	28	27
19	22475A0307	RAMAVATH VASU DEVA NAIK	4	14	7	25	5	9	9	23	25
20	22475A0308	PASALA SYAM KUMAR	4	11	10	25	5	8	10	23	25
21	22475A0309	THURIMELLA VAMSI GANESH	3	3	10	16	5	8	8	21	20
22	22475A0310	KUKKAMALLA KARTHIK	3	8	10	21	4	8	5	17	21
23	22475A0311	VUTLA KISHORE	3	9	9	21	5	9	10	24	24
24	22475A0312	DHARMANA APPALA NAIDU	4	11	8	23	5	9	4	18	22
25	22475A0313	NIKKU SURESH	5	11	10	26	5	11	10	26	26
26	22475A0314	GORANTLA SIVA KOTESWARA RAO	4	9	9	22	5	11	9	25	25
27	22475A0315	POGUNOLLA KARUN KUMAR	2	2	10	14	5	6	9	20	19
28	22475A0316	VIPPARLA RAVI TEJA	4	13	10	27	5	11	10	26	27
29	22475A0317	BANDLAMUDI NAGA RAJU	4	14	10	28	5	11	8	24	28
30	22475A0318	BOJJA SYAM BABU	3	3	7	13	5	11	8	24	22

BRANCH - ME			FLUID MECHANICS AND HYDRAULIC MACHINERY(R20ME2102)								
S.NO	H.T.NO.	STUDENT NAME	A1	D1	Q1	CYCLE-1	A2	D2	Q2	CYCLE-2	TOTAL
31	22475A0319	ATHULURI PURNA VENKATA RAMARAO	3	8	10	**21**	5	8	7	**20**	**21**
32	22475A0320	BATTULA LAKSHMI NARAYANA	A	A	A	**0**	A	A	A	**0**	**0**
33	22475A0321	GUDIKANDULA ANJANEYULU	2	8	8	**18**	4	9	8	**21**	**21**
34	22475A0322	AYINAMPUDI KISHORE BABU	4	7	3	**14**	5	10	9	**24**	**22**
35	22475A0323	KETHABOYINA MAHESH	3	8	9	**20**	5	8	10	**23**	**23**
36	22475A0324	SHAIK BABULAL	2	9	9	**20**	5	11	9	**25**	**24**
37	22475A0325	BANDARU VENU GOPAL	4	9	9	**22**	5	11	7	**23**	**23**
38	22475A0326	YADAVALLI LOKESH	2	7	8	**17**	5	12	10	**27**	**25**
3[illegible]	22475A0327	CHOUDAM VENKATESH	3	8	7	**18**	5	10	10	**25**	**24**
40	22475A0328	CHATTI MURALI KRISHNA	3	7	9	**19**	5	11	10	**26**	**25**
41	22475A0329	DARAM PRUDHVI KRISHNA	2	6	9	**17**	5	12	7	**24**	**23**
42	22475A0330	SHAIK NAGUR BASHA	3	4	9	**16**	4	3	9	**16**	**16**
43	22475A0331	GOLLAPUDI SARATH KUMAR	4	11	6	**21**	4	11	7	**22**	**22**
44	22475A0332	ADAKA VINOD	3	8	4	**15**	4	11	5	**20**	**19**
45	22475A0333	JANNI ARUN	3	7	10	**20**	4	12	9	**25**	**24**
46	22475A0334	NOWPADA MEGHANADH	2	8	10	**20**	4	11	9	**24**	**24**
47	22475A0335	BALAGA YUGANDHAR	4	9	4	**17**	5	12	9	**26**	**25**
48	22475A0336	NEYYELA KUMAR BEHERA	3	6	6	**15**	5	8	10	**23**	**22**
49	22475A0337	KUNITI PAVAN KUMAR	0	7	9	**16**	5	13	9	**27**	**25**
50	22475A0338	BHUKYA DIWAKAR NAIK	2	9	9	**20**	4	11	7	**22**	**22**
51	22475A0339	VOONA NARENDRA	5	11	9	**25**	5	14	10	**29**	**29**
52	22475A0340	CHANDARLAPATI GANESH	3	10	2	**15**	4	10	6	**20**	**19**
53	22475A0341	BALAGA MOHAN	2	12	9	**23**	5	11	10	**26**	**26**
54	22475A0342	BOMMALI MAHESH	4	12	9	**25**	5	10	8	**23**	**25**
55	22475A0343	DUDDETI NAGA SAI	4	14	9	**27**	5	15	10	**30**	**30**
56	22475A0344	BASWA DILLESWARA RAO	2	11	9	**22**	5	14	8	**27**	**26**
57	22475A0345	KORRAPATI MOHAN KRISHNA	4	13	10	**27**	5	15	10	**30**	**30**
58	22475A0346	NAKKANABOINA NAGA SRIDHAR	4	12	6	**22**	5	14	10	**29**	**28**
59	22475A0347	GONDU GANESH PAVAN	4	12	9	**25**	5	14	9	**28**	**28**
60	22475A0348	BASWA DILLESWARA RAO	2	9	8	**19**	5	9	10	**24**	**23**
61	22475A0349	KORRAPATI MOHAN KRISHNA	4	11	8	**23**	5	11	7	**23**	**23**
62	22475A0350	NAKKANABOINA NAGA SRIDHAR	4	9	9	**22**	5	12	9	**26**	**26**
63	22475A0351	GONDU GANESH PAVAN	4	10	9	**23**	5	11	7	**23**	**23**
64	22475A0352	LINGA SRINIVAS	3	14	9	**26**	5	12	9	**26**	**26**

NARASARAOPETA ENGINEERING COLLEGE::NARASARAOPET

(AUTONOMOUS)

(R20) 2020 BATCH II B.TECH I SEMESTER FINAL INTERNAL MARKS - FEB/MARCH- 2022

BRANCH - ME-A			FLUID MECHANICS AND HYDRAULIC MACHINERY (R20ME2102)								
SL.NO.	H.T.NO.	STUDENT NAME	A1	D1	Q1	CYCLE-1	A2	D2	Q2	CYCLE-2	TOTAL
1	20471A0301	ALAVALA ADITHYA VARA PRASAD	5	15	5	25	4	10	2	16	24
2	20471A0302	BATTULA RAJESH	5	15	4	24	4	11	7	22	24
3	20471A0303	BHIMAVARAPU HEMANTH KUMAR	A	A	A	0	A	7	3	10	8
4	20471A0304	BONAM JAYA PRAKASH	5	14	3	22	3	11	8	22	22
5	20471A0305	BOYAPATI PAVAN KUMAR	A	12	2	14	3	5	4	12	14
6	20471A0306	DADDANALA VEERANJIREDDY	4	11	2	17	4	8	5	17	17
7	20471A0307	DERANGILA PARDHU GANESH	4	12	9	25	5	8	8	21	25
8	20471A0308	DOPPALAPUDI S S NAGA RAVITEJA	4	14	8	26	5	8	7	20	25
9	20471A0309	EEDARA MOHON SAI	4	14	6	24	3	9	2	14	22
10	20471A0310	GANESH SAI PAVAN	5	14	10	29	4	11	3	18	27
11	20471A0311	GANGARAPU VENKATA REDDY	2	A	A	2	A	5	A	5	5
12	20471A0312	GERA KOTESWARA RAO	5	14	3	22	5	14	A	19	22
13	20471A0313	KARASALA PRASANTH	3	14	2	19	5	6	1	12	18
14	20471A0314	KARASANI PAVAN KUMAR REDDY	5	15	2	22	3	10	2	15	21
15	20471A0315	KATTA MAHESWAR	4	15	3	22	5	14	3	22	22
16	20471A0316	KATUMALA PRASANTH KUMAR	A	A	A	0	-	-	-	0	0
17	20471A0317	KESARI DHANUNJAYA REDDY	4	11	3	18	4	9	3	16	18
18	20471A0318	KOMARAGIRI SASIKUMAR	5	14	9	28	4	14	4	22	27
19	20471A0319	KOMERA SIVA NAGARAJU	2	12	5	19	0	6	4	10	18
20	20471A0320	KOTHA GOPI	5	15	1	21	5	14	6	25	25
21	20471A0321	KUNDURTHI NAVEEN	5	14	3	22	4	8	3	15	21
22	20471A0323	MADANU JOSEPH VINAY KUMAR	4	9	9	22	5	8	6	19	22
23	20471A0324	MADDUMALA RAMAKRISHNA	5	9	4	18	4	6	6	16	18
24	20471A0325	MAGANTI SASI PAVAN	4	15	9	28	4	11	3	18	26
25	20471A0326	MAKKENA SAMBASIVA RAO	5	10	9	24	5	10	5	20	24
26	20471A0327	MIRIYALA SASHANK	A	14	7	21	5	12	5	22	22
27	20471A0328	NALLA ABHIRAM CHOWDARY	5	12	5	22	5	7	2	14	21
28	20471A0329	NUTHAKKI RAKESH	4	12	7	23	4	10	6	20	23
29	20471A0330	ARAVAPALLI SAI SRINIVAS	3	12	6	21	4	14	3	21	21
30	20471A0331	PALETI JOHN HOSANNA	5	14	9	28	4	11	3	18	26
31	20471A0332	PERUMAALLA SRIKANTH	5	15	5	25	5	13	5	23	25
32	20471A0333	POLURI KRISHNA CHAITHANYA	5	13	6	24	5	12	7	24	24

33	20471A0334	PONNAGANTI CHANDU HARSHA VARDHAN	4	5	10	19	4	10	9	23	23
34	20471A0336	PATHAN MEERA VALI	4	2	4	10	0	6	2	8	10
35	20471A0337	POTTIMURTHI PURNA CHANDRA RAO	5	15	10	30	5	13	10	28	30
36	20471A0338	PRUDHVI DURGA BHARATH CHANDAN	5	6	5	16	5	12	3	20	20
37	20471A0339	RAMAVATHU BADDUNAIK	2	9	7	18	3	2	5	10	17
38	20471A0341	SHAIK APPAPURAM MAHABOOB SUBHANI	5	9	3	17	3	5	3	11	16
39	20471A0342	SHAIK ASIF	A	A	A	0	A	A	A	0	0
40	20471A0343	SHAIK GANGARAM ABDUL RAHAMAN	4	13	10	27	4	5	2	11	24
41	20471A0344	SHAIK GULLAPALLI NAGURVALI	3	9	6	18	2	8	3	13	17
42	20471A0345	SHAIK LAL AHAMAD BASHA	3	5	5	13	0	0	1	1	11
43	20471A0346	SHAIK MAHAMMAD FAREED	4	8	4	16	3	8	3	14	16
44	20471A0347	SHAIK MAHAMMAD YUNUS	4	6	6	16	0	0	3	3	14
45	20471A0348	SHAIK MANISHA	5	15	9	29	5	15	8	28	29
46	20471A0349	SHAIK PARVEZ	5	9	4	18	4	9	9	22	22
47	20471A0350	SHAIK SADHIK	5	9	9	23	5	6	2	13	21
48	20471A0351	SHAIK SALMAN	4	6	3	13	4	5	4	13	13
49	20471A0352	TIPPIREDDY AMARNATHREDDY	2	6	10	18	5	5	7	17	18
50	20471A0353	VADLAVALLI GANESH	3	5	4	12	3	5	3	11	12
51	20471A0354	VEERAGANDHAM VENKATA MANIKANTA	5	15	9	29	4	14	4	22	28
52	20471A0356	ADAKA GOPIRAJU	5	15	8	28	5	14	3	22	27

NARASARAOPETA ENGINEERING COLLEGE::NARASARAOPET

(AUTONOMOUS)

(R20) 2020 BATCH II B.TECH I SEMESTER FINAL INTERNAL MARKS - FEB/MARCH- 2022

BRANCH - ME-B			FLUID MECHANICS AND HYDRAULIC MACHINERY(R20ME2102)								
SL.NO.	H.T.NO.	STUDENT NAME	A1	D1	Q1	CYCLE-1	A2	D2	Q2	CYCLE-2	TOTAL
1	20471A0357	ATCHYUTHA PAVAN KUMAR	4	9	4	17	5	8	3	16	17
2	20471A0358	BALLE RAMANJANEYULU	5	9	6	20	5	9	8	22	22
3	20471A0359	BANDARU SAI GANESH	4	8	8	20	4	6	1	11	19
4	20471A0360	BERAM NARENDRA REDDY	5	11	7	23	5	2	3	10	21
5	20471A0361	CHEBROLU MANIKANTA SAI NITHIN	4	A	A	4	5	9	5	19	16
6	20471A0362	CHENNAMSETTY GOPI	5	10	9	24	5	11	8	24	24
7	20471A0363	GANGULA SUNNY	5	14	8	27	5	11	4	20	26
8	20471A0364	GANJI HANUMA KOTI GANESH	2	9	6	17	5	8	3	16	17
9	20471A0365	GANNNAVARAPU JAYA SRIKANTH	2	9	5	16	5	2	2	9	15
10	20471A0366	GUTTIKONDA AYYAPPA REDDY	5	12	3	20	5	11	9	25	24
11	20471A0367	MADDINENI AJAY	5	12	6	23	5	13	10	28	27
12	20471A0368	MANNEPALLI VEERA NARASIMHA	3	4	4	11	5	6	3	14	14
13	20471A0369	MARAGANI NAGA THIRUMALA RAO	5	10	9	24	5	10	2	17	23
14	20471A0370	PARELLA BALA GURAVAIAH	A	3	A	3	5	5	5	15	13
15	20471A0371	SETLAM RANENDRA VAMSHI	5	12	7	24	5	10	6	21	24
16	20471A0372	SHAIK GUTHIKONDA SALIM	5	11	9	25	5	11	8	24	25
17	20471A0373	SHAIK JAKIR	4	12	9	25	4	12	3	19	24
18	20471A0374	SHAIK MOHAMMAD TAHEER	4	11	10	25	5	11	7	23	25
19	20471A0375	THOTA SRIVAMSI NADH	1	3	A	4	4	7	2	13	12
20	20471A0376	YAKKANTI SAI KIRAN REDDY	3	14	10	27	5	12	4	21	26
21	21475A0301	PALLAPOTHU SAIKIRAN YAD	5	15	10	30	5	14	10	29	30
22	21475A0302	SYED SARDAR VALI	5	15	10	30	5	10	9	24	29
23	21475A0303	DERANGULA GOPI KRISHNA	5	15	10	30	5	12	10	27	30
24	21475A0304	VADDANI RAKESH	5	14	10	29	5	12	5	22	28
25	21475A0305	SHAIK ADIL	5	15	8	28	5	14	4	23	27
26	21475A0306	JANAPAREDDI PRASAD	5	15	10	30	4	15	10	29	30
27	21475A0307	REPALLE YASHWANTH	4	14	10	28	4	12	8	24	28
28	21475A0308	RAMAVATHU PAVAN KUMAR N	4	14	10	28	5	12	9	26	28
29	21475A0309	NELAVALLI VIKAS	5	15	10	30	5	14	7	26	30
30	21475A0310	DUDDU JOSEPH	5	14	9	28	5	13	10	28	28
31	21475A0311	MUNIKOLA SANTHOSH KUMAR	5	9	10	24	4	11	8	23	24
32	21475A0312	MORAPAKULA CHARAN TEJA	5	13	8	26	5	14	4	23	26
33	21475A0313	GODA SANDEEP	4	11	9	24	5	12	9	26	26
34	21475A0314	MOGILI PRAKASH	4	12	10	26	5	9	6	20	25

ANCH - ME-B			FLUID MECHANICS AND HYDRAULIC MACHINERY(R20ME2102)								
..NO.	H.T.NO.	STUDENT NAME	A1	D1	Q1	CYCLE-1	A2	D2	Q2	CYCLE-2	TOTAL
35	21475A0315	SHAIK MABU SUBHANI	4	12	9	25	3	9	9	21	25
36	21475A0316	DAGGUPATI VENKATA PRADE	5	15	6	26	5	15	4	24	26
37	21475A0317	NAGASURENDRA CHARI UPPA	5	14	8	27	5	10	7	22	26
38	21475A0318	NALLURI NAVEEN	5	15	10	30	5	12	6	23	29
39	21475A0319	ORCHU VENKATA RAVINDRA	5	15	9	29	4	12	6	22	28
40	21475A0320	NELLURI YASWANTH	5	15	9	29	5	14	9	28	29
41	21475A0321	PENUMALA PAVAN KUMAR	5	14	10	29	5	12	9	26	29
42	21475A0322	BAANANA PRADEEP KUMAR	5	15	10	30	5	13	9	27	30
43	21475A0323	BOJANKI DEMUDU BABU	5	15	10	30	5	12	10	27	30
44	21475A0324	DATTI CHANDU	A	12	10	22	5	14	10	29	28
45	21475A0325	BORUGADDA NITHIN	5	13	9	27	5	12	5	22	26
46	21475A0326	VARIKUTI KARTHIK VENKAT	4	14	10	28	5	13	9	27	28
47	21475A0327	GOLLA SUNDARA SAMRAJYA	5	14	9	28	5	13	4	22	27
48	21475A0328	CHATTA VENKATRAMAIAH	5	11	10	26	5	11	6	22	26
49	21475A0329	KSHATRIYA JITHENDRA SIN	5	14	10	29	5	11	3	19	27
50	21475A0330	BOMMALI BALA SIVA YOGEN	5	13	10	28	5	12	6	23	27
51	21475A0331	REVALLA SAI	3	13	10	26	5	13	7	25	26
52	21475A0332	BANDI SRINIVAS	5	7	8	20	5	12	6	23	23
53	21475A0333	GURRAM SIVA GANESH	4	12	7	23	4	11	4	19	23
54	21475A0334	EMANI LEELA SHANKAR	5	9	9	23	4	9	8	21	23
55	21475A0335	KUPPALA SRINU	4	13	6	23	5	10	2	17	22

NEC NARASARAOPETA ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT WISE IMPORTANT QUESTIONS

Unit wise Sample assessment questions

COURSE OUTCOMES: Students are able to

CO1: Explain about Fluid Properties and hydrostatic forces acting on different surfaces

CO2: Apply conversation laws to fluid flow problems in engineering applications

CO3: Compute theory of Boundary layer flows, Identifies dimensionless parameters

CO4: Illustrate the force required to move the vane using by Jet

CO5: Demonstrate the turbines and its functions & Operating conditions of Centrifugal and

S NO	QUESTION	KNOWLEDGE LEVEL	CO
	UNIT I		
1	Explain the terms dynamic viscosity and kinematic viscosity.	K3	CO1
2	A simple manometer is used to measure the pressure of oil (sp.gr=0.8) flowing in pipe line. Its right limb is open to the atmosphere and left limb is connected to the pipe. The centre of the pipe is 9cm below the level of mercury in the right limb. If the difference of mercury level in the two limbs is 15cm, determine the absolute pressure of the oil in the pipe.	K4	CO1
3	Explain the phenomenon of capillarity. Obtain an expression for capillary rise of a liquid.	K3	CO1
4	An oil film of thickness 1.5 mm is used for lubrication between a square plate of size 0.9 m × 0.9 m and an inclined plane having an angle of inclination 20^0 . The weight of the square plate is 392.4 N and it slides down the plane with a uniform velocity of 0.2 m/s. Find the dynamic viscosity of the oil.	K3	CO1
	UNIT 2		
1	Explain the terms: (i) Path line (ii) Streak line (iii) Stream line, (iv) Stream tube.	K3	CO2
2	For steady incompressible flow verify whether the following values of u and v are possible: i) $u = 6xy + 2y^2$, $v = 7xy + 5x$ ii) $u = x^2 + y^2$, $v = -4xy$ iii) $u = -2x/(x^2 + y^2)$, $v = -2y/(x^2 + y^2)$.	K3	CO2
3	Derive the continuity equation for one dimensional flow	K4	CO2
	UNIT 3		
1	Explain the development of boundary layer formation over a flat plate.	K3	CO3
2	Find the displacement thickness, the momentum thickness and energy thickness for the velocity distribution in the boundary layer given by $(u/U) = 2(y/\delta) - (y/\delta)^2$.	K3	CO3
3	What do you understand by Boundary Layer ? Explain the development of	K3	CO3

	Boundary layer over a flat plate.		
4	Discuss displacement thickness, energy thickness and momentum thickness	K3	CO3
	UNIT 4		
1	Show that the efficiency of a free jet striking normally on a series of flat plates mounted on the periphery of a wheel can never exceed 50%.	K3	CO4
2	Derive the Equation for impact of jet striking a curved plate when the plate is moving in the direction of the jet?	K3	CO4
3	Differentiate between Francis turbine and Kaplan turbine.	K3	CO4
4	Classify the different types of turbines?	K2	CO4
5	Explain the function of various main components of Pelton Turbine with neat sketches.	K3	
	UNIT 5		
1	What is meant by NPSH (Net Positive Suction Head) ?	K3	CO5
2	Explain about main parts of a centrifugal pump.	K3	CO5
3	A centrifugal pump works against a head of 30 m and discharges 0.25 m3/s while running at 1000 rpm. The velocity of flow at the outlet is 3 m/s and the vane angle at outlet is 300. Determine the diameter and width of impeller at outlet if the hydraulic efficiency is 80 per cent.	K4	CO5
4	Draw and discuss the operating characteristics of a centrifugal pump	K3	CO5

NARASARAOPETA ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

PREVIOUS QUESTION PAPERS

Model Question Paper

Code:II B.Tech II Semester Regular Examinations

Month/Year: OCTOBER/2021

Sub Code: R20ME2102

SUBJECT NAME: FLUID MECHANICS AND HYDRAULIC MACHINES

(ME)

MODEL PAPER

Time: 3 hours **Max. Marks: 70**

Note: Answer All **FIVE** Questions.
All Questions Carry Equal Marks (5 X 14 = 71M)

Time: 3 Hrs **Max. Marks: 70**

Note: 1.Answer FIVE Questions, choice from each unit.

Execution Plan

Sl. No	Activities	Time (Minutes)
1	To study the Question Paper and choose to attempt	5
3	33 Minutes x 5 Questions	165
4	Quick revision & Winding up	10
Total		180

Answer any FIVE Questions

Q.No.		Questions	Marks
		Unit-I	
1	a	A simple manometer is used to measure the pressure of oil (sp.gr=0.8) flowing in pipe line. Its right limb is open to the atmosphere and left limb is connected to the pipe. The centre of the pipe is 9cm below the level of mercury in the right limb. If the difference of mercury level in the two limbs is 15cm, determine the absolute pressure of the oil in the pipe.	[14M]
		OR	
	b	An oil film of thickness 1.5 mm is used for lubrication between a square plate of size 0.9 m × 0.9 m and an inclined plane having an angle of inclination 20^0. The weight of the square plate is 392.4 N and it slides down the plane with a uniform velocity of 0.2 m/s. Find the dynamic viscosity of the oil.	[14M]

	Unit-II		
2	a	Explain the terms: (i) Path line (ii) Streak line (iii) Stream line, (iv) Stream tube	[14M]
	OR		
	b	Derive the continuity equation for one dimensional flow	[14M]
	Unit-III		
3	a	Explain the development of boundary layer formation over a flat plate.	[7M]
		Discuss displacement thickness, energy thickness and momentum thickness	[7M]
	OR		
	b	What do you understand by Boundary Layer ? Explain the development of Boundary layer over a flat plate.	[14M]
	Unit-IV		
4	a	Show that the efficiency of a free jet striking normally on a series of flat plates mounted on the periphery of a wheel can never exceed 50%.	[7M]
		Derive the Equation for impact of jet striking a curved plate when the plate is moving in the direction of the jet?	[7M]
	OR		
	b	Explain the function of various main components of Pelton Turbine with neat sketches.	[14M]
	Unit-V		
5	a	What is meant by NPSH (Net Positive Suction Head) ?	[7M]
		Explain about main parts of a centrifugal pump.	[7M]
	OR		
	b	A centrifugal pump works against a head of 30 m and discharges 0.25 m3/s while running at 1000 rpm. The velocity of flow at the outlet is 3 m/s and the vane angle at outlet is 300. Determine the diameter and width of impeller at outlet if the hydraulic efficiency is 80 per cent.	[7M]
		Draw and discuss the operating characteristics of a centrifugal pump	[7M]

NEC NARASARAOPETA ENGINEERING COLLEGE (AUTONOMOUS)

Subject Code: R20ME2102

II B.Tech. - I Semester Regular Examinations, February-2022

FLUID MECHANICS AND HYDRAULIC MACHINERY

(ME)

Time: 3 hours

Max. Marks: 70

Note: Answer All FIVE Questions.
All Questions Carry Equal Marks (5 X 14 =70M)

QNo		Questions	KL	CO	Marks
		Unit-I			
1	a	i) Differentiate between: A) Absolute pressure and gauge pressure B) Piezometer and simple manometer	K3	1	7M
		ii) The right limb of a simple U – tube manometer containing mercury is open to the atmosphere, while the left limb is connected to a pipe in which a fluid of sp.gr.0.9 is flowing. The centre of pipe is 12cm below the level of mercury in the right limb. Estimate the pressure of fluid in the pipe, if the difference of mercury level in the two limbs is 20 cm.	K3	1	7M
		OR			
	b	i) Compare the Pascal's law and the Hydrostatic law?	K4	1	6M
		ii) Define viscosity. A plate having an area of 0.7 m^2 is sliding down the inclined plane at 45^0 to the horizontal with a velocity of 0.45 m/s. there is a cushion of fluid 2 mm thick between the plane and the plate. Find the viscosity of the fluid if the weight of the plate is 300N.	K3	1	8 M
		Unit-II			
2	a	i) Define and distinguish between: A) (I) uniform flow and non- uniform flow (II) laminar and turbulent flow B) stream lines, path lines, streak lines and stream tube	K2	2	7M
		ii) State the momentum equation. How will you apply momentum equation for determining the force exerted by a floating liquid on a pipe bend?	K4	2	7M
		OR			
	b	Derive Euler's Equation of Motion? How will you obtain Bernoulli's equation from it?	K4	2	14M
		Unit-III			
3	a	i) Two water carrying circular pipes are connected in parallel. The length L_1, diameter d_1, and friction factor f_1 for the first pipe are 200m, 0.5m and 0.025m respectively, while L_2=100m, d_2=1.0m and f_2=0.02. What is the velocity ratio V_2/V_1.	K3	2	7M
		ii) What is a Venturimeter? Derive an expression for the discharge through a Venturimeter.	K4	2	7M
		OR			
	b	i) Explain the procedure for solving problem by buckingham's π theorm	K3	3	14M
4		**Unit-IV**			
	a	i) By means of a neat sketch, explain the governing mechanism of Francis Turbine.	K2	4	7M
		ii) A Pelton wheel has a mean bucket speed of 10 meters per second with a jet of water flowing at the rate of 700 litres/s under a head of 30 meters. The buckets deflect the jet through an angle of 160^0. Calculate the power given	K3	4	7M

		by water to the runner and hydraulic efficiency of the turbine. Assume co-efficient of velocity as 0.98.			
		OR			
	b	i) Differentiate between Francis turbine and Kaplan turbine.	K2	4	7M
		ii) A Nozzle of 50mm diameter delivers a stream of water at 20m/s perpendicular to a plate that moves away from the jet at 5m/s. Find the force on the plate, the work don and the efficiency of jet.	K2	4	7M
		Unit-V			
5	a	i) Draw and discuss the characteristic curves of centrifugal pump.	K2	5	7M
		ii) A centrifugal pump having outer diameter equal to two times the inner diameter and running at 1000rpm works against total head of 40m. The velocity of flow through the impeller is constant and equal to 2.5m/s. the vanes are set back at an angle of 40^0 at outlet. If the outer diameter of the impeller is 500mm and width at outlet is 50mm, Calculate (i)Vane angle at inlet (ii) Work done by impeller on water per second and (iii) Manometric efficiency	K3	5	7M
		OR			
	b	I)Define the centrifugal pump. Explain the working of a single stage centrifugal pump with a neat sketch	K2	5	14M

NEC NARASARAOPETA ENGINEERING COLLEGE

(AUTONOMOUS)

Subject Code: R20ME2102

II B.Tech. - I Semester Regular & Supple Examinations, December-2022

FLUID MECHANICS AND HYDRAULIC MACHINERY

(ME)

Time: 3 hours | Max. Marks: 70

Note: Answer All FIVE Questions,

All Questions Carry Equal Marks (5 X 14 =70M)

Q. No		Questions	K L	CO	Marks
		Unit-I			
1	a	i). Define the following fluid properties a) Weight density b) Density c) Specific gravity d) Specific volume e) Surface tension f) Capillarity g) Compressibility		01	7M
		ii). An oil of viscosity 5 poise is used for lubrication between a shaft and sleeve. The diameter of the shaft is 0.5 *m* and it rotates at 200 *r.p.m.* Calculate the power lost in oil for a sleeve length of 100 *mm*. The thickness of oil film is 1.0 *mm*.	K5	01	7M
		OR			
	b	i) Compare the Pascal's law and the Hydrostatic law?	K5	01	6M
		ii) The right limb of a simple U- tube manometer containing mercury is open to the atmosphere while the left limb is connected to a pipe in which a fluid of specific gravity as 0.9 is flowing. The center of the pipe is 12 *cm* below the level of mercury in the right limb. Find the pressure of the fluid in the pipe if the difference of mercury level in the limbs is 20 *cm*.	K5	01	8M
		Unit-II			
2	a	i). Distinguish between followings: (a) steady flow and un-steady flow, (b) uniform and non-uniform flow, (c) compressible and incompressible flow,	K4	02	6M
		ii). Water flows through a pipe AB 1.2 *m* diameter at 3 *m/s* and then passes through a pipe BC 1.5 *m* diameter. At C, the pipe branches. Branch CD is 0.8 *m* in diameter and carries one-third of the flow in AB. The flow velocity in branch CE is 2.5 *m/s*. Find the volume rate of flow in AB, the velocity in BC, the velocity in CD and the diameter of CE	K5	02	8M
		OR			
	b	Derive Euler's Equation of Motion? How will you obtain Bernoulli's equation from it?	K5	02	14M

		Unit-III			
3	a	i). Explain the development of boundary layer formation over a flat plate.	K3	03	7M
		ii). List the methods of dimensional analysis ? Describe the Rayleigh's method for dimensional analysis.	K3	03	7M
		OR			
	b	The pressure difference ΔP in a pipe of diameter D and length L due to viscous flow depends on the velocity V, viscosity μ and density ρ. Using Buckingham's π-theorem, obtain an expression for ΔP.	K5	03	14
		Unit-IV			
4	a	i) Show that the force exerted by a jet of water on an inclined fixed plate in the direction of the jet is given by, $$F_x = \rho a V^2 \sin^2 \theta$$ where a = Area of jet, V= Velocity of the jet, and θ = Inclination of the plate with the jet.	K5	04	7M
		ii) A jet of water of diameter 7.5 *cm* moving with a velocity of 25 *m/s* strikes a fixed plate in such a way that the angle between the jet and the plate is 60°. Find the force exerted by the jet on the plate i) in the direction normal to the plate and ii) in the direction of the jet.	K5	04	7M
		OR			
	b	i) What is a draft tube? Why is it used in a reaction turbine? Explain briefly with sketch two different types of draft tubes.	K3	04	7M
		ii) A Pelton wheel has a mean bucket speed 10 *m/s*, with a jet of water flowing at the rate of 700 *litres/s* under a head of 30 *m*. The buckets deflect the jet through an angle of 160°. Calculate the power given by water to the runner and the hydraulic efficiency of the turbine. Assume coefficient of velocity as 0.98.	K5	04	7M
		Unit-V			
5	a	The internal and external diameters of the impeller of a centrifugal pump at 20 *cm* and 40 *cm* respectively. The pump is running at 1200 *r.p.m*. The vane angles of the impeller at inlet and outlet at 20° and 30° respectively. The water enters the impeller radially and velocity of the flow is constant. Draw the inlet and outlet velocity triangles of the impeller and also determine the work done by the impeller per unit weight of water.	K5	05	14
		OR			
	b	A double-acting reciprocating pump, running at 40 *r.p.m*. is discharging 1.0 m^3 of water per minute. The pump has a stroke length of 40 *cm*. The diameter of the piston is 20 *cm*. The delivery and suction heads are 20 *m* and 5 *m* respectively. Find the slip of the pump and power required to drive the pump.	K5	05	14

KL: Blooms Taxonomy Knowledge Level CO: Course Outcome M:Marks

NEC NARASARAOPETA ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

CO-POs & CO-PSOs ATTAINMENT

Course Code: C212	Course Name: FLUID MECHANICS AND HYDRAULIC MACHINERY	Year/Sem: II/I

External Examination Assessment

S. No	Q.No		1	1	1	1	2	2	2	2	3	3	3	3	4	4	4	4	5	5	5	5
			a		b		a		b		a		b		a		b		a		b	
			i	ii	i	ii	i	ii	i	ii	i	ii	i	ii	i	ii	i	ii	i	ii	i	ii
	COs		I	I	I	I	II	II	II	II	III	III	III	III	IV	IV	IV	IV	V	V	V	V
	Max. Marks		7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
1			7		7		7	7														
2			7	7			7	7			3	4					2		2			
3									3	3			2	3			4	3			4	3
4							2	3														
5					4	2			2	3					4	3						
6					3	3			5	5			6	4			4	3				
7					3	3			2	2	3	2			4	4			4	4		
8			3	3			4	3					3	3			4	4			2	2
9			3	3						5	2	2			3	2			4	4		
10					3	2			3	3			3	3			3	3			3	
11			2	4			5	2			4	3			3	3			3			
12			5	6			4	4			3	2			5	5					2	2
13					2	2			3	4			3	4			3	3	2	3		
14			7	7			4	4					3	3	2	2			5	6		
15					3	3				6			4	4	4	3			4	4		
16			4	3			2	1			3	4			2	3					3	2
17					2	2				6			2	3			2	3			4	5
18					3	3			4	2	2	4			4	4			5	5		
19			3	2			3	4					3	3			4	4			5	6
20					4	4			3	3			4	4	3	3			6	6		
21			3	3			5	5			6	4			4	4			3	5		
22					3	4			3	4			4	2			4	3			4	4
23			2	2			3	3			2	3			4	2			2	2		
24			2	3			4	1			3	2			3	3			3	3		
25					4	3			4	3	2	4			4	4					5	4
26					2	2			4				3	3					3	2		
27			7	7			6	6			5	5							5	4		
28					5	4			3	3			4	2			5	4			2	2
29					6	7	3	4			4	2			4	6			5	5		
30			2	2			5	5					3	2			4	5			4	4
31			4	4			5	4			4	1			4	3			6	5		
32					4	5			5				5				3	3			6	5
33																						
34			3	3			4	2			3	2			2	4			4	3		
35			6	6			7	7					6	5			5	6			3	3
36			4	3			5	4			4	3			4	4			3	3		
37			5	5			4	4			6	5			3	4			6	6		
38					4	5			4	2				5			4	5			6	5
39			4	4			3	3		3	2				5	4			6	5		
40			5	5			4	4			5	4			6	3			6	5		

41					3	2			4	3			4	2			4	4			3	3
42			3	3			4	4			5	5			6	4			4	6		
43					4	4			5	4			6	6			4	4			3	3
44					5	5			5	5			6	5			4	4			5	5
45			6	6			6	5			4	5			5	4					5	6
46					6	4			4	6			6	5			5	5	5	5		
47			3	3			4	3			2	4			4	6			6	6		
48					4	5				6			5				4	5			6	5
49					5	5			5	5			6	5			4	4			5	5
50			3	3			4	4			5	5			6	4			4	6		
51			7	6			6	5			4	5			5	4					5	6
52					5	5			5	5			6	5			4	4			5	5
53			3	3			4	3			2	4			4	6			6	6		
54			1	2			5	5						5			4	5			4	4
55			4	5			4	4			6	5			3	4			6	6		
56			6	6			6	5			4	5			5	4					5	6
57			6				4	3			2	4			4	6			6	6		
58			4				3	3				5			4	2			2	2		
59																						
60			4	4			4	4			2	4			4	6			6	6		
61			2	2			4	2			5				1	2			4	3		
62				5			5	5					3	2			4	5			4	4
63			3	4			3	3				5			4	2			2	2		
No. of Students answered			35	33	24	23	37	37	20	23	30	30	24	24	34	34	23	22	32	30	25	24
50% of Max Marks			3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
No. of Students crossed 50% of Max Marks			19	17	14	12	29	23	12	12	15	20	14	12	24	20	18	15	22	21	17	16
% of Students crossed 50% of Max Marks			54	52	58	52	78	62	60	52	50	67	58	50	71	59	78	68	69	70	68	67
Attainment Level			1	1	1	1	3	2	2	1	1	2	1	1	3	1	3	2	2	3	2	2
Course Outcome			I	II	III	IV	V															
No.of Times CO Repeated			4	4	4	4	4															
Final CO Attainment Level			**1**	**2**	**1**	**2**	**2**															

Rubrics:

If 5[illegible]% of the students crossed 50% of the marks: Attainment Level 1
If 60% of the students crossed 50% of the marks: Attainment Level 2
If 70% of the students crossed 50% of the marks: Attainment Level 3

1. **Enter the question wise marks.**
2. **Identify the CO of each question.**
3. **Calculate the maximum marks of each CO.**
4. **Calculate the CO wise marks obtained by each student.**
5. **Calculate 50% of maximum marks of each CO.**
6. **Find number of students crossed 50% of maximum marks for each CO.**
7. **Find percentage of students crossed 50% of maximum marks for each CO.**
8. **Find the attainment level of each CO as per the above Rubrics.**

Course Code: C212			Course Name: FLUID MECHANICS AND HYDRAULIC MACHINERY														Year/Sem: II/I				
Internal Examination Assessment																					
S.No	Roll. No	Test	Mid1					A1	Quiz 1	Mid2					A2	Quiz 2	CO I	CO II	CO III	CO IV	CO V
		Q.No	1		2		3			1	2		3								
			1.a	1.b	2.a	2.b	3.a			1.a	2.a	2.b	3.a	3.b			Max. Marks	Max. Marks	Max. Marks	Max. Marks	Max. Marks
		COs	I	I	II	II	III	I		III	IV	IV	V	V							
		Max. Marks	5	5	5	5	5	5	10	5	5	5	5	5	5	10	25	20	35	25	20
1	21471A0301		5	5	3	5	2	5	9	4	5	5	5	4	5	10	24	17	30	25	19
2	21471A0302		3	3	3	3	4	5	5	4	4		4		5	6	16	11	24	15	10
3	21471A0303		5	5	4	4	3	5	9	3	3	5	3	3	5	9	24	17	29	22	15
4	21471A0304		5	3	2	4	4	5	10	3	5	2	3	2	5	6	23	16	28	18	11
5	21471A0305		1	2	2	2	0	4	9	2	3	4	1	3	5	9	16	13	25	21	13
6	21471A0306		1	2	5	3	0	5	8	3	4	3	0	3	5	10	16	16	26	22	13
7	21471A0307		5	5	4	4	4	4	7	5	4	3		4	5	8	21	15	29	20	12
8	21471A0309		5	5	4	5	3	5	4	5	2	5	1	0	5	10	19	13	27	22	11
9	21471A0310		2	3	2	5	0		8	5		4	2		5	6	13	15	24	15	8
10	21471A0311			3	1	2	2	4	5	3	4	1	4		5	10	12	8	25	20	14
11	21471A0312		5	5	5	5	5	5	10	5	5	5	5	5	5	9	25	20	34	24	19
12	21471A0314		2					4	10	5	3	4		1		7	16	10	22	14	8
13	22475A0301		5	5	5	4	3	5	10	5	5	2	5	5	5	10	25	19	33	22	20
14	22475A0302		5	5	5	3	3	4	9	5		1	3	3	5	9	23	17	31	15	15
15	22475A0303		5	5	4	4	3	2	4	4	4		3	4	5	8	16	12	24	17	15
16	22475A0304		5	3	2	4	4	3	8	5	5	4	3	1	5	10	19	14	32	24	14
17	22475A0305		5	3	2	0		3	10	4	5		5	4	5	10	21	12	29	20	19
18	22475A0306		5	3	4	4	0	3	10	3	5	3	5	5	5	10	21	18	28	23	20
19	22475A0307		5	4	3	5	5	4	7	5	5			4	5	9	20	15	31	19	13
20	22475A0308		4	1	5	4	3	4	10	3	3	3		3	5	10	19	19	31	21	13
21	22475A0309			5				3	10	5	3			5	5	8	18	10	28	16	13
22	22475A0310		2	5		5		3	10	2	3	1	4	3	4	5	20	15	21	13	12
23	22475A0311		5	3	1		5	3	9	3	2	3	3	3	5	10	20	10	32	20	16
24	22475A0312		5	5	5	1	1	4	8		3	4	4	3	5	4	22	14	18	16	11
25	22475A0313		5	5	5		2	5	10	5	5		3	5	5	10	25	15	32	20	18

26	22475A0314		4	4	4		3	4	9	5	4		4	5	5	9	**21**	**13**	**31**	**18**	**18**
27	22475A0315		2			1		2	10	4	2		2	2	5	9	**14**	**11**	**28**	**16**	**13**
28	22475A0316		5	5	2	5	4	4	10	4	4		5	4	5	10	**24**	**17**	**33**	**19**	**19**
29	22475A0317		5	5	5	3	4	4	10	3	4	4		4	5	8	**24**	**18**	**30**	**21**	**12**
30	22475A0318			2	1		2	3	7	5	3		4	5	5	8	**12**	**8**	**27**	**16**	**17**
31	22475A0319		4	4	2		3	3	10	3	3	1	2	3	5	7	**21**	**12**	**28**	**16**	**12**
32	22475A0321		5	2	5	1		2	8	5	3	3	3		4	8	**17**	**14**	**25**	**18**	**11**
33	22475A0322		4	2		4	1	4	3	5	4	3	4		5	9	**13**	**7**	**23**	**21**	**13**
34	22475A0323		2	5	4		2	3	9	5	2	5			5	10	**19**	**13**	**31**	**22**	**10**
35	22475A0324		2	3	3	4	2	2	9	5	3	5		4	5	9	**16**	**16**	**30**	**22**	**13**
36	22475A0325		5	5		5		4	9	5	3	5		4	5	7	**23**	**14**	**26**	**20**	**11**
37	22475A0326		5	3	1		2	2	8	4	4	5	3	3	5	10	**18**	**9**	**29**	**24**	**16**
38	22475A0327		4	3	2	2	2	3	7	5	4		2	5	5	10	**17**	**11**	**29**	**19**	**17**
39	22475A0328		4	1	2		4	3	9	5	4		4	5	5	10	**17**	**11**	**33**	**19**	**19**
40	22475A0329		2	4	2	2	10	2	9	4	5		5	5	5	7	**17**	**13**	**35**	**17**	**17**
41	22475A0330			3	2		1	3	6					4	4	9	**12**	**8**	**20**	**13**	**13**
42	22475A0331		4	3	4	4	3	4	8	4	5		4	5	4	7	**19**	**16**	**26**	**16**	**16**
43	22475A0332		5	3			5	3	4	3	4	2	3	5	4	5	**15**	**4**	**21**	**15**	**13**
44	22475A0333		3	4	4			3	10	5	5	1	4	4	4	9	**20**	**14**	**28**	**19**	**17**
45	22475A0334		2	5	3	2		2	10	5	5		3	5	4	9	**19**	**15**	**28**	**18**	**17**
46	22475A0335		3	4	3		4	4	4	2	5	4	5	3	5	9	**15**	**7**	**24**	**23**	**17**
47	22475A0336		3	1	5		1	3	6	3		5		5	5	10	**13**	**11**	**25**	**20**	**15**
48	22475A0337		5	4	1		2	0	9	5	5	2	4	5	5	9	**18**	**10**	**30**	**21**	**18**
49	22475A0338		5	5	1		3	2	9	5	5		2	5	4	7	**21**	**10**	**28**	**16**	**14**
50	22475A0339		5	5	4	4		5	9	5	5	5	4	4	5	10	**24**	**17**	**29**	**25**	**18**
51	22475A0340		5	4		4	3	3	2	4	4	4		4	4	6	**14**	**6**	**19**	**18**	**10**
52	22475A0341		5	5		4	5	2	9	4	5		5	4	5	10	**21**	**13**	**33**	**20**	**19**
53	22475A0342		5	5		4	5	4	9	4	4		4	4	5	8	**23**	**13**	**31**	**17**	**16**
54	22475A0343		5	5	4	4	5	4	9	5	5	5	5	5	5	10	**23**	**17**	**34**	**25**	**20**
55	22475A0344		5	5	3	3	2	2	9	5	2	5	5	5	5	8	**21**	**15**	**29**	**20**	**18**
56	22475A0345		4	4	5	4	4	4	10	5	5	4	5	5	5	10	**22**	**19**	**34**	**24**	**20**
57	22475A0346		4	5	3	4	4	4	6	4	5	5	4	5	5	10	**19**	**13**	**29**	**25**	**19**
58	22475A0347		5	4	4	4	2	4	9	5	4	5	4	5	5	9	**22**	**17**	**30**	**23**	**18**
59	22475A0348		5	5	5			2	8	4	3		3	4	5	10	**20**	**13**	**27**	**18**	**17**

60	22475A0349		4	5	4	4		4	8	4	3	5	3	3	5	7	**21**	**16**	**24**	**20**	**13**
61	22475A0350		5	5		5		4	9	5	4	5		5	5	9	**23**	**14**	**28**	**23**	**14**
62	22475A0351		5	5		4	2	4	9	4	4	2	4	4	5	7	**23**	**13**	**27**	**18**	**15**
63	22475A0352		5	5	4	5	4	3	9	5		5	5	4	5	9	**22**	**18**	**32**	**19**	**18**
50% of maximum marks																	**12.5**	**10**	**17.5**	**12.5**	**10**
No. of Students crossed 50% of max. marks																	**60**	**55**	**63**	**63**	**61**
% of students crossed 50% of max. marks																	**95**	**87**	**100**	**100**	**97**
Attainment Level																	**3**	**3**	**3**	**3**	**3**

Rubrics:

If 50% of the students crossed 50% of the marks: Attainment Level 1
If 60% of the students crossed 50% of the marks: Attainment Level 2
If 70% of the students crossed 50% of the marks: Attainment Level 3

1. **Enter the question wise marks for mid examinations, assignments & quiz.**
2. **Identify the CO of each question.**
3. **Calculate the maximum marks of each CO based mid exams, assignments and quiz.**
4. **Calculate the CO wise marks obtained by each student.**
5. **Calculate 50% of maximum marks of each CO.**
6. **Find number of students crossed 50% of maximum marks for each CO.**
7. **Find percentage of students crossed 50% of maximum marks for each CO.**
8. **Find the attainment level of each CO as per the above Rubrics.**

Course Code: C212	Course Name: FLUID MECHANICS AND HYDRAULIC MACHINERY				Year/Sem: II/I
CO Attainment					
CO	CO Attainment Level (Internal)	CO Attainment Level (External)	Direct CO Attainment Level (Internal * 30%) + (External * 70%)	Indirect CO Attainment Level	Total CO Attainment Level (Direct CO Attainment * 90% + Indirect CO Attainment * 10%)
C212.1	3	1	1.60	2.56	1.70
C212.2	3	2	2.30	2.60	2.33
C212.3	3	1	1.60	2.63	1.70
C212.4	3	2	2.30	2.67	2.34
C212.5	3	2	2.30	2.57	2.33
		C214			2.08

1. Copy the Direct CO Attainment Level (Internal) and Direct CO Attainment Level (External) from the previous
   sheets and then find the Direct CO Attainment Level.
2. Find Direct CO attainment level using the formula:
   CO Attainment Level (Internal) * 30% + CO Attainment Level (External) * 70%
3. Copy Indirect CO Attainment Level.
4. Find the CO attainment level using the formula:
   Direct CO Attainment Level *90% + Indirect CO Attainment Level * 10%

Course Code: C212	Course Name: FLUID MECHANICS AND HYDRAULIC MACHINERY	Year/Sem: II/I

CO-PO & CO-PSO Mapping

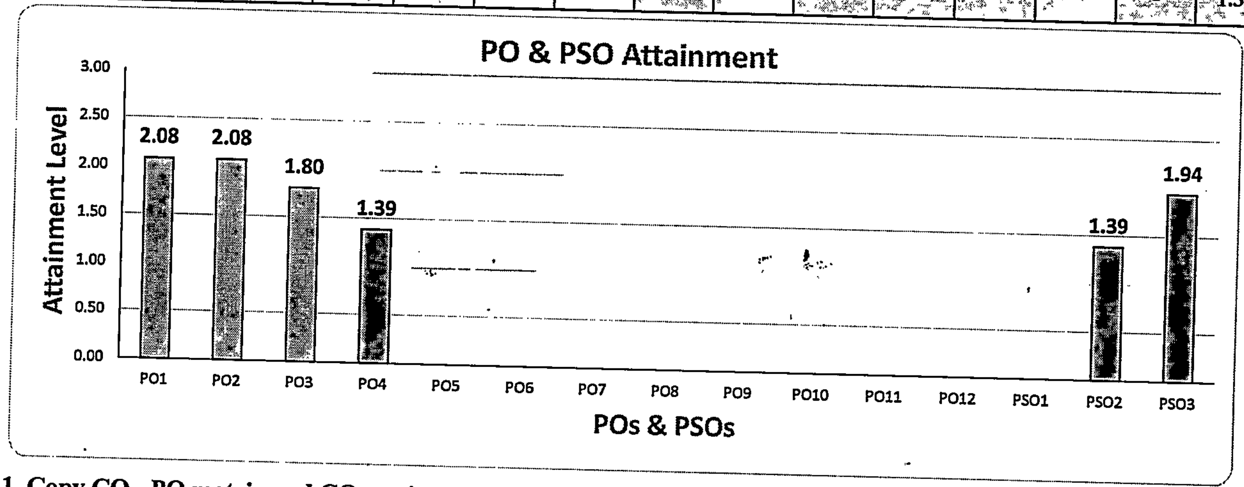
COs	POs & PSOs														
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
C212.1	3	3	2	-	-	-	-	-	-	-	-	-	-	-	2
C212.2	3	3	2	-	-	-	-	-	-	-	-	-	-	-	3
C212.3	3	3	3	2	-	-	-	-	-	-	-	-	-	2	3
C212.4	3	3	3	2	-	-	-	-	-	-	-	-	-	-	3
C212.5	3	3	3	2	-	-	-	-	-	-	-	-	-	-	3
C212	3.00	3.00	2.60	2.00	-	-	-	-	-	-	-	-	-	2.00	2.80

Total CO Attainment through Direct & Indirect Assessment

CO Attainment	2.08

PO & PSO Attainment

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
PO Attainment	2.08	2.08	1.80	1.39	-	-	-	-	-	-	-	-	-	1.39	1.94



1. Copy CO - PO matrix and CO attainment matrix from previous pages and find PO attainment.
2. PO attainment is calculated as per the following formula:
   POi * Total CO attainment Level / 3 where 'i' ranges from 1 to 12

1. Copy CO - PSO matrix and CO attainment matrix from previous pages and find PSO attainment.
2. PSO attainment is calculated as per the following formula:
   PSOi * Total CO attainment Level / 3 where 'i' ranges from 1 to 3