Department of Civil Engineering

Course File

Hydraulics and Hydraulic Machinery
(Course Code: CE404PC)

II B.Tech II Semester

2023-24

Mr. K. Upendar
Assistant Professor

ANURAG
Anurag
ENGINEERING COLLEGE
(An Autonomous Institution)
Ananthagiri, Kodad, Telangana 508 206, India.

Department of Civil Engineering

HYDRAULICS AND HYDRAULIC MACHINERY

Check List

Department of Civil Engineering

Int. Marks: 30 Ext. Marks: 70 Total Marks: 100

HYDRAULCS AND HYDRAULIC MACHINERY

Course code: CE404PC **L/T/P/C: 3/0/0/3**
II Year II Semester

UNIT-I: Open Channel Flow –I: Introduction to Open channel flow-Comparison between open channel flowandpipeflow,Classificationofopenchannelflows,Velocitydistribution.Uniformflow–Characteristics of uniform flow, Chezy's, Manning's and Bazin formulae for uniform flow –Factors affecting Manning's Roughness Coefficient, Most economical sections, Computation of Uniform flow, normal depth. Critical Flow: Specific energy, Specific force –critical depth -computation of critical depth –critical, subcritical and supercritical flows-Channel transitions.

UNIT-II: Open Channel Flow –II: Non-uniform flow –Gradually Varied Flow -Dynamic equation for G.V.F; Classification of channel bottom slopes–Classification and characteristics of Surface profiles–Computation of water surface profiles by Numerical and Analytical approaches. Direct step method. Rapidly varied flow: Elements and characteristics (Length and Height) of Hydraulic jump in rectangular channel–Types, applications and location of hydraulic jump, efficiency hydraulic jump, Energy dissipation and other uses – Positive and Negative Surges (Theory only).

UNIT–III: Dimensional Analysis and Hydraulic Similitude: Introduction to Dimensions, Dimensional homogeneity –Rayleigh's method and Buckingham's π methods –Dimensionless groups. Similitude, Model studies, Types of models, Application of dimensional analysis and model studies to fluid flow problems. Distorted models, Basics of Turbo Machinery: Hydrodynamic force of jets on stationary and moving flat, inclined and Curved vanes, Jet striking centrally and at tip, Velocity triangles at inlet and outlet, expressions for work Done and efficiency –Angular.

UNIT-IV: Hydraulic Turbines –I: Elements of a typical Hydro power installation –Heads and efficiencies – Classification of turbines – Pelton wheel – Francis turbine–Kaplan turbine–working, working proportions, velocity diagram, work done and efficiency, hydraulic design. Draft tube – Classification, functions and efficiency.
Hydraulic Turbines –II: Governing of turbines–Surge tanks – Unit and specific turbines – Unit speed–Unit quantity –Unit power –Specific speed –Performance characteristics –Geometric similarity –Cavitations, Selection of turbines.

UNIT-V Centrifugal Pumps: Component parts of centrifugal pumps - Pump installation details – classification –work done –Man metric head –minimum starting speed –losses and efficiencies –specific speed. Multistage pumps –pumps in parallel – performance of pumps –characteristic curves –NPSH – Cavitations. Reciprocating pumps–Working, discharge, and slip indicator diagrams.

TEXTBOOKS:
1. Fluid Mechanics by Modi and Seth, Standard Book House.
2. Fluid Mechanics and Hydraulic machines by Manish Kumar Goyal, PHI learning Private Limited, 2015
3. Open channel flow by V.T. Chow (McGraw Hill Book Company).
4. Fluid Mechanics and Hydraulic machines by R. K. Bansal, Lakshmi Publications House Pvt. Ltd.

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REFERENCE BOOKS:

1. Fluid Mechanics by R. C. Hibbeler, Pearson India Education Services Pvt. Ltd
2. Fluid Mechanic & Fluid Power Engineering by D. S. Kumar (Kataria & Sons Publications Pvt. Ltd.).
3. Introduction to Fluid Mechanics and Fluid Machines by SK Som, Gautam Biswas, Suman Chakra borthy, Mc Graw Hill Education (India)Private Limited4 Hydraulic Machines by Banga & Sharma (Khanna Publishers).

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Timetable

II B.Tech. II Semester – H&HM

Day/Hour	9:30-10:20	10:20-11:10	11:20-12:10	12:10-1:00	1:40-2:25	2:25-3:10	3:15-4:00
Monday		H&HM			H&HM		
Tuesday							
Wednesday							H&HM
Thursday							
Friday					H&HM		
Saturday				H&HM			

Department of Civil Engineering

Vision of the Institute

To be a premier Institute in the country and region for the study of Engineering,technology and Management by maintaining high academic standards which promotes the analytical thinking and independent judgment among the prime stakeholders, enabling them to function responsibly in the globalized society.

Mission of the Institute

To be a world- class Institute, achieving excellence in teaching, research and consultancy in cutting-edge Technologies and be in the service of society in promoting continued education in Engineering, Technology and Management.

Quality Policy

To ensure high standards in imparting professional education by providing world-class infrastructure, top-quality-faculty and decent work culture to sculpt the students into Socially Responsible Professionals through creative team-work, innovation and research

Vision of the Department

To impart knowledge, skill and excellence in civil engineering with a global perspective to enable the students as competent, qualitative & ethically strong engineers with an intuition to improve quality of life for the benefit of the society.

Mission of the Department

- To train the students in the civil engineering domain.
- To develop knowledge and skill to solve regional and global problems.
- To transform into qualitative and ethically strong professional engineers through research and Development.

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Program Educational Objectives (B.Tech – CIVIL)
Graduates will be able to

PEO1: To provide knowledge in mathematics, science and engineering principles for a successful Career in sectors of civil engineering and allied industry and/or higher education.

PEO2: To develop an ability to identify, formulate, solve problems along with adequate analysis, Design, synthesizing and interpretation skills in civil engineering systems.

PEO3: To exhibit professionalism, ethics, communication skills and team work in their profession and engaged in lifelong learning of contemporary civil engineering trends.

Program Outcomes (B.Tech – CIVIL)
Engineering Graduates will be able to:

PO 1: An ability to apply knowledge of mathematics, science, and engineering

PO 2: Ability to design and conduct experiments, as well as to analyze and interpret data

PO 3: An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability

PO 4: An ability to function on multidisciplinary teams

PO 5: An ability to identify, formulates, and solves engineering problems

PO 6: An understanding of professional and ethical responsibility

PO 7: An ability to communicate effectively

PO 8: The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

PO 9: Recognition of the need for, and an ability to engage in lifelong learning

PO 10: Knowledge of contemporary issues.

PO 11: An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

PO 12: An ability to carry out research in different areas of Civil Engineering including latest technology like GIS/Remote Sensing resulting in design, development, analyze and journal publications and technology development.

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COURSE OBJECTIVES

On completion of this Subject/Course the student shall be able to:

S.No	Objectives
1	To define the fundamental principles of water conveyance in open channels.
2	To Discuss and analyze the open channels in uniform and non-uniform flow conditions.
3	To Study the characteristics of hydroelectric power plant and its components.
4	To analyze and design of hydraulic machinery and its modelling.
5	To discuss about pumps and its classification.

COURSE OUTCOMES

The expected outcomes of the Course/Subject are:

S.No	Outcomes
1.	Apply their knowledge of fluid mechanics in addressing problems in open channels and hydraulic machinery.
2.	Understand and solve problems in uniform, gradually and rapidly varied flows in open Channel in steady state conditions.
3.	Apply dimensional analysis and to differentiate the model, prototype and similitude Conditions for practical problems.
4.	Get the knowledge on different hydraulic machinery devices and its principles that will be utilized In hydropower development and for other practical usages.
5.	To understand about pumps and its classification.

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Note: Please refer to Bloom's Taxonomy, to know the illustrative verbs that can be used to state the outcomes.

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GUIDELINES TO STUDY THE COURSE / SUBJECT

<u>Course Design and Delivery System (CDD):</u>

- The Course syllabus is written into number of learning objectives and outcomes.
- Every student will be given an assessment plan, criteria for assessment, scheme of evaluation and grading method.
- The Learning Process will be carried out through assessments of Knowledge, Skills and Attitude by various methods and the students will be given guidance to refer to the text books, reference books, journals, etc.

The faculty be able to –

- Understand the principles of Learning
- Understand the psychology of students
- Develop instructional objectives for a given topic
- Prepare course, unit and lesson plans
- Understand different methods of teaching and learning
- Use appropriate teaching and learning aids
- Plan and deliver lectures effectively
- Provide feedback to students using various methods of Assessments and tools of Evaluation
- Act as a guide, advisor, counsellor, facilitator, motivator and not just as a teacher alone

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Date:　　　　　　　　　　Date:

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COURSE SCHEDULE

S. No.	Description	Duration (Date)		Total No. of Periods
		From	To	
1.	UNIT - I: Open Channel Flow – I: Introduction to Open channel flow-Comparison between open channel flow and pipe flow, Classification of open channel flows, Velocity distribution. Uniform flow – Characteristics of uniform flow, Chezy's, Manning's and Bazin formulae for uniform flow – Factors affecting Manning's Roughness Coefficient. Most economical sections. Computation of Uniform flow, Normal depth. Critical Flow: Specific energy, Specific force – critical depth - computation of critical depth – critical, sub critical and super critical flows-Channel transitions.	05.02.2024	04.03.2024	19
2.	**UNIT-II: Open Channel Flow –II:** Non-uniform flow – Gradually Varied Flow -Dynamic equation for G.V.F; Classification of channel bottom slopes–Classification and characteristics of Surface profiles–Computation of water surface profiles by Numerical and Analytical approaches. Direct step method. Rapidly varied flow: Elements and characteristics (Length and Height) of Hydraulic jump in rectangular channel–Types, applications and location of hydraulic jump, efficiency hydraulic jump, Energy dissipation and other uses – Positive and Negative Surges (Theory only).	06.03.2024	30.03.2024	13
3.	**UNIT–III: Dimensional Analysis and Hydraulic Similitude**: Introduction to Dimensions, Dimensional homogeneity – Rayleigh's method and Buckingham's π methods – Dimensionless groups. Similitude, Model studies, Types of models, Application of dimensional analysis and model studies to fluid flow problems. Distorted models, Basics of Turbo Machinery: Hydrodynamic force of jets on stationary and moving flat, inclined and Curved vanes, Jet striking centrally and at tip, Velocity triangles at inlet and outlet, expressions for work Done and efficiency –Angular.	22.04.2024	06.05.2024	10
4.	**UNIT-IV: Hydraulic Turbines –I:** Elements of a typical Hydro power installation –Heads and efficiencies – Classification of turbines – Pelton wheel – Francis turbine–Kaplan turbine–working, working proportions, velocity diagram, work done and efficiency, Hydraulic design. Draft tube –Classification, functions and efficiency. Hydraulic Turbines –II: Governing of turbines–Surge tanks – Unit and specific turbines – Unit speed–Unit quantity – Unit power –Specific speed –Performance characteristics –	06.05.2024	06.06.2024	10

	Geometric similarity –Cavitations, Selection of turbines.			
5.	**UNIT-V Centrifugal Pumps:** Component parts of centrifugal pumps - Pump installation details –classification –work done –Man metric head –minimum starting speed –losses and efficiencies –specific speed. Multistage pumps –pumps in parallel – performance of pumps –characteristic curves –NPSH –Cavitations. Reciprocating pumps– Working, discharge, and slip indicator diagrams.	06.06.2024	14.06.2024	10

The Schedule for the whole Course / Subject is:

Total No. of Instructional periods available for the course: 62 Hours

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SCHEDULE OF INSTRUCTIONS - COURSE PLAN

Unit No.	Lesson No.	Date	No. of Periods	Topics / Sub-Topics	Objectives & Outcomes Nos.	References (Textbook, Journal)
1.	1	05.02.2024	1	Syllabus overview	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	2	07.02.2024	1	Unit-1: Open channel flow-introduction	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	3	12.02.2024	1	Difference between Open channel & closed or pipe flow	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	4	12.02.2024 & 13.02.2024	2	Classifications of open channel flow	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	5	14.02.2024	1	Discharge through open channel by chezy's formula	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	6	16.02.2024	2	Problems on chezy's and empirical formula	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	7	17.02.2024	1	Bazin's formula & it's problems	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	8	19.02.2024	1	Ganguillet- kutter formula & manning's formula	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	9	19.02.2024	1	Problems on Ganguillet-kutter formula & manning's formula	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	10	21.02.2024 & 28.02.2024	5	Most economical sections	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	11	0.1.03.2024	1	Critical depth, critical	1	Fluid Mechanics

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				velocity	1	and Hydraulic machines by R. K. Bansal
	12	01.03.2024	1	Specific energy& specific energy curve	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	13	04.03.2024	1	critical, Sub critical and super critical flows-Channel transitions.	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
2.	1	06.03.2024	1	UNIT - II: Open Channel Flow – II: Non-uniform flow	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	2	07.03.2024	1	Gradually Varied Flow	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	3	07.03.2024	1	Dynamic equation for G.V.F	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	4	11.03.2024	1	Classification of channel bottom slopes	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	5	12.03.2024 & 13.03.2024	2	Classification and characteristics of Surface profiles	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	6	15.03.2024	1	Numerical and Analytical approaches - Direct step method.	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	7	15.03.2024 & 16.03.2024	2	Hydraulic jump in rectangular channel- derivation	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	8	18.03.2024	1	Types, applications of hydraulic jump	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	9	18.03.2024	1	Efficiency and energy dissipation of hydraulic jump	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	10	22.03.2024	1	location of hydraulic jump	2	Fluid Mechanics

					2	and Hydraulic machines by R. K. Bansal
	11	30.03.2024	1	Positive and Negative Surges	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
3.	1	22.04.2024	1	UNIT – III: Dimensional Analysis and Hydraulic Similitude: Introduction to Dimensions	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	2	24.04.2024	1	Dimensional Homogeneity	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	3	24.04.2024	1	Buckingham's π methods, problems	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	4	25.04.2024	1	Rayleigh's method, problems	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	5	26.04.2024	1	Model studies, Types of models.	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	6	26.04.2024	1	Similitude, Application of dimensional analysis and	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	7	01.05.2024	1	Distorted models, model studies to fluid flow problems	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	8	02.05.2024	1	Hydrodynamic force of jets on stationary and moving flat & moving flat plate	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	9	04.05.2024	1	inclined and Curved vanes, jet striking centrally and at tip, Velocity triangles at inlet and outlet	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	10	06.05.2024	1	Expressions for work Done and efficiency	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal

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4.	1	06.05.2024	1	UNIT - IV: Hydraulic Turbines – I: Elements of a typical Hydropower installation	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	2	06.05.2024	1	Heads and efficiencies of hydraulic turbines	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	3	07.05.2024	1	Classification of turbines	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	4	07.05.024	1	velocity diagram, work done and efficiency	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	5	03.06.2024	1	Draft tube , Classification of draft tube .	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal Fluid Mechanics and Hydraulic machines by R. K. Bansal
	6	03.06.2024	1	functions and efficiency of draft tube	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	7	03.06.2024	1	Hydraulic Turbines – II: Governing of turbines	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	8	04.06.2024	1	Surge tanks, Unit and specific turbines	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	9	05.06.2024	1	Unit quantity, Performance characteristics	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	10	06.06.2024	1	Geometric similarity, Cavitations, Selection of turbines.	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal
5.	1	06.06.2024	1	UNIT - V Centrifugal Pumps: Component parts of centrifugal pumps	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	2	06.06.2024	1	Pump installation details	5	Fluid Mechanics

					5	and Hydraulic machines by R. K. Bansal
	3	07.06.2024	1	classification – work done	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	4	07.06.2024	1	Manometric head – minimum starting speed	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	5	10.06.2024	1	losses and efficiencies	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	6	10.06.2024	1	Specific speed.	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	7	10.06.2024	1	Multistage pumps	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	8	11.06.2024	1	pumps in parallel – performance of pump	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	9	14.06.2024	1	NPSH – Cavitations	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	10	14.06.2024	1	Reciprocating pumps – Working, discharge, and slip indicator diagrams	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal

Signature of HOD   Signature of faculty

Date: Date:

Note:

1. Ensure that all topics specified in the course are mentioned.
2. Additional topics covered, if any, may also be specified in bold.
3. Mention the corresponding course objective and outcome numbers against each topic.

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SCHEDULE OF INSTRUCTIONS: UNIT -I PLAN

Unit No.	Lesson No.	Date	No. of Periods	Topics / Sub-Topics	Objectives & Outcomes Nos.	References (Textbook, Journal)
1.	1	05.02.2024	1	Syllabus overview	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	2	07.02.2024	1	Unit-1: Open channel flow-introduction	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	3	12.02.2024	1	Difference between Open channel & closed or pipe flow	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	4	12.02.2024 & 13.02.2024	2	Classifications of open channel flow	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	5	14.02.2024	1	Discharge through open channel by chezy's formula	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	6	16.02.2024	2	Problems on chezy's and empirical formula	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	7	17.02.2024	1	Bazin's formula & it's problems	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	8	19.02.2024	1	Ganguillet- kutter formula & manning's formula	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	9	19.02.2024	1	Problems on Ganguillet- kutter formula & manning's formula	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	10	21.02.2024 & 28.02.2024	5	Most economical sections	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	11	0.1.03.2024	1	Critical depth, critical velocity	1 1	Fluid Mechanics and Hydraulic machines by

						R. K. Bansal
	12	01.03.2024	1	Specific energy& specific energy curve	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	13	04.03.2024	1	critical, Sub critical and super critical flows-Channel transitions.	1 1	Fluid Mechanics and Hydraulic machines by R. K. Bansal

Signature of HOD | Signature of faculty

Date: | Date:

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SCHEDULE OF INSTRUCTIONS: UNIT -II PLAN

Unit No.	Lesson No.	Date	No. of Periods	Topics / Sub-Topics	Objectives & Outcomes Nos.	References (Textbook, Journal)
2.	1	06.03.2024	1	UNIT - II: Open Channel Flow – II: Non-uniform flow	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	2	07.03.2024	1	Gradually Varied Flow	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	3	07.03.2024	1	Dynamic equation for G.V.F	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	4	11.03.2024	1	Classification of channel bottom slopes	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	5	12.03.2024 & 13.03.2024	2	Classification and characteristics of Surface profiles	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	6	15.03.2024	1	Numerical and Analytical approaches - Direct step method.	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	7	15.03.2024 & 16.03.2024	2	Hydraulic jump in rectangular channel- derivation	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	8	18.03.2024	1	Types, applications of hydraulic jump	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	9	18.03.2024	1	Efficiency and energy dissipation of hydraulic jump	2 2	Fluid Mechanics and Hydraulic machines

						by R. K. Bansal
	10	22.03.2024	1	location of hydraulic jump	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	11	30.03.2024	1	Positive and Negative Surges	2 2	Fluid Mechanics and Hydraulic machines by R. K. Bansal

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Date:

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Department of Civil Engineering

SCHEDULE OF INSTRUCTIONS: UNIT –III PLAN

Unit No.	Lesson No.	Date	No. of Periods	Topics / Sub-Topics	Objectives & Outcomes Nos.	References (Textbook, Journal)
3.	1	22.04.2024	1	UNIT – III: Dimensional Analysis and Hydraulic Similitude: Introduction to Dimensions	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	2	24.04.2024	1	Dimensional Homogeneity	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	3	24.04.2024	1	Buckingham's π methods, problems	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	4	25.04.2024	1	Rayleigh's method, problems	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	5	26.04.2024	1	Model studies, Types of models.	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	6	26.04.2024	1	Similitude, Application of dimensional analysis and	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	7	01.05.2024	1	Distorted models, model studies to fluid flow problems	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	8	02.05.2024	1	Hydrodynamic force of jets on stationary and moving flat & moving flat plate	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	9	04.05.2024	1	inclined and Curved vanes, jet striking centrally and at tip, Velocity triangles at inlet and outlet	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	10	06.05.2024	1	Expressions for work Done and efficiency	3 3	Fluid Mechanics and Hydraulic machines by R. K. Bansal

Signature of HOD

Date:

Signature of faculty

Date:

Note:
1. Ensure that all topics specified in the course are mentioned.
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SCHEDULE OF INSTRUCTIONS: UNIT –IV PLAN

Unit No.	Lesson No.	Date	No. of Periods	Topics / Sub-Topics	Objectives & Outcomes Nos.	References (Textbook, Journal)
4.	1	06.05.2024	1	UNIT - IV: Elements of a typical Hydropower installation	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	2	06.05.2024	1	Heads and efficiencies of hydraulic turbines	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	3	07.05.2024	1	Classification of turbines	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	4	07.05.024	1	velocity diagram, work done and efficiency	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	5	03.06.2024	1	Draft tube , Classification of draft tube .	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal Fluid Mechanics and Hydraulic machines by R. K. Bansal
	6	03.06.2024	1	functions and efficiency of draft tube	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	7	03.06.2024	1	Hydraulic Turbines – II: Governing of turbines	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	8	04.06.2024	1	Surge tanks, Unit and specific turbines	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	9	05.06.2024	1	Unit quantity, Performance characteristics	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	10	06.06.2024	1	Geometric similarity, Cavitations, Selection of turbines.	4 4	Fluid Mechanics and Hydraulic machines by R. K. Bansal

Signature of HOD

Signature of faculty

Date:

Date:

Note:

1. Ensure that all topics specified in the course are mentioned.
2. Additional topics covered, if any, may also be specified in bold.
3. Mention the corresponding course objective and outcome numbers against each topic.

Department of Civil Engineering

SCHEDULE OF INSTRUCTIONS: UNIT –V PLAN

Unit No.	Lesson No.	Date	No. of Periods	Topics / Sub-Topics	Objectives & Outcomes Nos.	References (Textbook, Journal)
5.	1	06.06.2024	1	UNIT - V Centrifugal Pumps: Component parts of centrifugal pumps	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	2	06.06.2024	1	Pump installation details	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	3	07.06.2024	1	classification – work done	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	4	07.06.2024	1	Manometric head –minimum starting speed	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	5	10.06.2024	1	losses and efficiencies	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	6	10.06.2024	1	Specific speed.	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	7	10.06.2024	1	Multistage pumps	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	8	11.06.2024	1	pumps in parallel – performance of pump	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	9	14.06.2024	1	NPSH – Cavitations	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal
	10	14.06.2024	1	Reciprocating pumps – Working, discharge, and slip indicator diagrams	5 5	Fluid Mechanics and Hydraulic machines by R. K. Bansal

Signature of HOD　　　　　　　　　　　　Signature of faculty

Date:　　　　　　　　　　　　　　　　　Date:

Note:
1. Ensure that all topics specified in the course are mentioned.
2. Additional topics covered, if any, may also be specified in bold.
3. Mention the corresponding course objective and outcome numbers against each topic.

Department of Civil Engineering

LESSON PLAN (U-I)

Lesson No: 01, 02 Duration of Lesson: 1 hr 40 min

Lesson Title: Introduction to Open channel flow

Instructional / Lesson Objectives:

- To make students understand Comparison between open channel flow and pipe flow
- To familiarize students on Chezy's, Manning's and Bazin formulae
- To understand students the concept of most economical sections, Specific energy, Channel transitions.
- To provide information on Specific force, critical, sub critical & super critical flow.

Teaching AIDS: PPTs, Digital Board

Time Management of Class :

2 mins for taking attendance 83 min for the lecture delivery 15 min for doubts session

Assignment / Questions:

(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-I)

Lesson No: 03, 04 Duration of Lesson: 2 hr 30 min

Lesson Title: Difference between open channel & closed or pipe flow, Classifications of open channel flow

Instructional / Lesson Objectives:

- To make students understand Comparison between open channel flow and pipe flow
- To familiarize students on Chezy's, Manning's and Bazin formulae
- To understand students the concept of most economical sections, Specific energy, Channel transitions.
- To provide information on Specific force, critical, sub critical & super critical flow.

Teaching AIDS: PPTs, Digital Board
Time Management of Class:

3 mins for taking attendance 12 for revision of previous class 120 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-I)

Lesson No: 05, 06 Duration of Lesson: 2 hr 30 min

Lesson Title: Discharge through open channel by chezy's formula, Problems on chezy's and empirical formula

Instructional / Lesson Objectives:

- To make students understand Comparison between open channel flow and pipe flow
- To familiarize students on Chezy's, Manning's and Bazin formulae
- To understand students the concept of most economical sections, Specific energy, Channel transitions.
- To provide information on Specific force, critical, sub critical & super critical flow.

Teaching AIDS: PPTs, Digital Board
Time Management of Class:

3 mins for taking attendance 12 for revision of previous class 120 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-I)

Lesson No: 07, 08 Duration of Lesson: 1 hr 40 min

Lesson Title: Bazin's formula & it's problems, Ganguillet- kutter formula & manning's formula

Instructional / Lesson Objectives:

- To make students understand Comparison between open channel flow and pipe flow
- To familiarize students on Chezy's, Manning's and Bazin formulae
- To understand students the concept of most economical sections, Specific energy, Channel transitions.
- To provide information on Specific force, critical, sub critical & super critical flow.

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

2 mins for taking attendance 83 min for the lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-I)

Lesson No: 09, 10 Duration of Lesson: 6 hr

Lesson Title: Discharge through open channel by chezy's formula, Problems on chezy's and empirical formula

Instructional / Lesson Objectives:

- To make students understand Comparison between open channel flow and pipe flow
- To familiarize students on Chezy's, Manning's and Bazin formulae
- To understand students the concept of most economical sections, Specific energy, Channel transitions.
- To provide information on Specific force, critical, sub critical & super critical flow.

Teaching AIDS: PPTs, Digital Board
Time Management of Class:

20 mins for taking attendance
50 for revision of previous class
180 min for lecture delivery
50 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-I)

Lesson No: 11, 12 Duration of Lesson: 1 hr 40 min

Lesson Title: Critical depth, critical velocity, Specific energy& specific energy curve

Instructional / Lesson Objectives:

- To make students understand Comparison between open channel flow and pipe flow
- To familiarize students on Chezy's, Manning's and Bazin formulae
- To understand students the concept of most economical sections, Specific energy, Channel transitions.
- To provide information on Specific force, critical, sub critical & super critical flow.

Teaching AIDS: PPTs, Digital Board

Time Management of Class :

2 mins for taking attendance 83 min for the lecture delivery 15 min for doubts session

Assignment / Questions:

(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-I)

Lesson No: 13 Duration of Lesson: 50 min

Lesson Title: critical, Sub critical and super critical flows-Channel transitions.

Instructional / Lesson Objectives:

- To make students understand Comparison between open channel flow and pipe flow
- To familiarize students on Chezy's, Manning's and Bazin formulae
- To understand students the concept of most economical sections, Specific energy, Channel transitions.
- To provide information on Specific force, critical, sub critical & super critical flow.

Teaching AIDS: PPTs, Digital Board

Time Management of Class :

2 mins for taking attendance 40 min for the lecture delivery 8 min for doubts session

Assignment / Questions:

(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-II)

Lesson No: 01, 02 Duration of Lesson: 1 hr 40 min

Lesson Title: Non-uniform flow, Gradually Varied Flow

Instructional / Lesson Objectives:

- To make students understand the Non-uniform flow, channel bottom slopes, surface profiles
- To familiarize students on hydraulic jump, types of surges
- To understand students the types of non-uniform flow, hydraulic jump
- To provide information on solution for Gradually Varied Flow, hydraulic jump

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

2mins for taking attendance 13 for revision of previous class 70 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-II)

Lesson No: 03, 04 Duration of Lesson: 1 hr 40 min

Lesson Title: Dynamic equation for G.V.F, Classification of channel bottom slopes

Instructional / Lesson Objectives:

- To make students understand the Non-uniform flow, channel bottom slopes, surface profiles
- To familiarize students on hydraulic jump, types of surges
- To understand students the types of non-uniform flow, hydraulic jump
- To provide information on solution for Gradually Varied Flow, hydraulic jump

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

2mins for taking attendance
13 for revision of previous class
70 min for lecture delivery
15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-II)

Lesson No: 05, 06 Duration of Lesson: 2 hr 30 min

Lesson Title: Classification and characteristics of Surface profiles, Numerical and Analytical approaches - Direct step method.

Instructional / Lesson Objectives:

- To make students understand the Non-uniform flow, channel bottom slopes, surface profiles
- To familiarize students on hydraulic jump, types of surges
- To understand students the types of non-uniform flow, hydraulic jump
- To provide information on solution for Gradually Varied Flow, hydraulic jump

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

3 mins for taking attendance 12 for revision of previous class 120 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-II)

Lesson No: 07, 08 Duration of Lesson: 2 hr 30 min

Lesson Title: Hydraulic jump in rectangular channel- derivation, Types, applications of hydraulic jump

Instructional / Lesson Objectives:

- To make students understand the Non-uniform flow, channel bottom slopes, surface profiles
- To familiarize students on hydraulic jump, types of surges
- To understand students the types of non-uniform flow, hydraulic jump
- To provide information on solution for Gradually Varied Flow, hydraulic jump

Teaching AIDS: PPTs, Digital Board

Time Management of Class :

3 mins for taking attendance 12 for revision of previous class 120 min for lecture delivery 15 min for doubts session

Assignment / Questions:

(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-II)

Lesson No: 09, 10 & 11 Duration of Lesson: 2 hr 30 min

Lesson Title: Efficiency and energy dissipation of hydraulic jump, location of hydraulic jump, Positive and Negative Surges

Instructional / Lesson Objectives:

- To make students understand the Non-uniform flow, channel bottom slopes, surface profiles
- To familiarize students on hydraulic jump, types of surges
- To understand students the types of non-uniform flow, hydraulic jump
- To provide information on solution for Gradually Varied Flow, hydraulic jump

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

3 mins for taking attendance 12 for revision of previous class 120 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-III)

Lesson No: 01, 02 Duration of Lesson: 1 hr 40 min

Lesson Title: Introduction to Dimensions, Dimensional Homogeneity

Instructional / Lesson Objectives:

- To make students understand the dimensions, dimensionless groups, types of similarities, models
- To familiarize students on dimensions, hydrodynamic forces on plates
- To understand students the dimensional homogeneity-Rayleigh's & bucking pie methods
- To provide information on solution for dimensionless groups, models, hydrodynamic forces on plates

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

2mins for taking attendance
13 for revision of previous class
70 min for lecture delivery
15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-III)

Lesson No: 03, 04 Duration of Lesson: 1 hr 40 min

Lesson Title: Buckingham's π methods, problems, Rayleigh's method, problems

Instructional / Lesson Objectives:

- To make students understand the dimensions, dimensionless groups, types of similarities, models
- To familiarize students on dimensions, hydrodynamic forces on plates
- To understand students the dimensional homogeneity-Rayleigh's & bucking pie methods
- To provide information on solution for dimensionless groups, models, hydrodynamic forces on plates

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

2mins for taking attendance 13 for revision of previous class 70 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-III)

Lesson No: 05, 06 Duration of Lesson: 1 hr 40 min

Lesson Title: Model studies, Types of models, Similitude, Application of dimensional analysis

Instructional / Lesson Objectives:

- To make students understand the dimensions, dimensionless groups, types of similarities, models
- To familiarize students on dimensions, hydrodynamic forces on plates
- To understand students the dimensional homogeneity-Rayleigh's & bucking pie methods
- To provide information on solution for dimensionless groups, models, hydrodynamic forces on plates

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

2mins for taking attendance 13 for revision of previous class 70 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-III)

Lesson No: 07, 08 Duration of Lesson: 1 hr 40 min

Lesson Title: Distorted models, model studies to fluid flow problems, Hydrodynamic force of jets on stationary and moving flat & moving flat plate

Instructional / Lesson Objectives:

- To make students understand the dimensions, dimensionless groups, types of similarities, models
- To familiarize students on dimensions, hydrodynamic forces on plates
- To understand students the dimensional homogeneity-Rayleigh's & bucking pie methods
- To provide information on solution for dimensionless groups, models, hydrodynamic forces on plates

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

2mins for taking attendance
13 for revision of previous class
70 min for lecture delivery
15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-III)

Lesson No: 09, 10 Duration of Lesson: 1 hr 40 min

Lesson Title: inclined and curved vanes, jet striking centrally and at tip, Velocity triangles at inlet and outlet, expressions for work done and efficiency

Instructional / Lesson Objectives:

- To make students understand the dimensions, dimensionless groups, types of similarities, models
- To familiarize students on dimensions, hydrodynamic forces on plates
- To understand students the dimensional homogeneity-Rayleigh's & bucking pie methods
- To provide information on solution for dimensionless groups, models, hydrodynamic forces on plates

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

2mins for taking attendance 13 for revision of previous class 70 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-IV)

Lesson No: 01, 02 Duration of Lesson: 1 hr 40 min

Lesson Title: Elements of a typical Hydropower installation, Heads and efficiencies of hydraulic turbines

Instructional / Lesson Objectives:

- To make students understand the Hydropower plant installation, types of turbines
- To familiarize students on heads and efficiencies of turbines
- To understand students the velocity diagrams, work done and efficiency, unit quantises, cavitations, draft tube
- To provide information on solution heads, efficiency, velocity triangles

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

2mins for taking attendance 13 for revision of previous class 70 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-IV)

Lesson No: 03, 04 Duration of Lesson: 1 hr 40 min

Lesson Title: Classification of turbines, velocity diagram, work done and efficiency

Instructional / Lesson Objectives:

- To make students understand the Hydropower plant installation, types of turbines
- To familiarize students on heads and efficiencies of turbines
- To understand students the velocity diagrams, work done and efficiency, unit quantises, cavitations, draft tube
- To provide information on solution heads, efficiency, velocity triangles

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

2mins for taking attendance 13 for revision of previous class 70 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-IV)

Lesson No: 05, 06 Duration of Lesson: 1 hr 40 min

Lesson Title: Draft tube, Classification of draft tube, Draft tube , Classification of draft tube

Instructional / Lesson Objectives:

- To make students understand the Hydropower plant installation, types of turbines
- To familiarize students on heads and efficiencies of turbines
- To understand students the velocity diagrams, work done and efficiency, unit quantises, cavitations, draft tube
- To provide information on solution heads, efficiency, velocity triangles

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

2mins for taking attendance 13 for revision of previous class 70 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-IV)

Lesson No: 07, 08 Duration of Lesson: 1 hr 40 min

Lesson Title: Hydraulic Turbines – II: Governing of turbines, Surge tanks, Unit and specific turbines

Instructional / Lesson Objectives:

- To make students understand the Hydropower plant installation, types of turbines
- To familiarize students on heads and efficiencies of turbines
- To understand students the velocity diagrams, work done and efficiency, unit quantises, cavitations, draft tube
- To provide information on solution heads, efficiency, velocity triangles

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

2mins for taking attendance
13 for revision of previous class
70 min for lecture delivery
15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-IV)

Lesson No: 09, 10 Duration of Lesson: 1 hr 40 min

Lesson Title: Unit quantity, Performance characteristics, Geometric similarity, Cavitations, Selection of turbines.

Instructional / Lesson Objectives:

- To make students understand the Hydropower plant installation, types of turbines
- To familiarize students on heads and efficiencies of turbines
- To understand students the velocity diagrams, work done and efficiency, unit quantises, cavitations, draft tube
- To provide information on solution heads, efficiency, velocity triangles

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

2mins for taking attendance 13 for revision of previous class 70 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U - V)

Lesson No: 01, 02 Duration of Lesson: 1 hr 40 min

Lesson Title: Component parts of centrifugal pumps, Pump installation details

Instructional / Lesson Objectives:

- To make students understand the centrifugal pumps, reciprocating pumps
- To familiarize students on heads and efficiencies of pumps
- To understand students the specific speed, work done and efficiency, performance & characteristic curves of pumps
- To provide information on solution manometric heads, efficiency, minimum starting speed of the pumps.

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

2mins for taking attendance 13 for revision of previous class 70 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U - V)

Lesson No: 03, 04 Duration of Lesson: 1 hr 40 min

Lesson Title: classification of pumps & work done, Manometric head –minimum starting speed

Instructional / Lesson Objectives:

- To make students understand the centrifugal pumps, reciprocating pumps
- To familiarize students on heads and efficiencies of pumps
- To understand students the specific speed, work done and efficiency, performance & characteristic curves of pumps
- To provide information on solution manometric heads, efficiency, minimum starting speed of the pumps.

Teaching AIDS: PPTs, Digital Board

Time Management of Class :

2mins for taking attendance
13 for revision of previous class
70 min for lecture delivery
15 min for doubts session

Assignment / Questions:

(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U - V)

Lesson No: 05, 06 Duration of Lesson: 1 hr 40 min

Lesson Title: Losses and efficiencies, Specific speed.

Instructional / Lesson Objectives:

- To make students understand the centrifugal pumps, reciprocating pumps
- To familiarize students on heads and efficiencies of pumps
- To understand students the specific speed, work done and efficiency, performance & characteristic curves of pumps
- To provide information on solution manometric heads, efficiency, minimum starting speed of the pumps.

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

2mins for taking attendance 13 for revision of previous class 70 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U - V)

Lesson No: 07, 08 Duration of Lesson: 1 hr 40 min

Lesson Title: Multistage pumps, pumps in parallel – performance of pump

Instructional / Lesson Objectives:

- To make students understand the centrifugal pumps, reciprocating pumps
- To familiarize students on heads and efficiencies of pumps
- To understand students the specific speed, work done and efficiency, performance & characteristic curves of pumps
- To provide information on solution manometric heads, efficiency, minimum starting speed of the pumps.

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

2mins for taking attendance 13 for revision of previous class 70 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U - V)

Lesson No: 09, 10 Duration of Lesson: 1 hr 40 min

Lesson Title: NPSH & Cavitation, Reciprocating pumps – Working, discharge, and slip indicator diagrams

Instructional / Lesson Objectives:

- To make students understand the centrifugal pumps, reciprocating pumps
- To familiarize students on heads and efficiencies of pumps
- To understand students the specific speed, work done and efficiency, performance & characteristic curves of pumps
- To provide information on solution manometric heads, efficiency, minimum starting speed of the pumps.

Teaching AIDS: PPTs, Digital Board
Time Management of Class :

2mins for taking attendance 13 for revision of previous class 70 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment-II & tutorial-II sheets.

Signature of faculty

Department of Civil Engineering

ASSIGNMENT – 1

This Assignment corresponds to Unit No. 1

Question No.	Question	Objective No.	Outcome No.
1	Derive the discharge through open channel by chezy's formula	1	1
2	Illustrate the classification of open channel flows.	1	1
3	Explain briefly about specific energy & specific energy curve	1	1

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

ASSIGNMENT – 2

This Assignment corresponds to Unit No. 2

Question No.	Question	Objective No.	Outcome No.
1	Derive the dynamic equation for gradually varied flow & it's assumptions.	2	2
2	A sluice gate discharges water into a horizontal rectangular channel with a velocity of 6 m/s and depth of flow is 0.4 m. The width of the channel is 8 m. Determine whether a hydraulic jump will occur, and if so, find its height and loss of energy per kg of water. Also determine the power lost in the hydraulic jump.	2	2
3	Explain different types of slopes in non uniform flow channel	2	2

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

ASSIGNMENT – 3

This Assignment corresponds to Unit No. 3

Question No.	Question	Objective No.	Outcome No.
1	Using bucking pie theorem show that the velocity through a circular orifice is given by $v = \sqrt{2gH}\ \text{Ø}\left[\frac{D}{H}, \frac{\mu}{pVH}\right]$, where H is the head causing flow, D is the diameter of the orifice, μ is the coefficient of viscosity, p is the mass density and g is the acceleration due to gravity.	3	3
2	A jet of water of 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 degrees. 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.	3	3
3	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 is deflected through an angle of 120 degrees at the outlet of the curved plate.	3	3

Signature of HOD   Signature of faculty

Date: Date:

Department of Civil Engineering

ASSIGNMENT – 4

This Assignment corresponds to Unit No. 4

Question No.	Question	Objective No.	Outcome No.
1	Define specific speed of a turbine? Derive an expression for the specific speed. What is the significance of the specific speed?	4	4
2	Explain the following efficiencies of a turbine A) Hydraulic efficiency B) Mechanical efficiency C) Volumetric efficiency D) Overall efficiency	4	4
3	Define draft tube and explain its types	4	4

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

ASSIGNMENT – 5

This Assignment corresponds to Unit No. 5

Question No.	Question	Objective No.	Outcome No.
1	Illustrate the classification of pumps	5	5
2	Illustrate the characteristics curves of pumps	5	5
3	A centrifugal pump is to discharge 0.118 m3/sec at a speed if 1450 r.p.m. Against a head of 25 m. The impeller diameter is 250 mm, its width at outlet is 50 mm and mano-metric efficiency is 75%. Determine the vane angle at the outer periphery of the impeller.	5	5

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

TUTORIAL – 1

This tutorial corresponds to Unit No. 1 (Objective Nos.: 1, Outcome Nos.: 1)

1. The flow characteristic of a channel does not change with time at any point. What type of flow is it?
   a) Steady flow b) Uniform flow c) Laminar flow d) Turbulent flow

2. The ratio of inertia force and gravitational force is called as ______
   a) Reynolds number b) Stokes number c) Froude's number d) Euler's number

3. The Froude's number for a flow in a channel section is 1. What type of flow is it?
   a) Sub Critical b) Critical c) Super critical d) Tranquil

4. For a channel to be economic which of the following parameters should be minimum?
   a) Wetted perimeter b) Wetted area c) Section factor d) Hydraulic depth

5. What is energy per unit head of water called as __________
   a) Total energy b) Specific energy c) Velocity head d) Datum head

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

TUTORIAL – 2

This tutorial corresponds to Unit No. 2 (Objective Nos.: 2, Outcome Nos.: 2)

Q1. Which of the following assumptions is true in case of GVF?

a) The flow is not steady b) The streamlines are parallel

c) Pressure distribution is not hydrostatic d) Channel has varying alignment and shape

Q2. What is the expression for the length of the backwater curve?

a) L = E_2-E_1/S_f-S_0 b) L = E_2-E_1/S_f c) L = E_2-E_1/S_0-S_f d) L = E_2-E_1/S_0

Q3. Classical jump occurs when________

a) Temperature changes b) Pressure changes

c) Supercritical to subcritical change d) Volumetric changes

Signature of HOD Signature of faculty

Date: Date:

Department of Civil Engineering

TUTORIAL – 3

This tutorial corresponds to Unit No. 3 (Objective Nos.: 3, Outcome Nos.: 3)

Q1. Which among the following is not a criteria to achieve similitude?
a) Geometric similarity b) Kinematic similarity
c) Dynamic similarity d) Conditional similarity

Q2. What are the dimensions of force?
a) MLT^{-2} b)) MLT^{-1}
c) $ML^{2}T^{-2}$ d)) $ML^{2}T^{2}$

Q3. Square root of the ratio of inertia force to elastic force is called as
a) Mach's Number b) Cauchy's Number
c) Both a & b d) None of the Above

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Date:

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TUTORIAL – 4

This tutorial corresponds to Unit No. 4 (Objective Nos.: 3, Outcome Nos.: 3)

Q1. Which principle is used in Hydraulic Turbines?
a) Faraday law b) Newton's second law
c) Charles law d) Braggs law

Q2. Buckets and blades used in a turbine are used to:
a) Alter the direction of water b) Switch off the turbine
c) To regulate the wind speed d) To regenerate the power

Q3. Which type of turbine is a Francis Turbine?
a) Impulse Turbine b) Screw Turbine
c) Reaction turbine d) Turgo turbine

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Date:

Signature of faculty

Date:

Department of Civil Engineering

TUTORIAL – 5

This tutorial corresponds to Unit No. 5 (Objective Nos.: 5, Outcome Nos.: 5)

Q1. Centrifugal pump is a_________
a) Turbo machinery b) Flow regulating device
c) Drafting device d) Intercooling device

Q2. Centrifugal pumps are used to transport ________
a) Pressure b) Speed c) Power d) Fluid

Q3. The velocity imparted by the impeller is converted into _________
a) Pressure energy b) Kinetic energy
c) Momentum d) Potential energy

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Date:

Signature of faculty

Date:

Department of Civil Engineering

EVALUATION STRATEGY

Target (s)

a. Percentage of Pass : -- %

Assessment Method (s) (Maximum Marks for evaluation are defined in the Academic Regulations)

a. Daily Attendance
b. Assignments
c. Online Quiz (or) Seminars
d. Continuous Internal Assessment
e. Semester / End Examination

List out any new topic(s) or any innovation you would like to introduce in teaching the subjects in this semester

Case Study of any one existing application

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

COURSE COMPLETION STATUS

Actual Date of Completion & Remarks if any

Units	Remarks	Objective No. Achieved	Outcome No. Achieved
Unit 1	completed on 04.03.2024	1	1
Unit 2	completed on 30.03.2024	2	2
Unit 3	completed on 06.05.2024	3	3
Unit 4	completed on 12.06.2024	4	4
Unit 5	completed on 14.06.2024	5	5

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Mappings

1. Course Objectives-Course Outcomes Relationship Matrix

(Indicate the relationships by mark "X")

Course-Outcomes / Course-Objectives	1	2	3	4	5
1	H		M		
2		H			
3			H		
4				H	
5					H

2. Course Outcomes-Program Outcomes (POs) & PSOs Relationship Matrix

(Indicate the relationships by mark "X")

P-Outcomes / C-Outcomes	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO 1	PSO 2
CO1		M			M								H	
CO2	H	L		M			L	H			M		H	H
CO3	L	M						L			L			M
CO4	M				H		M			H			M	
CO5		H						M		M	M			

Department of Civil Engineering

Rubric for Evaluation

Performance Criteria	Unsatisfactory	Developing	Satisfactory	Exemplary
	1	2	3	4
Research & Gather Information	Does not collect any information that relates to the topic	Collects very little information some relates to the topic	Collects some basic Information most relates to the topic	Collects a great deal of Information all relates to the topic
Fulfill team role's duty	Does not perform any duties of assigned team role.	Performs very little duties.	Performs nearly all duties.	Performs all duties of assigned team role.
Share Equally	Always relies on others to do the work.	Rarely does the assigned work - often needs reminding.	Usually does the assigned work - rarely needs reminding.	Always does the assigned work without having to be reminded
Listen to other team mates	Is always talking— never allows anyone else to speak.	Usually doing most of the talking-- rarely allows others to speak	Listens, but sometimes talks too much.	Listens and speaks a fair amount.

II B.TECH IV SEMESTER II MID EXAMINATIONS - JUNE 2024

Branch : B.Tech. (CE) **Max. Marks : 30M**
Date : 19-Jun-2024 **Session : Afternoon** **Time : 120 Min**
Subject : Hydraulics and Hydraulics Machinery,CE404PC

PART - A

ANSWER ALL THE QUESTIONS **10 X 1M = 10M**

Q.No	Question		CO	BTL
1.	In a stationery vertical plate, the jet after striking the plate will move ________ (A). In opposite direction (B). Along the plate (C). Perpendicular to the plate (D). Parallel to the plate	( )	CO3	L1
2.	At what angle does the jet deflect after striking a stationery vertical plate? (A). 30 (B). 60 (C). 90 (D). 0	( )	CO3	L2
3.	Which among the following which is not an efficiency of turbine? (A). Mechanical efficiency (B). Volumetric efficiency (C). Hydraulic efficiency (D). Electrical efficiency	( )	CO4	L1
4.	In a reaction turbine, the draft tube is used to ________ (A). To increase the head of water by an amount that is equal to the height of the runner outlet above the tail race (B). To prevent air to enter the turbine (C). To increase pressure energy of water (D). To transport water to downstream	( )	CO4	L2
5.	____________ is ratio of volume of water actually striking the runner and volume of water supplied to turbine. (A). Mechanical efficiency (B). Volumetric efficiency (C). Hydraulic efficiency (D). Overall efficiency	( )	CO4	L2
6.	Which kind of turbine is a Pelton Wheel turbine? (A). Tangential flow turbine (B). Radial flow turbine (C). Outward flow turbine (D). Inward flow turbine	( )	CO4	L1
7.	Multistage centrifugal pumps is use for which of the following factor.. (A). High head (B). High velocity (C). High discharge (D). High efficiency	( )	CO5	L1
8.	2. The volute pumps and vortex volute pumps are __________ pumps with _________ shaft. (A). multistage, horizontal (B). multistage, vertical (C). single stage, horizontal (D). single stage, vertical	( )	CO5	L1
9.	In centrifugal pump friction is more than reciprocating pump. (A). TRUE (B). FALSE (C). (D).	( )	CO5	L2
10.	centrifugal pump is suitable for low speed and high head in use. (A). True (B). False (C). (D).	( )	CO5	L2

PART - B

ANSWER ANY FOUR **4 X 5M = 20M**

Q.No	Question	CO	BTL
11.	A jet of water of 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 degrees. 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.	CO3	L3
12.	Derive the force exerted by the jet of water on the curved plate in the direction of the jet & work done by the jet on the plate per second.	CO3	L4

13.	A conical draft tube having inlet and outlet diameter 0.8 m and 1.2 m discharge water at outlet with velocity of 3 m/s. The total length of the draft tube is 8 m and 2 m of length of the draft tube is immersed in water. If the atmospheric pressure head is 10.3 m of water and loss of head due to friction in the tube equal to .25 times the velocity head at outlet of the tube, find the pressure head at inlet.	CO4	L3
14.	A pelton wheel is to be designed for a head of 60 m when the runing at 200 r.p.m. The pelton wheel develops 95.6475 KW shaft power. The velocity of the buckets=0.45 times the velocity of the jet, overall efficiency=0.85. coefficient of velocity is equal to 0.98	CO4	L3
15.	A) answer the following multistage pump with imeller in i) parallel ii) series with ner sketches B) with a neat sketch explain the working principle of centrifugal pump.	CO5	L4
16.	The internal and external diameter of the impeller of a centrifugal pump are 200 and 400 mm respectively. The pump is running at 1200 r.p.m. The vane angle of impeller radially and velocity of flow is constant. Determine the working by the impeller per unit weight of water.	CO5	L3

Continuous InternalAssessment (R-22)

Programme: **B.Tech** Year: **II** Course: **Theory** **A.Y: 2023-24**

Course: **Hydraulics & Hydraulic Machinery** Faculty Name: **Mr K Upendar**

S. No	Roll No	MID-I (35M)	MID-II (35M)	Avg. of MID I & II	Viva-Voce/Poster Presentation (5M)	Total Marks (40)
1	**21C11A0113**	05	20	13	5	18
2	**22C11A0101**	13	22	18	5	23
3	**22C11A0102**	28	31	30	5	35
4	**22C11A0103**	14	21	18	5	23
5	**22C11A0104**	09	19	14	5	19
6	**22C11A0105**	28	34	31	5	36
7	**22C11A0106**	14	20	17	5	22
8	**22C11A0107**	09	19	14	5	19
9	**23C15A0101**	19	21	20	5	25
10	**23C15A0102**	19	26	23	5	28
11	**23C15A0103**	33	32	33	5	38
12	**23C15A0104**	14	23	19	5	24
13	**23C15A0105**	23	35	29	5	34

No. of Absentees: 01

Total Strength: 13

Signature of Faculty: **Signature of HoD**

ANURAG ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Affiliated to JNTUH, Hyderabad; Accredited by NAAC with A+ Grade)

Ananthagiri (V & M), Kodad, Suryapet (Dist), Telangana.

Program		
B.Tech. ✓	M.Tech.	M.B.A.

YEAR	SEMESTER	MID EXAMINATION
II	II	II

HALL TICKET NO.: 2 3 C 1 5 A 0 1 0 5

Regulation : R22 Branch or Specialization: Civil

Course: HHM

Signature of Student: [signature]

Signature of invigilator with date: [signature] 19/6/24

Signature of the Evaluator: [signature] 21/6/24

Q.No. and Marks Awarded										
1	2	3	4	5	6	7	8	9	10	11

Maximum Marks: 30 Marks Obtained: 30

(Start Writing From Here)

PART-B

Q.NO-11-

Given- $d = 75mm = 0.075m$

$V = 25 m/s$

$\theta = 60°$

(i) The force exerted by the jet on the plate in the direction normal to the plate-

$F_n = \rho a v^2 \sin\theta$

$a = \frac{\pi}{4} \times d^2 = \frac{\pi}{4} \times 0.075^2 = 4.41 \times 10^{-3} m^2$

5

$F_n = 1000 \times 4.41 \times 10^{-3} \times \sin(60) \times 25^2$

$\therefore F_n = 2389.89 N$

(ii) The force exerted by the jet on the plate in the direction of jet-

$F_x = \rho a v^2 \sin^2\theta$

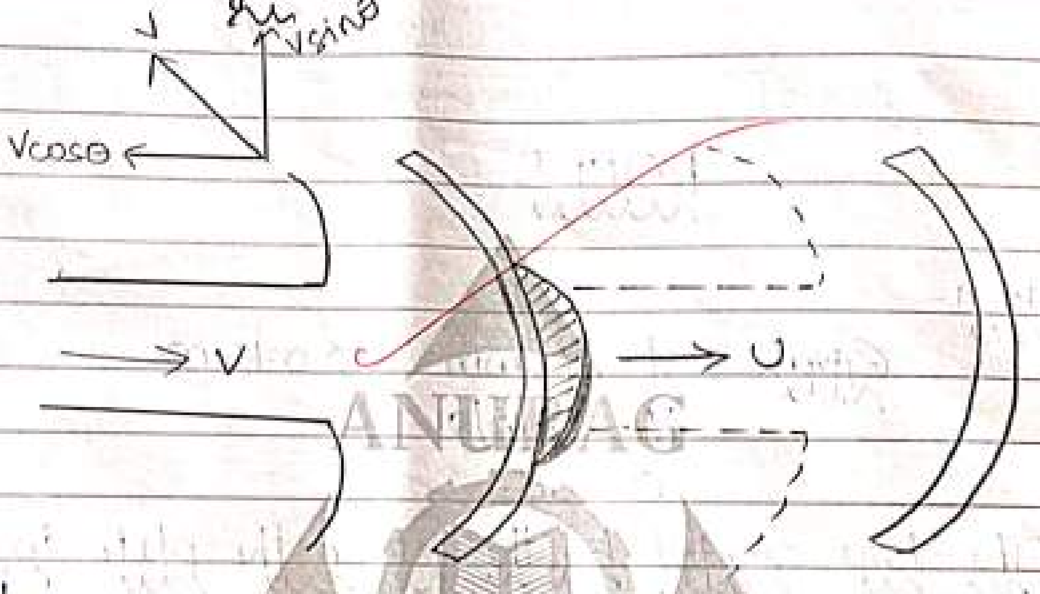
$= 1000 \times 4.41 \times 10^{-3} \times \sin^2(60) \times 25$

$\therefore F_x = 2067.18 N$

$\therefore F_n = 2389.89\ N$
$F_x = 2067.18\ N$

Q.NO-12 -

Expression for the force exerted by the Jet of water on the curved plate in the direction of Jet-



where,

V = velocity of the water - m/sec
U = velocity of the moving Jet - m/sec

Relative velocity of the fluid = $[V-U]$
Mass of the water striking the plate = $\rho a[V-U]$

The force exerted by the jet of water on the curved plate in the direction of Jet -

$$F_x = \rho a[V-U]\,[V_1x_1 - V_2x_2]$$
$$= \rho a[V-U]\,[V-U-(-V-U)]\cos\theta$$
$$= \rho a[V-U]\,[V-U]\,[1+\cos\theta]$$
$$= \rho a[V-U]^2(1+\cos\theta).$$

$$\therefore F_x = \rho a (V-U)^2 (1+\cos\theta)$$

(ii) workdone by the jet on the plate per second -

$W = F_x \times U$

$$\therefore W = \rho a (V-U)^2 (1+\cos) \times U \quad \text{Nm/s}$$

Q.NO-15 -

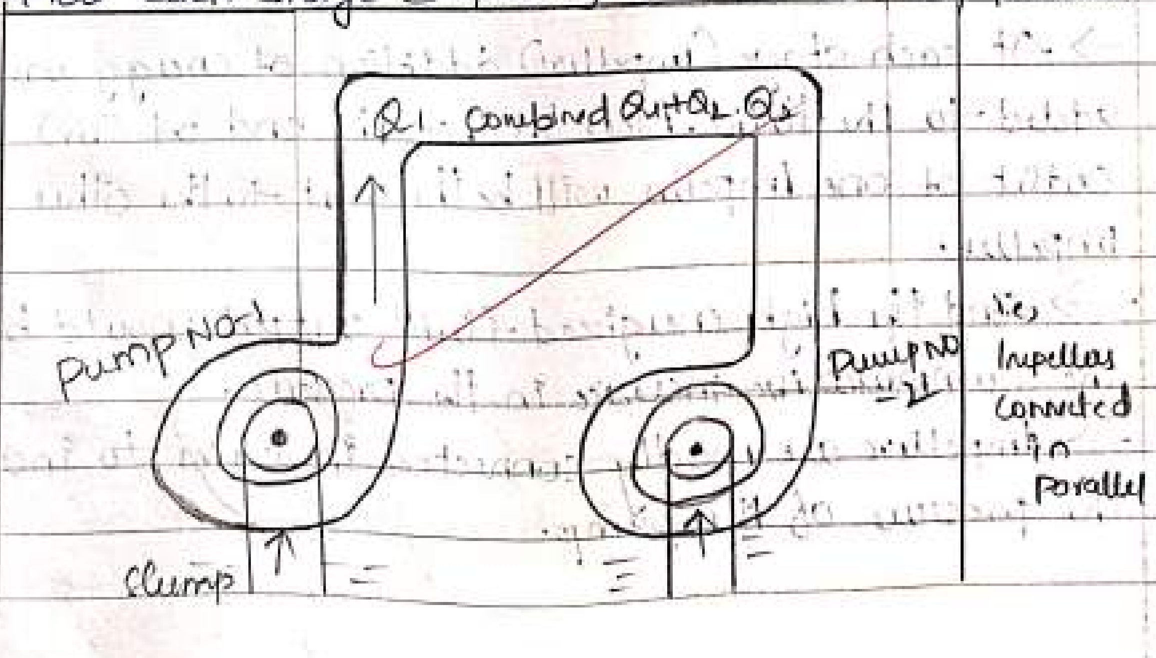
@ Multistage centrifugal pump - If a pump Consists of two (or) more no. of Impellers then that kind of pumps are known as Multistage centrifugal pump.

Impeller - It is a rotating parts which helps in Converting the drive energy into the kinetic energy. These Impellers are designed in parallel and Series too.

@(i) Impeller in parallel - Here the Impellers are designed in parallel to increase the flow rate (or) the discharge.

-> By Maintaing the same pressure as in single stage centrifugal pumps.

-> Here each stage [Impeller] will handle one portion



of this flowrate. And this combined output would be the sum of all this flow rates at each stage.

→ Impellers are mostly connected in so parallel to achieve high flowrate.

(ii) Impeller in Series

→ Impellers are connected in series to increase the pressure (or) head incrementantly.

→ This can be achieved by passing the fluid through these Impeller at each stage one after the other.

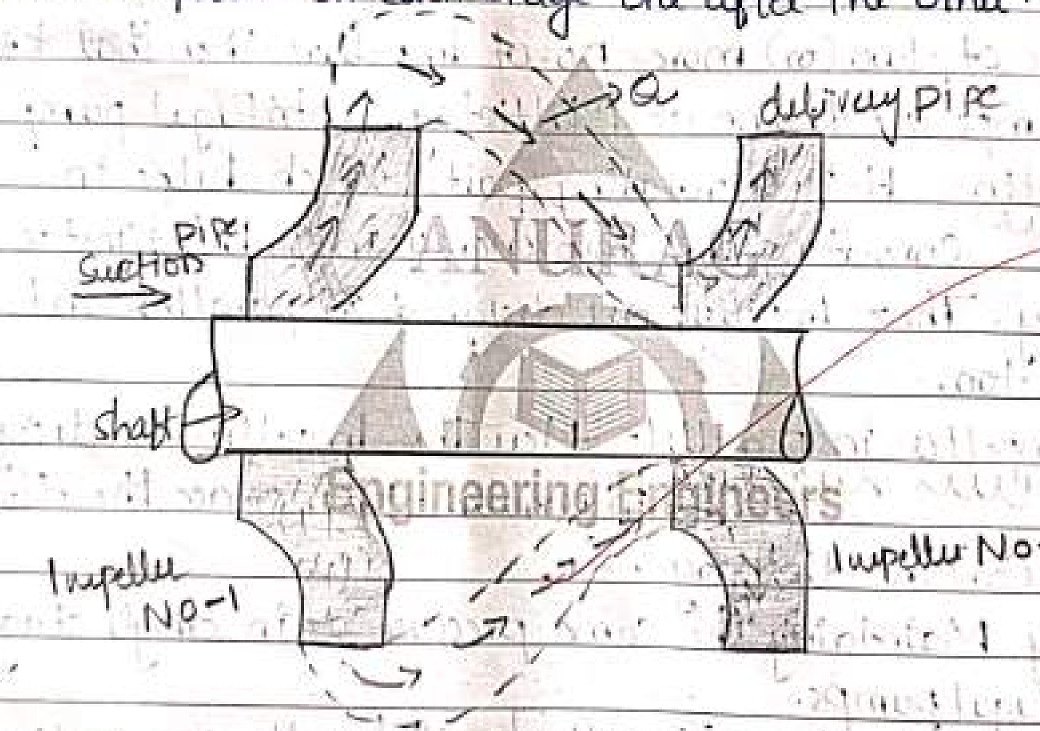


fig – Impeller connected in series.

→ At each stage (Impeller) addition of energy will be added to the fluid. Here in this the end of (or) outlet of one Impeller will be the inlet to the other Impeller.

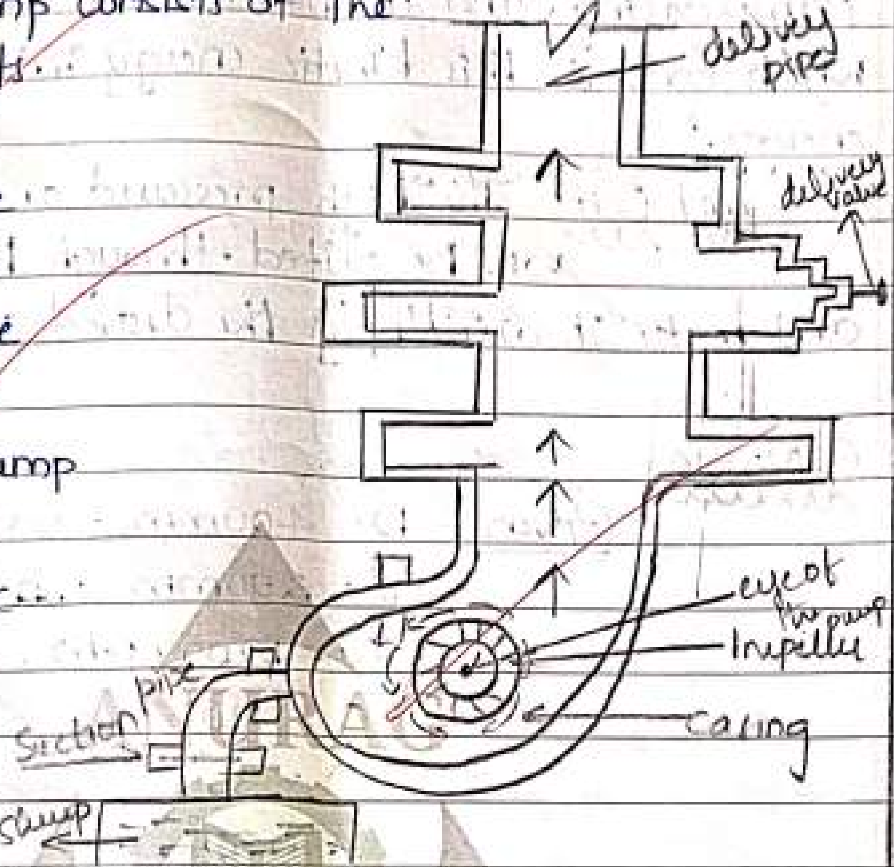
→ And the high energized fluid output would be the cummulative increase in the pressure.

→ Impellers are mostly connected in series to increase the pressure of the pump.

(B) Working Principle of Centrifugal pump-

Centrifugal pump consists of the following parts..

1. Impeller
2. Delivery pipe
3. Suction pipe
4. Delivery valve
5. Casing
6. eye of the pump
7. Seal
8. Bearing etc...



Working-

* Fluid Entry [Suction]- The fluid will be entired into the pump with the help of Suction pipe. The low-pressure area eye of the pump which is the center area of the Impeller. First the water will be entered there.

* Impeller Action- The Impeller is a rotating part which is running with high because of the motor. Here the Impeller because of its rotating speed. It converts the drive energy into the kinetic energy.

* Fluid Acceleration- The centrifugal force in the pump transfers the water in the eye of Impeller to it periphery.

→ Here the velocity of the fluid will be increased accordingly.

* **Conversion of Kinetic Energy** – The high velocity fluid will be entered into the pump casing. And it increases the width of the casing which converts this kinetic energy into the pressure energy.

* **Fluid Exit** – The high pressured and velocity fluid will be exited through the delivery pipe and make it available for the desired applications.

Q.NO-16–

<u>Given</u> – $D = 400mm = 0.40m$

$d = 200mm = 0.20m$

$N = 1200 r.p.m$

$\theta = 20^\circ$

$\phi = 30^\circ$

$\alpha = 90^\circ$

Tangential velocity –

$$U_1 = \frac{\pi d N}{60} = \frac{\pi \times 0.20 \times 1200}{60}$$

$$U_2 = \frac{\pi D N}{60} = \frac{\pi \times 0.40 \times 1200}{60}$$

$$\boxed{U_1 = 12.56\ m/sec \quad U_2 = 25.13\ m/sec}$$

From the Inlet triangle – $\theta = 20^\circ$

$$\tan\theta = \frac{V_{f1}}{U_1}$$

$$\tan(20) = \frac{V_{f1}}{U_1}$$

$$V_{f1} = \tan(20) \times 12.56$$

$$\boxed{V_{f1} = 4.571\ m/sec}$$

$$V_{f1} = V_{f2} = 4.57\ m/sec$$

From the outlet triangle - $\tan\phi = \frac{V_{f2}}{u_2 - V_{w2}}$

$$\tan(30) = \frac{4.57}{25.13 - V_{w2}}$$

$$25.13 - V_{w2} = \frac{4.57}{\tan(30)}$$

$$25.13 - V_{w2} = 7.91$$

$$-V_{w2} = 7.91 - 25.13$$

$$-V_{w2} = -17.22$$

$$\therefore V_{w2} = 17.22$$ per unit weight of the water

$$\therefore V_{w2} = 17.22\ N\text{-}m/s$$

PART-A -

1. B
2. C
3. D
4. A
5. B
6. A
7. A
8. C
9. A
10. B

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DEPARTMENT OF CIVIL ENGINEERING

MID- II ASSIGNMENT

25/5 = 5

YEAR & SEMESTER:	II-Year-II sem
HALL TICKET NO:	23C15A0105
STUDENT NAME:	B. Sruthi
SUBJECT:	HHM
SUBMISSION DATE:	12-06-2024

STUDENT SIGNATURE

FACULTY SIGNATURE

Explain the following Efficiencies of a Turbine.
(a) Hydraulic Efficiency.
(b) Mechanical Efficiency
(c) Volumetric Efficiency
(d) overall Efficiency.

* **Hydraulic Efficiency** - Ratio of power given by water to runner of a turbine to power supplied by the water at the inlet of the turbine.

$$\eta_h = \frac{\text{power delivered to runner}}{\text{Power supplied at Inlet}} = \frac{R.P}{W.P}$$

* **Mechanic Efficiency** - The power delivered by water to runner of a turbine is transfered to the shaft of the turbine. Due to mechanical losses, the power available delivered to the runners of the turbine.

"Ratio of power available at the shaft of the turbine to the power delivered to the runner".

$$\eta_m = \frac{\text{Power at the shaft of the turbine}}{\text{Power delivered by water to runner}} = \frac{S.P}{R.P}$$

* **Volumetric Efficiency** - The volume of water striking the runner of a turbine is slightly less than the volume of water supplied to the turbine.

$$\eta_v = \frac{\text{Volume of water actually striking the runner}}{\text{Volume of water supplied to the turbine.}}$$

* **Overall Efficiency** - Ratio of power available at the shaft of the turbine to the power supplied by the water at the inlet of the turbine.

Illustrate the classification of pumps.

* Classification of Pumps-

1. According to No. of Impellers
   (a) Single stage pump
   (b) Multistage pump
2. According to Disposition of shaft.
   (a) Vertical shaft pump
   (b) Horizontal pump
3. According to Head
   (a) Low Head pump
   (b) Medium Head pump
   (c) High Specific speed Turbine.

(Q2) Define specific speed of the pump and derive the specific speed equation.

* Specific Speed - Specific speed is a dimensionless rating of pump discharge performance derived from an equation involving shaft speed, flow rate and differential head at a pump's Best Efficiency point. It is an important factor used in the design and selection of pump and impellers.

* Specific speed of a centrifugal pump-

Speed of a geometrically similar pump that would deliver 1m³ of liquid per second against head of 1m. It is denoted by "Ns".

$$N_S = \frac{N\sqrt{Q}}{H^{3/4}}.$$

N = Normal speed of pump
Q = Flow rate of liquid.
Hm = Manometric Head, m

The flow through impeller [discharge] is given by

$$Q = \pi D_1 B_1 V_{f_1} = \pi D_2 B_2 V_{f_2}$$

$$Q \propto D_1 B_1 V_{f_1} \quad \therefore Q \propto D_2 B_2 V_f$$

$$Q \propto D^2 V_f \longrightarrow [B \propto D].$$

Tangential speed of Impeller is given by

$$U = \frac{\pi D N}{60} \qquad \therefore U \propto DN \longrightarrow (2)$$

But, $U = K_u \sqrt{2gH_m}$

$$U \propto \sqrt{H_m} \longrightarrow (3)$$

$$DN \propto \sqrt{H_m}$$

$$D \propto \frac{\sqrt{H_m}}{N} \longrightarrow (4)$$

$$V_f = K_f \sqrt{2gH_m}, \quad V_f \propto \sqrt{H_m} \longrightarrow (5)$$

putting (4) & (5) in eqn we get

$$Q \propto \left[\frac{\sqrt{H_m}}{N}\right]^2 \sqrt{H_m}$$

$$Q \propto \frac{H_m^{3/2}}{N^2}$$

$$N^2 \propto \frac{H_m^{3/2}}{Q}$$

$$N \propto \frac{H_m^{3/2}}{\sqrt{Q}}$$

$$N = \frac{C H^{3/4}}{\sqrt{Q}} \quad \therefore \text{where } C \text{ is constant} \longrightarrow (6)$$

where $Q = 1 m^3/sec$, $H_m = 1$, $C = N$

which is known as specific speed N_s,

putting $C = N_s$

$$N = \frac{N_s H_m^{3/4}}{\sqrt{Q}}$$

$$N_s = \frac{N\sqrt{Q}}{H^{3/4}}$$

(3) Illustrate the characteristics curves of pumps.

* Characteristics Curves of pump – Curves which are plotted from the results of a number of tests on the centrifugal pump.

→ These curves are necessary to predict the behaviour and performance of the pump, when the pump is working under different flow rate, head and speed.

The important characteristics curves of pump

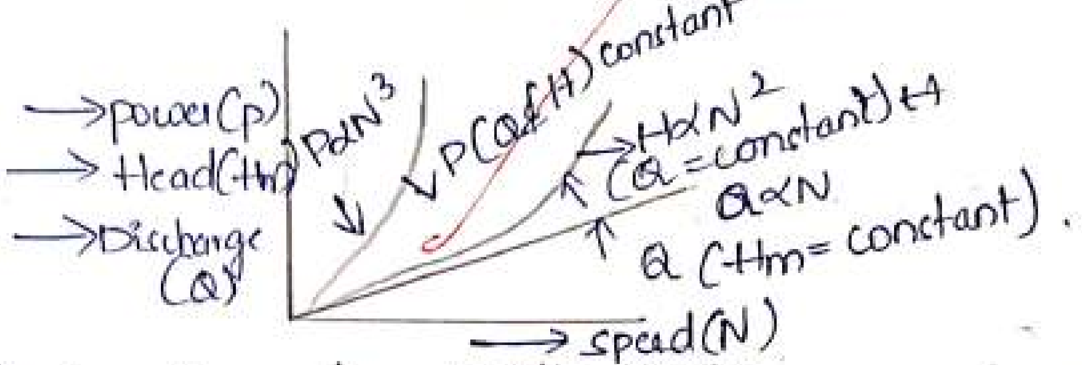
1. Main characteristics curves.
2. Operating characteristics curves
3. Constant Efficiency (or) Muschel curves.

(1) Main characteristic Curves – The main characteristic curves of centrifugal pump consist of variation of head [Manometric head], power and discharge with respect to speed.

(i) H_m vs N $\frac{\sqrt{H_m}}{DN}$ = constant, $H_m \propto N^2$, H_m vs N is parabolic

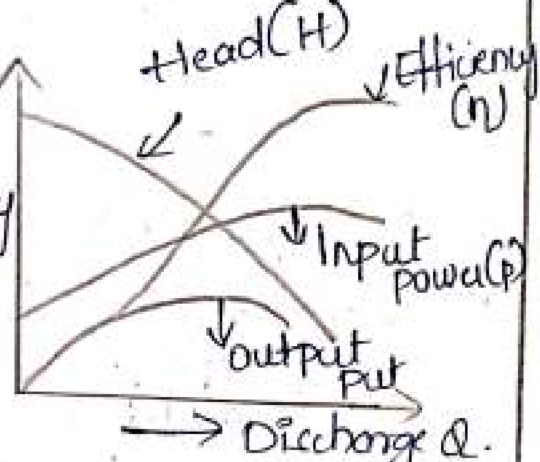
(ii) $\frac{P}{D^5N^3}$ = constant, $P \propto N^3$, P vs N → cubic curve

(iii) Q/D^3N = constant, $Q \propto N$ → Q vs N → straight curve

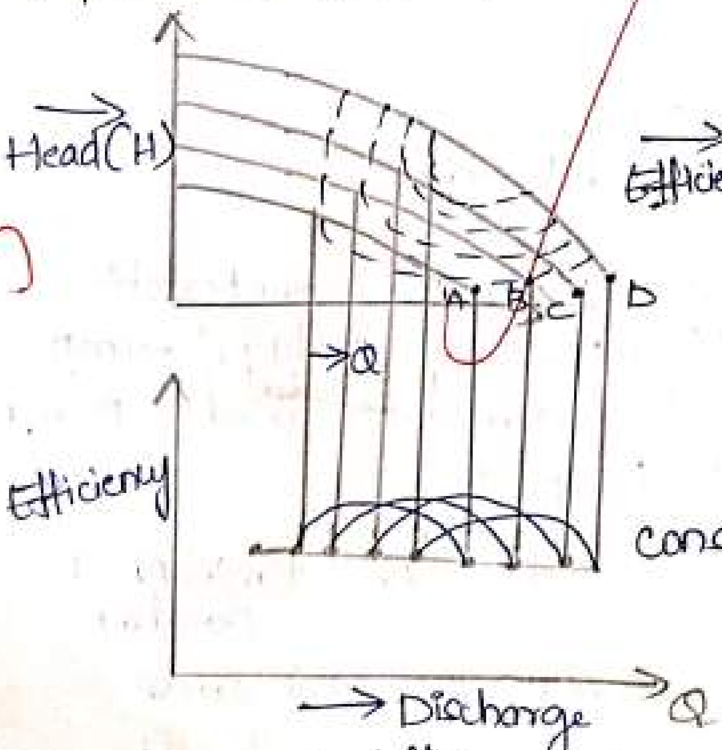


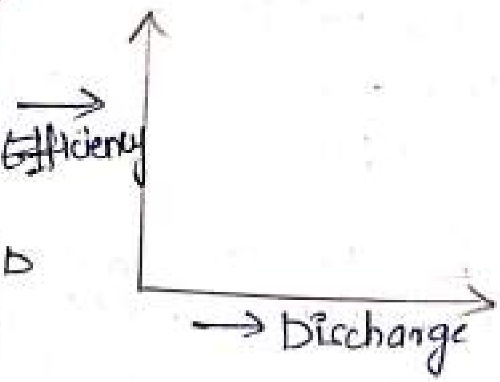
② **Operating characteristic curve-**

→ If the speed is kept constant, variation of head manometric, power and efficiency with respect to discharge gives the operating characteristics of pump.



③ **Constant Efficiency-** For obtaining efficiency curve of the pump the head vs discharge curves and efficiency vs discharge curves for different speed are used.





Constant Efficiency curves of a pump.

Overall Efficiency - The overall efficiency of a pump is the product of its mechanical efficiency (η_m) and its hydraulic efficiency (η_h). It represents the ratio of the hydraulic power output to the electrical power input, considering both mechanical and hydraulic losses.

$$\boxed{\eta_o = \eta_m \times \eta_h}$$

(5) A centrifugal pump is to discharge 0.118 m^3/s at a speed of 1450 r.p.m. against a head of 25m. The impeller diameter is 250 mm, its width at outlet is 50mm and manometric efficiency is 75%. Determine the vane angle at the outer periphery of the impeller.

Given- $Q = 0.118 m^3/s$

$N = 1450 r.p.m$

$H = 25m$

$D = 250mm = 0.25m$

$b = 50mm = 0.5m$

$\eta_m = 0.75$

$$W = \frac{2\pi N}{60} = \frac{2 \times \pi \times 1450}{60} = 151.84$$

$$H_t = \frac{H}{\eta_m} = \frac{25}{0.75}$$

$$\boxed{H_t = 33.3m}$$

$$u_2 = 38.38m = \frac{\pi D_2 N}{60}$$

$$u_2 = \frac{\pi \times 0.25 \times 1450}{60}$$

$$\boxed{u_2 = 19.02 \, m/s}$$

$Q = A_2 V_{f_2}$

where, $A_2 = \pi D_2 b_2$

$= \pi \times 0.25 \times 0.05$

$$\boxed{A_2 = 0.0392 \, m^2}$$

$$V_{f_2} = \frac{Q}{A_2} = \frac{0.118}{0.0392}$$

$$\boxed{V_{f_2} = 3.005 \, m/s}$$

theoritical head $(H_t) = \frac{u_2 V_{w_2}}{g}$

$$V_{w_2} = \frac{H_t g}{u_2} = \frac{33.33 \times 9.81}{19.02}$$

S

$$\boxed{V_{w_2} = 17.20 \, m/sec}$$

$$\tan \beta_2 = \frac{V_{f_2}}{u_2 - V_{w_2}} = \frac{3.005}{19.02 - 17.20}$$

$$\beta_2 = \tan^{-1}(1.65)$$

$$\boxed{\beta_2 = 58^\circ}$$

UNIT-4

Open Channel Flow

Introduction:

Flow in open channels is defined as the flow of a liquid with a free surface. A free surface is surface is having constant pressure such as atmospheric pressure. Thus a liquid flowing at atmospheric pressure through a passage is known as flow in open channels.

→ "In most of cases, the liquid is taken as water. Hence flow of water through a passage under atmospheric pressure is called flow in open channels."

Classification of flow in Channels :-

The flow in open channel is classified into following types

(1) steady flow and unsteady flow.

(2) Uniform flow and non-uniform flow.

(3) Laminar flow and turbulent flow.

(4) Sub critical, critical and super-critical flow.

(1) Steady flow and unsteady flow :-

If the flow charecterstics such as depth of flow, velocity of flow, rate of flow at any point in open channel flow donot change w.r.to time, the flow is said to be steady flow.

$\frac{\partial v}{\partial t} = 0$, $\frac{\partial Q}{\partial t} = 0$ (or) $\frac{\partial y}{\partial t} = 0$

v → velocity
Q → Rate of flow/discharge
y → depth of flow.

If at any point in open channel flow, the velocity of the flow, depth of flow, rate of flow changes with respect to time, the flow is said to be unsteady flow:

$$\frac{\partial v}{\partial t} \neq 0, \quad \frac{\partial Q}{\partial t} \neq 0 \quad \frac{\partial y}{\partial t} \neq 0.$$

Uniform flow and Non-Uniform flow :-

Uniform For a given length of the channel, the velocity of flow, depth of flow, slope of the channel and c/s remains constant, the flow is said to uniform.

$$\frac{\partial v}{\partial s} = 0, \quad \frac{\partial y}{\partial s} = 0 \quad \text{for uniform flow.}$$

Non-uniform

For a given length of channel, the velocity of flow, depth of flow, donot remain constant, the flow is said to be non-uniform flow.

$$\frac{\partial v}{\partial s} \neq 0 \quad \frac{\partial y}{\partial s} \neq 0 \rightarrow \text{for Non-uniform flow.}$$

Non-uniform flow in channel is also called varied flow which is classified as

(i) Rapidly varied flow (R.V.F)

(ii) Gradually varied flow (G.V.F)

Rapidly varied flow :- Flow in which depth of flow changes abruptly over a small length of the channel.

" The depth of flow changes rapidly over a short length of the channel. for this short length of the channel flow

- is called Rapidly varying flow.

(ii) Gradually varied flow :- [G.V.F]

If the depth of flow in a channel changes gradually over a long length of the channel, the flow is said to G.V.F.

(3) Laminar Flow and Turbulent flow :-

The flow in open channels is said to be laminar if the reynold number (R_e) is lessthan 500 (or 600. Reynold number in case of open channels

$$R_e = \frac{\rho V R}{\mu}$$

ρ - Density
μ → viscosity of water
R → Hydraulic mean radius
v → mean velocity of flow water

• If the reynolds number is more than 2000

• R_e → lies b/w 500 to 2000, the flow is considerd as transion state.

Sub-critical, critical and Super-critical flow :-

Sub-critical The flow in open channel is said to sub-critical if the froude number (F_e) is less than 1.0.

$$F_e = \frac{V}{\sqrt{gD}} \quad ; \quad F_e < 1$$

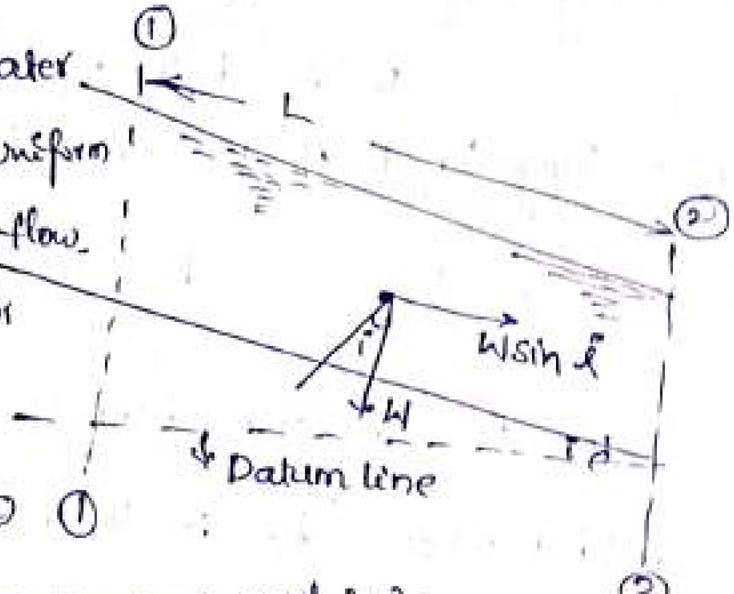
• sub-critical flow is also called tranquil (or) streaming flow.

Super-critical :- If froude number is more than 1, the flow is said to be super critical flow (or) shooting (or) Rapid (or) torrential flow. $F_e > 1$

Critical flow :- If froude number is equal to 1, the flow is called critical flow. $F_e = 1$

Discharge through Open Channel by Chezy's formula

Consider a uniform flow of water in a channel. As the flow uniform it means the velocity, depth of flow area of flow will be constant for a given length of the channel



Consider section ①-① & ②-②

The weight of water b/w section 1–1 and 2-2

W = Specific weight of water × Volume of water.

$W = w \times A \times L$

(i) Component of W along direction of flow $= W \times \sin i$

$= wAL\sin i$

(ii) Frictional resistence against motion of water

$= f \times \text{surface area} \times (\text{velocity})^n$

The value of n is found experimentally equal to 2 and

Surface area $= P \times L$

∴ Frictional resistance against motion $= f \times P \times L \times V^2$

∴ Resolving all forces in the direction of flow, we get

$$wAL\sin i - f \times P \times L \times V^2 = 0$$

$$wAL\sin i = f \times P \times L \times V^2$$

$$V^2 = \frac{wAL\sin i}{f \times P \times L}$$

$$= \frac{w}{f} \times \frac{A}{P} \times \sin i$$

$$V = \sqrt{\frac{w}{f}} \times \sqrt{\frac{A}{P}\sin i}$$

$\frac{A}{P} = m$

m → Hydraulic Mean depth (or) Hydraulic radius

$\sqrt{\frac{w}{f}} = C$ = Chezy's constant

Substituting the value of $\frac{A}{P}$ & $\sqrt{\frac{w}{f}}$ in equation

$$V = C\sqrt{mi}$$

for small values of i, $\sin i \approx \tan i = i$

$$V = C\sqrt{mi}$$

Discharge Q = Area × velocity

$= A \times V$

$$\boxed{Q = A \times C\sqrt{mi}}$$

① Find the velocity of flow and rate of flow water through a rectangular channel of 6m wide and 3m deep, when it's running full. The channel is having bed slope as 1 in 2000. Take Chezy's constant C = 55.

Sol

Width of the channel, b = 6m.

depth (d) = 3m.

Area = 6×3 = 18 m^2

Bed slope, i = 1 in 2000 = $\frac{1}{2000}$

C = 55.

∴ Hydraulic mean depth $m = \frac{A}{P} = \frac{18}{12} = 1.5$ m

Velocity of flow is given

$V = C\sqrt{mi}$

$= 55\sqrt{1.5 \times \frac{1}{2000}}$

$$\boxed{V = 1.506 \text{ m/s}}$$

Rate of flow (or) discharge $Q = A \times V$

$= 1.506 \times 18$

$$\boxed{Q = 27.108 \text{ m}^3/\text{sec}}$$

① Find the bed slope of the bed of a rectangular Channel of width 5m when depth of water is 2m and rate of flow is given as 20 m³/sec. Take Chezy's constant C= 50.

Sol

$b = 5m$

$d = 2m$

$Q = 20\ m^3/sec$

$C = 50$

bed slope $= i$

$Q = AC\sqrt{mi}$

Area (A) $= 5 \times 2 = 10\ m^2$

$m = \frac{A}{P} = \frac{10}{b+2d} = \frac{10}{5+2\times2}$

$= \frac{10}{5+4}$

$= \frac{10}{9}\ m$

$Q = A \times V$

$20 = 10 \times 50 \times \sqrt{\frac{10}{9}i}$

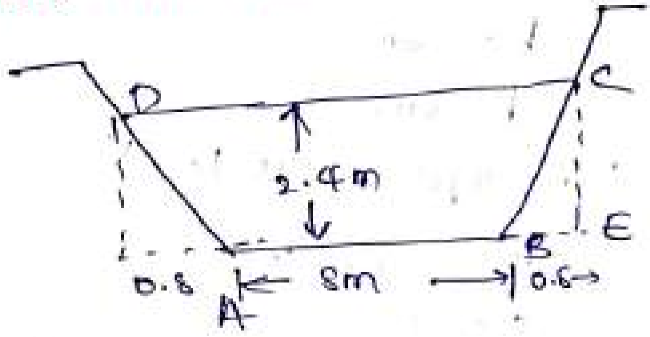
$\frac{20}{500} = \sqrt{\frac{10}{9}i}$

Squaring on both sides $\frac{10}{9} i = \frac{4}{2500}$

$i = \frac{4}{2500} \times \frac{9}{10}$

$$\boxed{i = \frac{1}{694.44}}$$

① Find the discharge through a trapezoidal channel of width 8m and sideslope of 1H to 3V. The depth of flow of water is 2.4m and value of chezy's constant $C = 50$. The slope of the bed of the channel is given 1 in 4000.



$b = 8m$

side slope = 1H to 3V

$d = 2.4m$

$c = 50$

Bed slope ⇒ $i = \frac{1}{4000}$

$CE = 2.4$

horizontal distance, $BE = 2.4 \times \frac{1}{3}$

$= 0.8m.$

Top width of the channel

$CD = AB + 2 \times BE$

$= 8 + 2 \times 0.8$

$CD = 9.6m$

∴ Area of trapezoidal channel, ABCD is given as

$A = (AB + CD) \times \frac{CE}{2}$

$= (8 + 9.6) \times \frac{2.4}{2} = 17.6 \times 1.2$

$A = 21.12 \; m^2$

Wetted perimeter. $P = AB + BC + AD$

$= AB + 2BC$

$BC = \sqrt{BE^2 + CE^2} = \sqrt{0.8^2 + 2.4^2}$

$BC = 2.529m$

$P = 8 + 2 \times 2.529$ $P = 13.058$

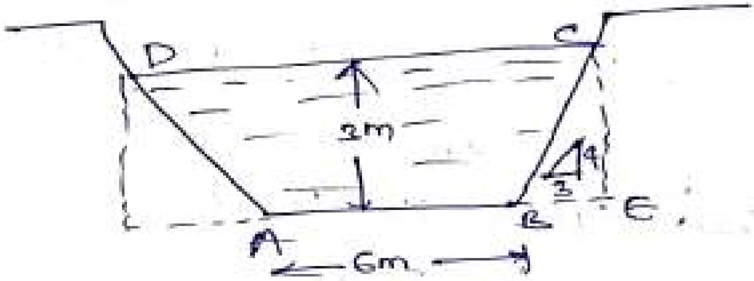
Hydraulic mean depth $m = \frac{A}{P} = \frac{21.12}{13.058} = 1.617m$

$Q = AC\sqrt{mi}$

$= 21.12 \times 50 \times \sqrt{1.617 \times \frac{1}{4000}}$

$Q = 21.23 \; m^3/sec$

② Find the bed slope of trapezoidal channel of bed width 6m, depth of water 3m. and side slope of 3H to 4V, when the discharge through the channel is 30m³/sec. Take Chezy's constant C = 70



$b = 6m$

$d = 3m$

Side slope = 3H to 4V

$Q = 30 m^3/sec$

$C = 70$

depth of flow = 3m = CE

$BE = 3 \times \frac{3}{4} = \frac{9}{4} = 2.25m$

Top width $CD = AB + 2 \times BE$

$= 6 + 2 \times 2.25$

$CD = 10.50m$

Wetted perimeter $P = AD + AB + BC$

$= AB + 2BC$

$= AB + 2\sqrt{BE^2 + CE^2}$

$= 6 + 2\sqrt{(2.25)^2 + 3^2}$

$\boxed{P = 13.5m}$

Area of flow. $A = \frac{1}{2}(AB + CD) \times CE$

$= \frac{6 + 10.50}{2} \times 3.0$

$\boxed{A = 24.75 m^2}$

Hydraulic mean depth: $m = \frac{A}{P} = \frac{24.75}{13.50}$

$\boxed{m = 1.833}$

$Q = AC\sqrt{mi}$

$30 = 24.75 \times 70 \times \sqrt{1.833 \times i}$

$i = \left(\frac{30}{2345.6}\right)^2$

$\boxed{i = \frac{1}{6133}}$

Empirical formulae for the Value of chezy's constant

Chezy's formula after name of french engineer, Antoine chezy who developed this formula in 1775. In this eqn, C is known as chezy's constant, which is not a dimensionless coefficient

$$V = C\sqrt{mi}$$

The dimention of $C = \frac{V}{\sqrt{mi}}$

$$= \frac{L/T}{\sqrt{A/P\, i}}$$

$$= \frac{L/T}{\sqrt{\frac{L^2}{L} i}} = \sqrt{\frac{L}{T}}$$

$$C = L^{1/2} T^{-1}$$

Hence the value of C depends upon the system of units

The following are the empirical formulae, after the name use to determine the value of C.

① Bazins formula

$$C = \frac{157.6}{1.81 + \frac{K}{\sqrt{m}}}$$

K → Bazin's constant and depends upon the roughness of the surface of the channel.

m → Hydraulic Mean depth.

S.NO.	Nature of the channel inside surface	value of K
1	Smooth Cemented (or) planned wood	0.11
2	Brick (or) concrete	0.21
3	Rubble mashonary / Ashlar / poor brick	0.83
4	Earthen channel of very good surface	1.54
5	Earthern channel of ordinary surface	2.36
6	Earthern channel of rough surface	3.17

② Ganguillet – Kutter formula :-

$$C = \frac{23 + \frac{0.00155}{i} + \frac{1}{N}}{1 + \left(23 + \frac{0.00155}{i}\right)\frac{N}{\sqrt{m}}}$$

N → Roughness Co-efficient which is known Kutter Constant

i → slope of the bed

m → Hydraulic mean depth

S.NO	Nature of channel inside surface	Value of N
1	very smooth surface of glass, plastic	0.010
2	Smooth surface of concrete	0.012
3	Rubble masonary (or) poor brick earth	0.017
4	Earthern channel neatly excavated	0.018
5	Earthern channel of Ordinary surface	0.027
6	Earthern channel of rough surface	0.030
7	Natural streams, clean and straight	0.030
8	Natural streams with weeds	0.035

(3) Mannings Formula :- The value of 'C' according to the formula

$$C = \frac{1}{N} m^{1/6}$$

m = Hydraulic Mean depth.

N = Mannings constant which is having same value of Kutter's constant.

① Find the discharge through a rectangular channel 2.5 m wide having depth of water 1.5m and bed slope as 1 in 2000. Take the value of K = 2.36 in Bazin's formula.

b = 2.5m

d = 1.5m

A = b×d = 2.5×1.5

A = 3.75 m²

Wetted perimeter (P) = d+b+d

= 1.5+2.5+1.5

= 5.5m

∴ Hydraulic Mean depth $m = \frac{A}{P} = \frac{3.75}{5.50} = 0.682$

Bed slope, $(i) = \frac{1}{2000}$

Bazin's constant K = 2.36.

Using Bazins constant

$$C = \frac{157.6}{1.81 + \frac{K}{\sqrt{m}}} = \frac{157.6}{1.81 + \frac{2.36}{\sqrt{0.682}}}$$

$C = 33.76$

Discharge $Q = AC\sqrt{mi}$

$= 3.75 \times 33.76 \sqrt{0.682 \times \frac{1}{2000}}$

$Q = 2.337 \ m^3/sec$

② Find the discharge through a rectangulas channel 14m wide having depth of water 3m and bedslope 1 in 1500. Take the value of N = 0.03 in the Kutter's formula.

$b = 4m$

$d = 3m$

$i = \frac{1}{1500}$

$N = 0.03$

Area = $b \times d = 4 \times 3 = 12 m^2$

Wetted perimeter, $P = d + b + d = 3 + 4 + 3 = 10m$

Hydraulic Mean depth $m = A/P = \frac{12}{10} = 1.2m$

Using Kutter's formula

$$C = \frac{23 + \frac{0.00155}{i} + \frac{1}{N}}{1 + \left(23 + \frac{0.00155}{i}\right) \times \frac{N}{\sqrt{m}}}$$

$$C = \frac{23 + \frac{0.00155}{0.000667} + \frac{1}{0.03}}{1 + \left(23 + \frac{0.00155}{0.000667}\right) \times \frac{0.03}{\sqrt{1.20}}}$$

$C = 32.01$

Discharge

$Q = AC\sqrt{mi}$

$= 12 \times 32.01 \sqrt{12 \times 0.000667}$

$Q = 10.867 \; m^3/sec$

③ Find the discharge through a rectangular channel of width 2m having a bed slope of 4 in 8000. the depth of flow is 1.5m. and take the value of N in mannings formula as 0.012.

$b = 2m$

$d = 1.5m$

Area (A) $= b \times d$

$= 2 \times 1.5$

$= 3 m^2$

Wetted perimeter $P = b + d + d$

$= 2 + 1.5 + 1.5$

$P = 5m$

∴ Hydraulic Mean depth $m = \frac{A}{P} = \frac{3}{5} = 0.6$

Bed slope $i = 4 \text{ in } 8000 = \frac{4}{8000} = \frac{1}{2000}$

$N = 0.012$

Using Manning's formula

$C = \frac{1}{N} m^{1/6}$

$= \frac{1}{0.012} \times 0.6^{1/6}$

$C = 76.54$

Discharge $Q = AC\sqrt{mi}$

$= 3 \times 76.54 \times \sqrt{0.6 \times \frac{1}{2000}}$

$Q = 3.977 \ m^3/sec$

Most Economical section of channels :-

A section of channel is said to be most economical when the cost of the construction of channel is minimum. But the cost of the construction of channel depends upon the excavation and lining. To keep the cost down (or) minimum., the wetted perimeter, for a given discharge, should be minimum.

→ This condition is utilized for determining the dimension of the economical section of different form of channels.

* Most economical section is also called the best section or most efficient section.

$$Q = AC\sqrt{mi}$$
$$= AC\sqrt{\frac{A}{P}i}$$

the above eqn is written as

$$Q = K \times \frac{1}{\sqrt{P}} \qquad \text{where } K = AC\sqrt{Ai} = \text{constant}$$

∴ Hence the discharge, Q will be maximum; when the wetted perimeter P is minimum.

→ This condition will be used for determining the best section of channel, the following shapes of the channels will be considerd.

① Rectangular channel.

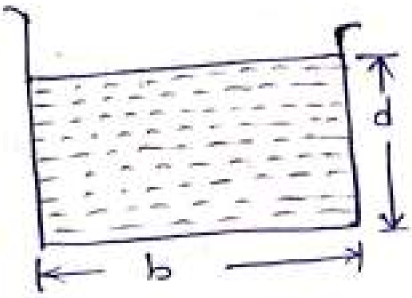
② Trape-zoidal channel.

③ Circular channel

(1) Most economical Rectangular Channel :-

the condition for the most economical section is that for a given area, the perimeter should be minimum.

Area of flow $A = b \times d$



Wetted perimeter $P = d + b + d$

$P = b + 2d$

$b = \frac{A}{d}$

$P = \frac{A}{d} + 2d$

For most economical section P should be minimum for given area

$$\frac{dP}{d(d)} = 0$$

Differentiate above eqn with respect to d and equating same to zero

$$\frac{d}{d(d)}\left[\frac{A}{d} + 2d\right] = 0$$

$$-\frac{A}{d^2} + 2 = 0$$

$$A = 2d^2$$

$$b \times d = 2d^2$$

$$\boxed{b = 2d}$$

Now hydraulic mean depth $m = \frac{A}{P} = \frac{b \times d}{b + 2d}$

$$= \frac{2d \times d}{2d + 2d}$$

$$= \frac{2d^2}{4d}$$

$$m = d/2$$

∴ It is clear that rectangular channel will be most economical when

i) Either $b = 2d$, means width is two times depth of flow.

ii) $m = d/2$ means hydraulic depth is half the depth of flow

① A rectangular channel of width 4m is having a bed slope of 1 in 1500. Find the max. discharge through the channel. Take value of C = 50.

$b = 4m$

$i = 1$ in 1500

$C = 50$

Discharge will be max, when the channel is most economical

i) $b = 2d$ (or) $d = b/2 = 4/2 = 2m$.

ii) $m = d/2 = 2/2 = 1$

Area (A) $= b \times d = 4 \times 2 = 8 m^2$

$Q = AC\sqrt{mi}$

$= 8 \times 50 \times \sqrt{1 \times \frac{1}{1500}}$ $\boxed{Q = 10.328 \ m^3/sec}$

② A rectangular channel 4m wide hase a depth of water 1.5m. The slope of the bed of the Channel is 1 in 1000 and the value of chezy's constant C = 55. It is desired to increase the discharge is to a maximum by changing the dimensions of the section for constant area of c/s, slope of the bed and roughness of the channel. Find the new dimensions of the channel and increase in discharge.

$b = 4m.$

$d = 1.5m$

Slope of bed $i = \frac{1}{1000}$

$C = 55$

Area (A) $= b \times d = 4 \times 1.5 = 6m^2$

$P = d + b + d = 1.5 + 4 + 1.5 = 7m.$

$m = \frac{A}{P} = \frac{6}{7} = 0.857$

$Q = AC\sqrt{mi}$

$= 6 \times 55\sqrt{0.857 \times \frac{1}{1000}}$

$Q = 9.66\ m^3/sec$

For max. discharge for given area, slope of bed & roughness we proceed as

b' = new width of channel

d' = new depth " "

$A = b' \times d'$

$6 = b' \times d'$

Also for max. discharge $b' = 2d'$

$2d' \times d' = 6$

$d'^2 = 3$

$d' = \sqrt{3}$

$d' = 1.732$

$b' = 2 \times 1.732$, $b' = 3.464$

perimeter $p = d' + b' + d' = 1.732 + 3.464 + 1.732$

$P = 6.928$

Hydraulic mean depth $m' = \frac{A}{p'} = \frac{6}{6.928}$

$m' = 0.866m$

$m' = \frac{d'}{2} = \frac{1.932}{2} = 0.866m$

max. discharge $Q' = AC\sqrt{m'i} = 6 \times 55 \times \sqrt{0.866 \times \frac{1}{1000}}$

$Q' = 9.71\ m^3/sec$

Increase in discharge $= Q' - Q$

$= 9.71 - 9.66$

$= 0.05\ m^3/sec.$

① find the most economical c/s of rectangular channel which is to be dug in the rocky portion of a soil. The Channel is to convey 8 m³/sec. of water with an avg. velocity of 2 m/sec Take chezy's Constant C = 50.

Rectangular channel

$Q = 8\ m^3/sec$

$V = 2\ m/sec$

chezy's constant $C = 50$

Most economical rectangular channel is

i) $b = 2d$

ii) $m = d/2$

chezy's formula, $V = C\sqrt{mi}$

$Q = AV$

$Q = bd \times V$

$bd = \frac{Q}{V} = \frac{8\ m^3/sec}{2\ m/sec}$

$bd = 4m^2$

$b = 2d,\quad 2d^2 = \frac{4}{2}m^2$

$d = \sqrt{2}$

$\boxed{d = 1.414\ m}$ flow depth

$m = d/2 = \frac{1.414}{2} = 0.707\ m$

$b = 2 \times 1.414$

$= 2.828\ m$

$V = C\sqrt{mi}$

$i = \frac{V^2}{C^2 m} = \frac{2^2 \times}{50^2 \times 0.707}$

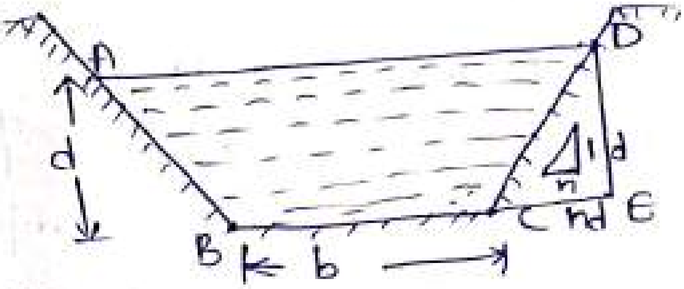
$\boxed{i = 0.00133}$

Slope of Bed

$m = 0.707\ m.$

Most Economical Trapezoidal channel :-

The trapezoidal section of a channel will be most economical when the wetted perimeter is minimum.



Area of flow

$$A = \frac{BC + AD}{2} \times d$$

$$= \frac{b + (b + 2nd)}{2} d$$

$$= \frac{(2b + 2nd)}{2} d = (b + nd) d$$

$$A = (b + nd) d$$

$$\frac{A}{d} = b + nd$$

$$b = \frac{A}{d} - nd.$$

$$P = AB + BC + CD$$

$$= BC + 2CD$$

$$= b + 2\sqrt{CE^2 + DE^2}$$

$$= b + 2\sqrt{n^2 d^2 + d^2}$$

$$= b + 2d\sqrt{n^2 + 1}$$

$$P = \frac{A}{d} - nd + 2d\sqrt{n^2+1}$$

for most economical section, P should be minimum

$$\frac{dP}{d(d)} = 0$$

$$\frac{d}{d(d)}\left[\frac{A}{d} - nd + 2d\sqrt{n^2+1}\right] = 0$$

$$-\frac{A}{d^2} - n + 2\sqrt{n^2+1} = 0$$

$$\frac{A}{d^2} + n = 2\sqrt{n^2+1}$$

Substitute the value of A from eqⁿ (i)

$$\frac{(b+nd)d}{d^2} + n = 2\sqrt{n^2+1}$$

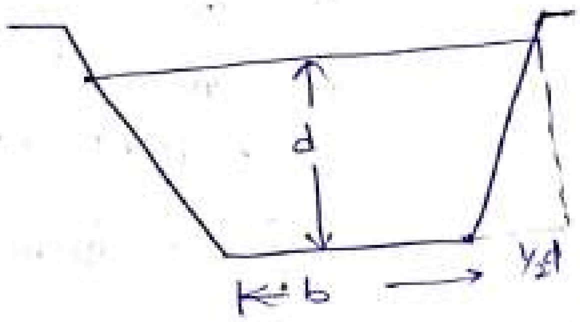
$$\frac{b+nd+nd}{d} = \frac{b+2nd}{d} = 2\sqrt{n^2+1}$$

$$\frac{b+2nd}{2} = d\sqrt{n^2+1}$$

$\frac{b+2nd}{2}$ = Half of top width

$d\sqrt{n^2+1}$ = CD = One of the sloping side

① A trapezoidal channel has side slope of 1H to 2V and the slope of the bed is 1 in 1500. The area of the section is 40 m². Determine find the dimension of the section if it most economical. Determine the discharge of the most economical section if C = 50.



sol

side slope $n = \frac{\text{Horizontal}}{\text{Vertical}} = \frac{1}{2}$

Bed slope (i) = $1/1500$

Area of section (A) = $40 m^2$

Chezy's Constant C = 50

For most Economical section

$$\frac{b+2nd}{2} = d\sqrt{n^2+1}$$

$$\frac{b+2\times\frac{1}{2}d}{2} = d\sqrt{(\frac{1}{2})^2+1}$$

$$\frac{b+d}{2} = d\sqrt{\frac{1}{4}+1}$$

$\frac{b+d}{2} = 1.118d$

$b = 2 \times 1.118d - d$

$b = 1.236d$

But area of trapezoidal section

$A = \frac{b + (b+2nd)}{2} \times d$

$A = (b+nd)d$

$= (1.236d + \frac{1}{2}d)\,d$

$A = 1.936d^2$

$A = 40m^2$

$40 = 1.936d^2$ $\quad d = 4.80m$

$b = 1.236 \times 4.80 \Rightarrow b = 5.933m$

Discharge for most economical section

Hydraulic mean depth for most economical section

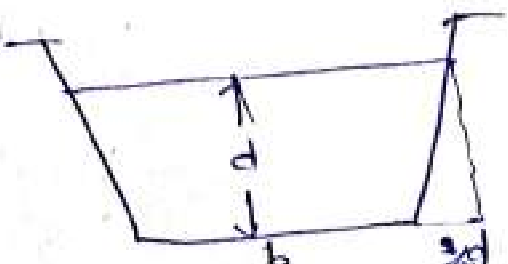
$m = \frac{d}{2} = \frac{4.80}{2} = 2.40m$

$Q = AC\sqrt{mi}$

$= 40 \times 50 \times \sqrt{2.40 \times \frac{1}{1500}}$

$Q = 80\ m^3/sec$

(2) A trapezoidal channel has a side slope of 3H to 4V and slope of it's bed is 1 in 2000. Determine the optimum dimension of the channel, if it is to carry water at 0.5 m³/sec. Take chezy's constant as 80.



side slope (n) = $\frac{\text{Horizontal}}{\text{Vertical}} = \frac{3}{4}$

slope of bed (i) = $\frac{1}{2000}$

$Q = 0.5\ m^3/sec$

for most economical section

$$\frac{b+2nd}{2} = d\sqrt{n^2+1}$$

$$\frac{b+2\times\frac{3}{4}d}{2} = d\sqrt{(\frac{3}{4})^2+1}$$

$$\frac{b+1.5d}{2} = 1.25d$$

$$b = 2\times1.25d - 1.5d$$

$$Q = AC\sqrt{mi}$$

$$0.50 = A\times80\sqrt{d/_2\times\frac{1}{2000}}$$

But area of trapezoidal section

$$A = (b+nd)d \qquad b=d,\ n=3/4$$

$$= (d+\frac{3}{4}d)d$$

$$= \frac{7}{4}d^2$$

$$\boxed{A = 1.75d^2}$$

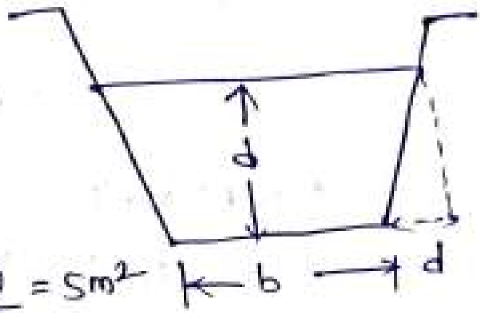
$$0.50 = 1.75d^2\times80\times\sqrt{d/_2\times\frac{1}{2000}}$$

$$d = \left(\frac{0.50}{2.2135}\right)^{2/5}$$

$$\boxed{d = 0.55m} \quad \boxed{b = d = 0.55m}$$

∴ Optimum dimension of depth of channel are width = depth = 0.55m

③ A trapezoidal channel with side slope of 1 to 1 has a designed to convey 10 m³/sec at a velocity of 2 m/sec so that the amount of concrete lining for the bed and sides is the minimum. Calculate the area of lining required for one mt length of canal.



Side slope (n) = $\frac{Horizontal}{Vertical} = 1$

$Q = 10\ m^3/sec$

$V = 2\ m/sec$

Area of flow (A) = $\frac{Discharge}{Velocity} = \frac{10}{2} = 5m^2$

for most economical section

Half of the top width = One of the sloping side

$\frac{b+2nd}{2} = d\sqrt{n^2+1}$

for n=1, $\frac{b+2\times1d}{2} = d\sqrt{1^2+1}$

$b = 2\times(1.414d) - 2d$

$b = 0.828d$

But area(A) = $(b+nd)d$

$= (0.828d + 1\times d)d$

$= 1.828d^2$

$A = 5m^2$

$5 = 1.828d^2$ $d = 1.654\ m$

$b = 0.828d$, $b = 1.369\ m$

Area of lining required for one mt length of canal

= wetted peremeter × length of canal

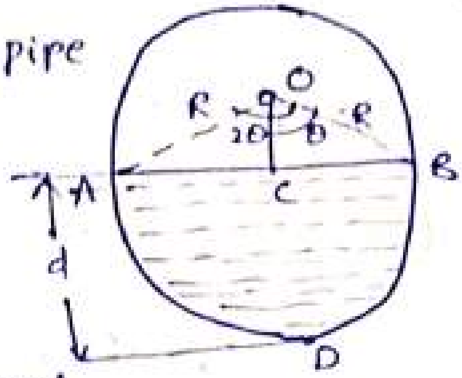
$= P\times1$

$P = b + 2d\sqrt{n^2+1}$ $P = 6.047\ m$

∴ Area of lining = $6.049\times1 = 6.047\ m^2$

Flow through Circular Channel :-

The flow of liquid through a circular pipe when the level of liquid in the pipe below the top of the pipe is classified as open channel.



→ The rate of flow through circular channel is determined from the depth of flow and angle subtended by the liquid surface at the centre of the circular channel.

$d \rightarrow$ depth of water

$2\theta \rightarrow$ Angle subtended by water surface AB

$R \rightarrow$ Radius of the channel.

Then the wetted perimeter and wetted area.

Wetted perimeter $P = \frac{2\pi R}{2\pi} \times 2\theta = 2R\theta$

Wetted area A = Area ADBA

= Area of sector OADBO − Area of $\triangle ABO$

$= \frac{\pi R^2}{2\pi} \times 2\theta - \frac{AB \times CO}{2}$

$= R^2\theta - \frac{2BC \times CO}{2}$ $\quad (\because AB = 2BC)$

$= R^2\theta - \frac{2R\sin\theta \times R\cos\theta}{2}$

$= R^2\theta - \frac{R^2 \times 2\sin\theta\cos\theta}{2}$

$= R^2\theta - \frac{R^2\sin 2\theta}{2}$

$= R^2\left(\theta - \frac{\sin 2\theta}{2}\right)$

Hydraulic Mean depth $m = \frac{A}{P} = \frac{R^2\left(\theta - \frac{\sin 2\theta}{2}\right)}{2R\theta}$

$$= \frac{R}{2\theta}\left(\theta - \frac{\sin 2\theta}{2}\right)$$

$Q = AC\sqrt{mi}$

(B)

Condition for Maximum Discharge for Circular section

$$Q = AC\sqrt{mi}$$

$$= AC\sqrt{\frac{A}{P}i}$$

$$= C\sqrt{\frac{A^3}{P}i}$$

$$\frac{d}{d\theta}\left(\frac{A^3}{P}\right) = 0$$ → differentiate above Eqn

$$\frac{P \times 3A^2\frac{dA}{d\theta} - A^3\frac{dP}{d\theta}}{P^2} = 0 \Rightarrow 3PA^2\frac{dA}{d\theta} - A^3\frac{dP}{d\theta} = 0$$

Dividing by A^2, $3P\frac{dA}{d\theta} - A\frac{dP}{d\theta} = 0$

$$P = 2R\theta$$

$$\frac{dP}{d\theta} = 2R$$

$$A = R^2\left(\theta - \frac{\sin 2\theta}{2}\right)$$

$$\frac{dA}{d\theta} = R^2(1 - \cos 2\theta)$$

Substitute the values of P, A, $\frac{dP}{d\theta}$

$$3 \times 2R\theta \times R^2(1 - \cos 2\theta) - R^2\left(\theta - \frac{\sin 2\theta}{2}\right) \times 2R = 0$$

$$6R^3\theta(1 - \cos 2\theta) - 2R^3\left(\theta - \frac{\sin 2\theta}{2}\right) = 0$$

Dividing by $2R^3$, we get

$$3\theta(1 - \cos 2\theta) - \left(\theta - \frac{\sin 2\theta}{2}\right) = 0$$

$$3\theta - 3\theta\cos 2\theta - \theta + \frac{\sin 2\theta}{2} = 0$$

$$2\theta - 3\theta\cos 2\theta + \frac{\sin 2\theta}{2} = 0$$

$4\theta - 60\cos 2\theta + \sin 2\theta = 0$

The solution of this eqn by hit and trial gives

$2\theta = 308$

$\theta = 154^\circ$

Depth of flow for max. discharge

$d = OD - OC$

$= R - R\cos\theta$

$= R(1-\cos\theta) = R(1-\cos 154^\circ)$

$= R[1 - \cos(180^\circ - 26^\circ)] = R[1+\cos 26^\circ] = 1.898R$

$= 0.95D$ D → Dia of circular channel.

① The rate of flow water through a circular channel diameter 0.6m is 150 lit/sec. Find the slope of the bed of the channel for max. velocity. Take C=60

$Q = 150$ lit/sec $= 0.15\,m^3/sec$

$D = 0.6m$

$C = 60$

Condition for max velocity $= 0.81D$

$d = 0.81D = 0.81 \times 0.6 = 0.486\,m.$

$\theta = 128^\circ 45'$

$= 128.45 \times \frac{\pi}{180} = 2.247$ radians

$m = 0.3 \times D$

$= 0.3 \times 0.6 \doteq 0.18$

$P = 2R\theta = D \times \theta = 0.6 \times 2.247 = 1.3482\,m$

$m = \frac{A}{P} = 0.18m$, $A = 0.18 \times P = 0.18 \times 1.3482$

$A = 0.2426\,m^2$

$Q = AC\sqrt{mi}$

$= 0.2426 \times 60 \times \sqrt{0.18 \times i}$

$i = \left(\frac{0.15}{6.135}\right)^2 = \frac{1}{1694.7}$

(5) Determine the max. discharge of water through a circular channel of diameter 1.5m when the bed slope of the channel is 1 in 1000. Take $C = 60$.

$D = 1.5m$, $R = \frac{1.5}{2} = 0.75m$

$i = \frac{1}{1000}$, $C = 60$

max discharge $\theta = 154^{\circ}$ (or) $154 \times \frac{\pi}{180} = 2.6878$ radians

$P = 2R\theta$

$= 2 \times D/2 \times 2.6878$ $D = 1.5$

$P = 4.0317$

$A = R^2 \left[\theta - \frac{\sin 2\theta}{2} \right]$

$= 0.75^2 \left[2.6878 - \frac{\sin(2 \times 154^{\circ})}{2} \right]$

$= 0.75^2 \left[2.6878 - \frac{\sin 308^{\circ}}{2} \right]$

$= 0.75^2 \left[2.6878 - \frac{\sin(360^{\circ} - 52^{\circ})}{2} \right]$

$= 0.75^2 \left[2.6878 + \frac{\sin 52^{\circ}}{2} \right]$

$A = 1.9325$

$\therefore$ Hydraulic mean depth (m) $= \frac{A}{P} = \frac{1.9335}{4.0317} = 0.4779$

Max. discharge is given by $Q = AC\sqrt{mi}$

$= 1.9335 \times 60 \times \sqrt{0.4779 \times \frac{1}{1000}}$

$Q = 2.1565 \; m^3/sec$

Non-Uniform flow through open channel

Uniform flow A flow is said to uniform if the velocity of flow, depth of flow, slope of the bed of the channel and area of c/s remains constant for a given depth of channel.

Non-uniform flow:- If velocity of flow, depth of flow, area of c/s and slope of the bed channel do not remains constant for a given length of pipe, the flow is said to be non-uniform flow.

* Specific Energy and Specific Energy Curve :-

The total energy of flowing liquid per unit weight is given by

$$\text{Total Energy } (E) = z + h + \frac{V^2}{2g}$$

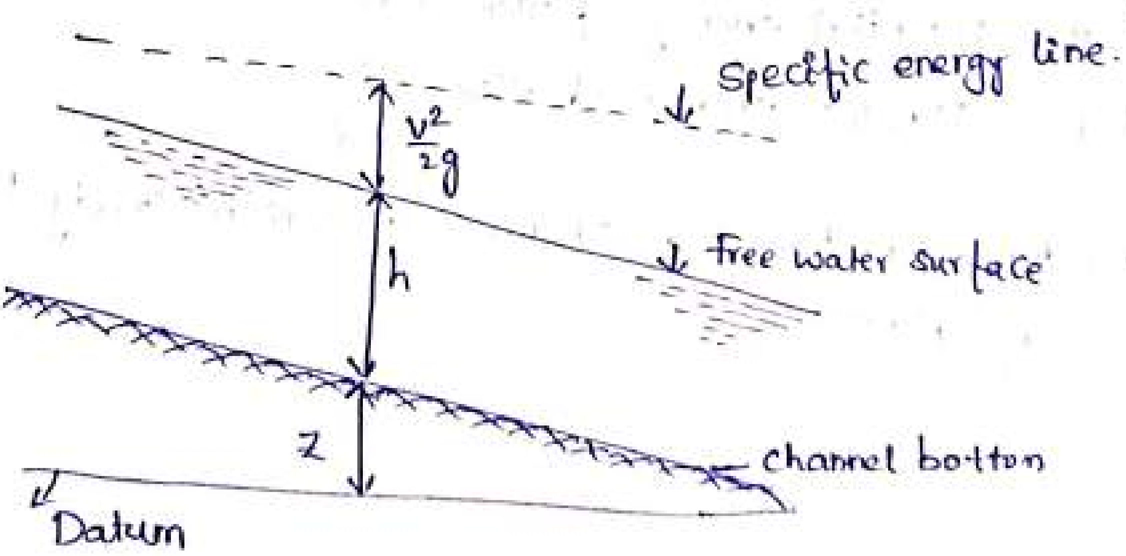


fig: Specific energy

Z = Height of the bottom of channel above datum.

h = Depth of liquid

V = mean velocity of flow.

∴ ~~the~~ If the channel bottom taken as datum, then the total energy per unit weight of liquid will be

$$\boxed{E = h + \frac{V^2}{2g}}$$

The above eq^n known as Specific energy.

* **Specific energy :-** Specific energy of flowing liquid is defined as energy per unit weight of liquid with respect to the bottom of the channel.

* **Specific energy curve :-**

It is defined as the curve which shows the variation of specific energy with depth of flow

$$E = h + \frac{V^2}{2g}$$

$$E = E_p + E_k$$

E_p = potential energy of flow = h

E_k = Kinetic energy of flow = $\frac{V^2}{2g}$

Consider a rectangular channel in which steady but non-uniform flow taking place.

Q = Discharge through the channel

b = width of the channel

h = depth of flow

q = discharge per unit width

$$q = \frac{Q}{\text{width}} = \frac{Q}{b} = \text{constant}$$

velocity of flow $V = \frac{Q}{A} = \frac{Q}{b \times h} = \frac{q}{h}$ $\boxed{\frac{Q}{b} = q}$

$$\therefore E = h + \frac{V^2}{2g}$$

$$\boxed{E = h + \frac{q^2}{2gh^2}}$$

$$E = E_p + E_k$$

The above Eqn gives the variation of specific energy (E) with the depth of flow (h).

→ The graph b/w specific energy (along x-x axis) and depth of flow h, (along y-y axis)

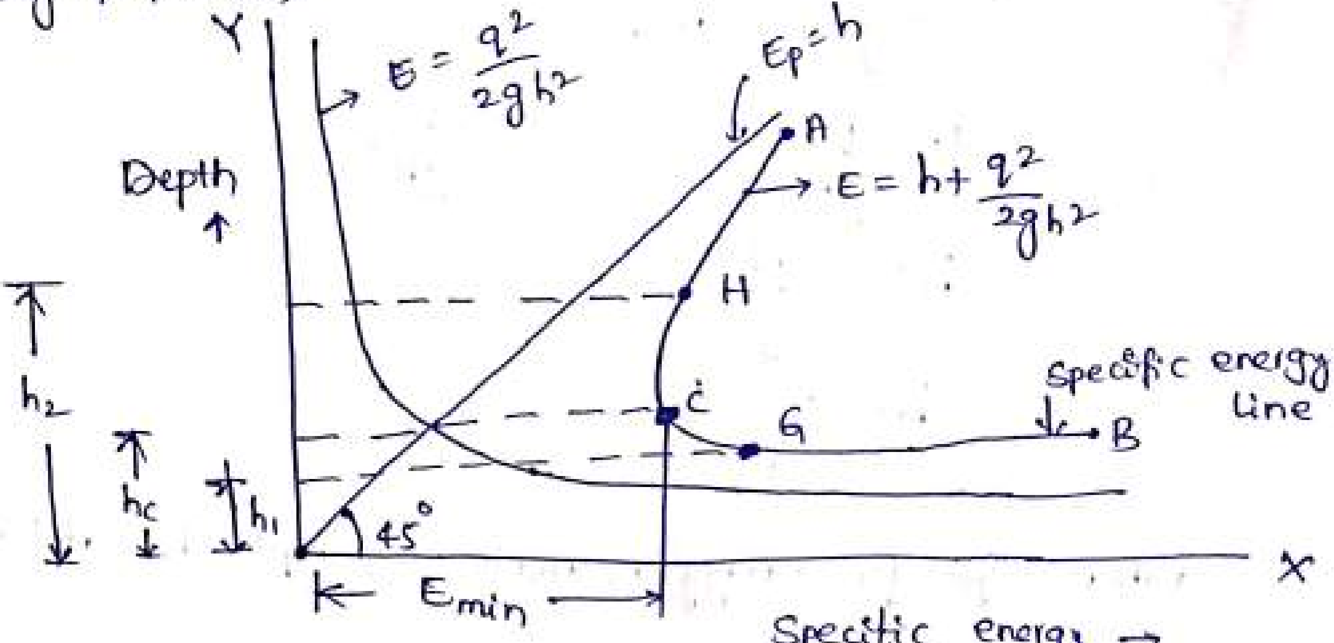


fig:- Specific energy Curve

The specific energy curve may also be obtained by first drawing a curve for potential energy, which will straight line passing through the Origin, making an angle 45° with the axis

ACB → denotes specific energy curve.

Critical depth :-

defined as that depth of flow of water at which the specific energy is minimum.

→ Denoted by 'h_c'

→ ACB - specific energy curve and point C - Corresponding minimum specific energy

The depth of flow of water at C is known as Critical depth.

$$\frac{dE}{dh} = 0 \qquad E = h + \frac{q^2}{2gh^2}$$

$$\frac{d}{dh}\left[h + \frac{q^2}{2gh^2}\right] = 0$$

$$1 + \frac{q^2}{2g}\left[-\frac{2}{h^3}\right] = 0$$

$$1 - \frac{q^2}{gh^3} = 0 \Rightarrow 1 = \frac{q^2}{gh^3}$$

$$h^3 = \frac{q^2}{g}$$

$$h = \left(\frac{q^2}{g}\right)^{1/3}$$

∴ when specific energy is minimum, depth is critical

then critical depth

$$\boxed{h_c = \left(\frac{q^2}{g}\right)^{1/3}}$$

UNIT - 5

NON UNIFORM FLOW IN CHANNELS

Non-uniform flow through open channels :-

If velocity of flow, depth of flow, area of cross-section and slope of the bed channel do not remain constant for a given length of pipe the flow is said to non-uniform.

Non-uniform flow is further divided into two types depends upon the change of depth of flow over the length of the channel.

(1) Gradually varying flow (G.V.F)

(2) Rapidly varying flow (R.V.F).

(1) Gradually varying flow (GVF) :- If the depth of flow in a channel changes gradually over a long length of channel, the flow is said to be gradually varying flow.

(2) Rapidly varying flow (R.V.F) :-

If depth of flow changes suddenly over a small length of channel is said as rapidly varying flow.

(1) Gradually Varying Flow (G.V.F) :-

* If the depth of flow changes in a channel gradually over a long length of the channel, the flow is said to be gradually varying flow.
* It is denoted by G.V.F.

Assumption of G.V.F :-

(1) The bed slope of the channel is small

(2) The flow is steady hence discharge Q is constant

(3) The energy correction factor is unity.

(4) The roughness co-efficient is constant for the length of the channel and it does not depends on depth of flow.

(5) Chezy's formula, mannings formula which are applicable to the uniform flow are also applicable to GVF for determining slope of energy line

(6) The channel is prisamatic.

Equation of GVF :-

Consider a rectangular channel having gradually varied flow. The depth of flow gradually decreasing in the direction of flow.

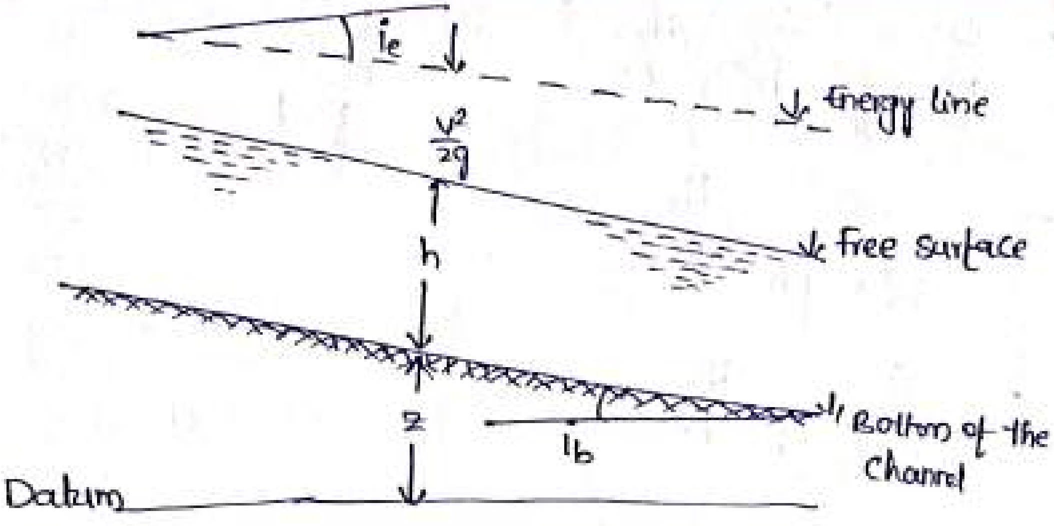


Fig:- Equation of GVF.

z = height of bottom of channel above datum.

h = depth of flow.

V = Mean velocity of flow.

i_b = slope of the Channel bed

i_a = slope of the energy line

b = width of the Channel

Q - Discharge through the Channel.

the energy Equation at any section is given by Bernoulli's eqn.

$$E = z + h + \frac{V^2}{2g}$$

Differentiate this equation w.r. to x, where x is measured along bottom of the channel in the direction of flow.

$$\frac{dE}{dx} = \frac{dz}{dx} + \frac{dh}{dx} + \frac{d}{dx}\left(\frac{V^2}{2g}\right)$$

$Q = AV$

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

$V^2 = \frac{Q^2}{A^2}$

$$\frac{d}{dx}\left(\frac{V^2}{2g}\right) = \frac{d}{dx}\left(\frac{Q^2}{A^2 \times 2g}\right)$$

$$= \frac{d}{dx}\left(\frac{Q^2}{b^2h^2 \times 2g}\right)$$

$$= \frac{Q^2}{b^2 2g} \frac{d}{dx}\left(\frac{1}{h^2}\right)$$

$$= \frac{Q^2}{b^2 \times 2g}\left[\frac{-2}{h^3}\right]\frac{dh}{dx}$$

$$\frac{d}{dx} x^n = n x^{n-1}$$

$$\frac{d}{dx} h^{-2} = -2 h^{-2-1} = -2h^{-3} = \frac{-2}{h^3}$$

$$= \frac{-2Q^2}{b^2 \times 2g h^3}\frac{dh}{dx}$$

$$= \frac{-Q^2}{b^2 h^2 g h}\frac{dh}{dx}$$

$$\boxed{\frac{d}{dx}\left(\frac{V^2}{2g}\right) = -\frac{V^2}{gh}\frac{dh}{dx}}$$

$$\frac{dE}{dx} = \frac{dz}{dx} + \frac{dh}{dx} - \frac{V^2}{gh}\frac{dh}{dx}$$

$$= \frac{dz}{dx} + \frac{dh}{dx}\left(1 - \frac{V^2}{gh}\right)$$

$\frac{dE}{dx}$ = slope of energy line $= -i_e$

$\frac{dz}{dx}$ = slope of the bed of the channel $= -i_b$

$$-i_e = -i_b + \frac{dh}{dx}\left[1 - \frac{V^2}{gh}\right]$$

$$i_b - i_a = \frac{dh}{dx}\left[1 - \frac{V^2}{gh}\right]$$

$$\frac{dh}{dx} = \frac{i_b - i_e}{1 - \frac{V^2}{gh}}$$

$$F_e = \frac{V}{\sqrt{gh}}$$

$$\boxed{\frac{dh}{dx} = \frac{i_b - i_e}{(1 - (F_e)^2)}}$$

i) when $\frac{dh}{dx} = 0$, h is constant (or) depth of water above the bottom of channel.

ii) when $\frac{dh}{dx} > 0$, $\frac{dh}{dx}$ is +ve, depth of water increases in the direction of flow. The profile of water is called back water curve

iii) when $\frac{dh}{dx} < 0$, $\frac{dh}{dx}$ = -ve, depth of water decreases in the direction of flow. The profile of water drop down curve

① Find the rate of change of depth of water, in a rectangular channel of width 20m, having depth of flow 5m. the discharge through the channel of bed slope 1 in 4000, is regulated such away that energy line having a slope of 0.00004.

Sol Given data;

$b = 10m$

$h = 3m$

$v = 1$ m/sec

Bed slope, $i_b = \frac{1}{4000} = 0.00025$

slope of energy line, $i_e = 0.00004$

change of depth of water $\frac{dh}{dx} = \frac{(i_b - i_e)}{1 - \frac{v^2}{gh}}$

$$\frac{dh}{dx} = \frac{0.00025 - 0.00004}{\left(1 - \frac{1 \times 1}{9.81 \times 3}\right)}$$

$$\boxed{\frac{dh}{dx} = 0.000217}$$

② Find the slope of free water surface in rectangular channel of width 20m, having a depth of flow 5m. the discharge through the channel is 50m³/sec. the bed slope of the channel is having a slope of 1 in 4000. Take the value of Chezy's constant C: 60.

$b = 20$

$h = 5m$

$Q = 50\ m^3/sec$

$i_b = \frac{1}{4000} = 0.00025$

$C = 60$

$$Q = AV$$
$$= AC\sqrt{mi}$$

$A = b \times h = 20 \times 5 = 100 m^2$

Hydraulic mean depth $m = A/P = \frac{100}{b+2h} = \frac{100}{20+2\times5} = \frac{100}{30} = \frac{10}{3}$

Slope of the energy line is determined from Chezy's formula

$$50 = 100 \times 60 \times \sqrt{\frac{10}{3} \times i_e}$$

$$i_e = \left(\frac{50}{10954.45}\right)^2$$

$$i_e = 0.0000208$$

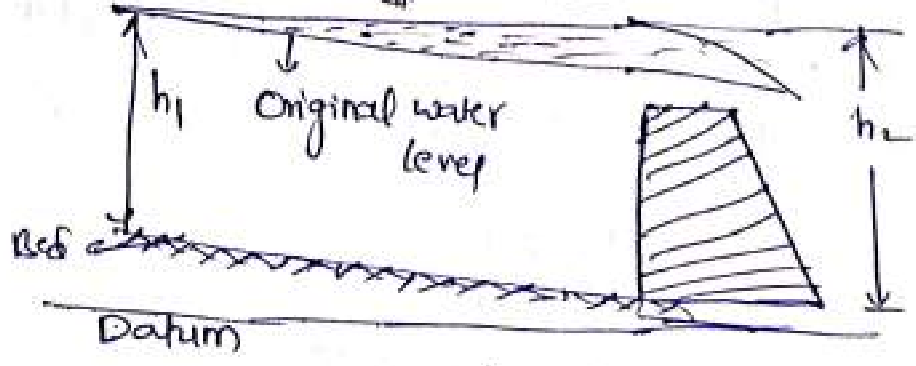
$$\frac{dh}{dx} = \frac{i_b - i_e}{1 - \frac{V^2}{gh}} = \frac{0.00025 - 0.0000208}{1 - \frac{V^2}{9.81 \times 5.0}}$$

$$V = \frac{Q}{A} = \frac{50}{b \times h} = \frac{50}{20 \times 5} = 0.5$$

$$\frac{dh}{dx} = \frac{0.00025 - 0.0000208}{1 - \frac{0.5 \times 0.5}{9.81 \times 5.0}}$$

$$\boxed{\frac{dh}{dx} = 0.00023}$$

Back water Curve & Afflux



Consider flow of water over a dam. On the u/s of the dam the depth of the water will be rising. If there had not been any obstruction (dam) in the path of water in the Channel, the depth of water have been Constant shown by dotted line parallel to the bed of the channel.

→ Due to obstruction, the water level rises and it has max depth from the bed at some section

h_1 = depth of water at the point, where water start rise up

h_2 = Max. height of rising water from bed.

$h_2 - h_1$ = Afflux

Afflux:- Max. increasing of water level due to Obstruction in the path of flow of water.

→ The profile of the rising water on u/s of the obstruction in the path of flow of water. is

→ The profile of the rising water on u/s side of the dam is Called "back water Curve"

Hydraulic Jump (or) Standing Wave

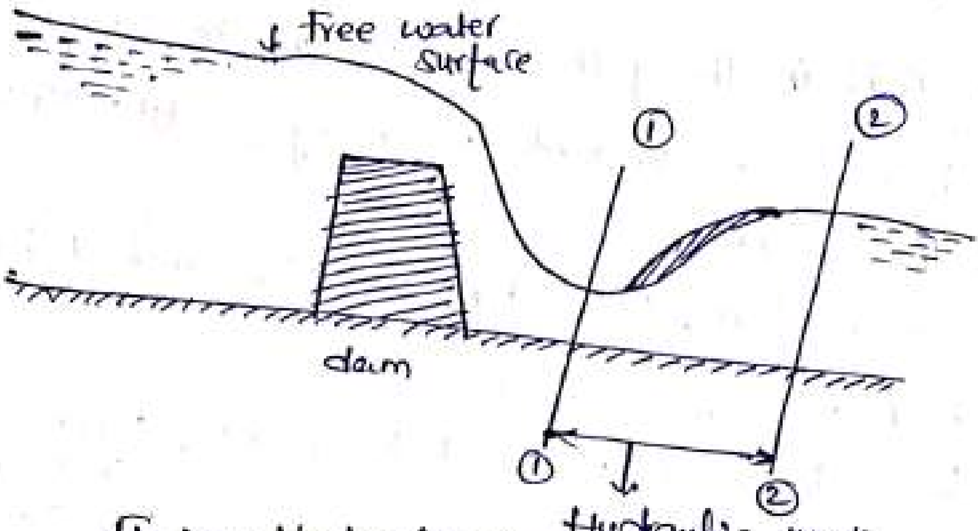


fig :- Hydraulic jump

Consider the flow of water over a dam.

→ The height of water at the section 1-1 is small. As we move towards d/s, the height (or) depth of water increases rapidly over a short length of the channel.

* This is because at the section 1-1, the flow is shooting flow as the depth of the water at section 1-1 is less than critical depth

→ shooting flow is an unstable type of flow and does not continu on the d/s side.

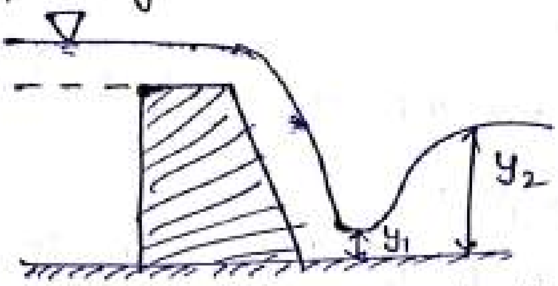
→ shooting flow will convert itself into a streaming flow hence the depth of water will increase

→ This sudden increase of depth of water is called "hydraulic jump (or) a standing wave"

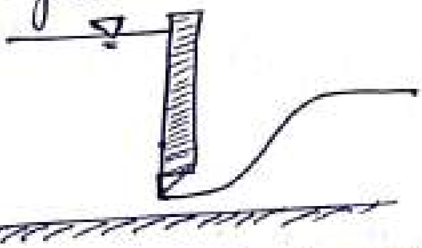
Hydraulic jump :- Rise of water level, which takes place due to the transformation of unstable shooting flow (super-critical flow) to stable streaming flow (sub-critical flow)

Application of hydraulic jump

* Foot of spillway.



* D/s of sluice gate where velocities are high.



Practical application of Hydraulic jump

(1) As energy dissipater to dissipate the excess energy of flowing water d/s of hydraulic structures such as spillway and sluice gates.

(2) Efficient operation of flow measurment flumes.

(3) Mixing of chemicals.

(4) To aid intense mixing and gas transfer in chemical processes

(5) In the desalination of sea water

(6) In the aeration of streams which are polluted by biodegradable wastes.

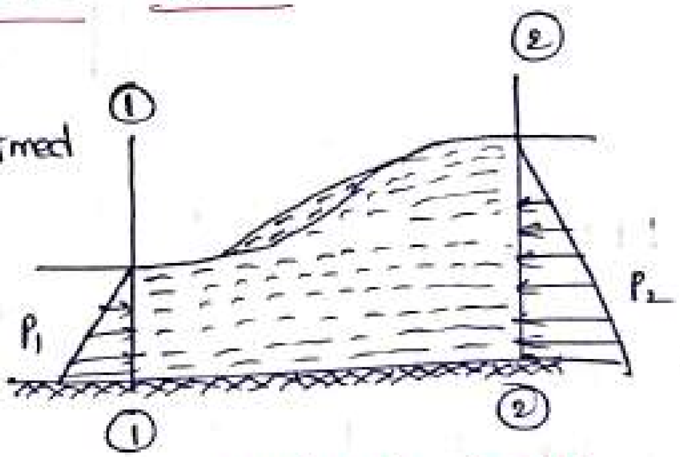
Assumptions of Hydraulic jump

(1) The flow is uniform and pressure distribution is due to hydrostatic before and after the jump

(2) Losses due to friction on the surface of the bed of the channel are small and hence neglected.

(3) The slope of the bed of the channel is small.

Expression for depth of Hydraulic jump



Hydraulic jump

Consider a hydraulic jump formed in a channel of horizontal bed.

Consider two sections 1–1 and 2–2 before and after hydraulic jump

d_1 = depth of flow at section 1-1

d_2 = Depth " " , 2-2

V_1 = Velocity of " " 1-1

V_2 = " " " 2-2

$\bar{Z}_1$ = Depth of centroidal of area at 1-1

$\bar{Z}_2$ = " " 2-2

A_1 = Area of c/s 1-1

A_2 = " " 2-2

Let q = discharge per unit width

$$V_1 d_1 = V_2 d_2$$

pressure force P_1 on the section 1-1

$$= \rho g A_1 \bar{z}_1$$

$$= \rho g d_1 \times 1 \times \frac{d_1}{2} \qquad A_1 = d_1 \times 1, \; \bar{z}_1 = \frac{d_1}{2}$$

$$= \frac{\rho g d_1^2}{2}$$

pressure force on section 2-2

$$P_2 = \rho g A_2 \bar{z}_2$$

$$= \rho g \times (d_2 \times 1) \times \frac{d_2}{2}$$

$$= \frac{\rho g d_2^2}{2}$$

Net force $= P_2 - P_1$

$$= \frac{\rho g d_2^2}{2} - \frac{\rho g d_1^2}{2} = \frac{\rho g}{2}\left[d_2^2 - d_1^2\right]$$

Rate of change of momentum in the direction of force

= mass of water per sec × change of velocity in direction of force

∴ mass of water per second = ρ × discharge per unit width × width

$$= \rho \times q \times 1$$

$$= \rho q$$

change in velocity in the direction of force $= V_1 - V_2$

∴ Rate of change of momentum $= \rho q (V_1 - V_2)$

$$\frac{\rho g}{2}(d_2^2 - d_1^2) = \rho q (V_1 - V_2)$$

$$V_1 = \frac{q}{d_1} \quad \text{and} \quad V_2 = \frac{q}{d_2}$$

$$\frac{\rho g}{2}(d_2^2 - d_1^2) = \rho q \left(\frac{q}{d_1} - \frac{q}{d_2}\right)$$

$$\frac{g}{2}(d_2+d_1)(d_2-d_1) = q^2\frac{(d_2-d_1)}{d_1 d_2}$$

$$\frac{g}{2}(d_2+d_1) = \frac{q^2}{d_1 d_2}$$

$$(d_2+d_1) = \frac{2q^2}{g d_1 d_2}$$

Multiplying both side by d_2, we get

$$d_2^2 + d_1 d_2 = \frac{2q^2}{g d_1}$$

$$d_2^2 + d_1 d_2 - \frac{2q^2}{g d_1} = 0$$

$$d_2 = \frac{-d_1 \pm \sqrt{d_1^2 - 4\times 1\times\left(-\frac{2q^2}{g d_1}\right)}}{2\times 1}$$

$$= \frac{-d_1 \pm \sqrt{d_1^2 + \frac{8q^2}{g d_1}}}{2}$$

$$d_2 = -\frac{d_1}{2} \pm \sqrt{\frac{d_1^2}{4} + \frac{2q^2}{g d_1}}$$

first root is not possible as it gives -ve depth, Hence (take +)

$$\boxed{d_2 = -\frac{d_1}{2} + \sqrt{\frac{d_1^2}{4} + \frac{2q^2}{g d_1}}}$$

$$= -\frac{d_1}{2} + \sqrt{\frac{d_1^2}{4} + \frac{2\times(V_1 d_1)^2}{g d_1}} \qquad q = V_1 d_1$$

$$d_2 = -\frac{d_1}{2} + \sqrt{\frac{d_1^2}{4} + \frac{2V_1^2 d_1}{g}}$$

Expression for loss of energy due to Hydraulic jump

When hydraulic jump takes place, a loss of energy due to eddies formation and turbulence occurs. This loss of energy is equal to the difference of specific energies at section 1-1 and 2-2.

Loss of hydraulic jump

$$h_L = E_1 - E_2$$

$$= \left(d_1 + \frac{V_1^2}{2g}\right) - \left(d_2 + \frac{V_2^2}{2g}\right)$$

$$= \left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right) - (d_2 - d_1)$$

$$= \left(\frac{q^2}{2gd_1^2} - \frac{q^2}{2gd_2^2}\right) - (d_2 - d_1).$$

$$= \frac{q^2}{2g}\left[\frac{1}{d_1^2} - \frac{1}{d_2^2}\right] - (d_2 - d_1)$$

$$= \frac{q^2}{2g}\left[\frac{d_2^2 - d_1^2}{d_1^2 d_2^2}\right] - (d_2 - d_1)$$

$$q^2 = g d_1 d_2 \frac{(d_2 + d_1)}{2}$$

Loss of energy, $h_L = g d_1 d_2 \frac{(d_2 + d_1)}{2} \times \frac{d_2^2 - d_1^2}{2g d_1^2 d_2^2} - (d_2 - d_1)$

$$= \frac{(d_2 + d_1)(d_2^2 - d_1^2)}{4 d_1 d_2} - (d_2 - d_1)$$

$$= \frac{(d_2 + d_1)(d_2 + d_1)(d_2 - d_1)}{4 d_1 d_2} - (d_2 - d_1)$$

$$= (d_2-d_1)\left[\frac{(d_2+d_1)^2}{4d_1d_2}-1\right]$$

$$= (d_2-d_1)\left[\frac{d_2^2+d_1^2+2d_1d_2-4d_1d_2}{4d_1d_2}\right]$$

$$= (d_2-d_1)\frac{[d_2-d_1]^2}{4d_1d_2}$$

$$\boxed{h_L = \frac{(d_2-d_1)^3}{4d_1d_2}}$$

Expression of depth of Hydraulic jump in terms of Froude number :-

V_1 = velocity of flow on u/s side

d = depth of water on u/s side

$$(Fe)_1 = \frac{V_1}{\sqrt{gd_1}}$$

$$d_2 = -\frac{d_1}{2}+\sqrt{\frac{d_1^2}{4}+\frac{2V_1^2d_1}{g}}$$

$$= -\frac{d_1}{2}+\sqrt{\frac{d_1^2}{4}\left(1+\frac{8V_1^2}{gd_1}\right)}$$

$$= -\frac{d_1}{2}+\frac{d_1}{2}\sqrt{1+\frac{8V_1^2}{gd_1}}$$

$$(Fe)_1 = \frac{V_1}{\sqrt{gd_1}} \quad (\text{or}) \quad (Fe)_1^2 = \frac{V_1^2}{gd_1}$$

$$d_2 = -\frac{d_1}{2}+\frac{d_1}{2}\sqrt{1+8(Fe)_1^2}$$

$$= \frac{d_1}{2}\left(\sqrt{1+8(Fe)_1^2}-1\right)$$

① The depth of flow of water, a certain section of rectangular channel of 4m wide is 0.5m. This discharge through channel is 16 m³/sec. If a hydraulic jump takes places on the d/s side, find the depth of flow after the jump.

width, $b = 4m$

Depth of flow before jump $d_1 = 0.5m$

Discharge $Q = 16\ m^3/sec$

∴ Discharge per unit width $q = \frac{Q}{b} = \frac{16}{4} = 4\ m^2/sec$

Depth of flow after the jump is given by

$$d_2 = -\frac{d_1}{2} + \sqrt{\frac{d_1^2}{4} + \frac{2q^2}{gd_1}}$$

$$= -\frac{0.5}{2} + \sqrt{\frac{0.5^2}{4} + \frac{2\times 4^2}{9.81\times 0.5}}$$

$$\boxed{d_2 = 2.316m}$$

② The depth of flow of water, at a certain section of a rectangular channel of 2m wide, is 0.3m. The discharge through channel is 1.5 m³/sec. Determine whether a hydraulic jump will occur, and if so, find its height and loss of energy per kg of water.

Depth of flow $D_1 = 0.3M$

$b = 2m$

$Q = 1.5\ m^3/sec$

Discharge per unit width $q = \frac{Q}{b} = \frac{1.5}{2} = 0.75\ m^2/sec$

$$h_c = \left(\frac{q^2}{g}\right)^{1/3}$$

$$= \left(\frac{0.75}{9.81}\right)^{1/3}$$

$$\boxed{h_c = 0.3859}$$

∴ The depth of flow after hydraulic jump

$$d_2 = -\frac{d_1}{2} + \sqrt{\frac{d_1^2}{4} + \frac{2q^2}{gd_1}}$$

$$= -\frac{0.3}{2} + \sqrt{\frac{0.3^2}{4} + \frac{2\times 0.75^2}{9.81\times 0.3}}$$

$$\boxed{d_2 = 0.4862}$$

Height of the hydraulic jump $= d_2 - d_1$

$= 0.4862 - 0.30$

$= 0.1862\,m$

Loss of energy per kg of water due to hydraulic jump

$$h_L = \frac{(d_2 - d_1)^3}{4d_1d_2}$$

$$= \frac{(0.4862 - 0.30)^3}{4\times 0.4862\times 0.30}$$

$h_L = 0.01106$ m.kg/kg

* (3) A sluice gate discharge water into a horizontal rectangular channel with avg velocity of 10 m/sec and depth of flow of 1m. Determine the depth of flow after the jump and consequent loss in total head

Velocity of flow before hydraulic jump $V_1 = 10$ m/sec

Depth of flow before hydraulic jump $d_1 = 1$m.

Discharge per unit width

$$q = V_1 \times d_1$$

$$q = 10 \times 1 = 10$$

The depth of flow after the jump

$$d_2 = -\frac{d_1}{2} + \sqrt{\frac{d_1^2}{4} + \frac{2q^2}{gd_1}}$$

$$= -\frac{1.0}{2} + \sqrt{\frac{1^2}{4} + \frac{2 \times 10^2}{9.81 \times 1}}$$

$$d_2 = -0.50 + \sqrt{0.25 + 20.387}$$

$$\boxed{d_2 = 4.043\,m}$$

Loss in total head is given by

$$h_L = \frac{(d_2 - d_1)^3}{4d_1d_2}$$

$$h_L = \frac{(4.043 - 1.0)^3}{4 \times 1.0 \times 4.043}$$

$$\boxed{h_L = 1.742\,m}$$

Classification of channel slopes

For uniform flow in a channel

$S_n = S_0$ = Slope of uniform flow / Normal slope

$Y_n = Y_0$ = Depth of uniform flow / Normal depth.

For critical flow in a channel

S_c = Slope of critical

& Y_c = Critical depth.

(1) Mild Slope.

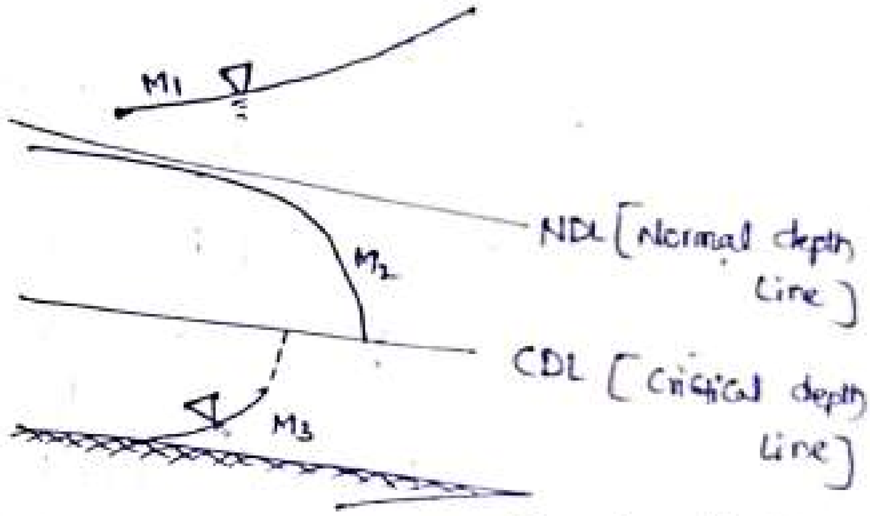
(2) steep slope

(3) Critical slope.

(4) Horizontal slope.

(5) Adverse slope.

(1) Mild slope :-



$S_0 < S_c \Rightarrow y_n > y_c$

It means normal depth line NDL is above critical depth line

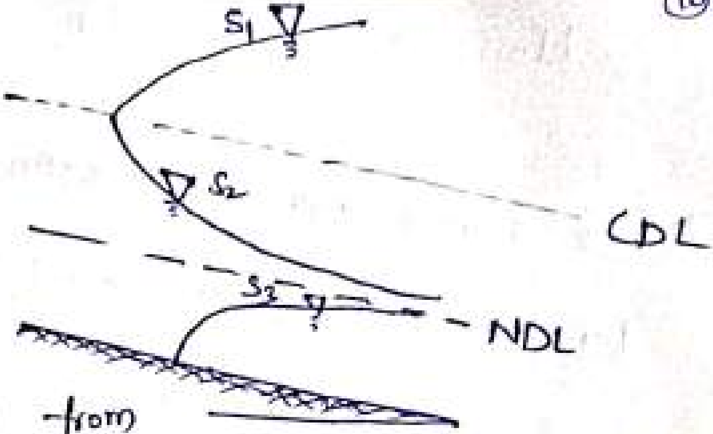
* M_1 profile is a back water curve due to obstruction to flow such as weir, dame etc. Being $y > y_c$ the flow is sub-critical

* M_2 profile occur at sudden drop in the bed of a channel, at the canal outlet into pool etc

Being $y > y_c$ the flow is sub-critical

* M_3 profile occur of the flow through sluice or leading from spillway. Being $y < y_c$, M_3 are super-critical and hence hydraulic jump forms

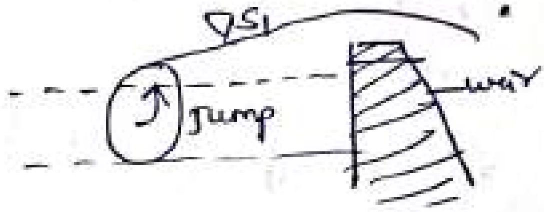
(b) Steep slope :-



$S_0 > S_c \Rightarrow y_n < y_c$

It means NDL is below CDL

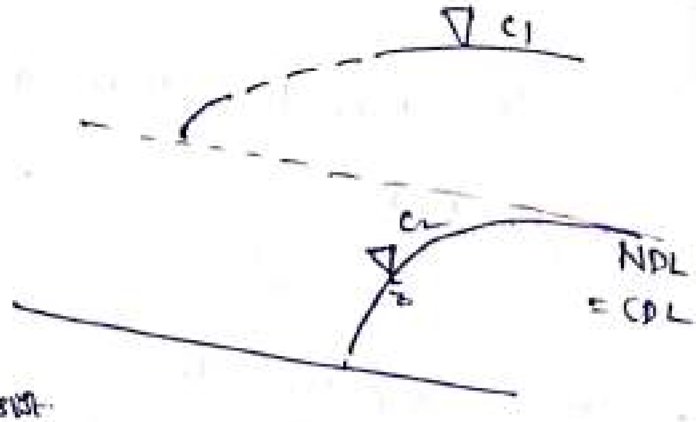
* S_1 profile is developed in the flow from a steep channel is termed by a deep pool created by an obstruction such as dam (or) weir.



* S_2 profile, At the entrance region of steep channel leading from a reservoir
* A sudden change of slope from mild to steep.

* S_3 profile are, At the toe.
* If a flow passes a steeper slope to a less steep slope

(c) Critical slope :



$S_0 = S_c \Rightarrow y_n = y_c$

It means NDL will coincide CDL

water profile C_2 doesn't exist.

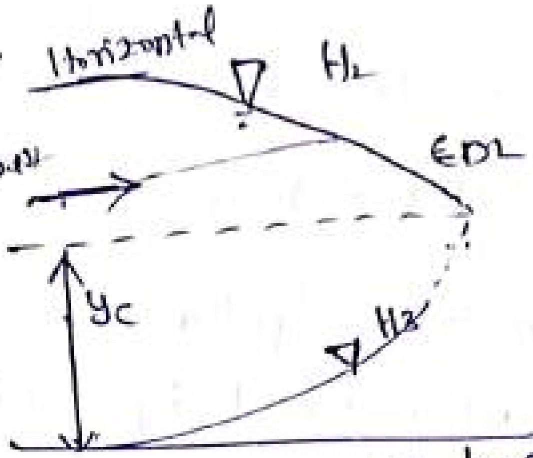
C_1 & C_3 profile are highly unstable, they occur very rarely.

(4) Horizontal Slope (H)

$S_0 = 0$

Hence normal depth $y_n \to$ depth.

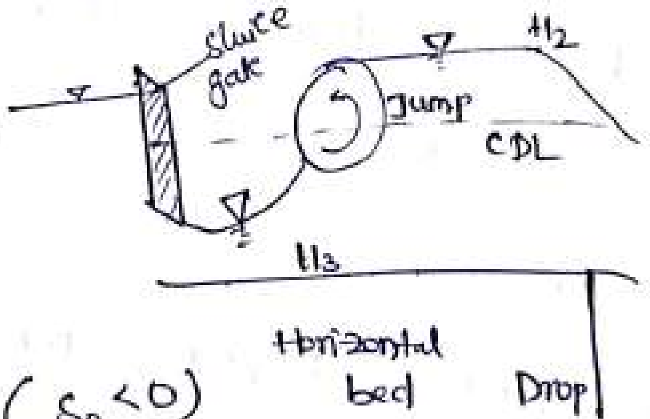
Let $y_n \to \infty$ then H_3, do not exist



H_2 & H_3 profile are similar

∴ H_2 & H_3 profiles are similar to m_2 + m_3

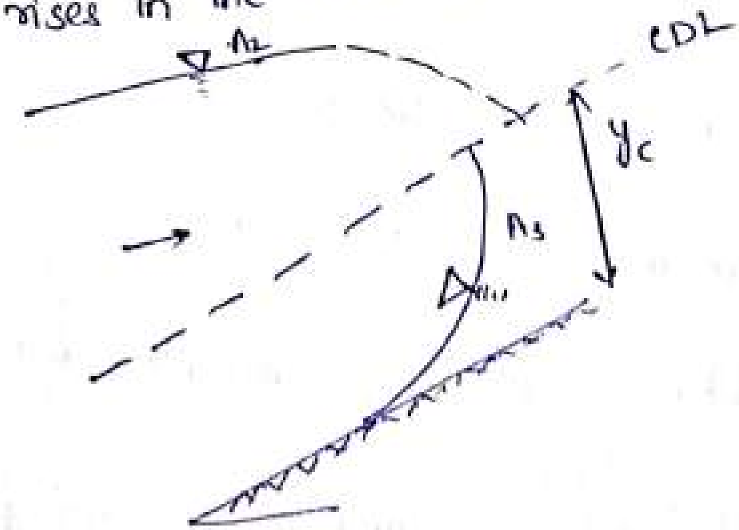
* As $y < y_c$, profile is super critical. Hence hydraulic jump is possible from spim..



(5) Adverse Slope :- ($S_0 < 0$)

The channel bottom rises in the direction of flow

(S_0 is -ve)



→ $y_n \to \infty$. Hence the water surface profile A_1 doesn't exisist

• A_2, A_3 profile are very rare. (e) Adverse slope

Surge in Open Channel

Surge is an unsteady phenomenon that occus under the situation like closure (or) opening of valves, gates, loading (or) unloading of turbines, start (or) stopping of pumps, failure of dams..

→ Depending on the direction of movement of these waves, flow depth either may decrease (or) increase in the flow direction

Surge may be classified into two types.

1> Positive surge.
2> Negative surge.

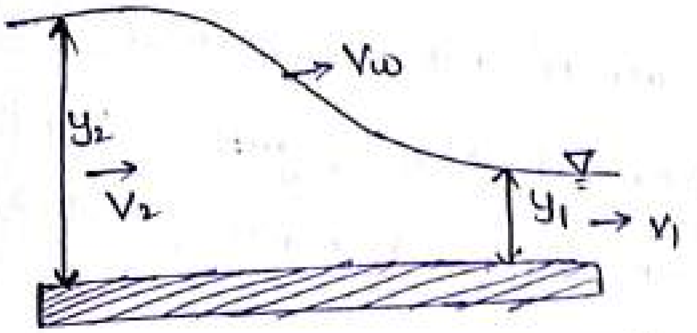
(1) **Positive Surge** :- A surge producing an increase in flow depth is called positive surge.

(2) **Negative Surge** :- A surge producing an decrease in flow depth is called a negative surge.

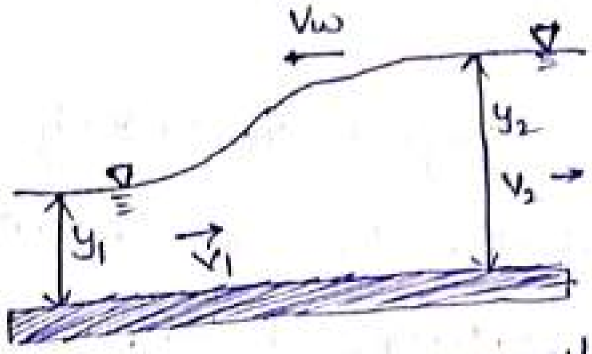
(or)

If wave is higher than the original steady flow depth we call it a positive surge, In a negative surge, the situation is just the opposite

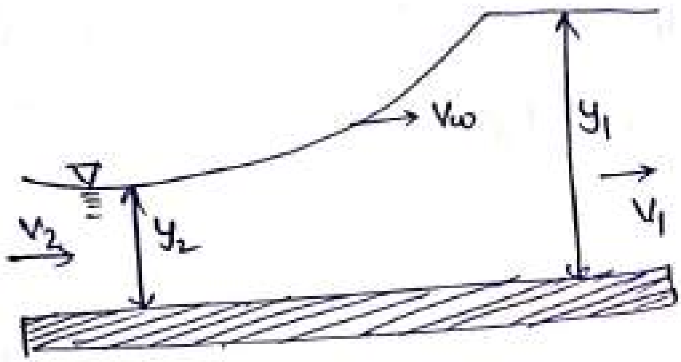
Types of Surges



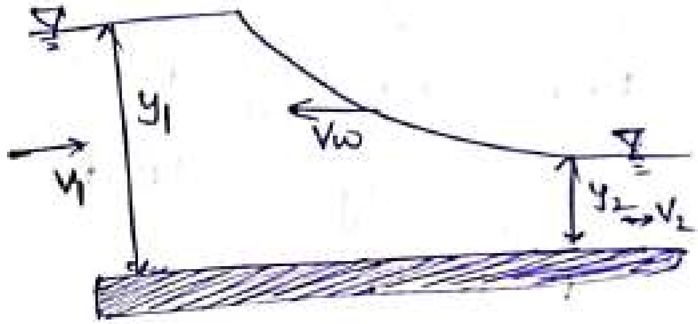
Positive surge moving downwards



Positive surge moving u/s



Negative surge moving downwards



Negative surge moving u/s

Surge Type	Example
positive surge moving d/s	D/s to sluice gate when suddenly open
positive surge moving u/s	U/s to sluice gate when suddenly closed
Negative surge moving d/s	D/s to sluice gate when suddenly closed
Negative surge moving u/s	U/s to sluice gate when suddenly open

Hydraulics and Hydraulic Machines

UNIT - 1

DIMENSIONAL ANALYSIS

Dimensional analysis: Dimensional analysis is a method of analysis dimensions. It is a mathematical technique used in research work for design and for conducting model tests.

* It deals with the dimensions of the physical quantities involved in the phen-omenon.

i) primary dimension:

It is also known as fixed dimensions, fundamental dimensions (or) fixed dimensions (or) fundamental quantity.

* Length (L), Mass (M) and Time (T) are three fixed dimensions which are of importance in fluid mechanics.

* If any problem of fluid mechanics, heat is involved then temperature is also taken as primary dimensions.

S.NO	Physical Quantity	Symbol	Dimensions.
	(a) fundamental/primary/Fixed dimensions.		
1	Length	L	L
2	Mass	M	M
3	Time	T	T

(ii) Secondary (or) Derived quantities :

Quantities which posses more than one fundamental dimension is called secondary dimension.

① Determine the dimensions of the quantities given below
i) Angular velocity ii) Angular acceleration iii) Discharge iv) Kinematic viscosity
v) Force vi) specific weight vii) Dynamic viscosity.

i) Angular velocity = $\frac{\text{Angle covered in radians}}{\text{Time}} = \frac{1}{T} = T^{-1}$

ii) Angular acceleration = $\frac{\text{radian}}{sec^2} = \frac{1}{T^2} = T^{-2}$

(iii) Discharge = Area × velocity = $m^2 \times \frac{\text{distance}}{\text{time}} = \frac{m^2 \times m}{t} = \frac{m^3}{T} = L^3T^{-1}$

(iv) Kinematic viscosity (ν) = $\frac{\mu}{\rho}$, $\tau = \mu \frac{du}{dy}$

$\mu = \frac{\tau}{\frac{du}{dy}} = \frac{\text{shear stress}}{\text{velocity gradient}}$ → $\frac{\text{velocity}}{\text{distance}}$

$= \frac{\frac{F}{A}}{\frac{L}{T} \times \frac{L}{L}}$

$= \frac{\frac{kg.m}{sec^2}}{\frac{m^2}{1/T}} = \frac{MLT^{-2}}{L^2T^{-1}} = ML^{-1}T^{-1}$ $\left[F = \frac{kg.m}{sec^2}\right]$

$\rho = \frac{\text{mass}}{\text{Volume}} = \frac{M}{L^3} = ML^{-3}$

∴ Kinematic viscosity $\nu = \frac{\mu}{\rho} = \frac{ML^{-1}T^{-1}}{ML^{-3}} = L^2T^{-1}$

(v) Force = Mass × acceleration = $M \times \frac{L}{T^2} = \frac{ML}{T^2} = MLT^{-2}$

(vi) Specific weight = $\frac{\text{weight}}{\text{Volume}} = \frac{\text{Force}}{\text{Volume}} = \frac{MLT^{-2}}{L^3} = ML^{-2}T^{-2}$

(vii) Dynamic viscosity , $\mu = ML^{-1}T^{-1}$

$\tau = \mu \frac{du}{dy}$ $\mu = \frac{\tau}{\frac{du}{dy}}$

Physical Quantity	Symbol	Dimensions
(a) Geometric		
Area	A	L^2
volume	V	L^3
(b) Kinematic Quantities		
Velocity	v	LT^{-1}
* Angular velocity	ω	T^{-1}
* Acceleration	a	LT^{-2}
* Angular acceleration	α	T^{-2}
Discharge	Q	L^3T^{-1}
Acceleration due to gravity	g	LT^{-2}
Kinematic viscosity	ν	L^2T^{-1}
(c) Dynamic Quantites		
Force	F	MLT^{-2}
weight	W	MLT^{-2}
Density	ρ	ML^{-3}
Specific weight	w	$ML^{-2}T^{-2}$
*– Dynamic viscosity	μ	$ML^{-1}T^{-1}$
*– pressure intensity	p	$ML^{-1}T^{-2}$
Modulus of Elasticity	E	$ML^{-1}T^{-2}$
Surface tension	σ	MT^{-2}
Shear stress	τ	$ML^{-1}T^{-2}$
Work (or) Energy	W	$ML^{-1}T^{-2}$
*– Power	P	ML^2T^{-3}
Torque	T	ML^2T^{-2}

Dimensional Homogeneity :-

Dimension of each terms in an equation on both sides are equal. Thus if the dimensions of each term on bothsides of an equation are the same the equation is known as dimensionally homogeneous equation.

Ex: Let us consider the equation, $V = \sqrt{2gH}$

Dimension of L.H.S $= V = \frac{L}{T} = LT^{-1}$

Dimension of R.H.S $= \sqrt{2gH} = \sqrt{\frac{L}{T^2} \times L} = \sqrt{\frac{L^2}{T^2}}$

$= LT^{-1}$

Dimension of L.H.S = Dimension of R.H.S $= LT^{-1}$

Equation $V = \sqrt{2gH}$ is dimensionally homogeneous. So it can be used in any system of units.

Methods of Dimensional Analysis

If the number of variable involved in a physical phenomenon are known, then the relation among the variables can be determined, by two methods.

(1) Rayleigh's method.

(2) Buckingham's π - theorem.

(1) Rayleigh's method :-

→ This method is used to determine the expression for a variable which depends upon maximum three (or) four variables only.

→ If the number of independent variables becomes more than four then it is very difficult to find the expression for the dependent variable

let X is a variable, which depends upon X_1, X_2, X_3 variable

X is function of X_1, X_2, X_3.

Mathematically, it's written as $X = f[X_1, X_2, X_3]$

This can also be written as $X = K X_1^{a_1}, X_2^{b}, X_3^{c}$

where K = Constant

a, b, c = arbitary powers.

The values of a, b, c obtained by comparing the powers of the fundamental dimension on both sides.

Procedure for problem solving of Rayleighs method

(1) Formation of Equation.
(2) Substituting dimensions on both sides.
(3) Equating powers of M, L, T on both sides.
(4) Substituting the values of (a, b) in equation (1) (or) step(1).
(5) final expression

① The time period (t) of a pendulum depends upon the length (L) of the pendulum and acceleration due to gravity (g). Derive an expression for the time period.

Step(1):- formation of Equation:

time period (t), is the function of (i) L
(ii) g

$$t = K L^a g^b \rightarrow ①$$

Step(2):- Substituting the dimensions on both sides.

$$T^1 = K L^a (LT^{-2})^b$$

$$g = \frac{m}{sec^2} = \frac{L}{T^2} = LT^{-2}$$

Step(3):- Equating powers of M, L and T on both sides

power of M: $0 = 0$

power of L: $0 = a + b$

Power of T: $1 = -2b$, $b = -1/2$

$a = 1/2$

Step(4):- Substituting the values of a and b in equation(1) (or) step(1)

$$t = K L^{1/2} g^{-1/2}$$

$$t = K \sqrt{\frac{L}{g}}$$

The value of K is determined from experiments which given as

$$K = 2\pi$$

$$t = 2\pi \sqrt{\frac{L}{g}}$$

Step(5):- final expression

$$t = 2\pi \sqrt{\frac{L}{g}}$$

② Find the expression for the drag force on smooth sphere of diameter D, moving with a uniform velocity V in a fluid of density ρ and dynamic viscosity μ.

Soln Drag force F is the function of

Step(1):- Formation of Equation (or) Expression.

F is the function of i) Diameter D, ii) Velocity, V iii) Density ρ. iv) Viscosity μ.

$$F = K D^a . V^b \rho^c \mu^d$$

Step(2):- Substituting dimensions on both sides

$$F = K D^a . V^b . \rho^c . \mu^d$$

$$MLT^{-2} = K (L)^a (LT^{-1})^b (ML^{-3})^c (ML^{-1}T^{-1})^d$$

$\rightarrow F = N = \frac{Kg.m}{sec^2} = MLT^{-2}$

$D = m = L$

$V = \frac{Distance}{time} = \frac{m}{T} = LT^{-1}$

$\rho = \frac{m}{V} = ML^{-3}$

μ = Pascal.sec

$= \frac{N}{m^2} \times sec$

$= \frac{Kg.m}{sec^2 \times m^2} \times sec$

$= ML^{-1}T^{-1}$

Step(3):- Equating powers on both sides. (M,L,T)

Power of M; $1 = c + d$, $d = 1 - c$, $c = 1 - d$

Power of L; $1 = a + b - 3c - d$

Power of T; $-2 = -b - d$

$b = 2 - d$

$1 = a + (2-d) - 3(1-d) - d$

$1 = a + 2 - d - 3 + 3d - d$

$a = 1 - 2 + d + 3 - 3d + d$

$$a = 2 - d$$

Step(4):- Substituting these values of a, b and c in (i), we get

$$F = K D^a V^b \rho^c \mu^d$$

$$F = K (D)^{2-d} (V)^{2-d} (\rho)^{1-d} \mu^d$$

$$= K D^2 V^2 \rho \left(D^{-d} V^{-d} \rho^{-d} \mu^d \right)$$

$$F = K \rho D^2 V^2 \left(\frac{\mu}{\rho V D} \right)^d$$

Step(5):- final expression

$$F = K \rho D^2 V^2 \left(\frac{\mu}{\rho V D} \right)^d$$

Drawbacks of Rayleigh's method

(1) It does not provide any information regarding the number of dimensionless groups to be obtained a result of dimensional analysis.

(2) If a variable depends upon 3 (or) 4 variables only, it is simple.

Buckingham's π- Theorem :-

Rayleigh's method of dimensional analysis becomes more laborious if the variables are more than the no. of fundamental dimensions (M, L, T). This difficulty is overcame by using Buckingham's π theorem.

" If there are n variables (independent and dependent variables) in 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 - are the variables involved in a physical problem

let x_1 be the dependent variable

$x_2, x_3 ---- x_n$ → independent variable

$$x_1 = f(x_2, x_3 ---- x_n)$$

$$f_1(x_1, x_2, x_3 ---- x_n) = 0$$

$$f(\pi_1, \pi_2, ---- \pi_{n-m}) = 0$$

Procedure for solving problems by Buckingham's π-theorem:-

Step(1) :- List all the variables that are involved in the problem.

Step(2) :- Express each variables in terms of basic dimensions.

Step(3) :- Determine the required no. of π- terms.

Step(4) :- Selection of repeating variable.

Step(5) :- Form a pi- term equation.

Step(6) :- Each π- term solved by principle of dimensional homogeinity.

Step(7) :- Check all the resulting π- terms.

Step(8) :- Express the final formation.

Ex :- The Resisting force R of a super sonic plane during flight can be considerd as depends upon the length of the aircraft L, Velocity V, air viscosity μ, air density ρ and bulk modulus of air K. Express the functional relationship b/w these variables and the resisting force.

Step (1) :- List all the variables that are involved in the problem

$$R = f(L, V, \mu, \rho, K)$$

it can be written as

$$f(R, L, V, \mu, \rho, K) = 0$$

Methods of Selecting Repeating Variables :-

The number of repeating variables are equal to the number of fundamental dimension of the problem. The choice of repeating variable is

(1) As far as possible, the dependent variable should not be selected as repeating variable.

(2) The repeating variable should be chosen in such a way that one variable contains geometric property, other variable contain flow property and third variable contains fluid property.

Geometric property

Ex:- (i) Length (L) (ii) diameter (d) (iii) Height (H) etc.

Variables with fluid property

(i) Velocity, V (ii) Acceleration etc.

Variables with fluid property :

(i) Dynamic viscosity (ii) mass density (iii) Angular velocity (ω)

(3) The repeating variables selected should not form a dimensionless group

(4) The repeating variables together must have the same no. of fundamental dimension.

(5) No two repeating variables should have the same dimensions.

Step(2) :- Express each variables in terms of basic dimensions

R → Resisting force = Units $\frac{kg.m}{sec^2}$ = MLT^{-2}

V → velocity = $\frac{\text{Distance}}{\text{Time}}$ = LT^{-1}

μ → Dynamic viscosity = pascal.sec

$= \frac{1N}{m^2} \times sec$

$= \frac{kg.m}{sec^2 \times m^2} \times sec$

$= \frac{kg}{m \times sec}$ = $ML^{-1}T^{-1}$

ρ → density = $\frac{\text{mass}}{\text{Volume}}$ = ML^{-3}

Step(3) :- Selecting the repeating variable

Fundamental dimension in the problem
i) Length − L
ii) velocity − V
iii) Density − ρ
} repeating variables

π- terms = n−m
= 6−3
= 3

Step(4) :- Determine the required no. of π- terms.

These turbines say, π_1, π_2, π_3

Total no. of variables = 6

Number of fundamental dimension (m) = 3

∴ No. of π- terms = n−m
= 6−3
= 3.

thus three π- terms say π_1, π_2 and π_3

$f(\pi_1, \pi_2, \pi_3) = 0$

Step(5) :- form a phi term equation.

Each π - term is written as

$$\left.\begin{aligned} \pi_1 &= L^{a_1} V^{b_1} \rho^{c_1} R \\ \pi_2 &= L^{a_2} V^{b_2} \rho^{c_2} \mu \\ \pi_3 &= L^{a_3} V^{b_3} \rho^{c_3} K \end{aligned}\right\}$$

Step(6) :- Each π - term solved by principle of dimensional homogeinity.

first π term $\rightarrow$ $\pi_1 = L^{a} V^{b_1} \rho^{c_1} R$

$$\pi_1 = L^{a_1} (LT^{-1})^{b_1} (ML^{-3})^{c_1} MLT^{-2}$$

$M^0 L^0 T^0$

Equating the powers of M, L, T on both sides

power of M ; $0 = c_1 + 1$ $\boxed{c_1 = -1}$

power of L ; $0 = a_1 + b_1 - 3c_1 + 1$

$a_1 = -b_1 + 3c_1 + 1$

power of T ; $0 = -b_1 - 2$ $\boxed{a_1 = -2}$

$\boxed{b_1 = -2}$

Now , $\pi_1 = L^{-2} V^{-2} \rho^{-1} R$

$$\boxed{\pi_1 = \frac{R}{L^2 V^2 \rho}}$$

Second π - term :- $\pi_2 = L^{a_2} V^{b_2} \rho^{c_2} \mu$

$$M^0 L^0 T^0 = L^{a_2} (LT^{-1})^{b_2} (ML^{-3})^{c_2} ML^{-1}T^{-1}$$

power of M , $0 = c_2 + 1$, $\boxed{c_2 = -1}$

power of L , $0 = a_2 + b_2 - 3c_2 - 1$

$a_2 = -b_2 + 3c_2 + 1$ $\boxed{a_2 = -1}$

power of T , $0 = -b_2 - 1$

$\boxed{b_2 = -1}$

Third π- term :-

$$\pi_3 = L^{a_3} V^{b_3} \rho^{c_3} K$$

$$M^0 L^0 T^0 = L^{a_3} (LT^{-1})^{b_3} (ML^{-3})^{c_3} ML^{-1}T^{-2}$$

power of M, $0 = c_3 + 1$, $\boxed{c_3 = -1}$

power of L, $0 = a_3 + b_3 - 3c_3 - 1$

$a_3 = -b_3 + 3c_3 + 1$ $\boxed{a_3 = 0}$

power of T, $0 = -b_3 - 2$

$\boxed{b_3 = -2}$

$$\pi_3 = L^0 V^{-2} \rho^{-1} K$$

$$\boxed{\pi_3 = \frac{K}{V^2 \rho}}$$

Step (7) :- Check all the resulting π- terms.

$$\pi_1 = \frac{R}{\rho L^2 V^2}, \quad \pi_2 = \frac{\mu}{L V \rho}, \quad \pi_3 = \frac{K}{V^2 \rho}$$

Step (8) :- Express the final formation.

$$f_1\left(\frac{R}{\rho L^2 V^2}, \frac{\mu}{L V \rho}, \frac{K}{V^2 \rho}\right) = 0$$

$$\frac{R}{\rho L^2 V^2} = \phi\left[\frac{\mu}{L V \rho}, \frac{K}{V^2 \rho}\right]$$

$$\boxed{R = \rho L^2 V^2 \phi\left[\frac{\mu}{L V \rho}, \frac{K}{V^2 \rho}\right]}$$

② 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 the discharge Q. Express η in terms of dimensionless parameters.

Sol

Step(1) :- List all the variables that are involved in the problem

$$\eta = f(\rho, \mu, \omega, D, Q)$$

$$f_1(\eta, \rho, \mu, \omega, D, Q) = 0$$

Step(2) :- Express each variable in terms of basic dimensions

$\eta \rightarrow$ No basic dimensions.

$$\rho = \frac{\text{Mass}}{\text{Volume}} = \frac{M}{V} = ML^{-3}$$

$$\mu = \text{Pas. sec} = \frac{N}{m^2} \cdot sec = \frac{kg \cdot m}{sec^2} \times \frac{sec}{m^2} = ML^{-1}T^{-1}$$

$$\omega = \frac{1}{T} = T^{-1}$$

Diameter $D = L$

discharge $Q = A \times V = m^2 \times \frac{m}{sec} = L^3 T^{-1}$

Step(3) :- selection of repeating variable

Diameter — D
Angular velocity — ω
mass density — ρ
} Repeating variables

Step(4) :- Determine the required no. of π-terms.

∵ Total no. of variables = 6

Number of fundamental dimensions = 3

∴ No. of π-terms $= n - m = 6 - 3 = 3$

$$f_1(\pi_1, \pi_2, \pi_3) = 0$$

Step(5) :- Form a phi-term equation.

$$\pi_1 = D^{a_1} \omega^{b_1} \rho^{c_1} \eta$$

$$\pi_2 = D^{a_2} \omega^{b_2} \rho^{c_2} \mu$$

$$\pi_3 = D^{a_3} \omega^{b_3} \rho^{c_3} Q$$

Step(6) :- Each π-term solved by principle of dimensional homogenity.

First π-term :- $\pi_1 = D^{a_1} \omega^{b_1} \rho^{c_1} \eta$

$$M^0L^0T^0 = L^{a_1} (T^{-1})^{b_1} (ML^{-3})^{c_1} M^0L^0T^0$$

Equating power on both sides.

power of M, $0 = c_1 + 0$, $c_1 = 0$

power of L, $0 = a_1 + 0$, $a_1 = 0$

power of T, $0 = -b_1 + 0$, $b_1 = 0$

$$\pi_1 = D^0 \omega^0 \rho^0 . \eta$$

Second π-term

$$\pi_2 = D^{a_2} \omega^{b_2} \rho^{c_2} \mu$$

$$M^0L^0T^0 = L^{a_2} (T^{-1})^{b_2} (ML^{-3})^{c_2} ML^{-1}T^{-1}$$

power of M ; $0 = c_2 + 1$, $c_2 = -1$

power of L ; $0 = a_2 - 3c_2 - 1$, $a_2 = -2$

power of T, $0 = -b_2 - 1$, $b_2 = -1$

$$\pi_2 = D^{-2} \omega^{-1} \rho^{-1} \mu$$

$$\pi_2 = \frac{\mu}{D^2 \omega \rho}$$

Third π-term :- $\pi_3 = D^{a_3} \omega^{b_3} \rho^{c_3} Q$

$$M^0 L^0 T^0 = L^{a_3} (T^{-1})^{b_3} (ML^{-3})^{c_3} L^3 T^{-1}$$

power of M ; $0 = c_3$ $\boxed{c_3 = 0}$

power of L, $0 = a_3 - 3c_3 + 3$ $\boxed{a_3 = -3}$

power of T, $0 = -b_3 - 1$ $\boxed{b_3 = -1}$

$$\pi_3 = D^{-3} \omega^{-1} \rho^0 . Q = \frac{Q}{D^2 \omega}$$

step(7) :- check all the resulting π-terms.

$$\pi_1 = D^0 \omega^0 \rho^0 . \eta = \eta$$

$$\pi_2 = D^{-2} \omega^{-1} \rho^{-1} \mu = \frac{\mu}{D^2 \omega \rho}$$

$$\pi_3 = D^{-3} \omega^{-1} \rho^0 Q = \frac{Q}{D^3 \omega}$$

Step(8) :- Express the final formation

$$f_1 \left(\eta, \frac{\mu}{D^2 \omega \rho}, \frac{Q}{D^3 \omega} \right)$$

$$\eta = \phi \left[\frac{\mu}{D^2 \omega \rho}, \frac{Q}{D^3 \omega} \right]$$

③ ** Using Buckingham's π- theorem, show that the velocity through a circular orifice is given by $V = \sqrt{2gH}\, \phi\left[\frac{D}{H}, \frac{\mu}{\rho V H}\right]$ where H is head causing flow, D is diameter of the orifice, μ is the coefficient of viscosity, ρ is the mass density and g is the acceleration due to gravity.

Step (1) :- List all the variables that are involved in the problem.

$$V = f(H, D, \mu, \rho, g)$$

$$f_1(V, H, D, \mu, \rho, g) = 0.$$

Step (2) :- Express each variables in terms of basic dimensions

Velocity V → $\frac{\text{Distance}}{\text{time}} = \frac{L}{T} = LT^{-1}$

Head H → height = L

Diameter D → L

Co-efficient of viscosity μ → pascal.sec $= \frac{1N}{m^2} \times sec = \frac{kg.m}{sec^2} \times \frac{sec}{m^2} = ML^{-1}T^{-1}$

Mass density $\rho = \frac{\text{Mass}}{\text{Volume}} = ML^{-3}$

acceleration due to gravity g → $\frac{\text{velocity}}{\text{time}} = \frac{m}{sec \times sec} = LT^{-2}$

Step (3) :- Determine selection of repeating variable

Head → H
acceleration due to gravity → g
mass density → ρ

} Repeating variable.

design finally adopted.

Step(4) :- Determine the required no. of π - terms.

∴ Total no. of variables = 6

Thus number of fundamental dimension m = 3

No. of π - terms = n - m
= 6 - 3
= 3

$f(\pi_1, \pi_2, \pi_3) = 0$

Step(5) :- Form a phi - term equation.

$\pi_1 = H^{a_1} g^{b_1} \rho^{c_1} V$

$\pi_2 = H^{a_2} g^{b_2} \rho^{c_2} D$

$\pi_3 = H^{a_3} \cdot g^{b_3} \rho^{c_3} \mu$

Step(6) :- Each π - term solved by principle of dimensional homogeinity.

First π - term, $\pi_1 = H^{a_1} g^{b_1} \rho^{c_1} V$

$M^0 L^0 T^0 = L^{a_1} (LT^{-2})^{b_1} (MT^{-3})^{c_1} (LT^{-1})$

power of M, $0 = c_1$, $\boxed{c_1 = 0}$

power of L, $0 = a_1 + b_1 - 3c_1 + 1$, $a_1 = -b_1 + 3c_1 - 1$

power of T, $0 = -2b_1 - 1$, $\boxed{b_1 = -1/2}$ $\boxed{a_1 = -1/2}$

$\pi_1 = H^{-1/2} g^{-1/2} \rho^0 V$ $\boxed{\pi_1 = \frac{V}{\sqrt{gH}}}$

Second π - term, $\pi_2 = H^{a_2} g^{b_2} \rho^{c_2} D$

$M^0 L^0 T^0 = L^{a_2} (LT^{-2})^{b_2} (ML^{-3})^{c_2} L$

power of M, $0 = c_2$, $\boxed{c_2 = 0}$

power of L, $0 = a_2 + b_2 - 3c_2 + 1$ $a_2 = -b_2 + 3c_2 - 1$

power of T, $0 = -2b_2$ $\boxed{b_2 = 0}$ $\boxed{a_2 = -1}$

Third π- term :-

$$\pi_3 = H^{a_3} g^{b_3} \rho^{c_3} \mu$$

$$M^0L^0T^0 = L^{a_3} (LT^{-2})^{b_3} (ML^{-3})^{c_3} ML^{-1}T^{-1}$$

power of M, $0 = c_3 + 1$, $\boxed{c_3 = -1}$

power of L, $0 = a_3 + b_3 - 3c_3 - 1$

$a_3 = -b_3 + 3c_3 + 1 \Rightarrow \boxed{a_3 = -3/2}$

power of T, $0 = -2b_3 - 1$, $\boxed{b_3 = -1/2}$ $\pi_3 = \frac{\mu}{H\rho V} \cdot \pi_1$

Step(7) :- Check all the resulting π- terms

$$\pi_1 = \frac{V}{\sqrt{gH}}, \quad \pi_2 = \frac{D}{H}, \quad \pi_3 = \frac{\mu}{H\rho V} \cdot \pi_1$$

Step(8) :- Express the final formation.

$$f_1 \left(\frac{V}{\sqrt{gH}}, \frac{D}{H}, \pi_1 \frac{\mu}{H\rho V} \right) = 0$$

$$\frac{V}{\sqrt{gH}} = \phi \left[\frac{D}{H}, \frac{\mu}{H\rho V} \pi_1 \right]$$

Model Analysis

For predicting the performance of hydraulic structures (such as dams, spillways etc) (or) hydraulic machines (such as turbines, pump) before constructing (or) manufacturing, models of the structure (or) machines are made and tests performed on them to obtain desired information.

Model :- Model is the small scale replica of the actual structure (or) machine

Prototype :- The actual structure (or) machine is called prototype. ①

* It is not necessary that the models should be smaller than the prototypes, they may be larger than prototype.

* the study of models of actual structure (or) machine is called model analysis.

→ Model analysis is actually an experimental method of finding solution of complex flow probleme.

Advantages

① the performance of hydraulic structure (or) hydraulic machine can be easily predicted, in advance from it's model.

② with the help of dimension analysis, relationship b/w variables influencing a flow problems interms dimensional parameter are obtained

③ the merits of alternative design, can be predicted with the help of model testing. The most economical and safe design finally adopted.

Similitude – Types of Similarities

Similitude :– Similarities b/w model and prototype in every respect, which means that the model and prototype are similar properties (or) completely similar is called similitude.

Types of Similarities

They are classified into 3 – types

1> Geometric similarity
2> Kinematic similarity
3> Dynamic similarity

① Geometric similarity :–

The ratio of all corresponding linear dimension in the model and the prototype are equal

$L_m \rightarrow$ Length of model $A_m \rightarrow$ Area of model
$D_m \rightarrow$ Diameter of model $V_m \rightarrow$ Volume of model
$b_m \rightarrow$ Breadth of model

$L_p, D_p, B_p, A_p, V_p \rightarrow$ Corresponding values of the prototype

for Geometric similarity b/w model and prototype

$$\frac{L_p}{L_m} = \frac{B_p}{B_m} = \frac{D_p}{D_m} = L_r \rightarrow \quad L_r \rightarrow \text{scale ratio}$$

for area and volume's ratio relation

$$\frac{A_p}{A_m} = \frac{L_p \times B_p}{L_m \times B_m} = L_r \times L_r = L_r^2$$

$$\frac{V_p}{V_m} = \left(\frac{L_p}{L_m}\right)^3 = \left(\frac{B_p}{B_m}\right)^3 = \left(\frac{D_p}{D_m}\right)^3$$

(2) Kinematic Similarity :-

Kinematic similarity means the similarity of motion b/w model and prototype.

* The ratio of the velocity and acceleration at the corresponding points in the model and at the corresponding points in the prototype are same.

V_{P_1} = Velocity of fluid at point 1 in prototype

V_{P_2} = " " 2 in "

a_{P_1} = Acceleration of fluid at point 1 in prototype

a_{P_2} = " " 2 "

$V_{m_1}, V_{m_2}, a_{m_1}, a_{m_2}$ = Corresponding values at points of fluid velocity and acceleration in the model.

→ For kinematic similarity, $\frac{V_{P_1}}{V_{m_1}} = \frac{V_{P_2}}{V_{m_2}} = V_r$

$$\frac{a_{P_1}}{a_{m_1}} = \frac{a_{P_2}}{a_{m_2}} = a_r$$

Also directions of the velocity in the model and prototype should be same.

(3) Dynamic similarity :-

Dynamic similarity means similarity of forces b/w the model and prototype

→ Ratio of corresponding forces acting at the corresponding points in the model and at the corresponding points in the prototype are same

$(F_i)_p$ = Inertia force at point in prototype

$(F_\mu)_p$ = viscous force at the point in prototype

$(F_g)_p$ = Gravity force at the point in prototype

$(F_i)_m$, $(F_\mu)_m$, $(F_g)_m$ → corresponding values of force at the corresponding point in model.

dynamic similarity = $\frac{(F_i)_p}{(F_i)_m} = \frac{(F_\mu)_p}{(F_\mu)_m} = \frac{(F_g)_p}{(F_g)_m} = F_r$

→ Also directions of the corresponding forces at the points in the model and prototype are same

Types of forces acting in moving fluid

For the fluid flow problems, the forces acting on a fluid mass may be anyone (or) several forces.

1> Inertia force (F_i)

2> Viscous force (F_μ)

3> Gravity force (F_g)

4> pressure force (F_p)

5> Surface tension force (F_s)

6> Elastic force (F_e).

(1) Inertia force (F_i):- It is equal to product of mass and acceleration of the flowing fluid and acts in the direction oppositive to the direction of acceleration.

* It is always existing in the fluid flow problems.

(2) Viscous force (F_v):- It is equal to the product of shear stress due to viscosity and surface area of flow

* It is present in fluid, flow problems where viscosity is having imp. role to play.

(3) Gravity force (F_g):- It is equal to the product of mass and acceleration due to gravity of the flowing fluid.

* It present in case of open surface flow.

(4) pressure force (F_p):- It is equal to product of pressure intensity and c/s area of the flowing fluid.

* It present incase of pipe flow.

(5) Surface tension force (F_s):- It is equal to product of surface tension and length of the surface of the fluid.

(6) Elastic force (F_e):- It is equal to the product of elastic stress and area of flowing fluid.

Dimensionless number :-

Dimensionless numbers are those numbers which are obtained by dividing the inertia force by viscous force (or) gravity force (or) pressure force (or) surface tension force (or) elastic force.

→ As this is a ratio of one force to the other force. it will be a dimensionless number.

* Dimensionless numbers are also called Non-dimensional parameters.

The important dimensionless numbers.

1> Reynold's number
2> Froude's number
3> Euler's number
4> Weber's number.
5> Mach's number.

(1) Reynold's number :- Ratio of inertia force of a flowing fluid and the viscous force of the fluid.

$$Re = \frac{\text{Inertia force}}{\text{viscous force}} = \frac{F_i}{F_v}$$

Inertia force, F_i = Mass × acceleration of flowing fluid.

$= m \times a$

$= \rho \times \text{Volume} \times \frac{\text{Velocity}}{\text{Time}}$ $\left[\rho = \frac{m}{V}, \; m = \rho V \right.$

$= \rho \times AV \times V$

Volume per sec = Velocity × Area

$= \rho A V^2$

Viscous force (F_v) : shear stress × Area

$$= \tau \times A$$

$$= \mu \frac{du}{dy} \times A \qquad \frac{du}{dy} = \frac{V}{L}$$

$$= \mu \times \frac{V}{L} \times A$$

Reynolds number $R_e = \frac{F_i}{F_v} = \frac{\rho A V^2}{\mu \frac{V}{L} A}$

$$= \frac{\rho V L}{\mu}$$

$$= \frac{VL}{\left(\frac{\mu}{\rho}\right)}$$

Incase of pipe flow, the linear dimension 'L' is taken as diameter d, Hence reynold's number for pipe flow.

$$\boxed{R_e = \frac{\rho V d}{\mu}}$$

(2) Froude's number (F_e) :- the square root of the ratio of inertia force of a flowing fluid to the gravity force

$$F_e = \sqrt{\frac{F_i}{F_g}}$$

Inertia force, $F_i = \rho A V^2$

gravity force, F_g = mass × Acceleration due to gravity.

$$= \rho \times \text{volume} \times g \qquad (\text{volume} = L^3)$$

$$= \rho L^3 g \qquad L^2 = \text{Area}$$

$$= \rho \times L^2 \times Lg$$

$$F_e = \sqrt{\frac{\rho A V^2}{\rho L^2 L g}} = \sqrt{\frac{\rho A V^2}{\rho A L g}} = \frac{V}{\sqrt{Lg}}$$

(3) Euler's number (Eu) :-

It is the square root of the ratio of inertia force of a flowing fluid to pressure force

$$E_u = \sqrt{\frac{F_i}{F_p}}$$

Inertia force, $F_i = \rho A V^2$

pressure force F_p = Intensity of pressure x Area

$= p \times A$

$$E_u = \sqrt{\frac{\rho A V^2}{p A}} = \sqrt{\frac{V^2}{\left(\frac{p}{\rho}\right)}} = \frac{V}{\sqrt{\frac{p}{\rho}}}$$

(4) Weber's Number (We) :-

It is defined as the square root of the inertia force of a flowing fluid to the surface tension force

$$W_e = \sqrt{\frac{F_i}{F_s}}$$

Inertia force $F_i = \rho A V^2$

Surface tension force F_s = Surface tension per unit length x length

$= \sigma \times L$

$$= \sqrt{\frac{\rho A V^2}{\sigma \times L}} = \sqrt{\frac{\rho L^2 V^2}{\sigma \times L}}$$

$$= \sqrt{\frac{V^2}{\frac{\sigma}{\rho L}}} = \frac{V}{\sqrt{\frac{\sigma}{\rho L}}}$$

(5) Mach's Number (M) :- It is defined as the square root of the ratio of the inertia force of flowing fluid to the elastic force

$$M = \sqrt{\frac{F_i}{F_e}}$$

Inertia force $F_i = \rho A V^2$

elastic force F_e = Elastic stress x area

$= KA = KL^2$

$$= \sqrt{\frac{\rho A V^2}{KA}} = \sqrt{\frac{\rho L^2 V^2}{K L^2}} = \sqrt{\frac{V^2}{K/\rho}} = \frac{V}{\sqrt{\frac{K}{\rho}}}$$

$\sqrt{\frac{K}{\rho}} = C$ = Velocity of the sound in the fluid

$$\boxed{M = \frac{V}{C}}$$

Model laws (or) Similarity Laws

For dynamic similarity b/w the model and the prototype, the ratio of the corresponding forces acting at the corresponding points in the model and prototype should be equal.

→ It means for dynamic similarity b/w the model and prototype, the dimensionless numbers should be same for model and prototype.

→ "Models are designed on the basis of ratio of the forces, The laws on which the models are designed for dynamic similarity are called Model laws (or) laws of similarity"

Model laws are

(1) Reynold's model law.
(2) Froude model law
(3) Euler model law
(4) Weber model law.
(5) Mach model law.

(1) Reynold's model law :-

Reynold's model law in which models are designed are based on Reynolds number.

→ Model's based on reynolds number include

i) pipe flow.
ii) Resistance experienced by sub-marines, air planes, fully immersed bodies etc.

∴ Reynolds number of the model must be equal to reynolds number of prototype.

$$[Re]_m = [Re]_p$$

$$\frac{\rho_m V_m L_m}{\mu_m} = \frac{\rho_p V_p L_p}{\mu_p}$$

$$\frac{\rho_p}{\rho_m} \times \frac{V_p}{V_m} \times \frac{L_p}{L_m} \times \frac{\mu_m}{\mu_p} = 1$$

$$\frac{\rho_r V_r L_r}{\mu_r} = 1$$

ρ_r, V_r, L_r and μ_r are called scale ratio for density, velocity linear dimension, viscosity

The scale ratio for time, acceleration, force and discharge for reynolds models law

$t_r \rightarrow$ time scale ratio $= \frac{L_r}{V_r}$ $\left(V = \frac{L}{t}\right)$

$a_r \rightarrow$ acceleration scale ratio $= \frac{V_r}{t_r}$

$F_r \rightarrow$ force scale ratio $= m \times a$
$= m_r \times a_r \rightarrow \rho_r A_r V_r \times a_r$

$Q_r \rightarrow$ Discharge scale ratio $(\rho A V)_r$ $= \rho_r L_r^2 V_r \times a_r$
$= \rho_r A_r V_r = \rho_r L_r^2 V_r$

① ** A pipe of diameter 1.5m is required to transport an oil specific gravity 0.90 and viscosity 3×10^{-2} poise at the rate of 3000 lit/s Tests were conducted on a 15cm diameter pipe using water at 20°C. Find the velocity and rate of flow in model. Viscosity of water 20°C = 0.01 poise

Dia of prototype (D_p) = 1.5m

Viscosity of fluid (μ_p) = 3×10^{-2} poise

Q for prototype $Q_p = 3000$ lit/sec

$= 03.0\ m^3/sec$

Specific gravity of oil $(S_p) = S_p \times 1000$

$= 0.9 \times 1000$

$= 900\ kg/m^3$

Density of the model $D_m = 15cm = 0.15m$

velocity of water at 20°C = 0.01 poise

$= 1 \times 10^{-2}$ poise

$\mu_m = 1 \times 10^{-2}$ poise

$$\frac{\rho_m V_m D_m}{\mu_m} = \frac{\rho_p V_p D_p}{\mu_p}$$

$$\frac{V_m}{V_p} = \frac{\rho_p}{\rho_m} \cdot \frac{D_p}{D_m} \cdot \frac{\mu_m}{\mu_p}$$

$$= \frac{900}{1000} \times \frac{1.5}{0.15} \times \frac{1 \times 10^{-2}}{3 \times 10^{-2}} = 3.0m$$

Velocity ratio $V_p = \frac{\text{Rate of flow in prototype}}{\text{Area of prototype}}$

$$= \frac{30}{\pi/4 (D_p^2)} \times \frac{3}{\pi/4 (1.5)^2}$$

$$= \frac{30 \times 4}{\pi \times 22.5} = 1.697\ m/sec$$

$V_m =$ ~~0. 300~~ $\times\ 3.0 \times V_p$

$= 3 \times \pi/4\ (D_m)^2 \times V_m$

$= 0.0899\ m^3/sec$

$= 89.9$ lit/sec

② Froude Model law :-

Which the models are based on Froude number which means for dynamic similarity b/w the model and prototype, the Froude number for both of them should be equal.

Froude number model law is applied in the following fluid flow problems

(1) free surface flow such as over spillways, weirs, sluices, channels etc
(2) flow of jet from an orifice (or) nozzle.
(3) where waves are likely to be formed on surface.
(4) where fluids of different densities flow over one another

$$(F_e)_{model} = (F_e)_{prototype}$$

$$\frac{V_m}{\sqrt{g_m L_m}} = \frac{V_p}{\sqrt{g_p L_p}}$$

⇒ If the tests on the model are performed on the same place where prototype is to operate, then $g_m = g_p$

$$\frac{V_m}{\sqrt{L_m}} = \frac{V_p}{\sqrt{L_p}}$$

$$\frac{V_m}{V_p} \times \frac{\sqrt{L_p}}{\sqrt{L_m}} = 1$$

$$\frac{V_p}{V_m} = \sqrt{\frac{L_p}{L_m}} = \sqrt{L_r}$$

L_r = scale ratio for length, $\frac{V_p}{V_m} = V_r$ → scale ratio for velocity

Scale ratio for various physical quantity based on Froude models law.

Q for prototype $Q_p = 3000$ lit/sec

$= 03.0$ m3/sec

Specific gravity of oil $(S_p) = S_p \times 1000$

$= 0.9 \times 1000$

$= 900$ kg/m^3

Density of the model $D_m = 15cm = 0.15m$

velocity of water at 20°C = 0.01 poise

$= 1 \times 10^{-2}$ poise

$\mu_m = 1 \times 10^{-2}$ poise

$$\frac{\rho_m V_m D_m}{\mu_m} = \frac{\rho_p V_p D_p}{\mu_p}$$

$$\frac{V_m}{V_p} = \frac{\rho_p}{\rho_m} \cdot \frac{D_p}{D_m} \cdot \frac{\mu_m}{\mu_p}$$

$$= \frac{900}{1000} \times \frac{1.5}{0.15} \times \frac{1 \times 10^{-2}}{3 \times 10^{-2}} = 3.0m$$

Velocity ratio $V_p = \frac{\text{Rate of flow in prototype}}{\text{Area of prototype}}$

$$= \frac{30}{\pi/4 (D_p^2)} \times \frac{3}{\pi/4 (1.5)^2}$$

$$= \frac{30 \times 4}{\pi \times 22.5} = 1.697 \text{ m/sec}$$

$V_m =$ ~~0. 300~~ $\times\ 3.0 \times V_p$

$= 3 \times \pi/4 \, (D_m)^2 \times V_m$

$= 0.0899$ m3/sec

$= 89.9$ lit/sec

① ** In the model tests of spillway the discharge and velocity of flow over the model were 2 m^3/sec and 1.5 m/s respectively. Calculate the velocity and discharge over the prototype which is 36 times of the model size

Discharge over model $Q_m = 2\ m^3/sec$

Velocity of model $V_m = 1.5\ m/sec$

Linear scale ratio $L_r = 36$

For dynamic similarity, Froude number model law is used

$$\frac{V_p}{V_m} = \sqrt{L_r} = \sqrt{36} = 6$$

V_p → Velocity over prototype ⇒ $V_m \times 6 = 1.5 \times 6 = 9\ m/sec$

For discharge, we get, $\frac{Q_p}{Q_m} = L_r^{2.5} = (36)^{2.5}$

$$Q_p = Q_m \times (36)^{2.5} = 2 \times 36^{2.5}$$

$$\boxed{Q_p = 15552\ m^3/sec}$$

② In 1 in 40 model of spillway, the velocity and discharge are 2 m/sec and 2.5 m^3/sec. Find the corresponding velocity and discharge in the prototype.

Scale ratio of length $L_r = 40$

Velocity in the model $V_m = 2\ m/sec$

Discharge in the model $Q_m = 2.4\ m^3/sec$

For velocity ratio $\frac{V_p}{V_m} = \sqrt{L_r} = \sqrt{40}$

$$V_p = V_m \times \sqrt{40} = 2 \times \sqrt{40} = 12.65\ m/sec$$

For discharge ratio; $\frac{Q_p}{Q_m} = L_r^{2.5} = (40)^{2.5}$

$$Q_p = Q_m \times (40)^{2.5} = 2.5 \times 40^{2.5} = 25298.2\ m^3/sec$$

③ Euler's model law :-

Eulers model law is the law in which models are designed on Euler number.

→ Which means for dynamic similarity b/w the model and prototype should be equal, the Euler number for model and prototype should be equal.

$$(E_u)_{model} = (E_u)_{prototype}$$

$$\frac{V_m}{\sqrt{\frac{P_m}{\rho_m}}} = \frac{V_p}{\sqrt{\frac{P_p}{\rho_p}}}$$

If fluid is same in model and prototype

$$\frac{V_m}{\sqrt{P_m}} = \frac{V_p}{\sqrt{P_p}}$$

* Euler's model law valid ~~on~~ is applied for fluid flow problems where flow is taking place in a closed pipe.
* turbulence is fully developed so that viscous force are negligible and gravity force and surface tension force is absent.
* This law is also used where the phenomenon of cavitation takes place.

(4) Weber model law :-

Weber model law in which models are based on weber's number, which the ratio of square root of inertia force to surface tension force

→ The dynamic similarity b/w the model and prototype is obtained by equating weber number in model and prototype

$$(We)_{model} = (We)_{prototype}$$

$$\frac{V_m}{\sqrt{\frac{\sigma_m}{\rho_m L_m}}} = \frac{V_p}{\sqrt{\frac{\sigma_p}{\rho_p L_p}}}$$

Then according to weber law, we have

weber model law is applied in following cases.

(1) Capillary rise in narrow passages.

(2) Capillary movement of water in soil.

(3) Capillary waves in channels.

(4) Flow over weirs for small heads.

(5) Mach model law :-

Mach model law is the law in which models are designed on mach number, which is the ratio of square root of inertia force to elastic force of a fluid.

→ the dynamic similarity b/w the model and prototype are obtained by equating the mach number for the model and prototype ale same

$$(M)_{model} = (M)_{prototype}$$

$$\frac{V_m}{\sqrt{\frac{K_m}{\rho_m}}} = \frac{V_p}{\sqrt{\frac{K_p}{\rho_p}}}$$

Mach Model law is applied in following cases

(1) Flow of aeroplane and projectile through air at supersonic speed velocity more than velocity of sound.

(2) Aerodynamic testing.

(3) Under water testing of torpedoes.

(4) Water hammer probleme

Types of Models / classification of Model

The hydraulic models are classified as two types

(1) Undistorted model

(2) distorted model.

(1) **Undistorted Model** :- Undistorted models are those models which are geometrically similar to their prototype.

(or)

If the scale ratio for the linear dimensions of the model and its prototype is same, the model is called undistorted model

→ The behaviour of the prototype can be easily predicted from the results of undistorted model.

(2) **Distorted Model** :- A model is said to be distorted if it is not geometrically similar to its prototype.

→ For a distorted model different scale ratio for the linear dimensions are adopted.

Ex:- Rivers, harbours, reservoir etc.

- Two different scale ratio, One for horizontal dimensions and other for vertical dimensions are taken.

Advantages of distorted model

(1) The vertical dimensions of the model can be measured accurately.

(2) The cost of the model can be reduced.

(3) Turbulent flow in the model can be maintained

Limitations

(1) Mistakes may be made in the model (or) rules of simulation.

(2) The cost of the simulation (process) model can be high.

(3) The cost of running several different simulation may be high

Scale ratio for distorted models

Two different scale ratios, one for horizontal and for other vertical dimensions are taken for distorted model.

$(L_r)_H \rightarrow$ scale ratio for horizontal dimension.

$$\frac{L_p}{L_m} = \frac{B_p}{B_m} = \frac{\text{Linear horizontal dimension of prototype}}{\text{Linear horizontal dimension of model}}$$

$(L_r)_V \rightarrow$ Scale ratio for vertical dimensions

$$\frac{h_p}{h_m} = \frac{\text{Linear vertical dimension of prototype}}{\text{Linear vertical dimension of model}}$$

Scale ratio of velocity, area of flow, discharge etc.

(1) Scale ratio for velocity :-

V_p = Velocity in prototype

V_m = Velocity in model

$$\frac{V_p}{V_m} = \frac{\sqrt{2gh_p}}{\sqrt{2gh_m}} = \sqrt{\frac{h_p}{h_m}} = \sqrt{(L_r)_V}$$

(2) Scale ratio for area of flow :-

A_p = Area of flow in prototype

A_m = Area of flow in model

$$\frac{A_p}{A_m} = \frac{B_p \times h_p}{B_m \times h_m} = \frac{B_p}{B_m} \times \frac{h_p}{h_m} = (L_r)_H \times (L_r)_V$$

(3) Scaler ratio for discharge :-

Q_p = Discharge through prototype = $A_p \times V_p$

Q_m = Discharge through model = $A_m \times V_m$

$$\frac{Q_p}{Q_m} = \frac{A_p \times V_p}{A_m \times V_m} = (L_r)_H \times (L_r)_V \times \sqrt{(L_r)_V}$$

$$= (L_r)_H \times ((L_r)_V)^{3/2}$$

① The discharge through a weir is 1.5 m^3/sec. Find the discharge the model of the weir if the horizontal dimension of the model = $\frac{1}{50}$ the horizontal dimension of the prototype and vertical dimension of the model = $\frac{1}{10}$ the vertical dimension of the prototype.

Sol

Discharge through weir (prototype), $Q_p = 1.5\ m^3/sec$.

Horizontal dimension of model = $\frac{1}{50}$ × Horizontal dimension of prototype

$$\therefore \frac{\text{Horizontal dimension of prototype}}{\text{Horizontal dimensions of model}} = 50 \text{ (or) } (L_r)_H = 50$$

Vertical dimension of model = $\frac{1}{10}$ × Vertical dimension of prototype

$$\therefore \frac{\text{Vertical dimension of prototype}}{\text{Vertical dimension of model}} = 10$$

$$(L_r)_V = 10$$

$$\frac{Q_p}{Q_m} = (L_r)_H \times (L_r)_V^{3/2} = 50 \times 10^{3/2} = 1581.14$$

$$Q_m = \frac{Q_p}{1581.14} = \frac{1.50}{1581.14} = 0.000948\ m^3/sec$$

$$\boxed{Q_m = 0.948 \text{ litres/sec}}$$

UNIT- 2

Impact of jets
&
Hydraulic Turbines and performance of Turbines

The liquid Comes out in the form of a jet from the outlet of a nozzle, which is fitted to a pipe through which the liquid is flowing under pressure. If some plate, which may be fixed (or) moving, is placed in the path of the jet, a force exerted by the jet on the plate This force is obtained from Newton second law of motion (or) from Impulse momentum equation.

* Impact of jet means force exerted by the jet on a plate which may be stationary (or) moving.

→ The following Cases of the impact of jet.

(1) Force exerted by the jet on a stationary plate when

a) plate is vertical to the jet.
b) plate is inclined to the jet
c) plate is curved.

(2) Force exerted by the jet on a moving plate, when

a) plate is vertical to the jet
b) plate is inclined to the jet
c) plate is curved.

Impact of jet :- Force exerted by the jet on a plate which may be stationary (or) moving.

Impact :- The action of one object coming forcibly into contact with another object.

(or) The act (or) force of one thing hitting another.

jet :- Liquid (or) gas forced out of a small opening.

(1) Force exerted by the jet on a stationary plate when

a) Plate is vertical to the jet.

* **Force exerted by the jet on a stationary vertical plate :-**

Consider a jet of water coming out from the nozzle, strikes a a flat vertical plate

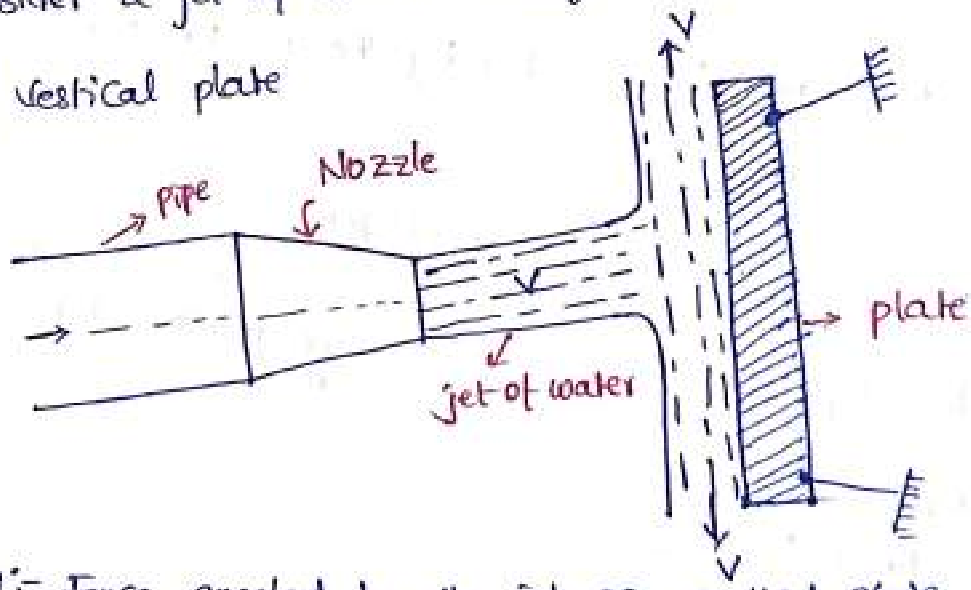


fig:- Force exerted by the jet on vertical plate

V = Velocity of the jet

d = diameter of the jet

a = area of c/s of the jet

The jet striking on the plate, will move along the plate, But the plate is right angles to the jet. Hence

→ Hence the jet after striking, will be get deflected through 90°. Hence the component of the velocity jet, in the direction of jet after striking will be zero.

F_x = Rate of change of momentum in the direction of a force

$$= \frac{\text{Initial momentum} - \text{final momentum}}{\text{Time}}$$

$$= \frac{(\text{Mass} \times \text{initial velocity} - \text{Mass} \times \text{Final velocity})}{\text{Time}}$$

$$= \frac{\text{Mass}}{\text{time}} [\text{Initial velocity} - \text{final velocity}]$$

$$= \frac{\text{mass}}{\text{sec}} \times [\text{velocity of jet before striking} - \text{velocity of jet after striking}]$$

$$= \rho a v [v - 0] \qquad \frac{\text{mass}}{\text{sec}} = \frac{M}{T} = \rho a v$$

$$= \rho a v^2$$

(b) Force exerted by a jet on stationary inclined flat plate

Let a jet of water, coming out from the nozzle, strikes an inclined flat plate.

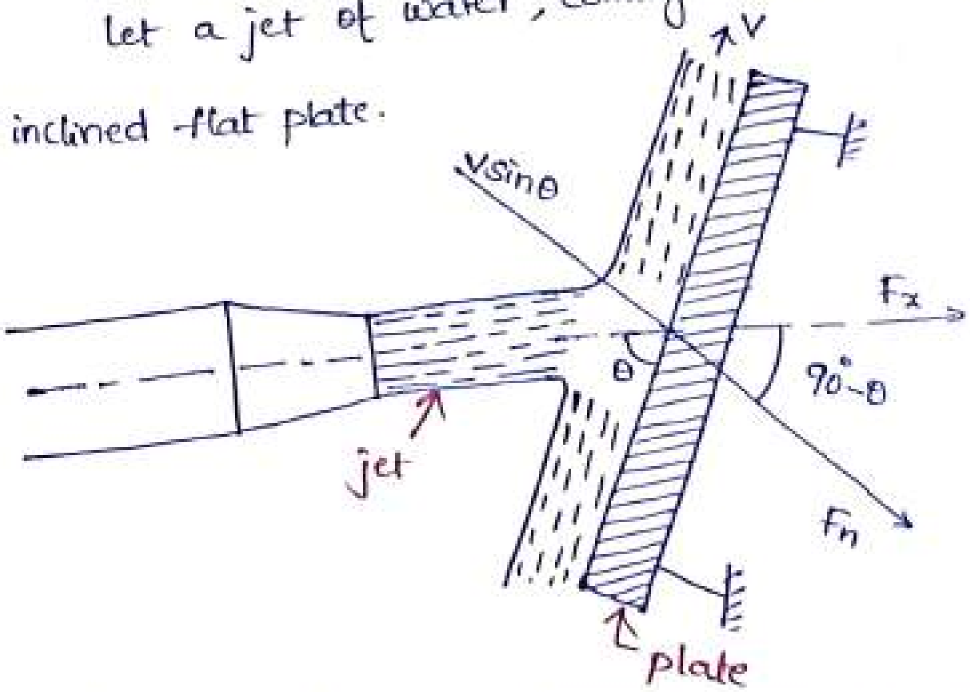


fig:- jet striking stationary inclined plate

If the plate is smooth and if it assumed that there is no losses of energy due to impact of the jet, then jet will move over the plate after striking with a velocity equal to initial velocity.

F_n = mass of jet striking per second × [initial velocity of jet before striking in the direction of n − Final velocity of jet after striking in the direction of jet]

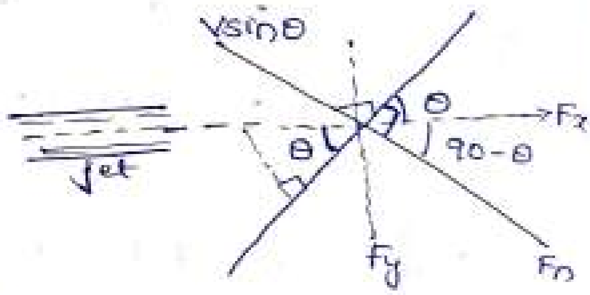
$$= \frac{m}{time} \times [V\sin\theta - 0]$$

$$= \rho a V [V\sin\theta]$$

$$\boxed{F_n = \rho a V^2 \sin\theta}$$

This force can be resolved in two components, F_x and F_y

F_x = Component of F_n in the direction of flow



$$= F_n \cos(90-\theta)$$

$$= F_n \sin\theta$$

$$= \rho A V^2 \sin\theta \times \sin\theta$$

$$\boxed{F_x = \rho A V^2 \sin^2\theta}$$

F_y = Component of F_n, perpendicular to flow

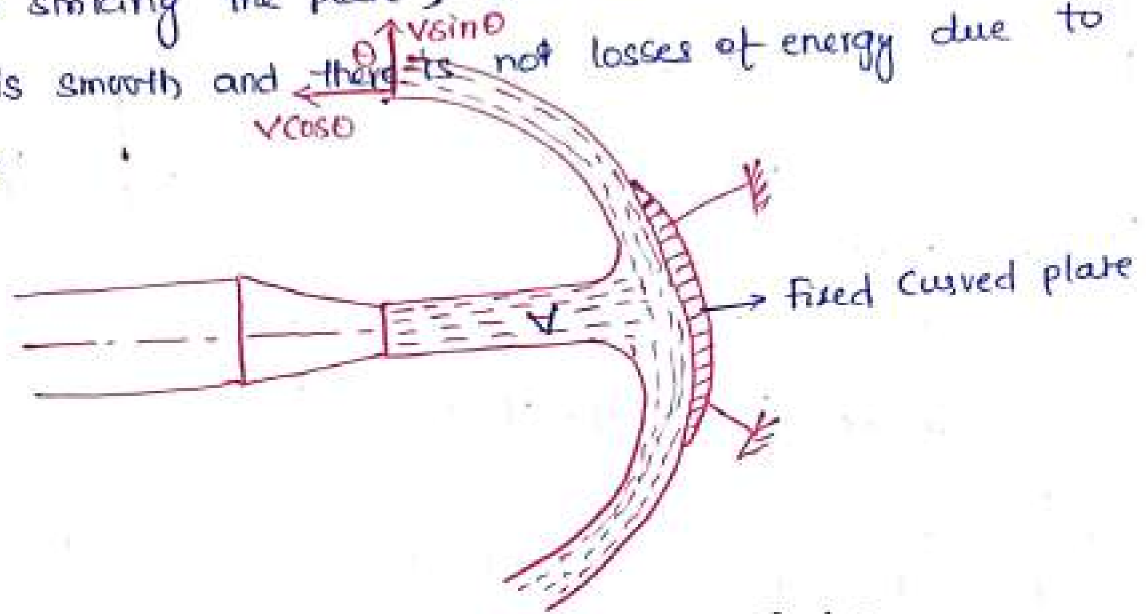
$$= F_n \sin(90-\theta)$$

$$= F_n \cos\theta$$

$$\boxed{F_y = \rho A V^2 \sin\theta \cos\theta}$$

Force exerted by a jet on stationary curved plate

(A) jet strikes the curved plate at the centre:- Let a jet of water strikes a fixed curved plate at the centre as shown in fig below. The jet after striking the plate, comes out with the same velocity if the plate is smooth and there is not losses of energy due to impact of jet



jet striking a fixed curved plate at centre.

Force exerted by the jet in the direction of the jet

$$F_x = \text{mass per sec}\,[V_{1x} - V_{2x}]$$

$$= \rho a v\,[v - (-v\cos\theta)]$$

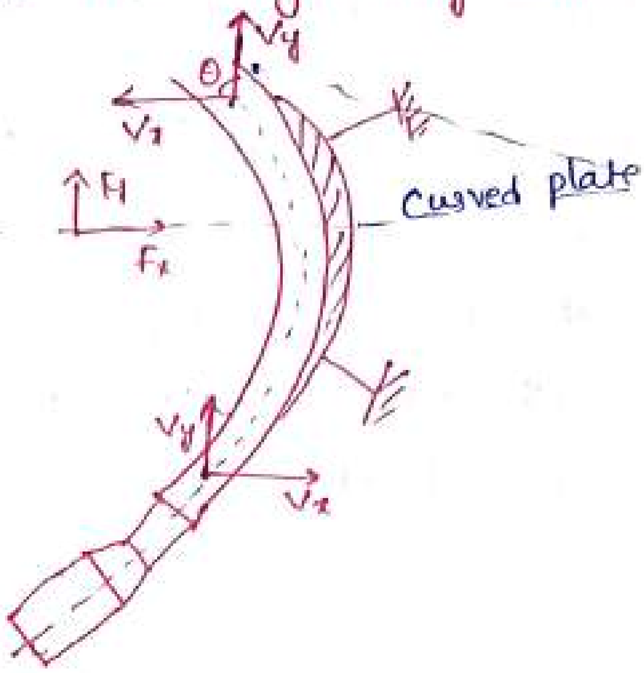
$$F_x = \rho a v^2 (1 + \cos\theta)$$

$$F_y = \text{mass per sec}\,[V_{1y} - V_{2y}]$$

$$= \rho a v\,[0 - v\sin\theta]$$

$$F_y = -\rho a v^2 \sin\theta$$

b) jet strikes the curved plate at one end tangentially when the plate is symmetrically



V = Velocity of the jet

θ = Angle made by jet with x-axis at the inlet tip of the curved plate.

$$F_x = \frac{mass}{sec} \times [V_{1x} - V_{2x}]$$

$$= \rho a v [V\cos\theta - (-V\cos\theta)]$$

$$\boxed{F_x = 2\rho a v^2 \cos\theta}$$

$$F_y = \frac{mass}{sec} \times [V_{1y} - V_{2y}]$$

$$= \rho a v \times [v\sin\theta - v\sin\theta] = 0$$

$$\boxed{F_y = 0}$$

(c) jet strikes the curved plate at one end tangentially when the plate is unsymmetrical

when the curved plate is unsymmetrical about x-axis

When the curved plate is unsymmetrical about x-axis the angle made by the tangents drawn at the inlet and outlet tips of the plate with x-axis will be different

θ → angle made by tangent at inlet tip with x-axis

φ → angle made by tangent at outlet tip with x-axis

force exerted by the jet of water in the direction of x and y are

$$F_x = \rho a v [V_{1x} - V_{2x}]$$

$$= \rho a v [v\cos\theta - (-v\cos\varphi)]$$

$$\boxed{F_x = \rho a v^2 [\cos\theta + \cos\varphi]}$$

$$F_y = \rho a v [V_{1y} - V_{2y}]$$

$$= \rho a v [v\sin\theta - v\sin\varphi]$$

$$\boxed{F_y = \rho a v^2 [\sin\theta - \sin\varphi]}$$

Problem on force exerted by the jet on a stationary vertical plate :-

① find the force exerted by a jet of water of diameter 75mm on a stationary flat plate, when the jet strikes the plate normally with velocity of 20 m/sec.

diameter (d) = 75 mm
= 0.075 m

Area (A) = $\frac{\pi}{4} d^2 = \frac{\pi}{4} (0.075)^2 = 0.004417 m^2$

Velocity of the jet $V = 20$ m/sec

force exerted by the jet of water on a stationary vertical plate

$F = \rho a v^2$

$F = 1000 \times 0.004417 \times 20^2$

$F = 1766.8 N$

(II) Problem on force exerted by a jet on stationary inclined flat plate

① A jet of water of diameter 50mm strikes a fixed plate in such a way that the angle b/w the plate and the jet is 30°. The force exerted in the direction of the jet is 1471.5 N. Determine the rate of flow of water

sol

diameter of jet (d) = 50mm
= 0.05 m

Area (A) = $\frac{\pi}{4} (d^2) = \frac{\pi}{4} (0.05)^2 = 0.001963 m^2$

$\theta = 30^\circ$

Force in the direction of the jet $F_x = 1471.5\ N$

$$F_x = \rho a v^2 \sin^2\theta$$

As the force given Newton second law

$$F_x = \rho a v^2 \sin^2\theta$$

$$1471.5 = 1000 \times 0.001963 \times V^2 \times \sin^2 30^\circ$$

$$V = 54.77\ m/s$$

Discharge Q = Area × velocity

$= 0.001963 \times 54.77$

$Q = 107.5$ liters/sec (or) $0.1075\ m^3/sec$.

(III) Problem on force exerted by the jet on stationary curved plate :-

① A jet of water of diameter 50mm moving with a velocity of 40 m/sec, strikes a curved fixed symmetrical plate at the centre. Find the force exerted by the jet of water in the direction of the jet is deflected through an angle of 120° at the outlet of the curved plate.

diameter (d) = 50mm = 0.05m

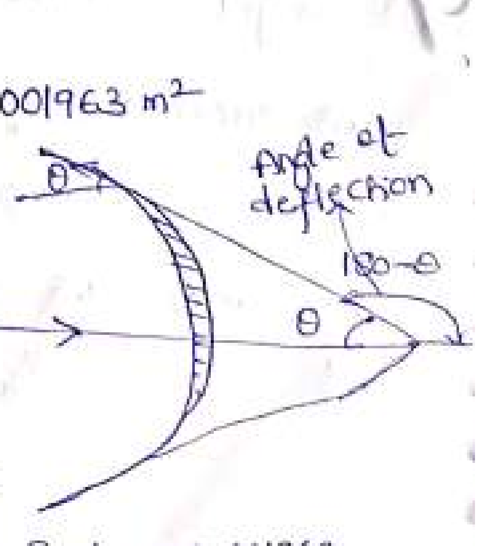
area, $a = \frac{\pi}{4} d^2 = \frac{\pi}{4}(0.05)^2 = 0.001963\ m^2$

Velocity of the jet $V = 40\ m/sec$.

Angle of deflection = 120°

$180^\circ - \theta = 120^\circ$, $\theta = 180^\circ - 120^\circ$

$\theta = 60^\circ$



Force exerted by the jet on curved plate in the direction of a jet

$$F_x = \rho a v^2 [1 + \cos\theta] \Rightarrow F_x = 1000 \times 0.001963 \times 40^2 \times [1 + \cos 60^\circ]$$

$$F_x = 4711.15\ N$$

Force exerted by a jet on Moving plates

① Flat vertical plate moving in the direction of the jet and away from the jet.

② Inclined plate moving in the direction of the jet

③ Curved plate moving in the direction of the jet in the horizontal direction

(I) Force on flat vertical plate moving in the direction of the jet :-

V = Velocity of the jet

a = area of c/s of the jet

u = velocity of the flat plate

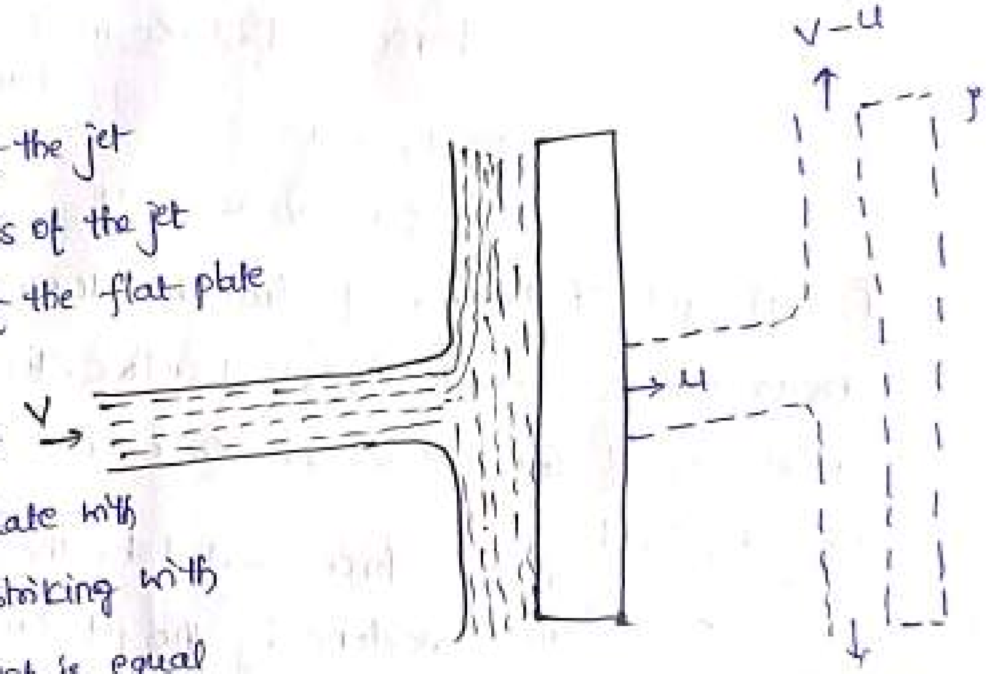


fig:- jet striking flat vertical moving plate.

→ In this case, the jet does not strike the plate with velocity V, but it striking with a relative velocity, which is equal to absolute velocity of jet of water minus the velocity of jet of the plate.

Relative velocity of the jet with respect to plate

$= V - u$

Mass of water striking the plate per sec

$= \rho \times$ Area of the jet $\times$ velocity

$= \rho a [V - u]$

Force exerted by the jet on moving plate in the direction of the jet

F_x = Mass of water striking per sec × [Initial velocity − final velocity]

$= \rho a [V-u] \cdot [(V-u) - 0]$

$= \rho a [V-u]^2$

In this case, the work will done by the jet on the plate as plate is moving. For stationary plates, the workdone is zero.

∴ Workdone per second by the jet on the plate

$= \text{force} \times \frac{\text{Distance in the direction of force}}{\text{time}}$

$= F_x \times u$

$= \rho a (V-u)^2 \times u$

① A jet of water of diameter 10cm strikes a flat plate normally with a velocity of 15m/sec. The plate is moving with a velocity of 6 m/sec in the direction of the jet and away from the jet. Find
i) The force exerted by the jet on the plate.
ii) Workdone by the jet on the plate per second.

diameter of the jet (d) = 10cm = 0.1m

Area (A) = $\pi/4 (d^2) = \pi/4 (0.1)^2 = 0.007854 m^2$

Velocity of the jet $V = 15$ m/sec

Velocity of the plate $u = 6$ m/sec

(i) Force exerted by the jet on a moving flat vertical plate

$F_x = \rho a (V-u)^2$

$= 1000 \times 0.007854 (15-6)^2$

$F_x = 636.17 N$

(ii) Workdone per second by the jet

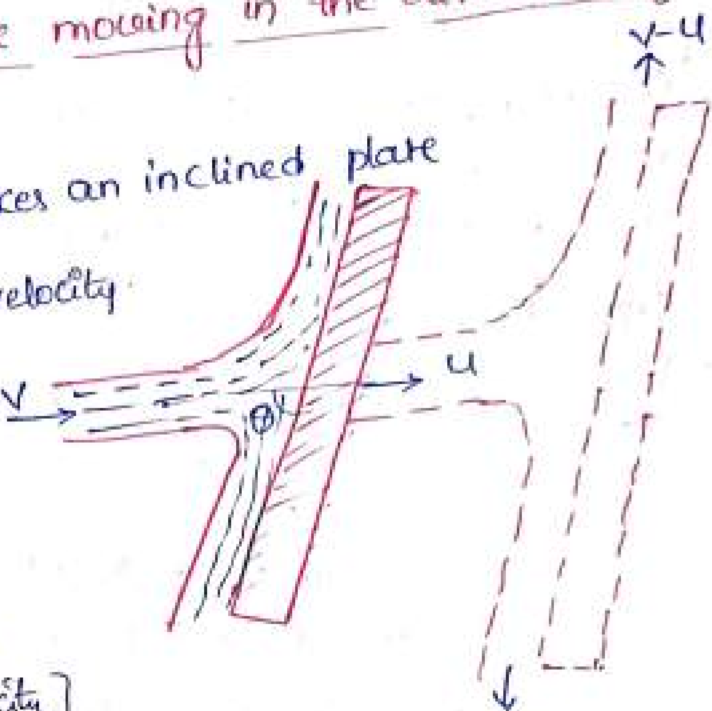
$= F_x \times u$

$= 636.17 \times 6 = 3817.02$ N m/sec.

Mass of water striking ...

② Force on the inclined plate moving in the direction of the jet :-

Let the jet of water strikes an inclined plate which is moving with a uniform velocity in the direction of the jet.



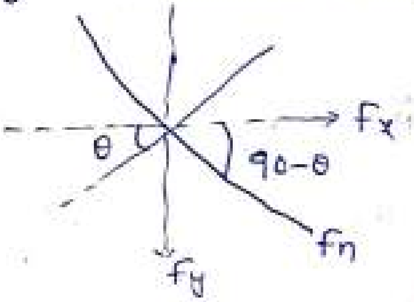
Relative velocity = (V-u)

F_n = mass striking per second × [Initial velocity in before jet strikes − final velocity]

$F_n = \rho a(V-u)\left[(V-u)\sin\theta - 0\right]$

$$\boxed{F_n = \rho a (V-u)^2 \sin\theta}$$

jet striking an inclined moving plate



F_n is resolved into two component, F_x & F_y

$F_x = F_n \sin\theta = \rho a (V-u)^2 \sin^2\theta$

$F_y = F_n \cos\theta = \rho a (V-u)^2 \sin\theta \cos\theta$

∴ Workdone per second by the jet on the plate

= F_x × distance per second in the direction of x

= $F_x \times u$

= $\rho a (V-u)^2 \sin^2\theta \times u = \rho a (V-u)^2 u \sin^2\theta$.

① A jet of water diameter 10cm strikes a flat plate normally with a vely

① A 7.5 cm diameter jet having a velocity of 30 m/sec strikes a flat plate and inclined plate at 45° to the axis of the jet. Find normal pressure on the plate

i) when the plate is moving with a velocity of 15 m/sec and away from the jet.

Sol

Diameter of the jet (D) = 7.5 cm = 0.075 m.

$\theta = 45°$

velocity of the jet $V = 30$ m/sec

plate moving velocity = 15 m/sec.

i) when the plate is stationary ; the normal force on the plate

$F_n = \rho a v^2 \sin\theta = 1000 \times \frac{\pi}{4}(0.075)^2 \times 30^2 \times \sin 45°$

$F_n = 2810.96$ N

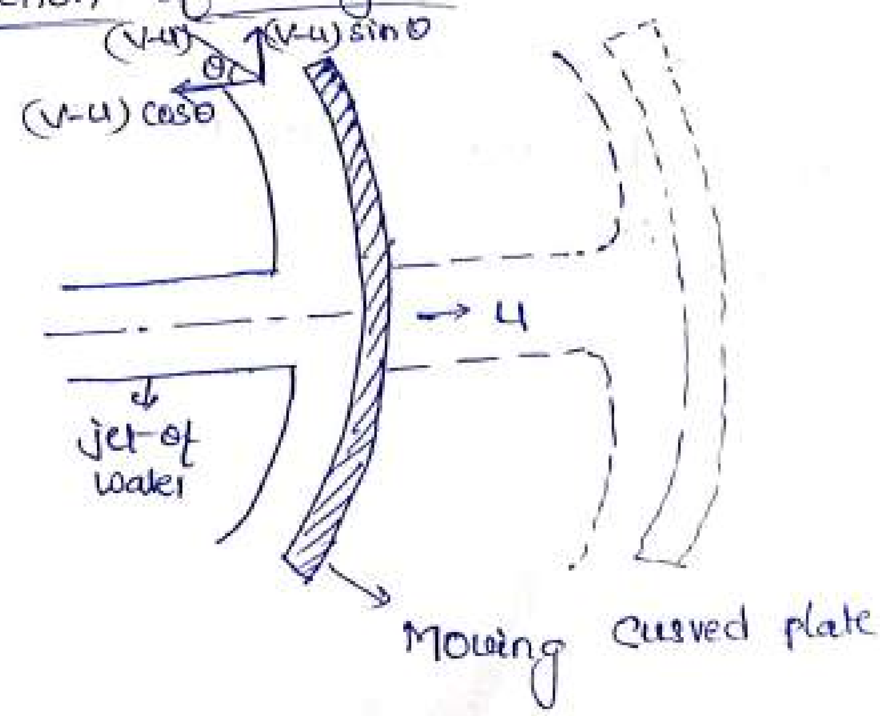
ii) When the plate is moving with a velocity 15 m/sec away from the jet, normal force on plate.

$F_n = \rho a (v-u)^2 \sin\theta$

$= 1000 \times \frac{\pi}{4}(0.075)^2 \times (30-15)^2 \sin 45°$

$F_n = 702.74$ N

III) Force on the curved plate when the plate is moving in the direction of the jet :-



Mass of water striking the plate

$= \rho \times a \times$ velocity with which jet strikes the plate

$= \rho a (V-u)$

Force exerted by the jet of water on the curved plate in the direction of the jet

F_x = mass striking per sec × [Initial velocity with which jet strikes the plate in the direction of the jet − Final velocity]

$= \rho a (V-u) [(V-u) - (-(V-u)\cos\theta)]$

$= \rho a (V-u)^2 [1+\cos\theta]$

Workdone by the jet on the plate per second

$= F_x \times u$

$= \rho a (V-u)^2 [1+\cos\theta) \times u$

$= \rho a (V-u)^2 \times u (1+\cos\theta)$

① A jet of water of diameter 7.5 cm strikes a curved plate at it's centre with a velocity of 20 m/sec. The curved plate is moving with a velocity of 8 m/sec in the direction of the jet. The jet is deflected through an angle of 165°.
The jet is deflected through an angle of 165°. Find the force exerted on the plate in the direction of the jet

i) Force exerted on the plate in the direction of the jet

ii) Workdone by the jet per second.

Sol

$d = 7.5 cm = 0.075 m$

$a = \pi/4 \times (0.075)^2$

velocity of jet, $V = 20$ m/sec

$= 0.004417$

velocity of plate $u = 8$ m/sec

$\theta = 180 - 165°$ $\theta = 15°$

i) Force exerted on the plate in the direction of the jet

$F_x = \rho a (V-u)^2 (1+\cos\theta)$

$= 1000 (0.004417) [1+\cos 15°]$

$= 1250.38 N$

ii) Workdone by the jet on the plate: $= F_x \times u$

$= 1250.38 \times 8$

$= 10003.04$ N.m/sec

Hydraulic Turbines

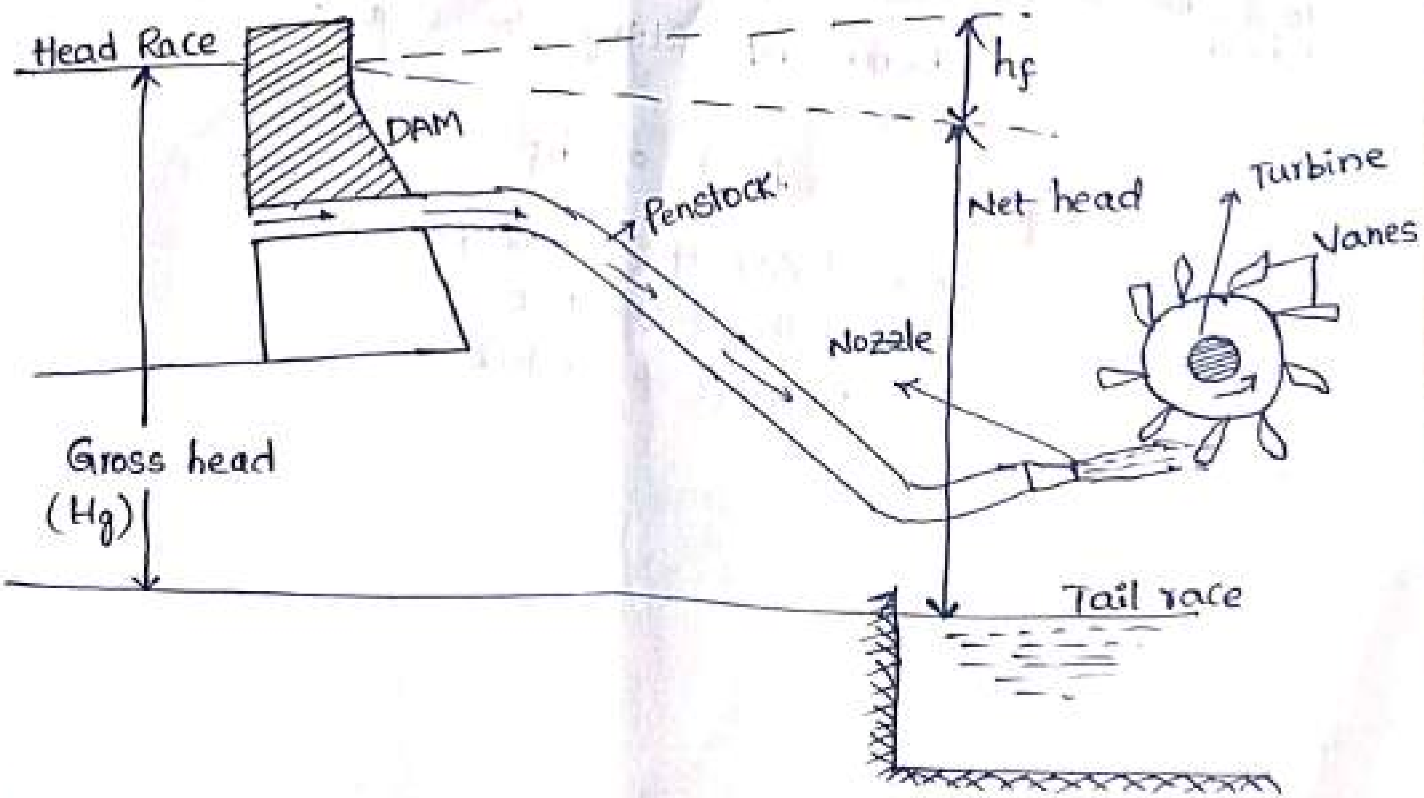
Hydraulic machines are defined as those machines which convert either hydraulic energy into mechanical energy.

Turbines :- The hydraulic machines, which convert the hydraulic energy into mechanical energy are called turbines.

Pumps :- Hydraulic machines which convert mechanical energy into hydraulic energy are called pumps.

Turbines :- "Hydraulic machines which convert hydraulic energy into mechanical energy. This mechanical energy is used in running an electric generator which is directly coupled to the shaft of the turbine. This M.E is converted into E.E. This electric power which is obtained from the hydraulic energy is known as hydroelectric power."

General layout of A hydroelectric power plant



(1) A dam constructed across a river to store water.

(2) 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) RC

(3) Turbines having different types of vanes fitted to the wheels.

(4) Tail race, which is a channel which carries water away from the turbines after the water has worked on the turbines. The surface water in the tail race channel is also known as tail race

Definations of Heads

(1) **Gross Head** :- The difference b/w the head race level and tail race level no water is flowing is known as Gross Head.

→ It is denoted by "Hg"

(2) **Net Head** :- It is also called effective head.

It is defined as head available at the inlet of the turbine.

loss due to of head
- i) Friction b/w water and penstock occurs.
- ii) bend, pipe fitting, losses at the entrance of penstock.

H_g = Gross head, $h_f = \frac{4fLV^2}{2gD}$

V → velocity of flow in penstock

L → Length of penstock

D → Diameter of penstock.

Efficiencies of a Turbine

(a) Hydraulic efficiency (η_h)
(b) Mechanical efficiency (η_m)
(c) Volumetric efficiency (η_v)
(d) Overall efficiency (η_o).

(a) Hydraulic efficieny :— Ratio of power given by water to runner of a turbine to power supplied by the water at the inlet of the turbine.

$$\eta_h = \frac{\text{Power deliverd to runner}}{\text{Power supplied at inlet}} = \frac{R.P}{W.P}$$

(b) Mechanic efficiency :— the power delivered by water to runner of a turbine is transfered to the shaft of the turbine. Due to mechanical losses, the power available at the shaft to the turbine is less than the power delivered to the runner of the turbine

" Ratio of power available at the shaft of the turbine to the power delivered to the runner "

$$\eta_m = \frac{\text{Power at the shaft of the turbine}}{\text{power delivered by water to runner}} = \frac{S.P}{R.P}$$

(c) Volumetric efficiency :—

The volume of water striking the runner of a turbine is slightly less than the volume of water supplied to the turbine

$$\eta_v = \frac{\text{Volume of water actually striking the runner}}{\text{Volume of water supplied to the turbine}}$$

(d) Overall efficiency :- Ratio of power available at the shaft of the turbine to the power supplied by the water at the inlet of the turbine

$$\eta_o = \frac{\text{Volume available at the shaft of the turbine}}{\text{power supplied at the inlet of the turbine}}$$

$$= \frac{\text{Shaft power}}{\text{Water power}}$$

$$= \frac{S.P}{W.P} \times \frac{R.P}{R.P}$$

$$= \frac{S.P}{R.P} \times \frac{R.P}{W.P}$$

$$\boxed{\eta_o = \eta_m \times \eta_h}$$

Classification of Hydraulic turbine

The hydraulic turbines are classified according to the inlet of the turbine, the types of energy available at the inlet of the turbine direction of flow through vanes, head at the inlet of the turbine and specific speed of the turbine

(1) According to the type of energy at inlet
i) Impulse turbine   ii) Reaction turbine

(2) According to the direction of flow through runner
i) Tangential flow turbine   (ii) Radial flow turbine
iii) Axial flow turbine   iv) Mixed flow turbine

(3) According to the head inlet of the turbine
i) High head turbine (ii) Medium head turbine (iii) Low head turbine

(4) According to Specific Speed of the turbine
i) Low Specific Speed of turbine (ii) Medium specific speed turbine
iii) High Specific Speed turbine

Impulse turbine :- If the inlet of the turbine, the energy is available
is only Kinetic energy, the turbine is known as Impulse turbine
→ As the water flows over the vanes, the pressure is atmospheric from
inlet to outlet of the turbine

Reaction turbine :- If the inlet of the turbine, the water possesses
Kinetic energy as well as pressure energy, the turbine is known as
reaction turbine.

Tangential flow turbine :- If the water flows along the tangent of the
runner, the turbine is known as tangential flow turbine

Radial flow turbine :- If the water flows in the radial direction
through runner, the turbine is called radial flow turbine.
→ If the water flows in the radial from outward to inwards,
the turbine is known as inward Radial flow turbine.
→ If the water flows from inwards to outwards, the turbine
is called outward radial flow turbine.

Axial 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.

mixed flow turbine :- If the water flows through the runner
in the radial direction but leaves in the direction parallel
to the axis of rotation of the runner, the turbine is called
mixed flow turbine.

① Pelton wheel 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 K.E.

→ 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

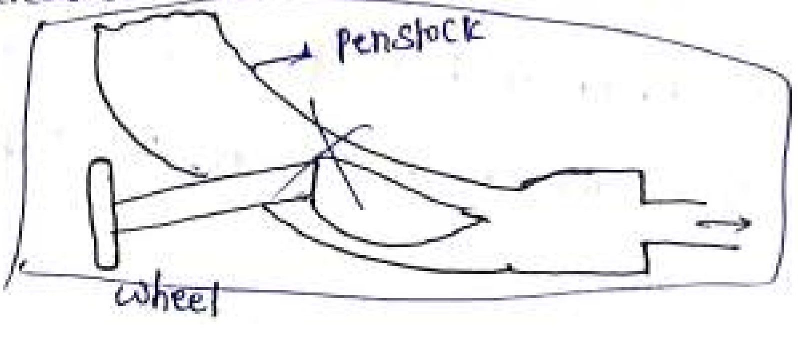
(1) Nozzle & Flow regulating arrangement.
(2) Runner and buckets
(3) Casing
(4) Breaking jet.

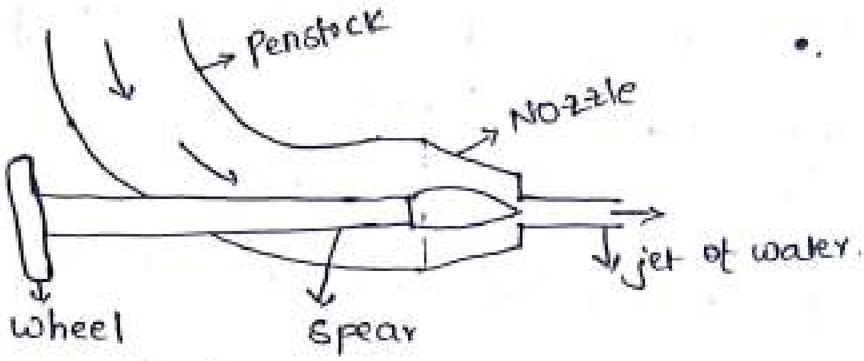
(1) Nozzle & Flow regulating arrangement :-

The amount of water striking the buckets (vanes) of the runner is controlled by providing a spear in the nozzle. The spear is conical needle which is operated either by hand wheel (or) automatically.

→ When the spear is pushed forward into the nozzle the amount of water striking the runner is reduced.

→ When the spear is pushed back, the amount of water striking the runner increases.





② Runner with Buckets :-

It consist of a circular disc on the periphery of which number of buckets evenly spaced are fixed.

→ The shape of the bucket is of a double hemispherical cup (or) bowl

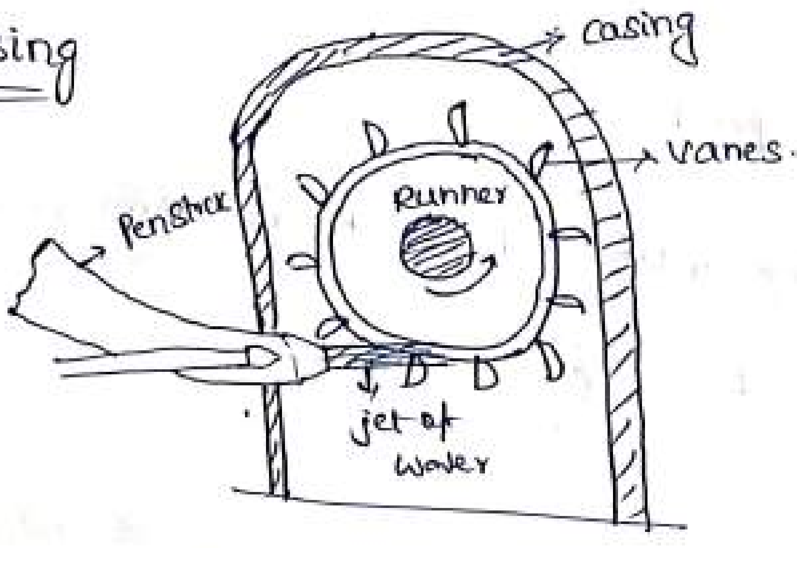
→ Each bucket is divided into two symmetrical parts by dividing wall which is known as splitter.

* The jet of water strikes on the splitter. The splitter divided into two equal parts and jet comes out from outer edge

* The buckets are shaped in such away that the jet get deflected through 160° (or) 170°.

* The buckets are made cast iron, cast steel bronze (or) stainless steel depending upon the head at the turbine

③ Casing



* The function of Casing is to prevent the splashing of the water and to discharge water to tail race.
* It also act safeguard against accident.
* It is made of cast iron on fabricated steel plates.
* The Casing of the pelton wheel doesn't perform any hydraulic function.

(4) <u>Breaking</u> jet :- When the nozzle is compleatly closed by moving the spear in forward direction, the amount of water striking the runner to zero. But the runner due to inertia goes on revolving for 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 bracing jet.

Important point in pelton wheel turbine

(1) It is a Impulse turbine

(2) Tangential flow direction.

(3) High head

(4) Low Specific Speed

(5) pressure at the inlet and outlet are atmospheric pressure.

(6) Less Quantity of water is required

Points to be remembered for pelton wheel :-

(1) The velocity of the jet at inlet. by $V_1 = C_v\sqrt{2gH}$

C_v = Co-efficient of velocity = 0.98 (to) 0.99

H → Nead Head on the turbine

(2) The velocity of the wheel (u) is given by $u = \varphi\sqrt{2gH}$

φ → speed ratio , varies b/w 0.43-0.48.

(3) Angle of deflection of the jet through the buckets is taken at 165°.

(4) The mean diameter (or) pitch diameter of pelton wheel to diameter of the jet (d).

$u = \frac{\pi DN}{60}$ $m = \frac{D}{d}$ (= 12 × most of the cases)

(5) jet ratio = $\frac{\text{pitch dia of pelton wheel (D)}}{\text{dia of the jet (d)}}$

$m = \frac{D}{d}$ = (12 for most cases)

(6) Number of buckets on a runner is given by

$$Z = 15 + \frac{D}{2d} = 15 + 0.5m$$

(7) 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

① **

A pelton wheel has a mean bucket speed of 10 m/sec with a jet of water flowing at the rate of 700 liters/sec under a head of 30 mts. The bucket deflect the jet through an angle of 160°. Calculate the power given by water to the runner and hydraulic efficiency of the turbine. Assume co-efficient of velocity as 0.98.

Sol

Speed of the bucket $u = u_1 = u_2 = 10$ m/sec

Discharge $Q = 700$ lit/sec $= 0.7\ m^3/sec$

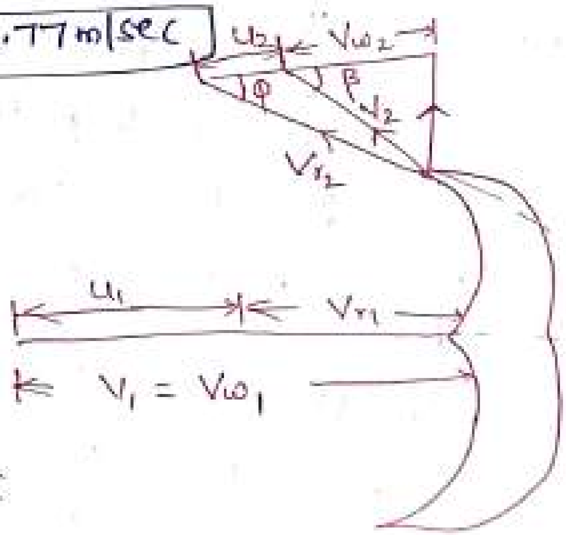
Head of water $(H) = 30m$

Angle of deflection $= 160^\circ$

∴ Angle, $180^\circ - 160^\circ = 20^\circ$

i) Velocity of jet $V_1 = C_v\sqrt{2gH} = 0.98\sqrt{2 \times 9.81 \times 30}$

$V_1 = 23.77$ m/sec



$V_{r1} = V_1 - u_1$

$= 23.77 - 10$

$= 13.77$ m/sec

$V_{w1} = V_1 = 23.77$ m/sec

From outlet velocity triangle

$V_{r2} = V_{r1} = 13.77$ m/sec

$V_{w2} = V_2\cos\phi - u_2$

$= 13.77\cos 20^\circ - 10$

$V_{w2} = 2.94$ m/sec

Workdone by the jet per second on the runner

$= \rho a V_1 [V_{w1} + V_{w2}] \times u$

$= 1000 \times 0.7 \times [23.77 + 2.94] \times 10$

$= 186970$ Nm/sec.

∴ power given to turbine $= \frac{186970}{1000}$

$= 186.97$ kW

The hydraulic efficiency of the turbine is given by

$$\eta_h = \frac{2\left[V_{w_1} + V_{w_2}\right] \times u}{V_1^2} = \frac{2\left[23.77 + 2.94\right] \times 10}{23.77 \times 23.77}$$

$\eta_h = 0.9454$

(or) $\boxed{\eta_h = 94.54\%}$

② A pelton wheel is to be designed for a head of 60m when the running at 200 r.p.m. The pelton wheel develops 95.6475 kW shaft power. The velocity of the buckets = 0.45 times the velocity of the jet, Overall efficiency = 0.85. Co-efficient of velocity is equal to 0.98.

Sol

Head $H = 60$m

Speed $N = 200$ rpm

Shaft power (S.P) = 95.6475 kW

velocity of bucket(u) = 0.45 × velocity of the jet

Overall efficiency $\eta_o = 0.85$

Co-efficient of velocity $C_v = 0.98$

i) ~~Velocity of the jet~~ Diameter of the jet (d)

Overall efficiency $\eta_o = 0.85$

$$\eta_o = \frac{S.P}{W.P} = \frac{95.6475}{\left(\frac{W.P}{1000}\right)} = \frac{95.6475 \times 1000}{\rho \times g \times Q \times H}$$

$$\eta_o = \frac{95.6475 \times 1000}{1000 \times 9.81 \times Q \times 60} \qquad \eta_o = 0.85$$

$Q = 0.1912$ m³/sec

$Q = A \times V$

$0.1912 = \frac{\pi}{4} d^2 \times V_1$

$0.1912 = \frac{\pi}{4} (d)^2 \times 33.62$

$\boxed{d = 85 mm}$

i) Velocity of the jet $V_1 = C_v \sqrt{2gH} = 0.98 \sqrt{2 \times 9.81 \times 60}$

$\boxed{V_1 = 33.62 m/sec}$

Bucket velocity $u = u_1 = u_2 = 0.45 \times V_1 = 0.45 \times 33.62$

$= 15.13 m/sec$

$u = \frac{\pi DN}{60}$

$15.13 = \frac{\pi \times D \times 200}{60}$ $\therefore \boxed{D = 1.44 m}$

(iii) Size of buckets

Width of bucket $= 5d = 5 \times 85 = 425 mm.$

Depth of bucket $= 1.2 \times d = 1.2 \times 85 = 102 mm$

(iv) Number of buckets on the wheel is given by

$Z = 15 + \frac{D}{2d} = 15 + \frac{1.44}{2 \times 0.85}$

$Z = 15 + 8.5$

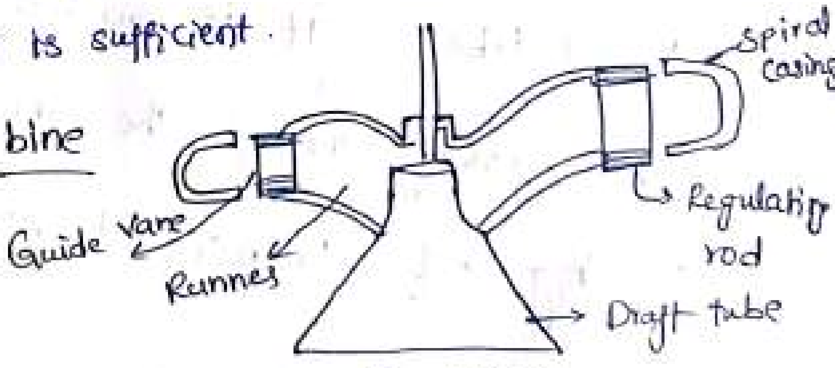
$\boxed{Z = 24}$

(Q) 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 begining design inward Radial flow.
* In modern Francis turbine, the water enters the runnes of the turbine in the radial direction at outlet and leaves in the axial direction at the inlet

Important points of Working condition

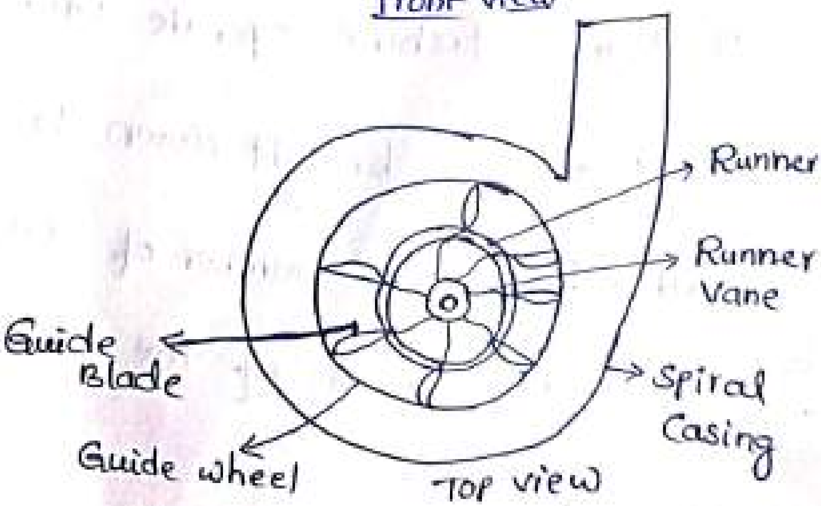
It is
(1) Reaction flow turbine [K.E and P.E enters the turbine]
(2) Mixed flow turbine [Water enters to runner radially and leaves axially]
(3) It is used for medium head
(4) It is a medium specific speed
(5) Medium quality of water is sufficient.



Front View

Components of Francis turbine

(1) Penstock
(2) Spiral Casing
(3) Guide vanes
(4) Governing Mechanism
(5) Runner and Runner Blades
(6) Draft tube



Top view

(1) Penstock :- It is a large size pipe which conveys water from the upstream to the dam/Reservoir to the turbine runner

(2) spiral Casing :- It constitutes a closed passage whose c/s area gradually decreases along the flow direction : area is maximum at inlet and nearly zero at exit.

(3) Guide vanes :- These vanes direct the water on to the runner at an angle appropriate to design, the motion of them is given by means of hand wheel (or) by a governor.

(4) Governing Mechanism :- It changes the position of the guide blades/vanes to affect the variation in water flow rate, when the load condition on the turbine change

(5) Runner and Runner blades :- The driving force on the runner is both due to impulse and reaction effect.

(6) Draft tube :- It is gradually expanding tube which discharge water, passing through the runner to the tail race.

Working of Francis turbine

(1) Francis turbine operate under medium heads.

(2) Water is brought down to the turbine through a penstock and directed to number of stationary blades fixed all around the circumference of the runner

(3) These stationary blades are called as Guide vanes.

(4) Water under pressure, enters the runner from the guide vanes towards the center in radial direction and discharge out of the runner axially. Due to diffn pressure b/w guide vane & runner the motion

(5) of the runner occurs

(5) As the water flows through the runner its pressure and angular momentum reduces, this will produce a reaction force on the runner blades.

(6) The pressure at the inlet is more than the outlet.

(7) The moment of runner is affected by the change of both the potential and K.E of water.

(8) After doing the work the water is discharged to the tail race through a closed tube called draft tube

Kaplan Tusbine

If the water flows parallel to the axis of the rotation of the shaft, the tusbine is known as axial flow tusbine

Axial flow reaction tusbine are classified into 2 types

1) propeller tusbine 2) Kaplan tusbine

propeller tusbine :- When the vanes are fixed to the hub and they are not adjustable the tusbine is known as propeller tusbine

Kaplan Tusbine :- If the vanes on the hub are adjustable the tusbine is known as Kaplan tusbine.

→ After the name of V. Kaplan, an Austrian Engineer.

(1) It is a Reaction flow tusbine

(2) It is the Axial flow direction

(3) Low head

(4) High specific speed

(5) Large quantity of water required

hub /boss :- The shaft of the tusbine is vertical, the lower end of the shaft made larger which is known as hub (or) boss.

Main parts of a kaplan turbine

(1) Scroll Casing

(2) Guide vane Mechanism

(3) Hub with vanes (or) Runner of the turbine

(4) Draft tube.

The water from the penstock enter the scroll casing and then moves to the guide vanes. From the guide vanes the water turns through 90° and flows axially through the runner.

→ The discharge through runner is obtained by

$$Q = \frac{\pi}{4}\left(D_o^2 - D_b^3\right) \times V_{f_1}$$

D_o → outer dia of runner m
D_b → Diameter of hub
V_{f1} → Velocity of flow at inlet

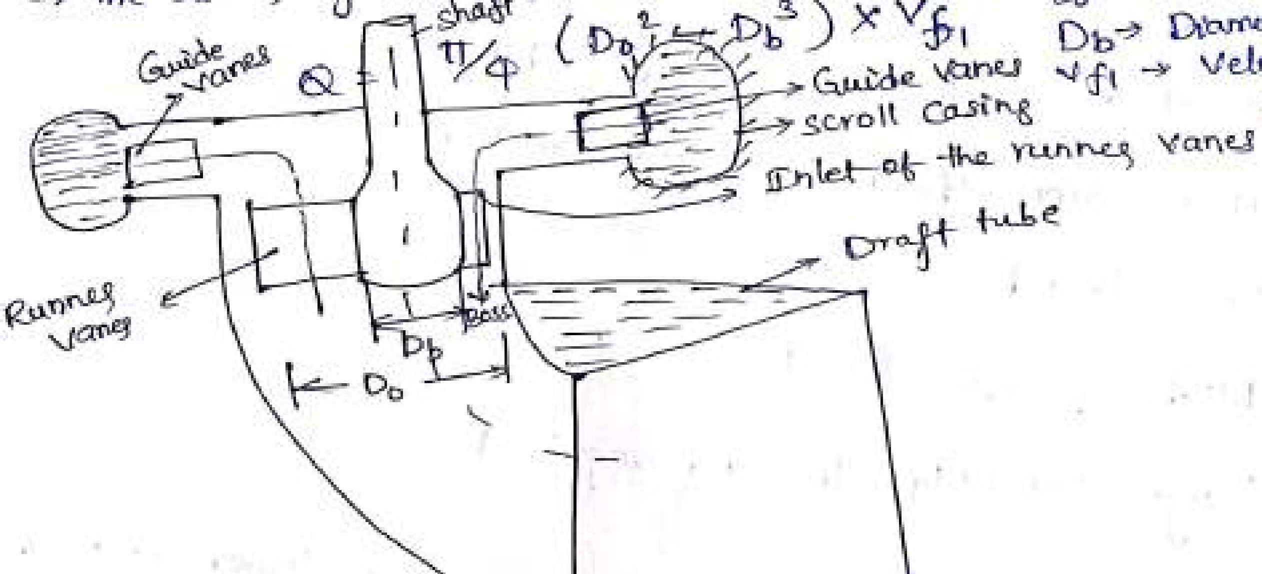


fig:- Main Components of kaplan turbine

Some important points propeller (or) Kaplan turbine

① The peripheral velocity at inlet and outlet are equal

$$u_1 = u_2 = \frac{\pi D_o N}{60}$$, where $D_o \rightarrow$ Outer dia of runner.

② Velocity of flow at inlet and outlet are equal

$$V_{f_1} = V_{f_2}$$

③ Area of flow at inlet = Area of flow at outlet

$$= \frac{\pi}{4}\left(D_o^2 - D_b^2\right)$$

* **Draft tube :-**

(1) The draft tube is a pipe of gradually increasing area which connects the outlet of the runner to the tail race.

(2) It is used for discharging water from the exit of the turbine to the tail race

(3) The pipe of gradually increasing area is called draft tube.

(4) It ~~permits~~ uses a negative head to be installed or established at the outlet of the runner and thereby increase the net head on the turbine

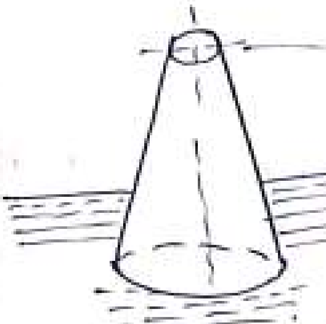
(5) It converts a large portion of the kinetic energy $\left(\frac{V_2^2}{2g}\right)$ rejected at the outlet of the turbine into useful pressure energy

→ By using draft tube the net head on the turbine increases and efficiency increases and develop more power

Types of draft tube :-

(1) Conical draft tube (2) Simple elbow tubes

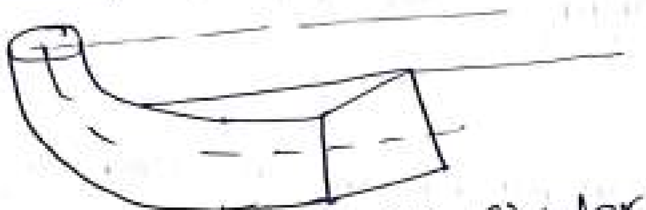
(3) Moody spreading tubes (4) Elbow draft tube with circular inlet and rectangular outlet



a) Conical draft tube

b) Simple Elbow tube

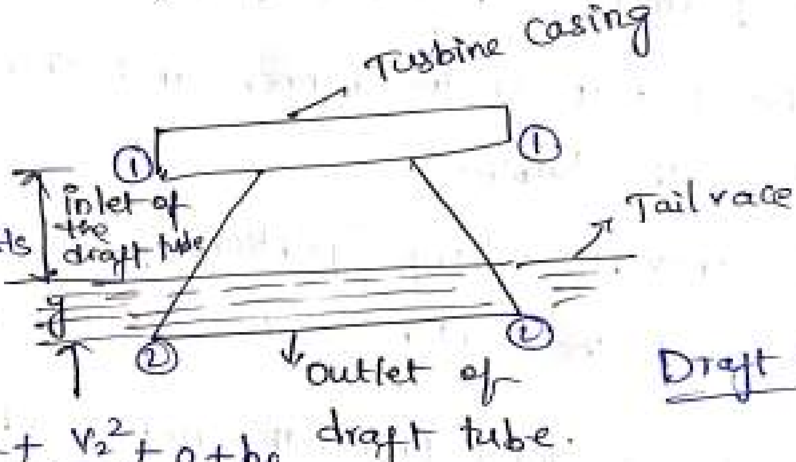
c) Moody spreading tube



d) Draft tube with circular inlet and rectangular outlet

* Conical draft tube and moody spreading draft tube are most efficient

Draft tube theory



Draft tube theory

Applying Bernoulli's eqn.

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + (H_s + y) = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + 0 + h_f$$

$$\frac{p_2}{\rho g} = \text{Atmospheric head} + y = \frac{p_a}{\rho g} + y$$

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + (H_s + y) = \frac{p_a}{\rho g} + y + \frac{v_2^2}{2g} + h_f$$

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + H_s = \frac{p_a}{\rho g} + \frac{v_2^2}{2g} + h_f$$

$$\frac{p_1}{\rho g} = \frac{p_a}{\rho g} + \frac{v_2^2}{2g} + h_f - \frac{v_1^2}{2g} - H_s$$

$$\boxed{\frac{p_1}{\rho g} = \frac{p_a}{\rho g} - H_s - \left[\frac{v_1^2}{2g} - \frac{v_2^2}{2g} - h_f\right]}$$

① A conical draft tube having inlet and outlet diameters 1m and 1.5m discharges water at outlet with a velocity of 2.5m/sec. the total length of the draft tube 6m and 1.20m of the length of the draft tube is immersed in water. If the atmospheric head is 10.3m of water and loss of head due to friction in the draft tube is equal to 0.2 x velocity of head at outlet of the tube

i) pressure head at inlet (ii) Efficiency of the draft tube

dia (d_1) of inlet = 1.0m

dia of outlet (D_2) = 1.5m

velocity at outlet (V_2) = 2.5 m/sec

Total length of the tube = $H_s + y$ = 6m

→ length of tube in water $y = 1.20m$

$H_s = 6 - 1.20$

$H_s = 4.80m$

i) pressure head at inlet

$$\frac{P_1}{\rho g} = \frac{P_a}{\rho g} - H_s - \left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g} - h_f\right)$$

$$= 10.3 - 4.8 - \left(\frac{5.625^2}{2\times 9.81} - \frac{2.5^2}{2\times 9.81} - \frac{0.2\times V_2^2}{2g}\right)$$

$= 4.27m$

(ii) Efficiency of ~~turbine~~ Draft tube

$$\eta_d = \frac{\left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right) - h_f}{\frac{V_1^2}{2g}} = \frac{\frac{V_1^2}{2g} - \frac{V_2^2}{2g} - \frac{0.2 V_2^2}{2g}}{\frac{V_1^2}{2g}}$$

$$= \frac{V_1^2 - 1.2 V_2^2}{V_1^2} = 1 - 1.2\left(\frac{V_2}{V_1}\right)^2$$

$$= 1 - 1.2\left(\frac{2.5}{5.625}\right)^2$$

$= 0.763$

(or) 76.3 %

Hydraulic performance

* ~~Specific~~

UNIT QUANTITIES

Inorder to predict the behaviour of turbine working under varying condition of head, speed, output and gate opening, the results are expressed in quantities which may be Obtained the head on the turbine is reduced to Unity.

3 important unit quantities which must be studied under unit head.

1. Unit speed
2. Unit discharge
3. Unit power.

UNIT SPEED :- defined as Speed of a turbine working under a unit head

It is denoted by Nu

$$N_u = \frac{N}{\sqrt{H}}$$

Nu → Unit speed

N → speed of a turbine under a unit head

H → Head under which a turbine is working

(2) **UNIT DISCHARGE** :— It is defined as discharge passing through a turbine which working under a unit head

→ It is denoted by Q_u

$$Q_u = \frac{Q}{\sqrt{H}}$$

Q_u → Unit discharge

Q → Discharge passing through turbine

H → Head of water on the turbine

(3) **UNIT POWER** :— It is defined as power developed by a turbine, working under a unit head

→ It is denoted by P_u.

$$P_u = \frac{P}{H^{3/2}}$$

P_u → unit power

P → Power developed by the turbine under a head of H.

H → Head of water on turbine

① A turbine develops 9000 KW when running at 10 r.p.m. The head on the turbine is 30m. If the head on the turbine is reduced to 18 m, determine the speed and power developed by turbine.

Power $(P_1) = 9000$ KW

Speed $(N_1) = 100$ r.p.m

Head $(H_1) = 30$m

Let for a head $(H_2) = 18$m

Speed

$$\frac{N_1}{\sqrt{H_1}} = \frac{N_2}{\sqrt{H_2}}$$

$$N_2 = \frac{N_1 \sqrt{H_2}}{\sqrt{H_1}} = \frac{100\sqrt{18}}{\sqrt{30}}$$

$$\boxed{N_2 = 77.46 \text{ r.p.m}}$$

Power

$$\frac{P}{H_1^{3/2}} = \frac{P_2}{H_2^{3/2}}$$

$$P_2 = \frac{P\, H_2^{3/2}}{H_1^{3/2}}$$

$$= \frac{9000 \times 18^{3/2}}{30^{3/2}}$$

$$\boxed{P_2 = 4182.84 \text{ KW}}$$

According to head & Quantity of water required

(1) High head turbine — for very high heads ranging from several hundread metres to few thousand meters.

→ turbine use relatively less quantity of water

Ex :- pelton wheel turbine.

(2) Medium head turbines —

Water heading range from 60 m to 250 m.

→ Require relatively large quantity of water

Ex :- Francis turbine

(3) Low head turbine :-

→ Below 60 m

→ require large quantity of water

Ex :- Kaplan & propeller turbine

Specific Speed

It is defined as the speed of a turbine which is identical in shape, geometrical dimensions, blade angles, gate openings etc.

→ It is denoted by symbol 'Ns'.

* Specific speed is used in comparing the different types of turbine as every type of turbine has different specific speed.

From overall efficiency

$$\eta_o = \frac{\text{shaft power}}{\text{water power}}$$

$$N_S = \frac{N\sqrt{P}}{H^{5/4}}$$

Significance of Specific Speed

Specific speed plays an important role for selecting the type of turbine.

→ Also performance of a turbine can be predicted by knowing the specific speed of turbine

S.NO	Specific Speed		Types of turbines
	M.K.S	S.I	
1	10 - 35	8.5 - 30	Pelton wheel with single jet
2	35 - 60	30 to 51	Pelton wheel with two (or) more jets
3	60 - 300	51 to 225	Fransis turbine
4	300 - 1000	255 - 860	Kaplan (or) propeller turbine

① A turbine develops 7225 KW power under a head of 25mt at 135 r.p.m. Calculate the specific speed of the turbine and .

Sol:

power (P) = 7225 KW

Head (H) = 25m

Speed (N) = 135 r.p.m

Specific speed of the turbine

$$N_s = \frac{N\sqrt{P}}{H^{5/4}} = \frac{135 \times \sqrt{7225}}{25^{5/4}}$$

$$\boxed{N_s = 205.28}$$

② A turbine is operate under a head of 25m at 200 rpm The discharge is 9 cumec. If the efficiency is 90% determine i) Specific speed of machine (ii) Power generated (iii) Type of turbine

$H = 25m$

$N = 200 \text{ rpm}$

$Q = 9 \text{ cumec} = 9 \text{ m}^3/\text{sec}$

$\eta_o = 90\% = 0.90$

$$\eta_o = \frac{\text{Power developed}}{\text{Water power}} = \frac{P}{\frac{\rho g Q H}{1000}}$$

$$P = \eta_o \times \frac{\rho g Q H}{1000} = \frac{0.90 \times 9.81 \times 1000 \times 9 \times 25}{1000}$$

$$\boxed{P = 1986.5 \text{ KW}}$$

i) Specific speed of machine $N_s = \frac{N\sqrt{P}}{H^{5/4}} = \frac{200 \times \sqrt{1986.5}}{25^{5/4}}$

$\boxed{N_s = 189.167}$ SI units

ii) power generated $\boxed{P = 1986.5 \text{ KW}}$

(iii) As the specific speed lies b/w 51 and 255, then turbine is a Francis turbine

UNIT- 2

Impact of jets
&
Hydraulic Turbines and performance of Turbines

The liquid comes out in the form of a jet from the outlet of a nozzle, which is fitted to a pipe through which the liquid is flowing under pressure. If some plate, which may be fixed (or) moving, is placed in the path of the jet, a force exerted by the jet on the plate. This force is obtained from Newton second law of motion (or) from Impulse momentum equation.

* Impact of jet means force exerted by the jet on a plate which may be stationary (or) moving.

→ The following cases of the impact of jet.

(1) Force exerted by the jet on a stationary plate when

a) plate is vertical to the jet.
b) plate is inclined to the jet
c) plate is curved.

(2) Force exerted by the jet on a moving plate, when

a) plate is vertical to the jet
b) plate is inclined to the jet
c) plate is curved.

Impact of jet :- Force exerted by the jet on a plate which may be stationary (or) moving.

Impact :- The action of one object coming forcibly into contact with another object.

(or) The act (or) force of one thing hitting another.

jet :- Liquid (or) gas forced out of a small opening.

(1) Force exerted by the jet on a stationary plate when

a) Plate is vertical to the jet.

* **Force exerted by the jet on a stationary vertical plate :-**

Consider a jet of water coming out from the nozzle, strikes a a flat vertical plate

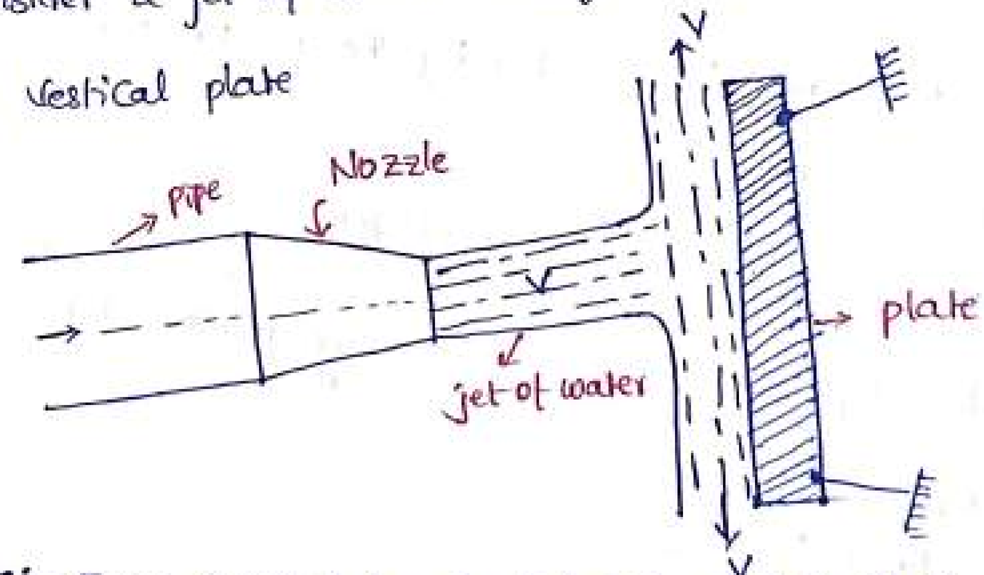


fig:- Force exerted by the jet on vertical plate

V = Velocity of the jet

d = diameter of the jet

a = area of c/s of the jet

The jet striking on the plate, will move along the plate, But the plate is right angles to the jet. Hence

→ Hence the jet after striking, will be get deflected through 90°. Hence the component of the velocity jet, in the direction of jet after striking will be zero.

F_x = Rate of change of momentum in the direction of a force

$$= \frac{\text{Initial momentum} - \text{final momentum}}{\text{Time}}$$

$$= \frac{(\text{Mass} \times \text{initial velocity} - \text{Mass} \times \text{Final velocity})}{\text{Time}}$$

$$= \frac{\text{Mass}}{\text{time}} [\text{Initial velocity} - \text{final velocity}]$$

$$= \frac{\text{mass}}{\text{sec}} \times [\text{velocity of jet before striking} - \text{velocity of jet after striking}]$$

$$= \rho a V [V - 0] \qquad \frac{\text{mass}}{\text{sec}} = \frac{M}{T} = \rho a V$$

$$= \rho a V^2$$

(b) Force exerted by a jet on stationary inclined flat plate

Let a jet of water, coming out from the nozzle, strikes an inclined flat plate.

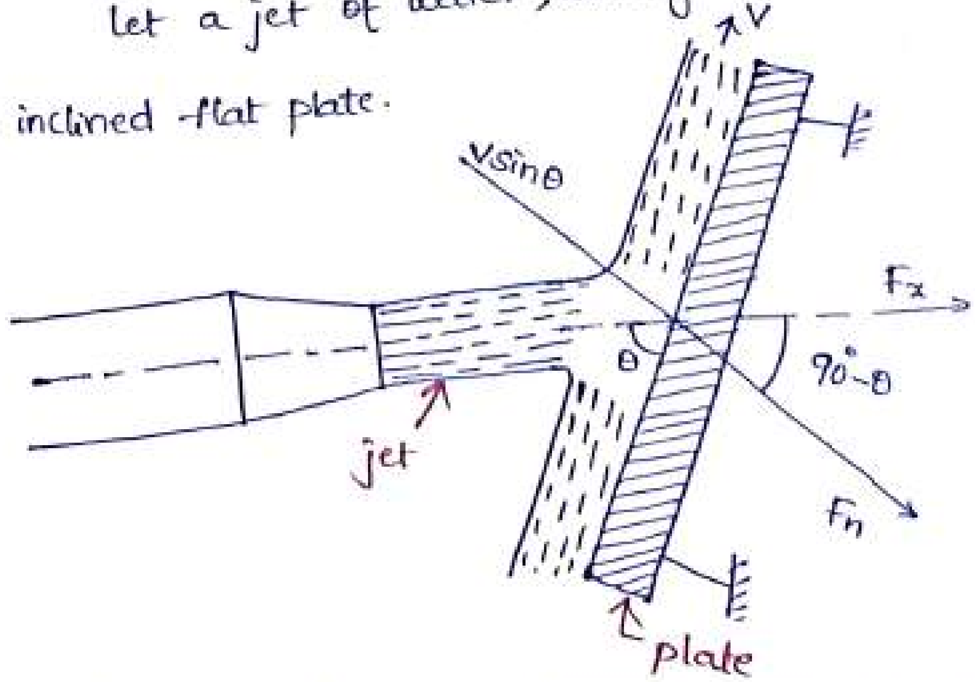


fig:- jet striking stationary inclined plate

If the plate is smooth and if it assumed that there is no losses of energy due to impact of the jet, then jet will move over the plate after striking with a velocity equal to initial velocity.

F_n = mass of jet striking per second × [initial velocity of jet before striking in the direction of n − Final velocity of jet after striking in the direction of jet]

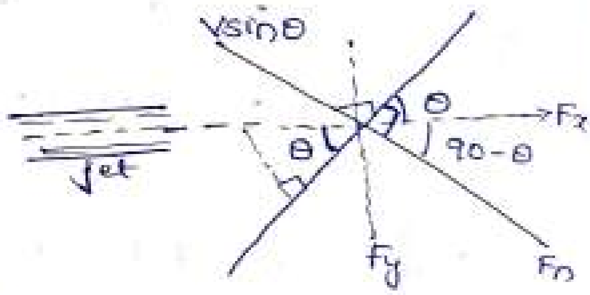
$= \frac{m}{time} \times [V\sin\theta - 0]$

$= \rho a V [V\sin\theta]$

$$\boxed{F_n = \rho a V^2 \sin\theta}$$

This force can be resolved in two components, F_x and F_y

F_x = Component of F_n in the direction of flow



$= F_n \cos(90-\theta)$

$= F_n \sin\theta$

$= \rho A V^2 \sin\theta \times \sin\theta$

$$\boxed{F_x = \rho A V^2 \sin^2\theta}$$

F_y = Component of F_n, Perpendicular to flow

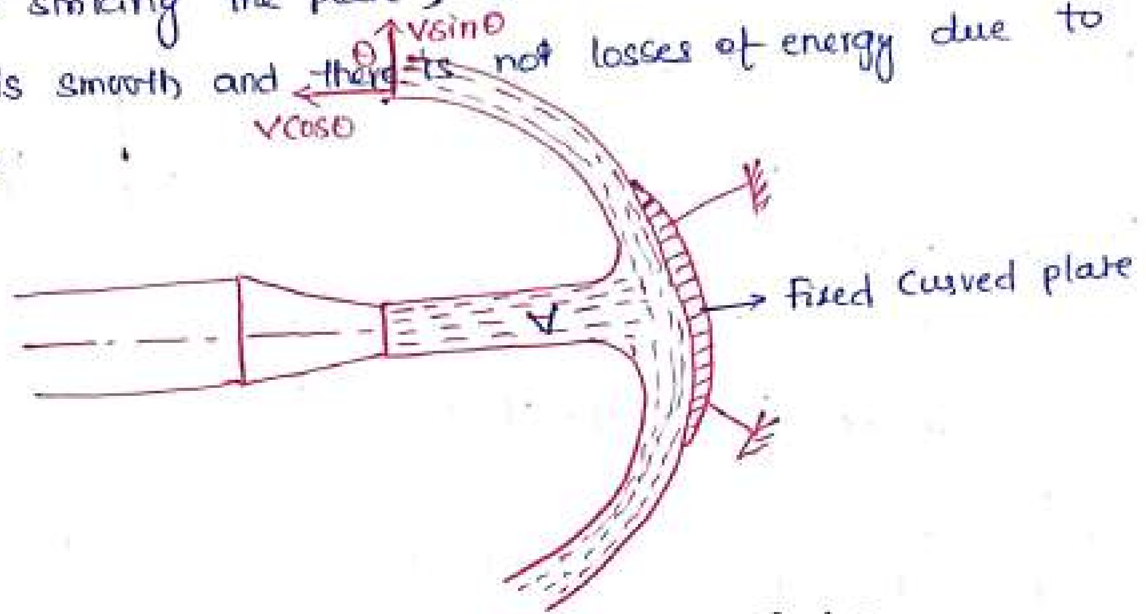
$= F_n \sin(90-\theta)$

$= F_n \cos\theta$

$$\boxed{F_y = \rho A V^2 \sin\theta \cos\theta}$$

Force exerted by a jet on stationary curved plate

(A) jet strikes the curved plate at the centre:- Let a jet of water strikes a fixed curved plate at the centre as shown in fig below. The jet after striking the plate, comes out with the same velocity if the plate is smooth and there is not losses of energy due to impact of jet



jet striking a fixed curved plate at centre.

Force exerted by the jet in the direction of the jet

$$F_x = \text{mass per sec} \left[V_{1x} - V_{2x} \right]$$

$$= \rho a V \left[V - (-V\cos\theta) \right]$$

$$\boxed{F_x = \rho a V^2 (1+\cos\theta)}$$

$$F_y = \text{mass per sec} \left[V_{1y} - V_{2y} \right]$$

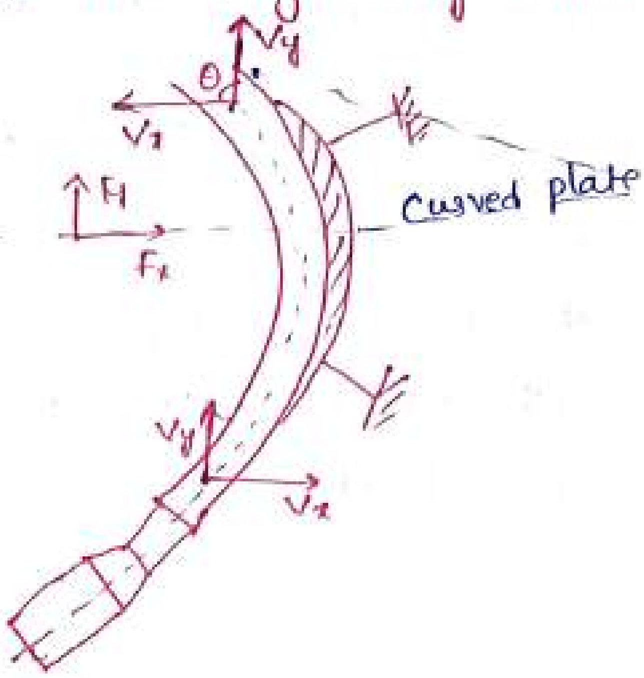
$$= \rho a V \left[0 - V\sin\theta \right]$$

$$\boxed{F_y = -\rho a V^2 \sin\theta}$$

b) jet strikes the curved plate at one end tangentially when the plate is symmetrically

V = Velocity of the jet

θ = Angle made by jet with x-axis at the inlet tip of the curved plate.



$$F_x = \frac{mass}{sec} \times [V_{1x} - V_{2x}]$$

$$= \rho a v [V\cos\theta - (-V\cos\theta)]$$

$$\boxed{F_x = 2\rho a v^2 \cos\theta}$$

$$F_y = \frac{mass}{sec} \times [V_{1y} - V_{2y}]$$

$$= \rho a v \times [v\sin\theta - v\sin\theta] = 0$$

$$\boxed{F_y = 0}$$

(c) jet strikes the curved plate at one end tangentially when the plate is unsymmetrical

when the plate is unsymmetrical about x-axis

When the curved plate is unsymmetrical about x-axis the angle made by the tangents drawn at the inlet and outlet tips of the plate. with x-axis will be different

θ → angle made by tangent at inlet tip with x-axis

φ → angle made by tangent at outlet tip with x-axis

force exerted by the jet of water in the direction of x and y are

$$F_x = \rho a v [V_{1x} - V_{2x}]$$

$$= \rho a v [v\cos\theta - (-v\cos\varphi)]$$

$$\boxed{F_x = \rho a v^2 [\cos\theta + \cos\varphi]}$$

$$F_y = \rho a v [V_{1y} - V_{2y}]$$

$$= \rho a v [v\sin\theta - v\sin\varphi]$$

$$\boxed{F_y = \rho a v^2 [\sin\theta - \sin\varphi]}$$

Problem on force exerted by the jet on a stationary vertical plate :-

① find the force exerted by a jet of water of diameter 75mm on a stationary flat plate, when the jet strikes the plate normally with velocity of 20 m/sec.

diameter (d) = 75 mm
= 0.075 m

Area (A) = $\frac{\pi}{4} d^2 = \frac{\pi}{4}(0.075)^2 = 0.004417 m^2$

Velocity of the jet V = 20 m/sec

force exerted by the jet of water on a stationary vertical plate

$F = \rho a V^2$

$F = 1000 \times 0.004417 \times 20^2$

$F = 1766.8 N$

(II) Problem on force exerted by a jet on stationary inclined flat plate

① A jet of water of diameter 50mm strikes a fixed plate in such a way that the angle b/w the plate and the jet is 30°. The force exerted in the direction of the jet is 1471.5 N. Determine the rate of flow of water

sol

diameter of jet (d) = 50 mm
= 0.05 m

Area (A) = $\frac{\pi}{4}(d^2) = \frac{\pi}{4}(0.05)^2 = 0.001963 m^2$

$\theta = 30°$

Force in the direction of the jet $F_x = 1471.5\,N$

$$F_x = \rho a v^2 \sin^2\theta$$

As the force given Newton second law

$$F_x = \rho a v^2 \sin^2\theta$$

$$1471.5 = 1000 \times 0.001963 \times V^2 \times \sin^2 30°$$

$$V = 54.77\ m/s$$

Discharge Q = Area × velocity

$$= 0.001963 \times 54.77$$

$$\boxed{Q = 107.5\ \text{liters/sec}}\ \text{or}\ 0.1075\ m^3/sec.$$

(11) Problem on force exerted by the jet on stationary curved plate :-

① A jet of water of diameter 50mm moving with a velocity of 40 m/sec, strikes a curved fixed symmetrical plate at the centre. Find the force exerted by the jet of water in the direction of the jet is deflected through an angle of 120° at the outlet of the curved plate.

diameter $(d) = 50mm = 0.05m$

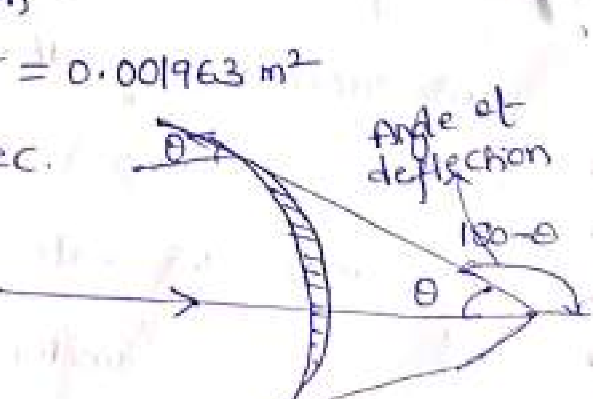
area, $a = \pi/4\, d^2 = \pi/4\,(0.05)^2 = 0.001963\ m^2$

Velocity of the jet $V = 40\ m/sec.$

Angle of deflection $= 120°$

$180° - \theta = 120°$, $\theta = 180 - 120°$

$\theta = 60°$



Force exerted by the jet on curved plate in the direction of a jet

$$F_x = \rho a v^2 [1 + \cos\theta] \Rightarrow F_x = 1000 \times 0.001963 \times 40^2 \times [1 + \cos 60°]$$

$$\boxed{F_x = 4711.15\ N}$$

Force exerted by a jet on Moving plates

① Flat vertical plate moving in the direction of the jet and away from the jet.

② Inclined plate moving in the direction of the jet

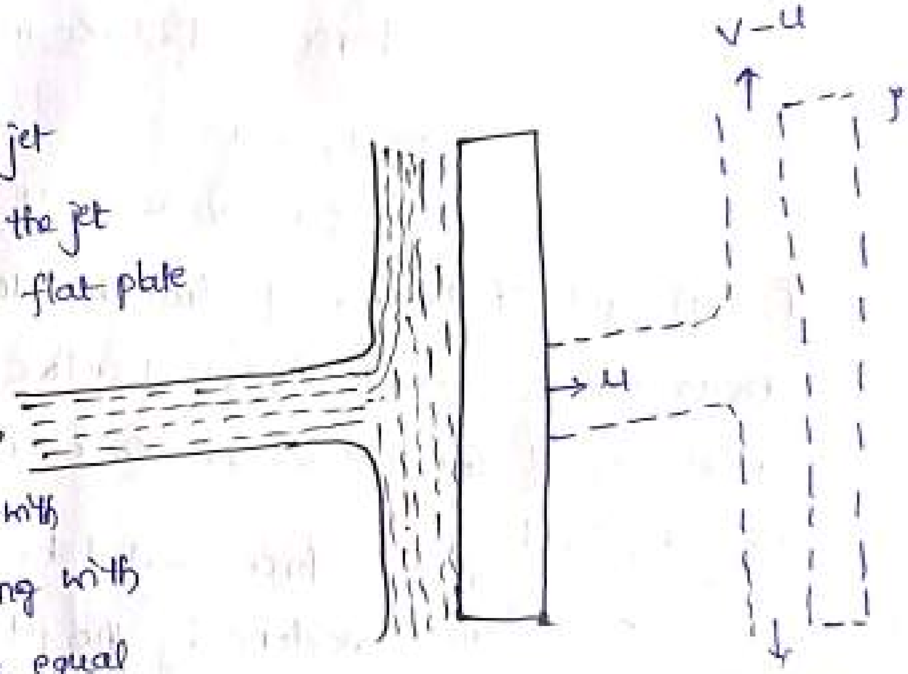
③ Curved plate moving in the direction of the jet in the horizontal direction

(I) Force on flat vertical plate moving in the direction of the jet:-

V = Velocity of the jet

a = area of c/s of the jet

u = velocity of the flat plate



→ In this case, the jet does not strike the plate with velocity V, but it striking with a relative velocity, which is equal to absolute velocity of jet of water minus the velocity of jet of the plate.

fig:- jet striking flat vertical moving plate.

Relative velocity of the jet with respect to plate

$= V - u$

Mass of water striking the plate per sec

$= \rho \times$ Area of the jet $\times$ velocity

$= \rho a [V - u]$

Force exerted by the jet on moving plate in the direction of the jet

F_x = Mass of water striking per sec × [Initial velocity − final velocity]

$= \rho a [V-u] \cdot [(V-u) - 0]$

$= \rho a [V-u]^2$

In this case, the work will done by the jet on the plate as plate is moving. For stationary plates, the workdone is zero.

∴ Workdone per second by the jet on the plate

$= \text{Force} \times \frac{\text{Distance in the direction of force}}{\text{time}}$

$= F_x \times u$

$= \rho a (V-u)^2 \times u$

① A jet of water of diameter 10cm strikes a flat plate normally with a velocity of 15m/sec. The plate is moving with a velocity of 6 m/sec in the direction of the jet and away from the jet. Find

i) The force exerted by the jet on the plate.

ii) Workdone by the jet on the plate per second.

diameter of the jet (d) = 10cm = 0.1m

Area (A) = $\pi/4 (d^2) = \pi/4 (0.1)^2 = 0.007854 m^2$

Velocity of the jet $V = 15$ m/sec

Velocity of the plate $u = 6$ m/sec

(i) Force exerted by the jet on a moving flat vertical plate

$F_x = \rho a (V-u)^2$

$= 1000 \times 0.007854 (15-6)^2$

$F_x = 636.17 N$

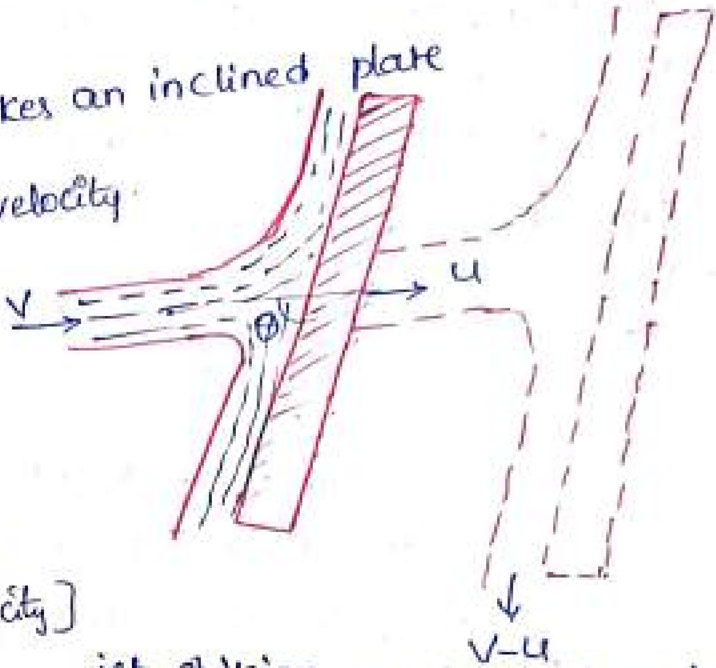
(ii) Workdone per second by the jet

$= F_x \times u$

$= 636.17 \times 6 = 3817.02$ N m/sec.

Mass of water striking ...

② Force on the inclined plate moving in the direction of the jet :-



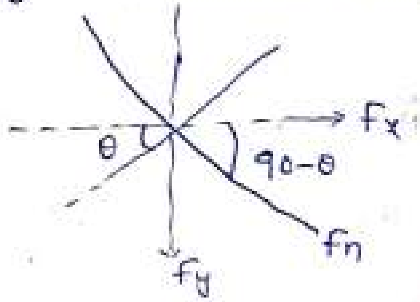
Let the jet of water strikes an inclined plate which is moving with a uniform velocity in the direction of the jet.

Relative velocity $= (V-u)$

$F_n =$ mass striking per second × [Initial velocity in before jet strikes − final velocity]

$F_n = \rho a(V-u)\left[(V-u)\sin\theta - 0\right]$

$$\boxed{F_n = \rho a\,(V-u)^2 \sin\theta}$$



F_n is resolved into two component, F_x & F_y

$F_x = F_n \sin\theta = \rho a\,(V-u)^2 \sin^2\theta$

$F_y = F_n \cos\theta = \rho a\,(V-u)^2 \sin\theta\cos\theta$

∴ Workdone per second by the jet on the plate

= F_x × distance per second in the direction of x

$= F_x \times u$

$= \rho a\,(V-u)^2 \sin^2\theta \times u = \rho a\,(V-u)^2 u \sin^2\theta$.

(1) A jet of water diameter 10cm strikes a flat plate normally with a vel^y

① A 7.5 cm diameter jet having a velocity of 30 m/sec strikes a flat plate and inclined plate at 45° to the axis of the jet. Find normal pressure on the plate

i) when the plate is moving with a velocity of 15 m/sec and away from the jet.

Sol

Diameter of the jet (D) = 7.5 cm
= 0.075 m.

$\theta = 45^\circ$

velocity of the jet $V = 30$ m/sec

plate moving velocity = 15 m/sec.

i) when the plate is stationary ; the normal force on the plate

$F_n = \rho a v^2 \sin\theta = 1000 \times \frac{\pi}{4}(0.075)^2 \times 30^2 \times \sin 45^\circ$

$F_n = 2810.96$ N

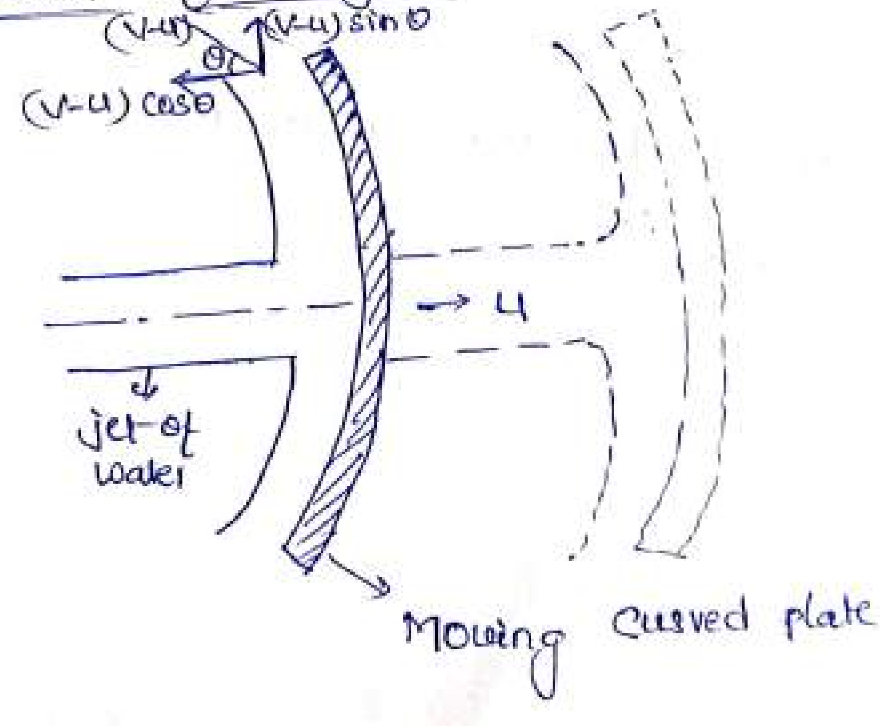
ii) When the plate is moving with a velocity 15 m/sec away from the jet, normal force on plate.

$F_n = \rho a (V-u)^2 \sin\theta$

$= 1000 \times \frac{\pi}{4}(0.075)^2 \times (30-15)^2 \sin 45^\circ$

$F_n = 702.74$ N

III) Force on the curved plate when the plate is moving in the direction of the jet :-



Mass of water striking the plate

$= \rho \times a \times$ velocity with which jet strikes the plate

$= \rho a(V-u)$

Force exerted by the jet of water on the curved plate in the direction of the jet

F_x = mass striking per sec × [Initial velocity with which jet strikes the plate in the direction of the jet − Final velocity]

$= \rho a(V-u)\left[(V-u)-(-(V-u)\cos\theta)\right]$

$= \rho a(V-u)^2[1+\cos\theta]$

Workdone by the jet on the plate per second

$= F_x \times u$

$= \rho a(V-u)^2(1+\cos\theta)\times u$

$= \rho a(V-u)^2 \times u(1+\cos\theta)$

① A jet of water of diameter 7.5 cm strikes a curved plate at it's centre with a velocity of 20 m/sec. The curved plate is moving with a velocity of 8 m/sec in the direction of the jet. The jet is deflected through an angle of 165°.

The jet is deflected through an angle of 165°. [sic: find]

i) Force exerted on the plate in the direction of the jet

ii) Workdone by the jet per second.

Sol

$d = 7.5\,cm = 0.075\,m$

velocity of jet, $V = 20\,m/sec$

velocity of plate $u = 8\,m/sec$

$\theta = 180 - 165^\circ \quad \theta = 15^\circ$

$a = \frac{\pi}{4}\times(0.075)^2$

$= 0.004417$

i) Force exerted on the plate in the direction of the jet

$F_x = \rho a(V-u)^2(1+\cos\theta)$

$= 1000(0.004417)[1+\cos 15^\circ]$

$= 1250.38\,N$

ii) Workdone by the jet on the plate: $= F_x \times u$

$= 1250.38 \times 8$

$= 10003.04\,N\cdot m/sec$

Hydraulic Turbines

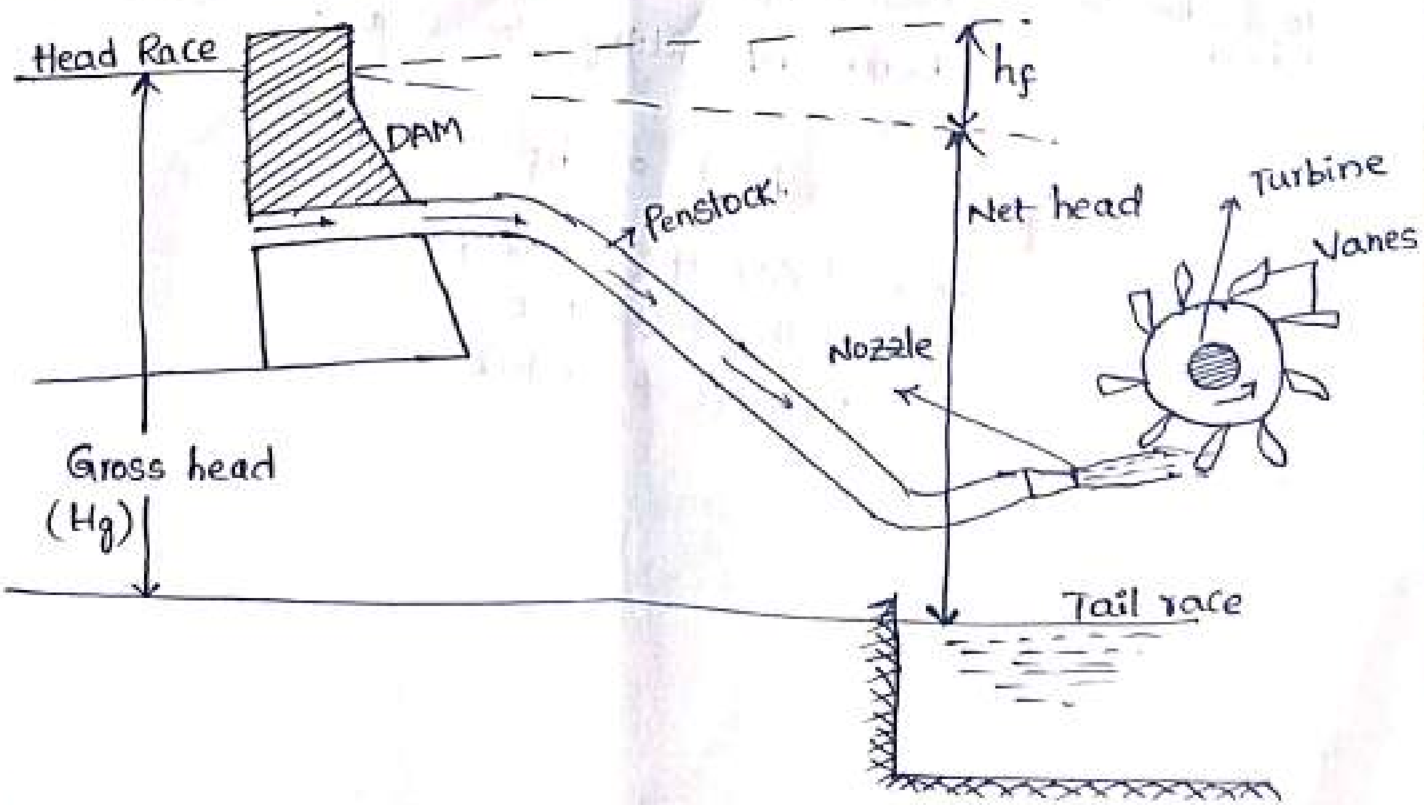
Hydraulic machines are defined as those machines which convert either hydraulic energy into mechanical energy.

Turbines :- The hydraulic machines, which convert the hydraulic energy into mechanical energy are called turbines.

Pumps :- Hydraulic machines which convert mechanical energy into hydraulic energy are called pumps.

Turbines :- "Hydraulic machines which convert hydraulic energy into mechanical energy. This mechanical energy is used in running an electric generator which is directly coupled to the shaft of the turbine. This m.E is converted into E.E. This electric power which is obtained from the hydraulic energy is known as hydroelectric power."

General layout of A hydroelectric power plant



(1) A dam constructed across a river to store water.

(2) 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) RC

(3) Turbines having different types of vanes fitted to the wheels.

(4) Tail race, which is a channel which carries water away from the turbines after the water has worked on the turbines. The surface water in the tail race channel is also known as tail race

Definations of Heads

(1) **Gross Head** :- The difference b/w the head race level and tail race level no water is flowing is known as Gross Head.

→ It is denoted by "Hg"

(2) **Net Head** :- It is also called effective head.

It is defined as head available at the inlet of the turbine.

loss due to of head
i) Friction b/w water and penstock occurs.
ii) bend, pipe fitting, losses at the entrance of penstock.

$$H_g = \text{Gross head}, \quad h_f = \frac{4fLV^2}{2gD}$$

V → velocity of flow in penstock.

L → Length of penstock

D → Diameter of penstock.

Efficiencies of a Turbine

(a) Hydraulic efficiency (η_h)

(b) Mechanical efficiency (η_m)

(c) Volumetric efficiency (η_v)

(d) Overall efficiency (η_o).

(a) Hydraulic efficieny :— Ratio of power given by water to runner of a turbine to power supplied by the water at the inlet of the turbine.

$$\eta_h = \frac{\text{Power deliverd to runner}}{\text{Power supplied at inlet}} = \frac{R.P}{W.P}$$

(b) Mechanic efficiency :— the power delivered by water to runner of a turbine is transfered to the shaft of the turbine. Due to mechanical losses, the power available at the shaft to the turbine is less than the power delivered to the runner of the turbine

" Ratio of power available at the shaft of the turbine to the power delivered to the runner "

$$\eta_m = \frac{\text{Power at the shaft of the turbine}}{\text{power delivered by water to runner}} = \frac{S.P}{R.P}$$

(c) Volumetric efficiency :—

The volume of water striking the runner of a turbine is slightly less than the volume of water supplied to the turbine

$$\eta_v = \frac{\text{Volume of water actually striking the runner}}{\text{Volume of water supplied to the turbine}}$$

(d) **Overall efficiency** :- Ratio of power available at the shaft of the turbine to the power supplied by the water at the inlet of the turbine

$$\eta_o = \frac{\text{Volume available at the shaft of the turbine}}{\text{power supplied at the inlet of the turbine}}$$

$$= \frac{\text{Shaft power}}{\text{Water power}}$$

$$= \frac{S.P}{W.P} \times \frac{R.P}{R.P}$$

$$= \frac{S.P}{R.P} \times \frac{R.P}{W.P}$$

$$\boxed{\eta_o = \eta_m \times \eta_h}$$

Classification of Hydraulic turbine

The hydraulic turbines are classified according to the inlet of the turbine, the types of energy available at the inlet of the turbine, direction of flow through vanes, head at the inlet of the turbine and specific speed of the turbine

(1) According to the type of energy at inlet
 i) Impulse turbine ii) Reaction turbine

(2) According to the direction of flow through runner
 i) Tangential flow turbine (ii) Radial flow turbine
 iii) Axial flow turbine iv) Mixed flow turbine

(3) According to the head inlet of the turbine
 i) High head turbine (ii) Medium head turbine (iii) Low head turbine

(4) According to Specific Speed of the turbine
 i) Low Specific Speed turbine (ii) Medium specific speed turbine
 iii) High Specific Speed turbine

Impulse turbine :- If the inlet of the turbine, the energy is available is only Kinetic energy, the turbine is known as Impulse turbine

→ As the water flows over the vanes, the pressure is atmospheric from inlet to outlet of the turbine

Reaction turbine :- If the inlet of the turbine, the water possesses Kinetic energy as well as pressure energy, the turbine is known as reaction turbine.

Tangential flow turbine :- If the water flows along the tangent of the runner, the turbine is known as tangential flow turbine

Radial flow turbine :- If the water flows in the radial direction through runner, the turbine is Called radial flow turbine.

→ If the water flows in the radial from outward to inwards, the turbine is known as inward Radial flow turbine.

→ If the water flows from inwards to outwards, the turbine is called outward radial flow turbine.

Axial 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.

mixed flow turbine :- If the water flows through the runner in the radial direction but leaves in the direction parallel to the axis of rotation of the runner, the turbine is Called mixed flow turbine.

(1) pelton wheel 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 K.E.

→ 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

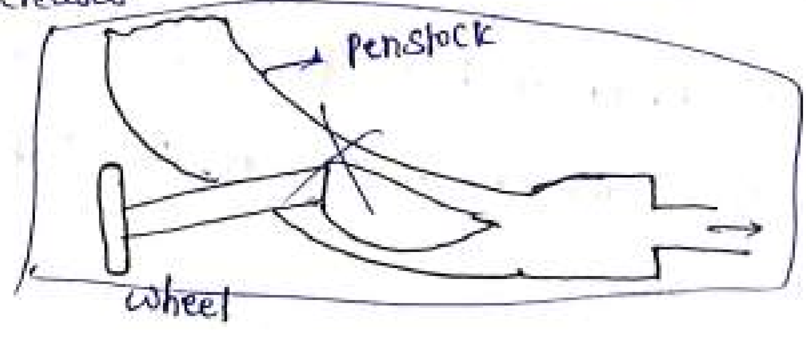
(1) Nozzle & Flow regulating arrangement.
(2) Runner and buckets
(3) Casing
(4) Breaking jet.

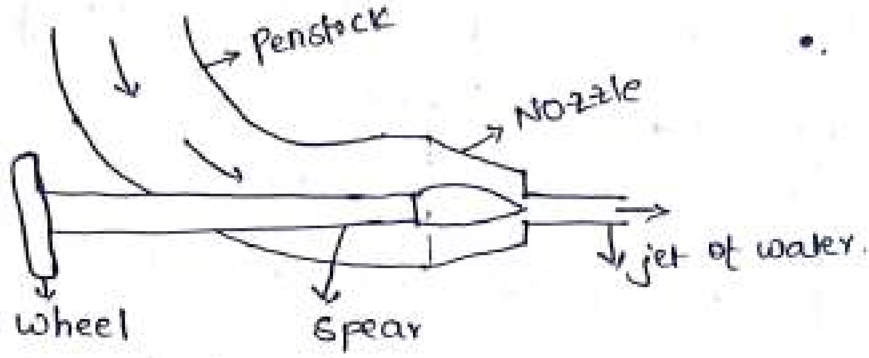
(1) Nozzle & Flow regulating arrangement :-

The amount of water striking the buckets (vanes) of the runner is controlled by providing a spear in the nozzle The spear is conical needle which is operated either by hand wheel (or) automatically.

→ When the spear is pushed forward into the nozzle the amount of water striking the runner is reduced.

→ When the spear is pushed back, the amount of water striking the runner increases.





② Runner with Buckets :-

It consist of a circular disc on the periphery of which number of buckets evenly spaced are fixed.

→ The shape of the bucket is of a double hemispherical cup (or) bowl

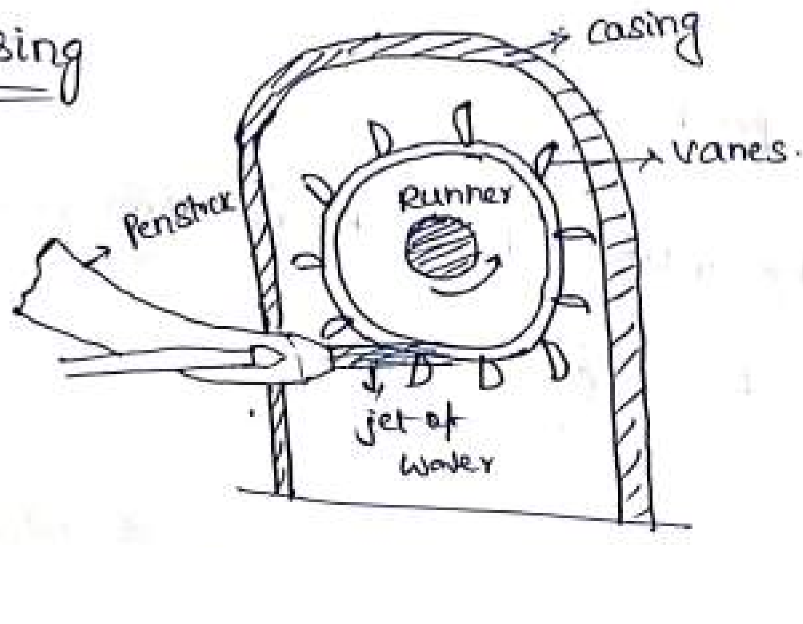
→ Each bucket is divided into two symmetrical parts by dividing wall which is known as splitter.

* The jet of water strikes on the splitter. The splitter divided into two equal parts and jet comes out from outer edge

* The buckets are shaped in such away that the jet get deflected through 160° (or) 170°.

* The buckets are made cast iron, cast steel bronze (or) stainless steel depending upon the head at the turbine

③ Casing



* The function of Casing is to prevent the splashing of the water and to discharge water to tail race.
* It also act safeguard against accident.
* It is made of cast iron or fabricated steel plates.
* The casing of the pelton wheel doesn't perform any hydraulic function.

(4) Breaking jet :- When the nozzle is compleatly closed by moving the spear in forward direction, the amount of water striking the runner to zero. But the runner due to inertia goes on revolving for 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 bracing jet.

Important point in pelton wheel turbine

(1) It is a Impulse turbine

(2) Tangential flow direction.

(3) High head

(4) Low Specific speed

(5) pressure at the inlet and outlet are atmospheric pressure.

(6) Less Qantity of water is required

Points to be remembered for pelton wheel :-

(1) The velocity of the jet at inlet by $V_1 = C_v\sqrt{2gH}$

C_v = Co-efficient of velocity = 0.98 to 0.99

H → Nead Head on the turbine

(2) The velocity of the wheel (u) is given by $u = \varphi\sqrt{2gH}$

φ → speed ratio, varies b/w 0.43–0.48.

(3) Angle of deflection of the jet through the buckets is taken at 165°.

(4) The mean diameter (or) pitch diameter of pelton wheel to diameter of the jet (d).

$u = \frac{\pi DN}{60}$ $m = \frac{D}{d}$ (= 12 most of the cases)

(5) jet ratio = $\frac{\text{pitch dia of pelton wheel (D)}}{\text{dia of the jet (d)}}$

$m = \frac{D}{d}$ = (12 for most cases)

(6) Number of buckets on a runner is given by

$$Z = 15 + \frac{D}{2d} = 15 + 0.5m$$

(7) 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

① ** A pelton wheel has a mean bucket speed of 10 m/sec with a jet of water flowing at the rate of 700 liters/sec under a head of 30 mts. The bucket deflect the jet through an angle of 160°. Calculate the power given by water to the runner and hydraulic efficiency of the turbine. Assume co-efficient of velocity as 0.98.

Sol

Speed of the bucket $u = u_1 = u_2 = 10$ m/sec

Discharge $Q = 700$ lit/sec $= 0.7\ m^3/sec$

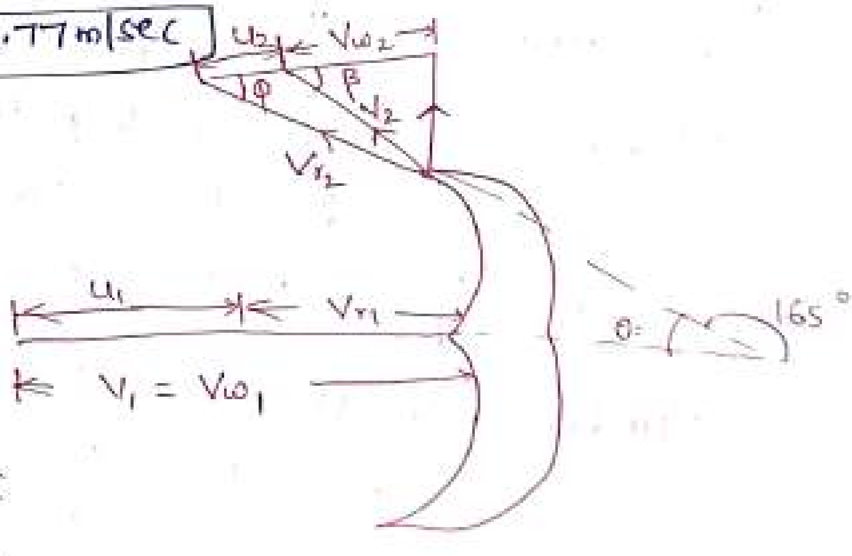
Head of water $(H) = 30m$

Angle of deflection $= 160°$

∴ Angle, $180° - 160° = 20°$

i) Velocity of jet $V_1 = C_v \sqrt{2gH} = 0.98\sqrt{2 \times 9.81 \times 30}$

$V_1 = 23.77$ m/sec



$V_{r_1} = V_1 - u_1$

$= 23.77 - 10$

$= 13.77$ m/sec

$V_{w_1} = V_1 = 23.77$ m/sec

From outlet velocity triangle

$V_{r_2} = V_{r_1} = 13.77$ m/sec

$V_{w_2} = V_2 \cos\phi - u_2$

$= 13.77 \cos 20° - 10$

$V_{w_2} = 2.94$ m/sec

Workdone by the jet per second on the runner

$= \rho a V_1 [V_{w_1} + V_{w_2}] \times u$

$= 1000 \times 0.7 \times [23.77 + 2.94] \times 10$

$= 186970$ Nm/sec.

∴ power given to turbine $= \frac{186970}{1000}$

$= 186.97$ kW

The hydraulic efficiency of the turbine is given by

$$\eta_h = \frac{2\left[V_{w_1} + V_{w_2}\right] \times u}{V_1^2} = \frac{2\left[23.77 + 2.94\right] \times 10}{23.77 \times 23.77}$$

$\eta_h = 0.9454$

(or) $\boxed{\eta_h = 94.54\%}$

② A pelton wheel is to be designed for a head of 60m when the running at 200 r.p.m. The pelton wheel develops 95.6475 kW shaft power. the velocity of the buckets = 0.45 times the velocity of the jet, Overall efficiency = 0.85. co-efficient of velocity is equal to 0.98.

Sol

Head $H = 60m$

Speed $N = 200$ rpm

Shaft power (S.P) = 95.6475 kW

velocity of bucket(u) = 0.45 × velocity of the jet

Overall efficiency $\eta_o = 0.85$

co-efficient of velocity $C_v = 0.98$

i) ~~Velocity of the jet~~ Diameter of the jet (d)

Overall efficieny $\eta_o = 0.85$

$$\eta_o = \frac{S.P}{W.P} = \frac{95.6475}{\left(\frac{W.P}{1000}\right)} = \frac{95.6475 \times 1000}{\rho \times g \times Q \times H}$$

$$\eta_o = \frac{95.6475 \times 1000}{1000 \times 9.81 \times Q \times 60} \qquad \eta_o = 0.85$$

$Q = 0.1912$ m³/sec

$Q = A \times V$

$0.1912 = \pi/4 \, d^2 \times V_1$

$0.1912 = \pi/4 (d)^2 \times 33.62$

$\boxed{d = 85mm}$

i) Velocity of the jet $V_1 = C_v\sqrt{2gH} = 0.98\sqrt{2 \times 9.81 \times 60}$

$\boxed{V_1 = 33.62 \, m/sec}$

Bucket velocity $u = u_1 = u_2 = 0.45 \times V_1 = 0.45 \times 33.62$

$= 15.13 \, m/sec$

$u = \frac{\pi DN}{60}$

$15.13 = \frac{\pi \times D \times 200}{60}$ $\therefore \boxed{D = 1.44 \, m}$

(iii) <u>Size of buckets</u>

Width of bucket $= 5d = 5 \times 85 = 425mm.$

Depth of bucket $= 1.2 \times d = 1.2 \times 85 = 102 \, mm$

(iv) Number of buckets on the wheel is given by

$Z = 15 + \frac{D}{2d} = 15 + \frac{1.44}{2 \times 0.85}$

$Z = 15 + 8.5$

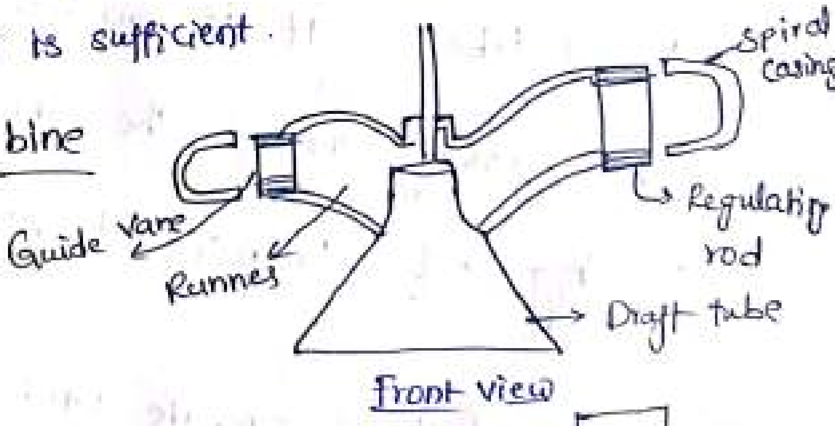
$\boxed{Z = 24}$

(Q) 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 begining design inward Radial flow.
* In 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

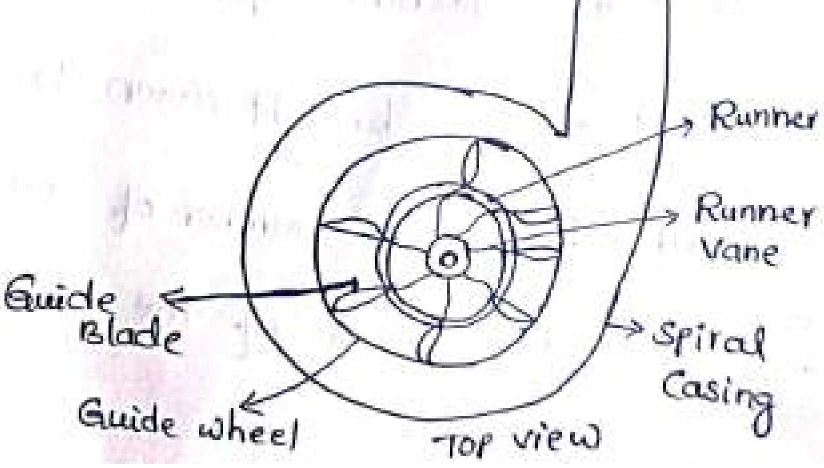
Important points of Working condition

It is
(1) Reaction flow turbine [K.E and P.E enters the turbine]
(2) Mixed flow turbine [Water enters to runner radially and leaves axially]
(3) It is used for medium head
(4) It is a medium specific speed
(5) Medium quality of water is sufficient.



Components of Francis turbine

(1) Penstock
(2) Spiral Casing
(3) Guide Vanes
(4) Governing Mechanism
(5) Runner and Runner Blades
(6) Draft tube



(1) Penstock :- It is a large size pipe which conveys water from the upstream to the dam/Reservoir to the turbine runner

(2) spiral Casing :- It constitutes a closed passage whose c/s area gradually decreases along the flow direction : area is maximum at inlet and nearly zero at exit.

(3) Guide vanes :- These vanes direct the water on to the runner at an angle appropriate to design, the motion of them is given by means of hand wheel (or) by a governor.

(4) Governing Mechanism :- It changes the position of the guide blades/vanes to affect the variation in water flow rate, when the load condition on the turbine change

(5) Runner and Runner blades :- The driving force on the runner is both due to impulse and reaction effect.

(6) Draft tube :- It is gradually expanding tube which discharge water, passing through the runner to the tail race.

Working of Francis turbine

(1) Francis turbine operate under medium heads.

(2) Water is brought down to the turbine through a penstock and directed to number of stationary blades fixed all around the circumference of the runner

(3) These stationary blades are called as Guide Vanes.

(4) Water under pressure, enters the runner from the guide vanes towards the center in radial direction and discharge out of the runner axially. Due to diffn pressure b/w guide vane & runner the motion

(5) of the runner occurs

(5) As the water flows through the runner its pressure and angular momentum reduces, This will produce a reaction force on the runner blades.

(6) The pressure at the inlet is more than the outlet.

(7) The moment of runner is affected by the change of both the potential and K.E of water.

(8) After doing the work the water is discharged to the tail race through a closed tube called draft tube

Kaplan Turbine

If the water flows parallel to the axis of the rotation of the shaft, the turbine is known as axial flow turbine

Axial flow reaction turbine are classified into 2 types

1) propeller turbine   2) Kaplan turbine

propeller turbine :- When the vanes are fixed to the hub and they are not adjustable the turbine is known as propeller turbine

Kaplan Turbine :-

If the vanes on the hub are adjustable the turbine is known as Kaplan turbine.

→ After the name of V. Kaplan, an Austrian Engineer.

(1) It is a Reaction flow turbine

(2) It is the Axial flow direction

(3) Low head

(4) High specific speed

(5) Large quantity of water required

hub :- /boss The shaft of the turbine is vertical, the lower end of the shaft made larger which is known as hub (or) boss.

Main parts of a kaplan turbine

(1) Scroll Casing

(2) Guide vane Mechanism

(3) Hub with vanes (or) Runner of the turbine

(4) Draft tube.

The water from the penstock enter the scroll casing and then moves to the guide vanes. From the guide vanes the water turns through 90° and flows axially through the runner.

→ The discharge through runner is obtained by

$$Q = \frac{\pi}{4}\left(D_0^2 - D_b^2\right) \times V_{f_1}$$

D_0 → outer dia of runner m

D_b → Diameter of hub

V_{f1} → Velocity of flow at inlet

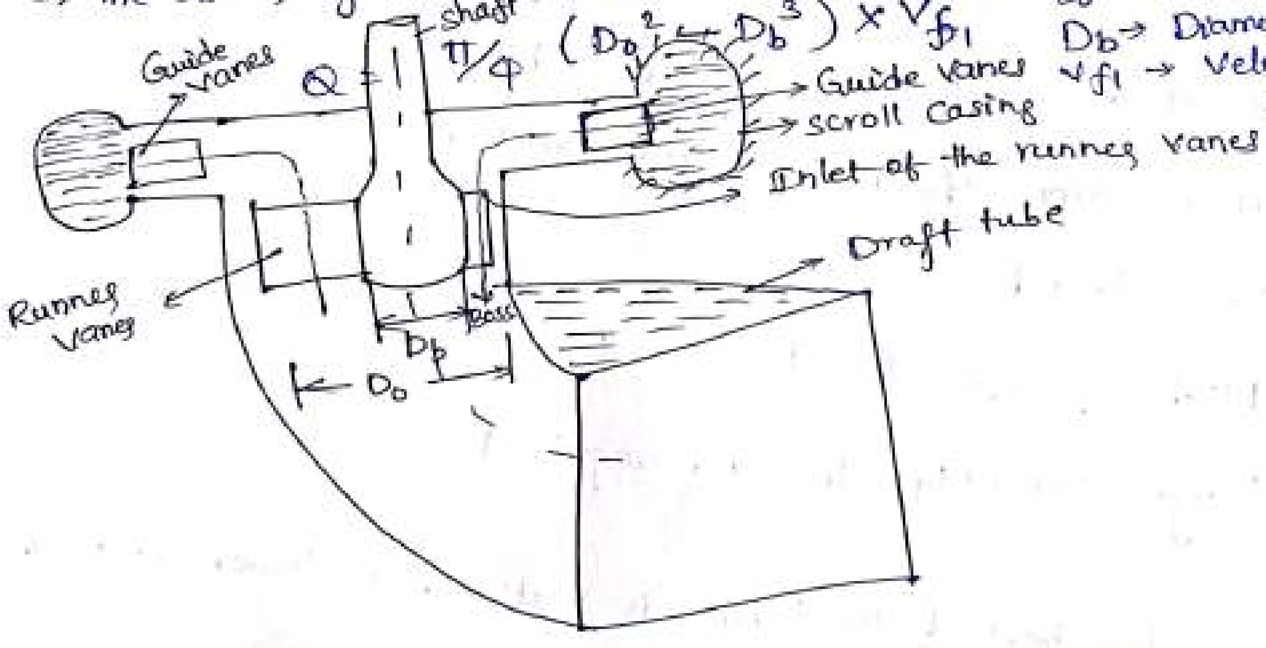


fig:- Main Components of kaplan turbine

Some important points propeller (or) Kaplan turbine

① The peripheral velocity at inlet and outlet are equal

$$u_1 = u_2 = \frac{\pi D_o N}{60}$$, where D_o → Outer dia of runner.

② Velocity of flow at inlet and outlet are equal

$$V_{f_1} = V_{f_2}$$

③ Area of flow at inlet = Area of flow at outlet

$$= \frac{\pi}{4}\left(D_o^2 - D_b^2\right)$$

* Draft tube :-

(1) The draft tube is a pipe of gradually increasing area which connects the outlet of the runner to the tail race.

(2) It is used for discharging water from the exit of the turbine to the tail race

(3) The pipe of gradually increasing area is called draft tube.

(4) It ~~permits~~ uses a negative head to be installed so established at the outlet of the runner and thereby increase the net head on the turbine

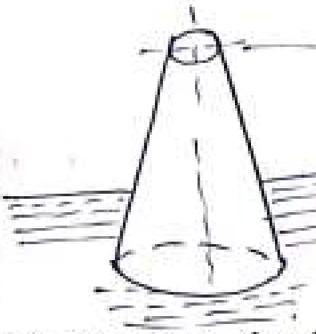
(5) It converts a large portion of the kinetic energy $\left(\frac{V_2^2}{2g}\right)$ rejected at the outlet of the turbine into useful pressure energy

→ By using draft tube the net head on the turbine increases and efficiency increases and develop more power

Types of draft tube :-

(1) Conical draft tube (2) Simple elbow tubes

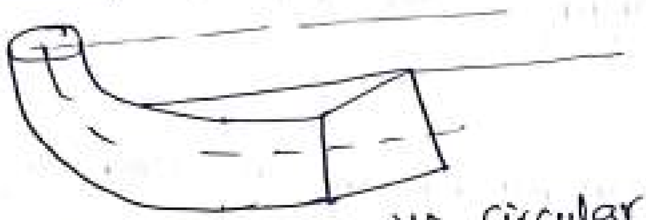
(3) Moody spreading tubes (4) Elbow draft tube with circular inlet and rectangular outlet



a) Conical draft tube

b) Simple Elbow tube

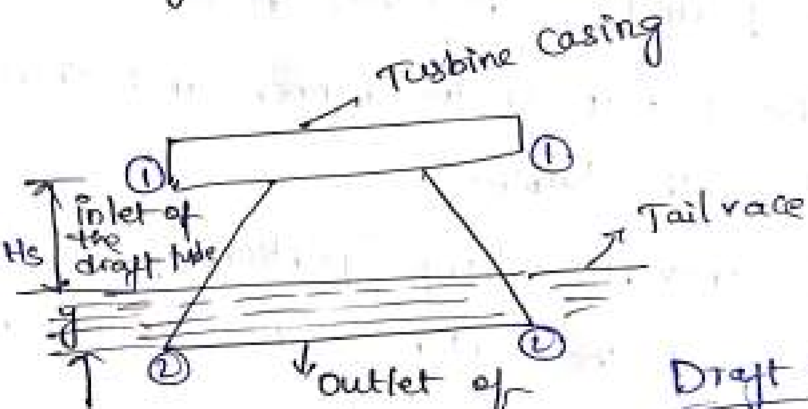
c) Moody spreading tube



d) Draft tube with circular inlet and rectangular outlet

* Conical draft tube and moody spreading draft tube are most efficient

Draft tube theory



Draft tube theory

Applying Bernoulli's eqn.

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + (H_s + y) = \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + 0 + h_f$$

$$\frac{p_2}{\rho g} = \text{Atmospheric head} + y = \frac{p_a}{\rho g} + y$$

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + (H_s + y) = \frac{p_a}{\rho g} + y + \frac{V_2^2}{2g} + h_f$$

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + H_s = \frac{p_a}{\rho g} + \frac{V_2^2}{2g} + h_f$$

$$\frac{p_1}{\rho g} = \frac{p_a}{\rho g} + \frac{V_2^2}{2g} + h_f - \frac{V_1^2}{2g} - H_s$$

$$\boxed{\frac{p_1}{\rho g} = \frac{p_a}{\rho g} - H_s - \left[\frac{V_1^2}{2g} - \frac{V_2^2}{2g} - h_f\right)}$$

① A conical draft tube having inlet and outlet diameters 1m and 1.5m discharges water at outlet with a velocity of 2.5m/sec. the total length of the draft tube 6m and 1.20m of the length of the draft tube is immersed in water. If the atmospheric head is 10.3m of water and loss of head due to friction in the draft tube is equal to 0.2 × velocity of head at outlet of the tube

i) pressure head at inlet (ii) Efficiency of the draft tube

dia (d_1) of inlet = 1.0m

dia of outlet (D_2) = 1.5m

velocity at outlet (V_2) = 2.5 m/sec

Total length of the tube = $H_s + y$ = 6m

→ length of tube in water $y = 1.20m$

$H_s = 6 - 1.20$

$H_s = 4.80m$

i) pressure head at inlet

$$\frac{P_1}{\rho g} = \frac{P_a}{\rho g} - H_s - \left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g} - h_f\right)$$

$$= 10.3 - 4.8 - \left(\frac{5.625^2}{2\times 9.81} - \frac{2.5^2}{2\times 9.81} - \frac{0.2\times V_2^2}{2g}\right)$$

$= 4.27m$

(ii) Efficiency of ~~turbine~~ Draft tube

$$\eta_d = \frac{\left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right) - h_f}{\frac{V_1^2}{2g}} = \frac{\frac{V_1^2}{2g} - \frac{V_2^2}{2g} - \frac{0.2 V_2^2}{2g}}{\frac{V_1^2}{2g}}$$

$$= \frac{V_1^2 - 1.2 V_2^2}{V_1^2} = 1 - 1.2\left(\frac{V_2}{V_1}\right)^2$$

$$= 1 - 1.2\left(\frac{2.5}{5.625}\right)^2$$

$= 0.763$

(or) 76.3 %

Hydraulic performance

* ~~Specific~~

UNIT QUANTITIES

Inorder to predict the behaviour of turbine working under varying condition of head, speed, output ad gate opening, the results are expressed in quantities which may be Obtained the head on the turbine is reduced to Unity.

3 important unit quantities which must be studied under unit head.

① Unit speed
② Unit discharge
③ Unit power.

UNIT SPEED :- defined as Speed of a turbine working under a unit head

It is denoted by Nu

$$N_u = \frac{N}{\sqrt{H}}$$

N_u → Unit speed

N → speed of a turbine under a unit head

H → Head under which a turbine is working

(2) **UNIT DISCHARGE** :- It is defined as discharge passing through a turbine which working under a unit head

→ It is denoted by Q_u

$$Q_u = \frac{Q}{\sqrt{H}}$$

Q_u → Unit discharge

Q → Discharge passing through turbine

H → Head of water on the turbine

(3) **UNIT POWER** :- It is defined as power developed by a turbine, working under a unit head

→ It is denoted by P_u.

$$P_u = \frac{P}{H^{3/2}}$$

P_u → unit power

P → Power developed by the turbine under a head of H.

H → Head of water on turbine

① A turbine develops 9000 KW when running at 10 r.p.m The head on the turbine is 30m. If the head on the turbine is reduced to 18 m. determine the speed and power developed by turbine.

Power (P_1) = 9000 KW

Speed (N_1) = 100 r.p.m

Head (H_1) = 30m

Let for a head (H_2) = 18m

<u>Speed</u>

$$\frac{N_1}{\sqrt{H_1}} = \frac{N_2}{\sqrt{H_2}}$$

$$N_2 = \frac{N_1 \sqrt{H_2}}{\sqrt{H_1}} = \frac{100\sqrt{18}}{\sqrt{30}}$$

$$\boxed{N_2 = 77.46 \text{ r.p.m}}$$

<u>power</u>

$$\frac{P}{H_1^{3/2}} = \frac{P_2}{H_2^{3/2}}$$

$$P_2 = \frac{P H_2^{3/2}}{H_1^{3/2}}$$

$$= \frac{9000 \times 18^{3/2}}{30^{3/2}}$$

$$\boxed{P_2 = 4182.84 \text{ KW}}$$

According to head & Quantity of water required

(1) High head turbine — for very high heads ranging from Several hundread metres to few thousand meters.

→ turbine use relatively less quantity of water

Ex:- pelton wheel turbine.

(2) Medium head turbines —

Water heading range from 60 m to 250 m.

→ Require relatively large quantity of water

Ex:- Francis turbine

(3) Low head turbine :-

→ Below 60 m

→ require large quantity of water

Ex:- Kaplan & propeller turbine

Specific Speed

It is defined as the speed of a turbine which is identical in shape, geometrical dimensions, blade angles, gate openings etc.

→ It is denoted by symbol 'Ns'.

* Specific speed is used in comparing the different types of turbine as every type of turbine has different specific speed.

From overall efficiency

$$\eta_o = \frac{\text{shaft power}}{\text{water power}}$$

$$\boxed{N_s = \frac{N\sqrt{P}}{H^{5/4}}}$$

Significance of Specific Speed

specific speed plays an important role for selecting the type of turbine.

→ Also performance of a turbine can be predicted by knowing the specific speed of turbine

S.NO	Specific Speed M.K.S	Specific Speed S.I	Types of turbines
1	10 – 35	8.5 – 30	Pelton wheel with single jet
2	35 – 60	30 to 51	Pelton wheel with two (or) more jets
3	60 – 300	51 to 225	Fransis turbine
4	300 – 1000	255 – 860	Kaplan (or) propeller turbine

① A turbine develops 7225 KW power under a head of 25mt at 135 r.p.m. Calculate the specific speed of the turbine and .

Sol

power (P) = 7225 KW

Head (H) = 25m

speed (N) = 135 r.p.m

Specific speed of the turbine

$$N_s = \frac{N\sqrt{P}}{H^{5/4}} = \frac{135 \times \sqrt{7225}}{25^{5/4}}$$

$$\boxed{N_s = 205.28}$$

② A turbine is operate under a head of 25m at 200 rpm The discharge is 9 cumec. If the efficiency is 90% determine i) Specific speed of machine (ii) Power generated (iii) Type of turbine

$H = 25m$

$N = 200$ rpm

$Q = 9$ cumec $= 9\ m^3/sec$

$\eta_o = 90\% = 0.90$

$$\eta_o = \frac{\text{Power developed}}{\text{Water power}} = \frac{P}{\frac{\rho g Q H}{1000}}$$

$$P = \eta_o \times \frac{\rho g Q H}{1000} = \frac{0.90 \times 9.81 \times 1000 \times 9 \times 25}{1000}$$

$$\boxed{P = 1986.5\ KW}$$

i) Specific speed of machine $N_s = \frac{N\sqrt{P}}{H^{5/4}} = \frac{200 \times \sqrt{1986.5}}{25^{5/4}}$

$\boxed{N_s = 189.167}$ SI units

ii) power generated $\boxed{P = 1986.5\ KW}$

iii) As the specific speed lies b/w 51 and 255, then turbine is a Francis turbine

Hydropower Engineering

Hydropower (or) Hydroelectricity refers to the convession of hydraulic energy from flowing wates into electricity.

→ It is considerd a renewable energy source because the water cycle is constantly renewed by the sun.

* Types of Hydropower plants

According to availability of head

According to availablity of heads are mainly classified into 3-types

i) Low head plant
ii) Medium head plant.
iii) High head.

i) Low head plant :-

* Head is less than 50m.
* No surge tank is required.
* Francis, propeller (or) Kaplan tusbine is used prime mover.

ii) Medium head :-

* Head is usually lies b/w 50m to 300m
* Surge tank is required.
* Francis, propeller (or) Kaplan tusbine is used prime mover.

iii) High head

* Head is greater than 300m
* Surge tank is provided to reduce water hammer effect
* Francis, pelton wheel tusbine is used prime mover.

II) <u>According to nature of load</u> :-

(1) Base load plant.
(2) peak load plant.

(1) <u>Base load plant</u> :-

→ This type of power plant generates power output continuously.
→ They run without stop and meet the avg demand of electricity.

(2) <u>peak load plant</u> :-

→ This plant, generates power during the peak load hours.
→ This plant do not runs continously and generate power to meet the demand of electricity.

III) <u>According to quantity of water available</u>

1) <u>Runoff river plant</u> —

* When a river flowing through a hilly region, the flowing water is directly fed to turbines, water is not being stored, the power plant is known as run-off river plant.

<u>Run-off river plant with reservoir</u> —

* The utility of runoff power plant is increased by providing reservoir in the plant
* The reservoir allow to store water during the peak off hours and use during peak hours of the same day.

(2) <u>Storage type plant</u>

* In this type of plant water is stored during rainy season and supply same duration the dry season.

Pump storage plant :-

* This type of power plant is used where less amount of water is available
* In this plant, water after passing through turbine is pumped back from the tail race to head race during the off period of other power plant.

Mini (Head is 5m - 20m) and Micro (Head is less than 5m) Hydro plant :-

* when power develops from low head as 5m to 20m plant is known as mini hydroplant.
* when power develops from head less than 5m, plant is known as micro-hydro power plant.

According to purpose

(1) Single purpose.

(2) Multipurpose.

① A hydropower plant has an installed capacity of 50 MW. The yearly output of the plant is 250×10^6 KWh. If peak load is 40,000 KW. find i) Annual load factor

ii) Utilization Factor.

iii) Capacity Factor

sol

i) Annual load Factor = $\frac{\text{Avg power}}{\text{Max. power}}$

$$= \frac{250 \times 10^6 \text{ KWh}}{40{,}000 \text{ KW}}$$

$$= 0.71$$

ii) Utilization factor = $\frac{\text{Peak load}}{\text{Installed Capacity}}$

$$= \frac{40{,}000 \text{ KW}}{50 \text{ MW}} = 0.8$$

iii) Capacity factor = $\frac{\text{Avg output of the plant}}{\text{Installed Capacity of the plant}}$

$$= \frac{250 \times 10^6 \text{ KWh}}{50 \text{ MW}} = 0.57$$

Definations :-

(1) Load factor :-

Load :- Amount of power deliverd (or) recieved at a given point at any instant.

Avg load :- The total load produced divided by the no. of hours in that time period.

Peak load :- Maximum instantaneaus load (or) Maximum avg load over a specificied period of time.

(1) **Load Factor** :- It is the ratio of average load by the peak load within the given time range.

* The degree of variation of the load over a period of time is measured by load factor.

* Load factor measures variation only. does not give any shape of load duration curve.

* Annual load factor 0.4 indicates that the machine are producing only 40 % of their yearly production capacity.

$$\text{Load factor} = \frac{\text{Avg (or) mean load}}{\text{Max (or) peak load}}$$

(2) Utilization factor :-

It defined as the ratio of the peak load and the rated capacity of the plant.

$$\text{Utilization factor} = \frac{\text{Power peak factor}}{\text{Installed Capacity of the plant}}$$

* Ratio of quantity of water actually utilized of power production to that available in the river.

* The value of Utilization factor varies b/w 0.4 - 0.9 depending upon the plant capacity, load factor and storage.

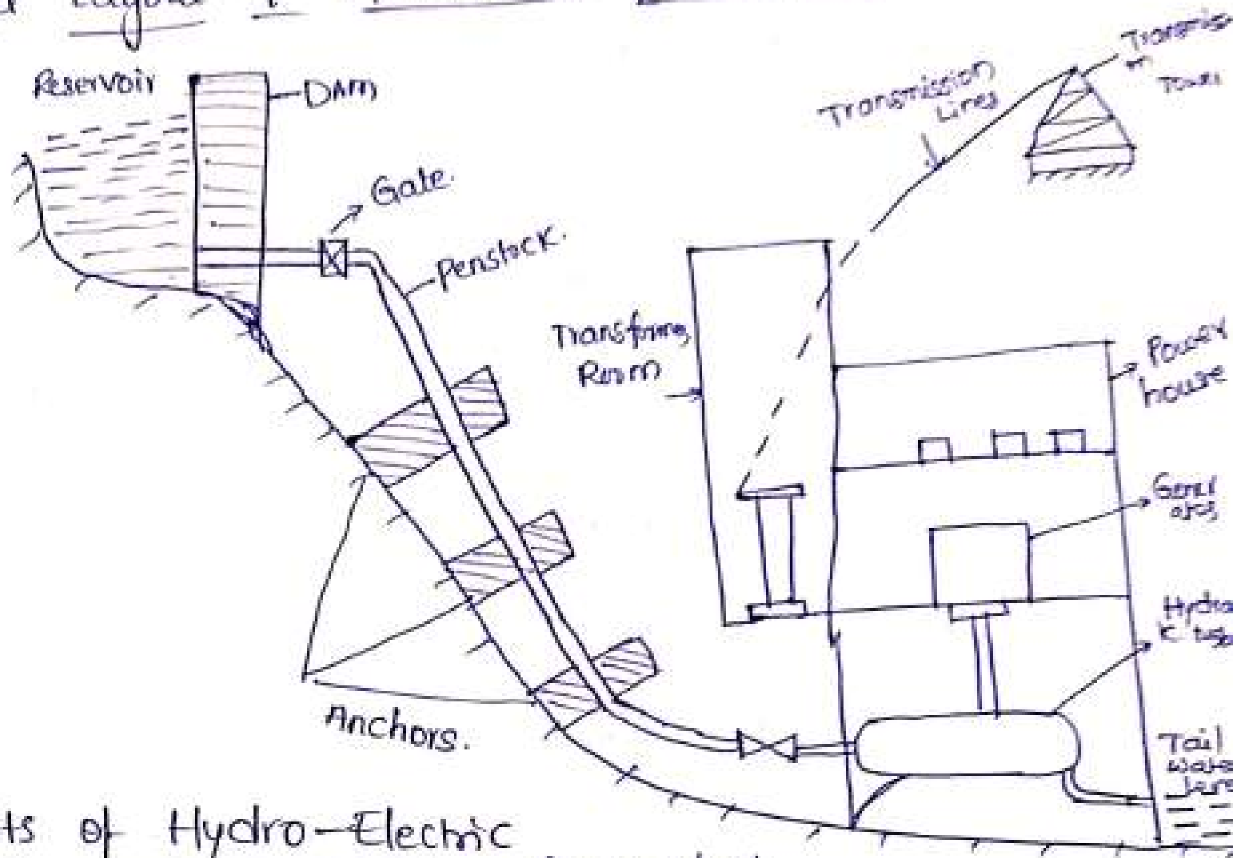
(3) Capacity factor :- It is the ratio of the avg output of the plant to installed capacity of plant.

$$\text{Capacity factor} = \frac{\text{Avg output of the plant}}{\text{Installed capacity of plant}}$$

* The extent of use of the generating plant is measured by the capacity factor.

* The capacity factor for hydroelectric plants generally varies b/w 0.25 - 0.75

General Layout of Hydroelectric power plant



Components of Hydro-Electric Power plant

1. storage reservoir.
2. Dam.
3. Forebay.
4. Spillway.
5. Surge tank
6. penstock.
7. Valves and Gates.
8. Tail Race.
9. Draft tube
10. Hydraulic turbine.

(1) Storage Reservoir :- It purpose is store water during excess flow periods and supply the same during dry periods.

(2) Dam :- A dam is a structure of consiterable height built across the river to provide working head of water for power plant

(3) forebay :- It is a small water reservoir at the end of water passage from the reservoir and before the water is fed to the penstock

→ It is temperory regulating reservoir. It store water when the load is light and supplied same water during peak period.

(4) Spillway :- It acts as safety valve. It discharge the overflow water to d/s side when the reservoir is full.

(5) Surge tank :- A reduction in load on generator causes the governor to close the turbine gates.

(6) penstock — It is a closed conduit which connect the forebay (or) surge tank to the case of turbine

(7) Valves and gates — Valves and gates provided for controlling of flow of water from reservoir to hydraulic turbine.

(8) Tail race :- after useful work in turbine the water discharge to tail race which may lead to the river (or) Reservoir.

9) Draft tube :- An air tight pipe giving passage to the runner outlet water of the turbine to tail race

10) Hydraulic turbine — Converting H.E to M.E.

Multistage Centrifugal pump

If a centrifugal pump consist of two (or) more impellers, the pump is called a multistage centrifugal pump.

→ The impellers may be mounted on the same shaft (or) different shaft.

A multistage pump is having two important functions

1) To produce high head

2) To discharge a large quantity of liquid.

- If high head is to be developed, the impellers are connected in series (or on the same shaft),

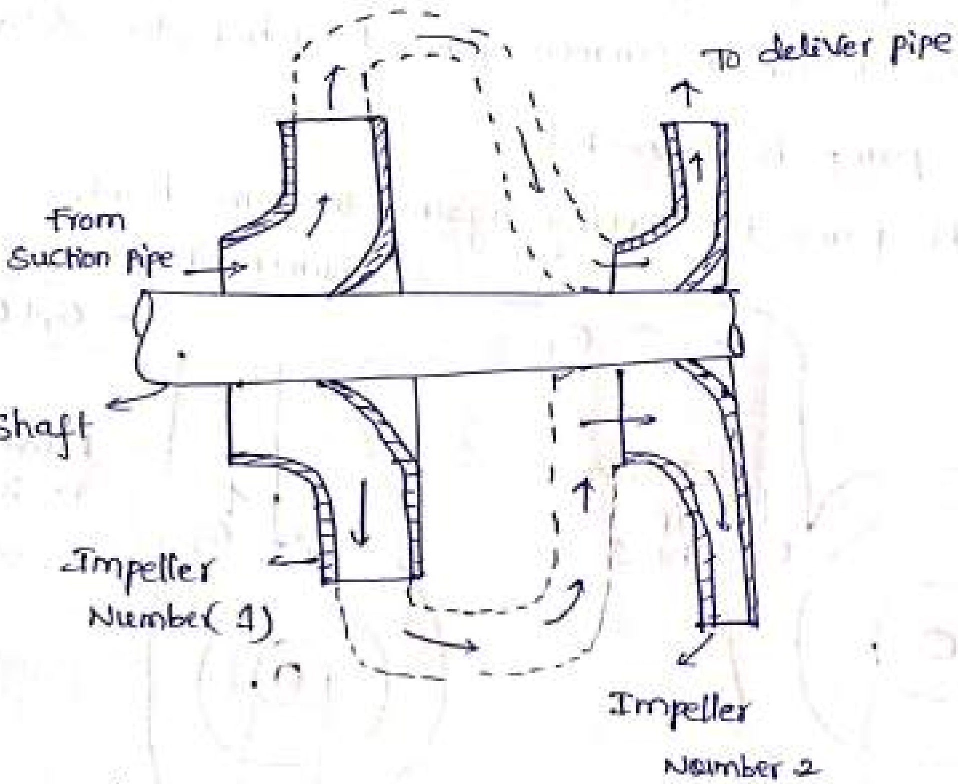
- While for discharging large quantity of liquid, the impellers are connected in parallel.

(1) Multistage Centrifugal pump for high heads :-

For developing a high head, number of impellers are mounted in series (or) on the same shaft.

→ The water from the suction pipe enters the 1st impeller are at inlet and discharged at outlet with increased pressure the water with increased pressure from outlet of the first impeller is taken to the inlet of the 2nd impeller with the help of connecting pipe.

At the outlet of the 2nd impeller, the pressure of water will be more than pressure of water at the outlet of the 1st impeller. Thus if more impellers are mounted on the same shaft the pressure at the outlet will be increased.



Pipe connecting outlet of 1st impeller to inlet of second impeller

fig :- Two - stage pumps with impeller in series

n = number of identical impellers mounted on the same shaft

H_m = Head developed by each impeller.

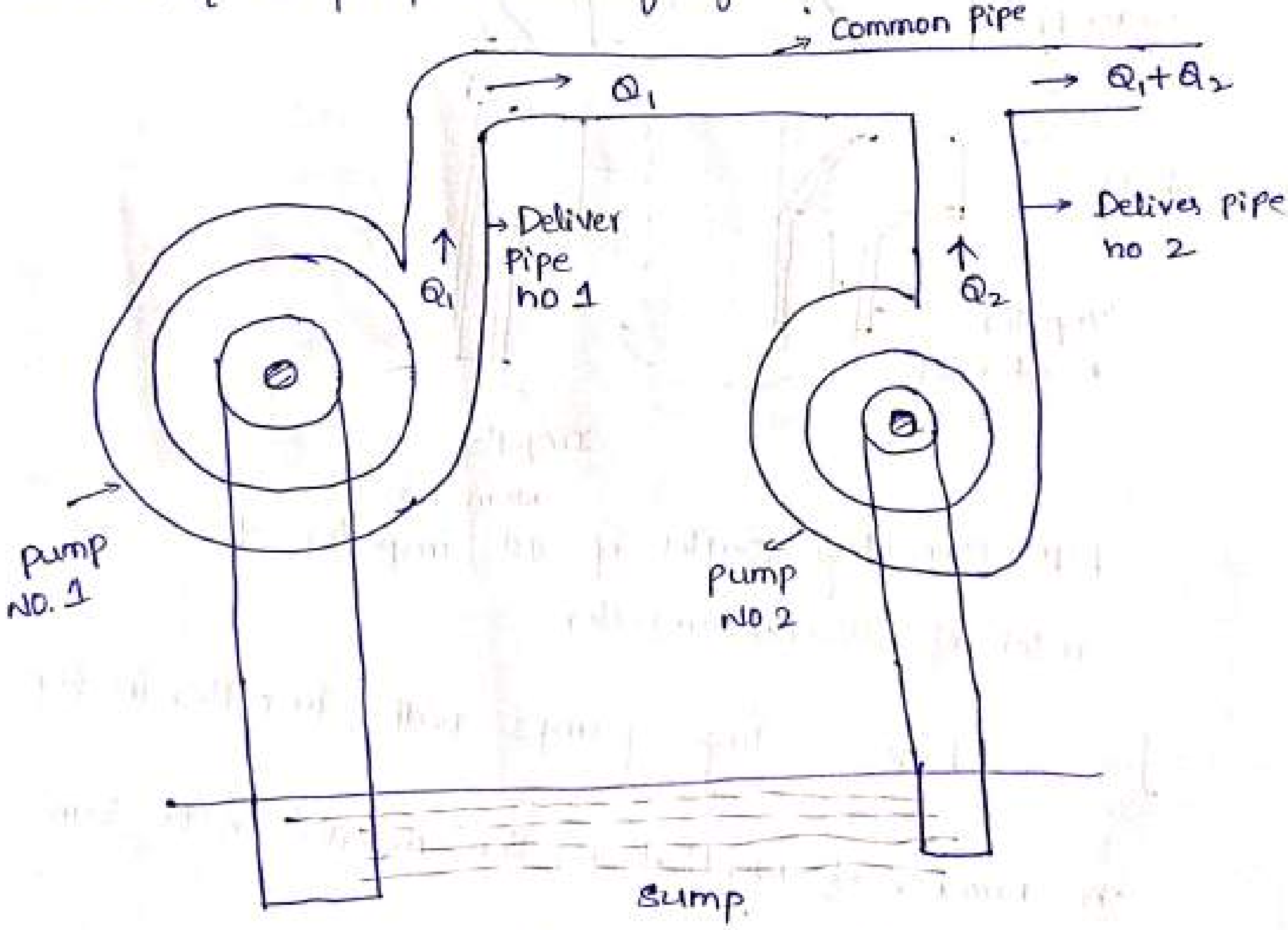
| Total head developed = $n \times H_m$ |

Multistage centrifugal pump for High discharge

For Obtain high discharge, the pumps should be connected in parallel

→ Each of the pumps lift the water from a common pump and discharge water to common pipe to which the delivery pipe of each pump is connected.

→ Each of the pump is working against the same head.



Pumps in parallel

n = no. of identical pumps arranged in parallel

Q = Discharge from one pump

Total discharge = nQ

① The internal and external diameter of the impeller of a Centrifugal pump are 200mm and 400mm respectively. The pump is running at 1200 r.p.m. The vane angle of impeller at inlet and outlet are 20° and 30°. The water enters the impeller radially and velocity of flow is constant. Determine the workdone by the impeller per unit weight of water.

Internal dia (D_1) = 200mm = 0.20m

External dia (D_2) = 400mm = 0.40m

Speed (N) = 1200 r.p.m

Vane angle at inlet $\theta = 20°$

Vane angle at outlet $\phi = 30°$

Water enters radially means $\alpha = 90°$ and $V_{w_1} = 0$

Velocity of flow, $V_{f_1} = V_{f_2}$

Tangential velocity of impeller at inlet and outlet are

$$u_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.20 \times 1200}{60} = 12.56 \text{ m/sec}$$

$$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.4 \times 1200}{60} = 25.13 \text{ m/sec}$$

From inlet velocity triangle $\theta = \frac{V_{f_1}}{u_1} = \frac{V_{f_1}}{12.56}$

$$V_{f_1} = 12.56 \tan\theta$$
$$= 12.56 \times \tan 20°$$

$$\boxed{V_{f_1} = 4.57 \text{ m/sec}}$$

$$V_{f_1} = V_{f_2} = 4.57 \text{ m/sec}$$

A four-stage centrifugal pump has 4 identical impellers

from outlet velocity triangle

$$\tan\phi = \frac{V_{f_2}}{u_2 - V_{w_2}}$$

$$\tan 30^\circ = \frac{4.57}{25.13 - V_{w_2}}$$

$$\boxed{V_{w_2} = 17.215 \text{ m/sec}}$$

The workdone by impeller per kg of water per second is given by

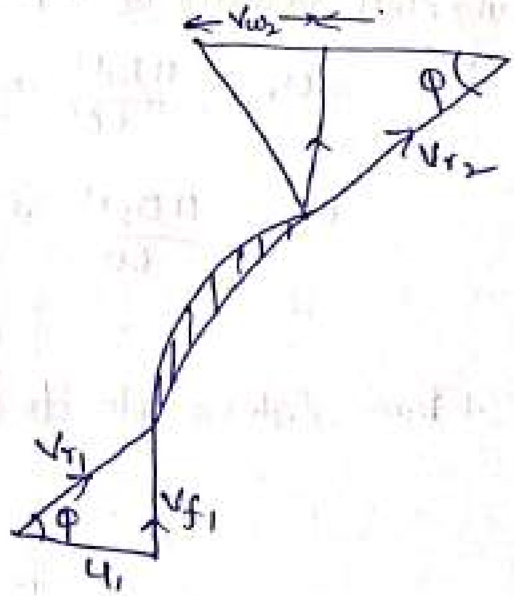
$$= \frac{V_{w_2} u_2}{g}$$

$$= \frac{17.215 \times 25.13}{9.81}$$

$$= 44.1 \frac{N.m}{N}$$

$$= 44.1 \text{m}$$

(2) A Centrifugal pump is to discharge 0.118 m³/sec at a speed of 1450 r.p.m against to head of 25m. The impeller diameter is 250mm, its width at outlet is 50mm and manometric efficiency is 75%. Determine the vane angle at the outer periphery of the impeller.



Discharge (Q) = 0.118 m³/sec.

Speed (N) = 1450 r.p.m

Head, H_m = 25m.

Diameter at outlet, D_2 = 250mm
= 0.25m

Width at outlet B_2 = 50mm
= 0.05m

① A four-stage centrifugal pump has 4 identical impellers keyed to the same shaft. The shaft is running at 400 r.p.m and the total manometric head developed by the multistage pump is 40m. The discharge through the pump is 0.2 m³/sec. The vanes of each impeller are having outlet angle as 45°. If the width and dia of each impeller at outlet is 5cm and 60cm. Find the manometric efficiency.

Sol

Number of stage = 4

$N = 400$ r.p.m

$H_m = 40m$

manometric head for each stage $H_m = \frac{40}{4} = 10m$

$Q = 0.2 \, m^3/sec.$

outlet angle $\phi = 45^\circ$

width at outlet $B_2 = 5cm = 0.05m$

Dia at outlet $D_2 = 60cm = 0.6m.$

Tangential velocity of impeller at outlet

$$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.6 \times 400}{60}$$

$$\boxed{u_2 = 12.56 \, m/sec}$$

Velocity of flow at outlet, $V_{f_2} = \frac{\text{Discharge}}{\text{Area of flow}}$

$$= \frac{0.20}{\pi D_2 B_2} = \frac{0.20}{\pi \times 0.6 \times 0.5}$$

$$= 2.122 \, m/sec$$

from velocity triangle at outlet

$$\tan\phi = \frac{V_{f_2}}{u_2 - V_{w_2}}$$

$$u_2 - V_{w_2} = \frac{V_{f_2}}{\tan\phi}$$

$$u_2 - V_{w_2} = \frac{2.122}{\tan 45^\circ}$$

$$V_{w_2} = u_2 - 2.122$$

$$V_{w_2} = 10.438$$

$$\eta_{man} = \frac{g H_m}{V_{w_2} u_2} = \frac{9.81 \times 10.0}{10.438 \times 12.56}$$

$$\eta_{man} = 0.7482$$

$$\boxed{\eta_{man} = 74.82\%}$$

Priming of a Centrifugal pump :-

When a pump is first put into service, it's passageways (suction pipe, Casing, delivery pipe) are filled with water.

→ Pressure head generated by air is negligible compare to pressure head generated by water, hence initially water may not be sucked by pump from sump.

→ Therefore to avoid this, before first time start the pump air must be removed from passageways.

Priming." Operation in which the suction pipe, casing of the pump and a portion of delivery pipe upto the delivery valve is compleatly filled up from outside source with the liquid to be raised by pump before starting the pump."

Characterstic curves of Centrifugal pump :-

Curves which are plotted from the results of a number of tests on the Centrifugal pump.

→ These curves are necessary to predict the behaviour and performance of the pump, when the pump is working under different flow rate, head and speed.

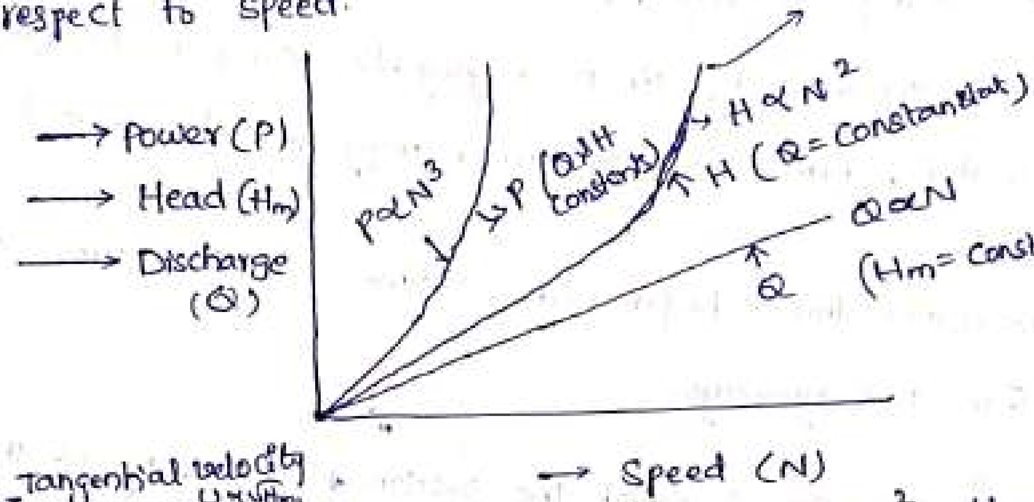
The important charecterstics curves of pump

1. Main charecteristic curves.
2. Operating charecteristic curves.
3. Constant efficiency (or) Muschel curves.

(3) Constant Efficiency

① Main charecteristic Curves :-

The main charecteristic curves of centrifugal pump consist of variation of head (Manometric head (H_m)), power, and discharge with respect to speed.



(i) H_m vs N, $\frac{\sqrt{H_m}}{DN}$ = constant, $H_m \propto N^2$, H_m vs N is parabolic curve.

Tangential velocity $u \propto \sqrt{H_m}$

(ii) $\frac{P}{D^5N^3}$ = constant, $P \propto N^3$, P vs N → Cubic curve.

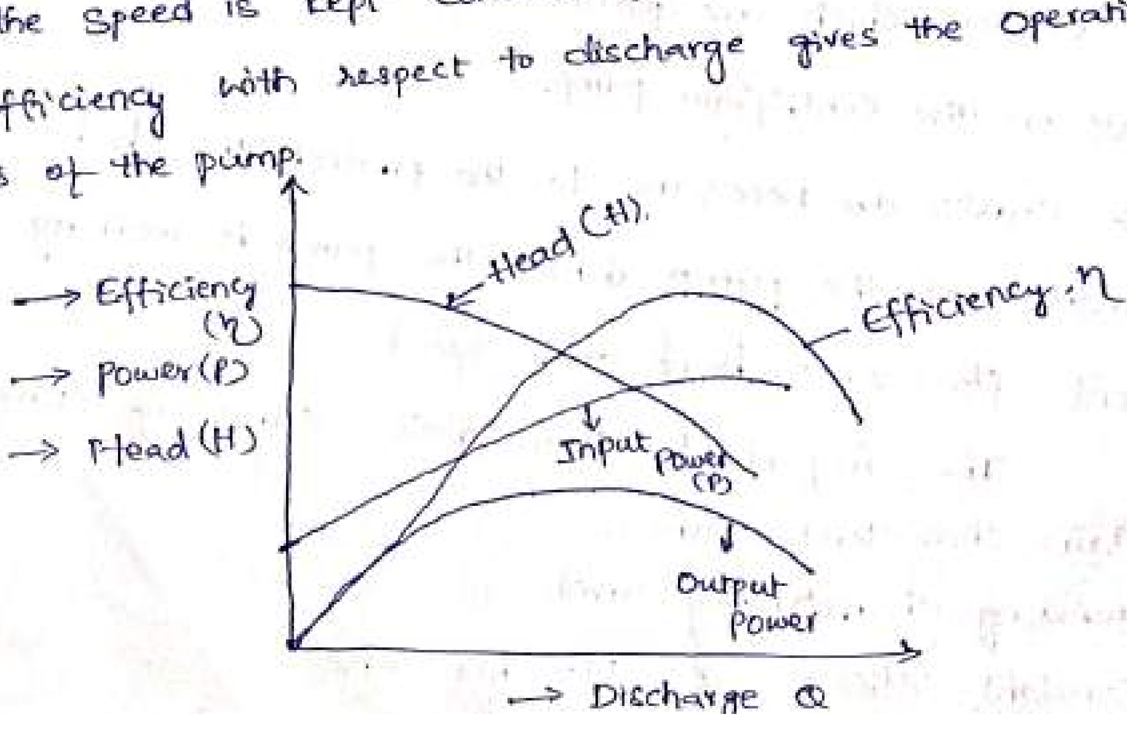
P → Power of the pump.

(iii) $\frac{Q}{D^3N}$ = Constant, $Q \propto N$ → Q vs N – Straight line

Q → Discharge of the pump

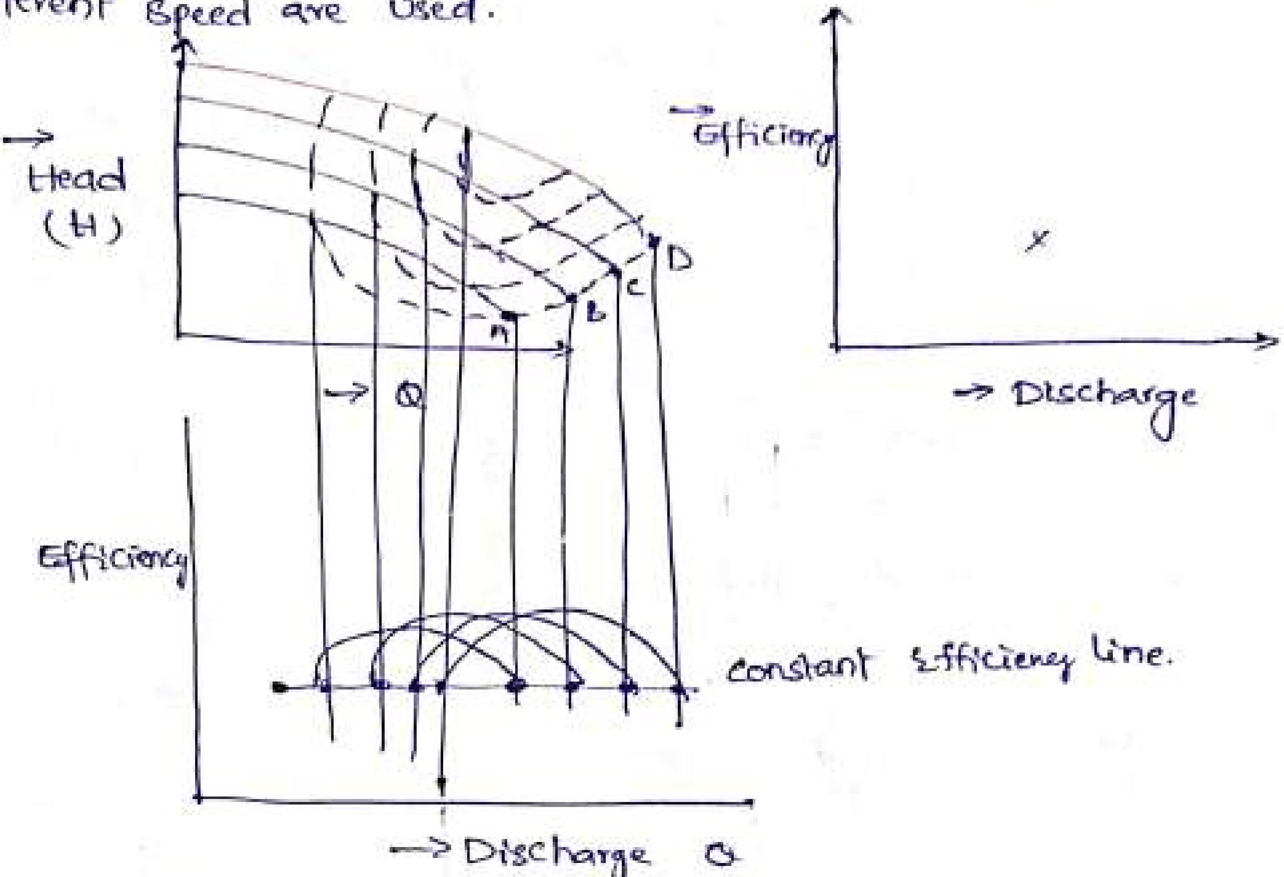
(2) Operating Charecteristic Curve :-

→ If the speed is kept constant, variation of manometric head, power and efficiency with respect to discharge gives the operating charecteristics of the pump.



(3) Constant Efficiency

For obtaining efficiency curve of the pump the head vs discharge curves and efficiency vs discharge curves for different speed are used.



Constant Efficiency curves of a pump

Cavitation in Centrifugal pump :-

- In centrifugal pump, the pressure is lowest at the inlet of the impeller, and hence vapour bubbles are formed in the suction region
- Vapour bubble are Create due to reason of pressure of water below the vapour pressure
- These bubbles are carried along with the flowing of liquid to higher pressure region near the exit of the impeller where these vapour bubble collapse
- Due to sudden collapsing of bubbles on metallic surface the high pressure is created.
- which cause pitting action on metallic surface and produce much noise and vibrations.

Factors or Reasons make more tendancy of Cavitation in pump

(1) High impeller speed

(2) small diameter of suction pipe and inlet of impeller

(3) Too high specific speed.

(4) High temperature of flowing fluid.

(5) Required NPSH $\geq$ = Available NPSH

Effects of Cavitation :-

(1) The metallic surface are damaged and cavities are formed on the surface

(2) Due to sudden collapse of vapour bubble, noise and vibrations are produced.

(3) The efficiency of turbine decreases due to cavitation.

precautions against Cavitation :-

(1) The pressure of the flowing liquid any part of the hydraulic system should not be allowed to fall below it's vapour pressure. If the flowing liquid is water, then the absolute pressure head should not be below 2.5m of water.

(2) The special material (or) Coatings such as aluminium bronze and stainless steel, which are

Cavitation in centrifugal pump :-

In Centrifugal pump the cavitation may occur the inlet of the impeller of the pump.

Thoma's cavitation factor for centrifugal pumps

$$\sigma = \frac{(H_b) - H_s - h_{LS}}{H}$$

$$= \frac{(H_{atm} - H_v) - H_s - h_{LS}}{H}$$

H_{atm} = Atmospheric pressure head in m of water.

H_v = Vapour pressure head in m of water.

H_s = Suction pressure head " "

h_{LS} = Head loss due to friction in suction pipe

H = Head developed by pump.

Specific speed of a Centrifugal pump :-

Speed of a geometrically similar pump that would deliver 1 m³ of liquid per second against head of 1m.

→ It is denoted by 'N_s'

$$N_s = \frac{N\sqrt{Q}}{H^{3/4}}$$

N → Normal speed of the pump
Q → flow rate of liquid
H_m → Manometric Head, m

The flow through impeller (discharge) is given by

$$Q = \pi D_1 B_1 V_{f_1} = \pi D_2 B_2 V_{f_2}$$

$$Q \propto D B V_f \quad \therefore \; Q \propto D_2 B_2 V_f$$

$$Q \propto D^2 V_f \rightarrow (1) \quad (B \propto D)$$

Tangential speed of impeller is given by

$$U = \frac{\pi D N}{60} \quad \therefore \; U \propto DN \rightarrow (2)$$

But $U = K_u \sqrt{2gH_m}$

$$U \propto \sqrt{H_m} \longrightarrow (3)$$

$$DN \propto \sqrt{H_m}$$

$$D \propto \frac{\sqrt{H_m}}{N} \longrightarrow (4)$$

$$V_f = K_f \sqrt{2gH_m}, \quad V_f \propto \sqrt{H_m} \longrightarrow (5)$$

putting (4) & (5) in eqn we get.

$$Q \propto \left(\frac{\sqrt{H_m}}{N}\right)^2 \sqrt{H_m}$$

$$Q \propto \frac{H_m^{3/2}}{N^2}$$

$$N^2 \propto \frac{H_m^{3/2}}{Q}$$

$$N \propto \frac{H_m^{3/4}}{\sqrt{Q}}$$

$$N = C \frac{H_m^{3/4}}{\sqrt{Q}}$$ ∴ where c is constant → (6)

where $Q = 1\ m^3/sec$, $H_m = 1$, $C = N$

which is known as specific speed N_s.

∴ putting $C = N_s$

$$N = N_s \cdot \frac{H_m^{3/4}}{\sqrt{Q}}$$

$$\boxed{N_s = \frac{N\sqrt{Q}}{H^{3/4}}}$$ → specific speed of centrifugal pump.

(1) find the number of pumps required to take water from a deep well under a total head of 89 m. All the pumps are identical and are running at 800 r.p.m. The specific speed of each pump is given by as 25 while the rated capacity of each pump is 0.16 m^3/sec.

$H = 89m$

$N = 800$ r.p.m

$N_s = 25$

$Q = 0.16\ m^3/sec$

$$N_s = \frac{N\sqrt{Q}}{H_m^{3/4}}$$

$$25 = \frac{800 \times \sqrt{0.16}}{H_m^{3/4}}$$

$$\boxed{H_m = 29.94m}$$

No. of pumps required

$$= \frac{\text{Total head}}{\text{Head developed by one pump}}$$

$$= \frac{89}{29.94}$$

$$= 3$$