NEC NARASARAOPETA
ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

COURSE FILE

Academic year : 2022-23

Department : ME

Course Name : B.Tech

Student's Batch : 2022-23

Regulation : R20

Year and Semester : III B.Tech I Semester

Name of the Subject : Heat Power Engineering

Subject Code : R20ME3102

Faculty In charge : P.SRINIVASARAO

P. Srinivas

Signature of Faculty

Head of the Department

COURSE FILE CONTENTS

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NEC NARASARAOPETA
ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

INSTITUTE VISION AND MISSION

NARASARAOPETA
ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

INSTITUTE VISION AND MISSION

VISION:

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

MISSION:

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

PRINCIPAL

NEC NARASARAOPETA
ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

DEPARTMENT VISION AND MISSION

NEC NARASARAOPETA
ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

DEPARTMENT VISION AND MISSION

VISION:

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

MISSION:

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

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

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

HOD-ME

NARASARAOPETA
ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

PROGRAM EDUCATIONAL OBJECTIVES (PEOs)

AND

PROGRAM SPECIFIC OUTCOMES (PSOs)

NARASARAOPETA
ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

PROGRAM EDUCATIONAL OBJECTIVES (PEOs)

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

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

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

PROGRAM SPECIFIC OUTCOMES (PSOs)

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

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

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

HOD-ME

NEC NARASARAOPETA
ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

PROGRAM OUTCOMES
(POs)

NARASARAOPETA
NEC ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

PROGRAM OUTCOMES (POs):

Engineering Graduates will be able to:

1. **Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis:** Identify, formulate, review research literature, and analyse complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modelling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
12. **Life-long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

HOD-ME

NEC NARASARAOPETA ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

BLOOM'S TAXONOMY LEVELS

REVISED Bloom's Taxonomy Action Verbs

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

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

NEC NARASARAOPETA
ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

COURSE OUTCOMES
(COs)

NARASARAOPETA
NEC ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING
B.TECH – R20 REGULATION
COURSE OUTCOMES

III B. TECH I SEMESTER

Course Name: HEAT POWER ENGINEERING		Course Code: C312
CO	**After successful completion of this course, the students will be able to:**	
C312.1	**Illustrate** the various types of efficiency improvements of Rankine cycle	
C312.2	**Describe** the various boilers, mountings and accessories.	
C312.3	**Identify** different types of nozzles used in steam turbines.	
C312.4	**Classify** different turbines based on utility and applications.	
C312.5	**Discuss** gas turbines, jet propulsion and rocket propulsion.	

NARASARAOPETA
ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

COURSE INFORMATION SHEET

NEC

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

COURSE INFORMATION SHEET (Academic year 2023-24)

PROGRAMME: B.Tech Mechanical Engineering		
COURSE: **Heat Power Engineering**	Semester : **I**	CREDITS: **3**
COURSE CODE: **R20ME3102** REGULATION: **R20**	COURSE TYPE (CORE /ELECTIVE / BREADTH/ S&H): **CORE**	
COURSE AREA/DOMAIN: **THERMAL**	PERIODS: **6** Per Week.	

COURSE PRE-REQUISITES:

C.CODE	COURSE NAME	DESCRIPTION	SEM
R20ME2104	Thermodynamics	Knowledge of Thermodynamic laws and relations are required	I

COURSE OUTCOMES:

SNO	Course Outcome Statement
CO1	Illustrate the various types of efficiency improvements of Rankine cycle [K2]
CO2	Demonstrate the various boilers, mountings and accessories [K2]
CO3	Identify different types of nozzles used in steam turbines. [K3]
CO4	Classify different turbines based on utility and applications [K4]
CO5	Discuss gas turbines, jet propulsion and rocket propulsion [K3]

SYLLABUS:

UNIT	DETAILS
I	**STEAM POWER PLANT:** Rankine cycle - Schematic layout, Thermodynamic Analysis, Concept of Mean Temperature of Heat addition, Methods to improve cycle performance – Regeneration & reheating. **COMBUSTION:** Fuels and combustion, concepts of heat reaction, adiabatic flame temperature, flue gas analysis- Orsat apparatus analysis.
II	**BOILERS** – Classification – Working principles with sketches including LP & H.P .Boilers – Mountings and Accessories – Working principles- Boiler horse power, Equivalent Evaporation, Efficiency and Heat balance. **DRAUGHT:** Classification – Height of chimney for given draught and discharge- Condition for maximum discharge- Efficiency of chimney.
III	**STEAM NOZZLES:** Stagnation Properties- Function of nozzle – Applications and Types- Flow through nozzles- Thermodynamic analysis – Assumptions -Velocity of nozzle at exit-Ideal and actual expansion in nozzle- Velocity coefficient- Condition for maximum discharge- Critical pressure ratio- Criteria to decide nozzle shape- Super saturated flow, its effects, Degree of super saturation and Degree of under cooling - Wilson line.
IV	**STEAM TURBINES:** Classification – **Impulse turbine;** Mechanical details – Velocity diagram – Effect of friction – Power developed, Axial thrust, Blade or diagram efficiency – Condition for maximum efficiency. De-Laval Turbine - its features- Methods to reduce rotor speed-Velocity compounding and Pressure compounding- Velocity and Pressure variation along the flow – Combined velocity diagram for a velocity compounded impulse turbine.

	Reaction Turbine: Mechanical details – Principle of operation, Thermodynamic analysis of a stage, Degree of reaction –Velocity diagram – Parson's reaction turbine – Condition for maximum efficiency.
V	**GAS TURBINES:** Simple gas turbine plant – Ideal cycle, essential components – Parameters of performance – Actual cycle – Regeneration, Inter cooling and Reheating –Closed and Semi-closed cycles – Merits and Demerits. **JET PROPULSION:** Principle of Operation –Classification of jet propulsive engines – Working Principles with schematic diagrams and representation on T-S diagram - Thrust, Thrust Power and Propulsion Efficiency – Turbo jet engines – Needs and Demands met by Turbo jet – Schematic Diagram, Thermodynamic Cycle, Performance Evaluation.

TEXT BOOKS

T	BOOK TITLE/AUTHORS/PUBLISHER
T1	Thermodynamics and Heat Engines, Volume 2, R.Yadav, Central book depot.
T2	Heat Engineering, V.P Vasandani and D.S Kumar, Metropolitan Book Company, New Delhi

REFERENCE BOOKS

R	BOOK TITLE/AUTHORS/PUBLISHER
R1	Gas Turbines and Propulsive Systems, P.Khajuria&S.P.Dubey, Dhanpatrai
2	Gas Turbines, Cohen, Rogers and Saravana Muttoo, Addison Wesley, Longman, John wiley& sons
R3	Thermal Engineering, R.S Khurmi, JS Gupta, S.Chand, Mechanical Engineering

TOPICS BEYOND SYLLABUS/ADVANCED TOPICS:

SNO	DESCRIPTION	Associated PO & PSO
1	Economic and environmental considerations of power plants	
2	Heat Exchangers	

WEB SOURCE REFERENCES:

1	http://home.iitk.ac.in/~suller/lectures/lec29.htm
2	https://nptel.ac.in/courses/112/103/112103277/
3	http://nptelvideos.com/video.php?id=1181
4	http://150.107.117.36/NPTEL_DISK4/NPTEL_Contents/Web_courses/Phase1_web/112104117/machine/ui/Course_home-lec24.htm
5	https://nptel.ac.in/courses/112/106/112106166/

DELIVERY/INSTRUCTIONAL METHODOLOGIES:

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

MAPPING CO'S WITH PO'S& PSOs

Course Code: C312	Course Name: HEAT POWER ENGINEERING														
COs	POs & PSOs														
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
C312.1	3	3	2	-	-	-	-	-	-	-	-	-	-	3	-
C312.2	3	3	2	1	-	-	-	-	-	-	-	-	-	3	2
C312.3	3	3	2	1	-	-	-	-	-	-	-	-	-	3	2
C312.4	3	3	2	1	-	-	-	-	-	-	-	-	-	3	2
C312.5	3	3	2	1	-	-		-	-	-	-	-	-	3	2
C312	3.00	3.00	2.00	1.00	-	-	-	-	-	-	-	-	-	3.00	2.00

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

Course Coordinator

Module Coordinator

Head of the Department

ANNEXURE I:

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

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

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

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

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

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

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

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

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

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

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

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

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

(B) PROGRAM SPECIFIC OUTCOMES (PSOs):

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

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

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

Cognitive levels as per Revised Blooms Taxonomy:

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

Model Question Paper

Code: R20ME3102

R16

Narasaraopeta Engineering College
(Autonomous)
Yallmanda(Post), Narasaraopet-522601
B. Tech V Semester Regular Examinations
HEAT POWER ENGINEERING
MECHANICAL ENGINEERING
[OUTCOME BASED EDUCATION PATTERN]

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

Note: Answer All **FIVE** Questions.
All Questions Carry Equal Marks (5 X 14 = 70M)

Q.No.		Questions	Marks
		Unit-I	
1	a	Explain the concept of "mean temperature of heat addition"?	[14M]
		OR	
	b	In a regenerative cycle the inlet conditions are 40 bar and 4000C. Steam is bled at 10 bar in regenerative heating. The exit pressure is 0.8 bar. Neglecting pump work, determine the efficiency of the cycle.	[14M]
		Unit-II	
2	a	What are the essentials of a good steam boiler? Estimate the factors which should be considered while selecting a boiler.	[7M]
		What do you understand by feed check valve? Explain the working of a feed check valve with a neat sketch	[7M]
		OR	
	b	A Lancashire boiler generates 2400 kg of dry steam per hour at a pressure of 11 bar. The grate area is 3m^2 and 90kg of coal is burnt per m^2 of grate area per hour. The calorific value of the coal is 33180 kJ/kg and the temperature of feed water is 17.5°C.Slove: 1.Actual evaporation per kg of coal 2. Equivalent evaporation from and at 100°C and 3. Efficiency of the boiler	[14M]
		Unit-III	
3	a	Explain the classification and working principle of a nozzle.	[14M]
		OR	

	b	Steam from nozzle enters into a single stage impulse turbine at 300 m/s absolute velocity. The nozzle angle=250. The blade rotor mean diameter is 100cm and rotating at a speed of 2000 rpm. Find the blade angles if the axial thrust is zero. Find the power developed when the steam flow rate is 600 kg/min. Take blade velocity coefficient=0.9.	[14M]

4	Unit-IV		
	a	A stage of impulse-reaction turbine is provided with single row wheel whose mean diameter is 100cm and it is rotating at 50 rps. The nozzle angle=200 and the velocity of steam coming out of the turbine is 350 m/sec. Determine the power developed if the axial thrust on the end bearings is limited to 118N. Take blade friction factor=0.8. Assume the blades are equi-angular.	[14M]
	OR		
	b	Show that for maximum diagram efficiency of a reaction turbine the blade-steam speed ratio is equal to cos α, where α is the angle of absolute velocity at inlet. State the assumptions made	[7M]
		What is the fundamental difference between the operation of impulse and reaction turbines? Explain the same with neat sketches.	[7M]
5	Unit-V		
	a	Discuss briefly the methods employed for the improvement of thermal efficiency of an open cycle gas turbine plant.	[14M]
	OR		
	b	What do you understand by after burning? Explain.	[14M]

❖

Model Question Paper

Code: R20ME3102

R16

Narasaraopeta Engineering College
(Autonomous)
Yallmanda(Post), Narasaraopet- 522601
B. Tech V Semester Regular Examinations
HEAT POWER ENGINEERING
MECHANICAL ENGINEERING
[OUTCOME BASED EDUCATION PATTERN]

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

Note: Answer All **FIVE** Questions.
All Questions Carry Equal Marks (5 X 14 = 70M)

Q.No.		Questions	Marks
1		Unit-I	
	a	Describe the various operations of a Rankine cycle. Derive its expression for the thermal efficiency	[14M]
		OR	
	b	Compare the Rankine efficiency of a high pressure plant operating from 80bar and 4000C and a low pressure plant operating from 40bar and 4000C, if the condenser pressure in both cases is 0.07bar.	[14M]
2		Unit-II	
	a	What do you understand by Boiler Draught? Discuss its classification in detail	[14M]
		OR	
	b	Explain why the blow-off cock is operated periodically when the boiler is working. Where is it located? Explain its working with a neat sketch.	[14M]
3		Unit-III	
	a	What are the different methods of compounding of steam turbine stages? List the advantages and limitations of velocity compounding.	[14M]
		OR	
	b	A convergent-divergent nozzle is required to discharge 2kg of steam per second. The nozzle is supplied with steam at 10bar and 2000C and the discharge takes place against a back pressure of 0.34bar. Estimate the throat and exit areas. Assume isentropic flow and take the index n=1.3. If the nozzle efficiency is assumed to be 85%, determine the exit area.	[14M]
4		Unit-IV	
	a	In a reaction turbine, the fixed blades and moving blades are of same shape but reversed in direction. The angles of the receiving tips are 350 and of the discharging tips are 200. Find the power developed per pair of blades for a steam consumption of 2.5 kg/s, when the blade speed is 50m/s. If the heat drop per pair is 10.04 kJ/kg, find the efficiency of the pair.	[7M]

		Discuss the merits and demerits of Impulse turbine and reaction turbine.	[7M]
	OR		
	b	In a reaction turbine, the fixed blades and moving blades are of same shape but reversed in direction. The angles of the receiving tips are 350 and of the discharging tips are 200 . Find the power developed per pair of blades for a steam consumption of 2.5 kg/s, when the blade speed is 50m/s. If the heat drop per pair is 10.04 kJ/kg, find the efficiency of the pair.	[14M]
5	Unit-V		
	a	Sketch and explain the line diagram of a semi closed gas turbine plant	[14M]
	OR		
	b	i. Write short notes on liquid propellant engines ii. What is meant by thrust augmentation? When is it necessary? Describe any one method of thrust augmentation.	[14M]

NARASARAOPETA
NEC ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

ACADEMIC CALENDAR

NEC NARASARAOPETA
ENGINEERING COLLEGE
(AUTONOMOUS)

ACADEMIC CALENDAR

(B.Tech. 2020 Admitted Batch, Academic Year 2022-23)

Description	From Date	To Date	Duration
2020 Batch 3rd Year 1st Semester			
Commencement of Class Work	25-07-2022		7 Weeks
1st Spell of Instructions	25-07-2022	10-09-2022	
Assignment Test-I	15-08-2022	20-08-2022	
I Mid examinations	12-09-2022	17-09-2022	1 Week
2nd Spell of Instructions	19-09-2022	05-11-2022	7 Weeks
Assignment Test-II	10-10-2022	15-10-2022	
II Mid examinations	07-11-2022	12-11-2022	1 Week
Preparation & Practicals	14-11-2022	19-11-2022	1Week
Semester End Examinations	21-11-2022	03-12-2022	2 Weeks
2020 Batch 3rd Year 2nd Semester			
Commencement of Class Work	05-12-2022		7 Weeks
1st Spell of Instructions	05-12-2022	21-01-2023	
Assignment Test-I	26-12-2022	31-12-2022	
I Mid examinations	23-01-2023	28-01-2023	1 Week
2nd Spell of Instructions	30-01-2023	18-03-2023	7 Weeks
Assignment Test-II	20-02-2023	25-02-2023	
II Mid examinations	20-03-2023	25-03-2023	1 Week
Preparation & Practicals	27-03-2023	01-04-2023	1 Week
Semester End Examinations	03-04-2023	15-04-2023	2 Weeks
Commencement of 4th Year 1st Sem Class Work	05-06-2023		

PRINCIPAL

NEC NARASARAOPETA
ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

TIME TABLE

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

ROOM NO: 1212

Wef: 12/06/2023

	1	2	BREAK	3	4		5	6	7
TIMINGS	9.10-10.00	10.00-10.50	10.50-11.00	11.00-11.50	11.50-12.40	12.40-1.30	1.30-2.20	2.20-3.10	3.10-4.00
MON	AI&ML			DME-I			AI&ML LAB		
TUE	HPE	HPE / ROB&3D PRINTING LAB				L	OR		AI&ML
WED	PEHV	AI&ML LAB				U	AI&ML	HPE	
THU	OR			MCMT		N	DME-I		PEHV
FRI	HPE			MCMT		C	HPE	OR	
SAT	DME-I			AI&ML		H	HPE / ROB&3D PRINTING LAB		

CODE	SUBJECT	FACULTY
AI&ML	Artificial Intelligence & Machine Learning	Dr.D.Jagadish
HPE	Heat Power Engineering	Mr.P.Srinivasa Rao
DME-I	Design of Machine Elements-I	Dr.B.Ravi Naik
OR	Operation Research	Mr.K.John Babu
MCMT	Metal Cutting & Machine Tools	Dr.D.Suneel
AI&ML LAB	Artificial Intelligence & Machine Learning Lab	Mr.T.Ashok Kumar/SK.N.Meeravali
HPE LAB	Heat Power Engineering	Mr.P.Srinivasa Rao/ P.Sravani
ROB&3D P LAB	Robotics & 3D-Printing Lab	Mr.CH.Sekhar/Dr.M.Venkanna Babu
PEHV	PE&HV	Dr.B.Anki Reddy

Signature of HOD

Signature of Principal

NEC NARASARAOPETA
ENGINEERING COLLEGE
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DEPARTMENT OF MECHANICAL ENGINEERING

SYLLABUS COPY

III B.TECH I SEMESTER	L	T	P	INTERNAL MARKS	EXTERNAL MARKS	TOTAL MARKS	CREDITS
	2	1	0	30	70	100	3
Code: R20ME3102	HEAT POWER ENGINEERING						

COURSE OBJECTIVES:

The course content enables students to:

- Inculcate the fundamental knowledge of the thermal power generation using steam and gas turbines.
- Discuss various types of rockets and its applications and preparation of rocket fuels and propellants.

COURSE OUTCOMES:

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

CO1: Illustrate the various types of efficiency improvements of Rankine cycle
CO2: Describe the various boilers, mountings and accessories.
CO3: Identify different types of nozzles used in steam turbines.
CO4: Classify different turbines based on utility and applications.
CO5: Discuss gas turbines, jet propulsion and rocket propulsion.

UNIT – I:

STEAM POWER PLANT: Rankine cycle - Schematic layout, Thermodynamic Analysis, Concept of Mean Temperature of Heat addition, Methods to improve cycle performance – Regeneration & reheating.

COMBUSTION: Fuel Types and combustion, concepts of heat reaction, adiabatic flame temperature, flue gas analysis- Orsat apparatus analysis.

UNIT - II:

BOILERS: Classification – Working principles with sketches including LP & H.P .Boilers – Mountings and Accessories – Working principles- Boiler horse power, Equivalent Evaporation, Efficiency and Heat balance.

DRAUGHT: Classification – Forced Draught and Natural Draught, Height of chimney for given draught and discharge- Condition for maximum discharge- Efficiency of chimney.

UNIT – III:

STEAM NOZZLES: Stagnation Properties- Function of nozzle – Applications and Types- Flow through nozzles- Thermodynamic analysis – Assumptions -Velocity of nozzle at exit-Ideal and actual expansion in nozzle- Velocity coefficient- Condition for maximum discharge- Critical pressure ratio- Criteria to decide nozzle shape- Super saturated flow, its effects, Degree of super saturation and Degree of under cooling - Wilson line.

UNIT – IV:

STEAM TURBINES: Classification – Impulse turbine, Mechanical details – Velocity diagram – Effect of friction – Power developed, Axial thrust, Blade or diagram efficiency – Condition for maximum efficiency. De-Laval Turbine - its features- Methods to reduce rotor speed-Velocity compounding and Pressure compounding.

REACTION TURBINE: Mechanical details – Principle of operation, Thermodynamic analysis of a stage, Degree of reaction –Velocity diagram – Parson's reaction turbine – Condition for maximum efficiency.

UNIT -V:

GAS TURBINES: Simple gas turbine plant – Ideal cycle, essential components – Parameters of performance – Actual cycle – Regeneration, Inter cooling and Reheating –Closed and Semi-closed cycles – Merits and Demerits.

JET PROPULSION: Principle of Operation –Classification of jet propulsive engines – Working Principles with schematic diagrams and representation on T-S diagram - Thrust, Thrust Power and Propulsion Efficiency, Turbo jet – Schematic Diagram, Thermodynamic Cycle, and Performance Evaluation.

TEXT BOOKS:

1. Thermal Engineering / Mahesh M Rathore/ Mc Graw Hill
2. Gas Turbines – V. Ganesan /Mc Graw Hill

REFERENCE BOOKS:

1. Gas Turbine Theory/ Saravanamuttoo, Cohen, Rogers/ Pearson
2. Fundamentals of Engineering Thermodynamics / Rathakrishnan/ PHI
3. Thermal Engineering/ Rajput/ Lakshmi Publications
4. Thermal Engineering/R.S. Khurmi / S.Chand Publications

WEB REFERENCES:

1. http://home.iitk.ac.in/~suller/lectures/lec29.htm
2. https://nptel.ac.in/courses/112/103/112103277/
3. http://nptelvideos.com/video.php?id=1181
4. http://150.107.117.36/NPTEL_DISK4/NPTEL_Contents/Web_courses/Phase1_web/112104117/machine/ui/Course_home-lec24.htm
5. https://nptel.ac.in/courses/112/106/112106166/

NEC NARASARAOPETA
ENGINEERING COLLEGE
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DEPARTMENT OF MECHANICAL ENGINEERING

LESSON PLAN

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

DEPARTMENT OF MECHANICAL ENGINEERING
LESSON PLAN(Academic year 2023-24)

Course Code	Course Title (Regulation)	Sem	Branch	Contact Periods/Week	Sections
R20ME3102	Heat Power Engineering (R20)	I	Mechanical Engineering	6	A

COURSE OUTCOMES:

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

- **CO1:** Illustrate the various types of efficiency improvements of Rankine cycle (K2)
- **CO2:** Describe the various boilers, mountings and accessories. (K2)
- **CO3:** Identify different types of nozzles used in steam turbines. (K3)
- **CO4:** Classify different turbines based on utility and applications. (K4)
- **CO5:** Discuss gas turbines, jet propulsion and rocket propulsion. (K3)

Unit No	Outcome	Topics/Activity		Ref Text book	Total Periods	Delivery Method
1	CO1: Interpret the steam power plant cycles [K2]	**Unit-1 STEAM POWER PLANT**				
		1.1	Schematic layout	T1, T2, R1	1	Chalk & Talk
		1.2	Thermodynamic analysis	T1, T2, R1	2	Chalk & Talk
		1.3	Methods to improve cycle performance	T1, T2, R1	2	Chalk & Talk, Tutorial
		1.4	Regeneration & reheating.	T1	3	Chalk & Talk, Tutorial
		COMBUSTION				
		1.5	Fuels and combustion	T2,R3	1	Chalk & Talk
		1.6	Concepts of heat reaction	T2,R3	1	Chalk & Talk, Tutorial
		1.7	Adiabatic flame temperature, flue gas analysis.	T2,R3	2	Chalk & Talk, PPT
2	CO2:Demonstrate the basics of combustion [K2]	**Unit-2. BOILERS**				
		2.1	Classification, working principles of L.P & H.P boilers	T1, T2, R3	2	Chalk & Talk
		2.2	Mountings and accessories	T1, T2, R3	2	Chalk & Talk
		2.3	Working principles, boiler horsepower, equivalent evaporation, efficiency.	T1, T2, R3	2	Chalk & Talk, Case Study
		DRAUGHT				

		2.4	Classification, Natural and Artificial draught, induced and forced draught	T1, T2, R3	2	Chalk & Talk, PPT
		2.5	Height of chimney for given draught and discharge	T1, T2, R3	2	Chalk & Talk
		2.6	Condition for maximum discharge, efficiency of chimney.	T1, T2, R3	2	Chalk & Talk, Case Study
3	CO3: Identify different types of nozzles used in steam turbines [K3]		**Unit-3. STEAM NOZZLES**			
		3.1	Function of a nozzle, applications, types, flow through nozzles	T1, T2, R1	2	Chalk & Talk, PPT, Tutorial
		3.2	Thermodynamic analysis, assumptions, velocity of fluid at nozzle exit	T1, T2, R1	3	Chalk & Talk, Tutorial
		3.3	Ideal and actual expansion in a nozzle, velocity coefficient, condition for maximum discharge	T1, T2, R1	3	Chalk & Talk, Case Study
			MID I EXAMINATION			
3	CO3: Identify different types of nozzles used in steam turbines [K3]	3.4	Critical pressure ratio, nozzle design, Super saturated flow, its effects	T1, T2, R1	3	Chalk & Talk, Case Study
		3.5	Degree of super saturation and degree of under cooling, Wilson line.	T1	3	Chalk & Talk, PPT
4	CO4: Classify different turbines based on utility and applications[K2]		**Unit-4. STEAM TURBINES**			
		4.1	Construction & working of steam turbines	T1, T2, R3	2	Chalk & Talk, PPT
		4.2	Impulse & reaction principles	T1, T2, R3	2	Chalk & Talk, PPT
		4.3	Inlet & outlet velocity diagrams. Work output & efficiencies	T1, T2, R3	3	Chalk & Talk, Case Study
		4.4	Pressure & velocity compounding	T1, T2, R3	2	Chalk & Talk, Case Study
		4.5	Regenerative feed water heating, reheat cycles	T1, T2, R3	3	Chalk & Talk, Case Study
		4.6	Reheat factor, governing of turbine, back pressure & pass out turbine.	T1, T2, R3	2	Chalk & Talk, Tutorial
5	CO5: Report different features of gas turbines and jet engines[K2]		**Unit 5. GAS TURBINES & JET PROPULSION**			
		5.1	Simple gas turbine plant, ideal cycle	T1, T2, R1	2	Chalk & Talk, PPT
		5.2	Essential components, parameters of performance, actual cycle	T1, T2, R1	2	Chalk & Talk, Tutorial
		5.3	Regeneration, inter-cooling and reheating	T1, T2, R1	3	Chalk & Talk, Case Study

		5.4	Closed and semi-closed cycles, merits and demerits and types of combustion chambers.	T1, T2, R1	2	Chalk & Talk, PPT
			JET PROPULSION			
		5.5	Working principle, thrust power	T1	2	Chalk & Talk
		5.6	propulsive force and efficiency	T1	2	Chalk & Talk
				Total	65	
			MID II EXAMINATION			
			END EXAMINATIONS			

Text Books:

T1 Thermodynamics and Heat Engines, Volume 2, R.Yadav, Centralbook depot.

T2 Heat Engineering, V.P Vasandani and D.S Kumar, MetropolitanBook Company, New Delhi

Reference Books:

R1 Gas Turbines and Propulsive Systems, P.Khajuria&S.P.Dubey, Dhanpatrai

R2 Gas Turbines, Cohen, Rogers and SaravanaMuttoo, Addison Wesley, Longman, John wiley& sons

R3 Thermal Engineering, R.S Khurmi, JS Gupta, S.Chand, Mechanical Engineering

Faculty HOD Principal

NARASARAOPETA
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DEPARTMENT OF MECHANICAL ENGINEERING

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

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DEPARTMENT OF MECHANICAL ENGINEERING
B.TECH – R20 REGULATION
COURSE ARTICULATION MATRIX

III B. TECH I SEMESTER

Course Code: C312	**Course Name: HEAT POWER ENGINEERING**														
COs	**POs & PSOs**														
	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
C312.1	3	3	2	-	-	-	-	-	-	-	-	-	-	3	-
C312.2	3	3	2	1	-	-	-	-	-	-	-	-	-	3	2
C312.3	3	3	2	1	-	-	-	-	-	-	-	-	-	3	2
C312.4	3	3	2	1	-	-	-	-	-	-	-	-	-	3	2
C312.5	3	3	2	1	-	-		-	-	-	-	-	-	3	2
C312	3.00	3.00	2.00	1.00	-	-	-	-	-	-	-	-	-	3.00	2.00

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DEPARTMENT OF MECHANICAL ENGINEERING

WEB REFERENCES

WEB REFERENCES:

1. http://home.iitk.ac.in/~suller/lectures/lec29.htm
2. https://nptel.ac.in/courses/112/103/112103277/
3. http://nptelvideos.com/video.php?id=1181
4. http://150.107.117.36/NPTEL_DISK4/NPTEL_Contents/Web_courses/Phase1_web/112104117/ma chine/ui/Course_home-lec24.htm
5. https://nptel.ac.in/courses/112/106/

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DEPARTMENT OF MECHANICAL ENGINEERING

STUDENT’S ROLL LIST

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45	22475A0334	SHAIK NAGUR BASHA
46	22475A0335	GOLLAPUDI SARATH KUMAR
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58	22475A0347	DUDDETI NAGA SAI
59	22475A0348	BASWA DILLESWARA RAO
60	22475A0349	KORRAPATI MOHAN KRISHNA
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PRINCIPAL

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DEPARTMENT OF MECHANICAL ENGINEERING
III.B.Tech I SEM

III.B.Tech

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59	20471A0364	GANJI HANUMA KOTI GANESH
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61	20471A0366	GUTTIKONDA AYYAPPA REDDY
62	20471A0367	MADDINENI AJAY
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68	20471A0373	SHAIK JAKIR
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86	21475A0315	SHAIK MABU SUBHANI
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96	21475A0325	BORUGADDA NITHIN
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100	21475A0329	KSHATRIYA JITHENDRA SINGH
101	21475A0330	BOMMALI BALA SIVA YOGENDRA SAI NANDU
102	21475A0331	REVALLA SAI
103	21475A0332	BANDI SRINIVAS
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105	21475A0333	EMANI LEELA SHANKAR
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NEC NARASARAOPETA
ENGINEERING COLLEGE
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DEPARTMENT OF MECHANICAL ENGINEERING

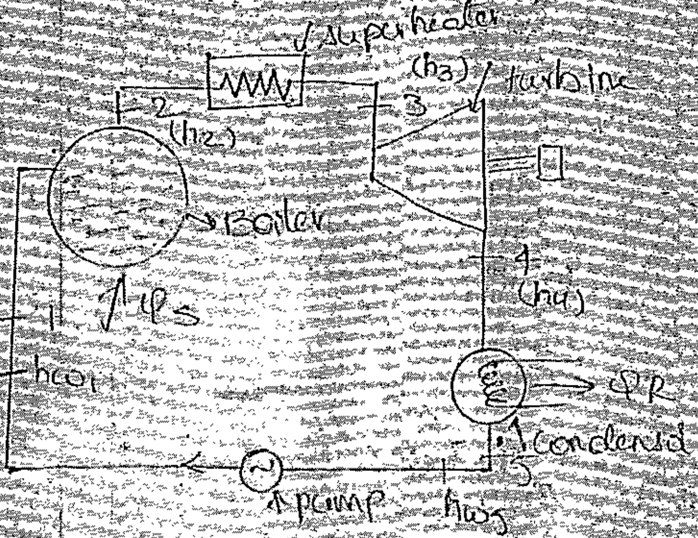
HAND WRITTEN/PRINTED LECTURE NOTES

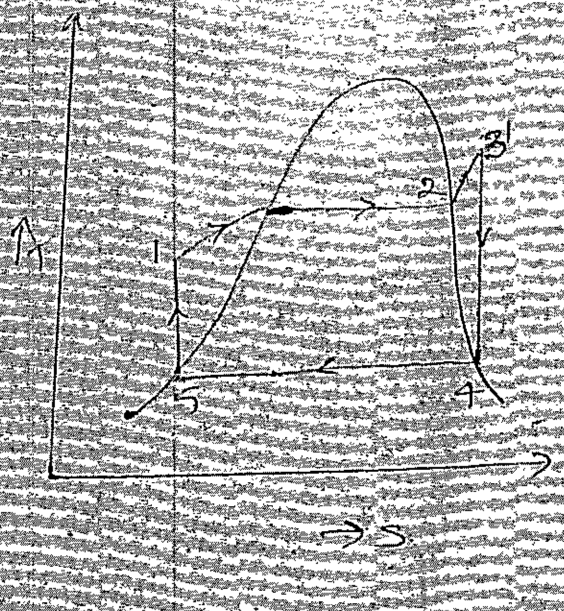
UNIT 1

Rankine Cycle

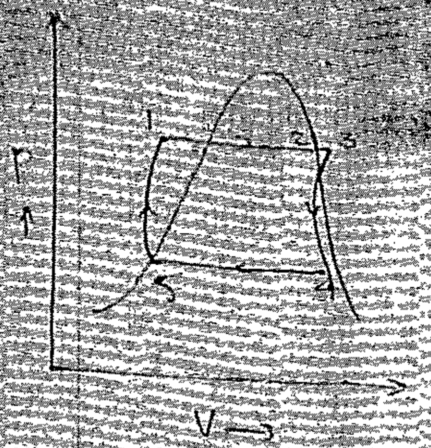
(i) Simple Rankine cycle
(ii) Reheat Rankine cycle
(iii) Regenerative Rankine cycle
(iv) combined Reheat & regenerative Rankine cycle
(v) modified Rankine cycle

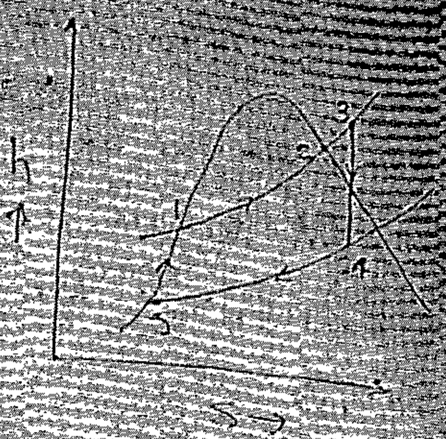
Simple Rankine cycle :





1 – 2 : heat addition to boiler
2 – 3 : superheating
3 – 4 : turbine expansion
4 – 5 : const pressure heat rejection
5 – 1 : isentropic compr.





* Thermal η of rankine cycle

consider energy balance

(i) boiler

$Q_s + h_{w1} = h_3$

$Q_s = (h_3 - h_{w1})$

(ii) Turbine

$h_3 = W_T + h_4$

$W_T = (h_3 - h_4)$

(iii) condenser

$h_4 = Q_R + h_{w5}$

$Q_R = (h_4 - h_{w5})$

(iv) pump

$h_{w5} + W_P = h_{w1}$

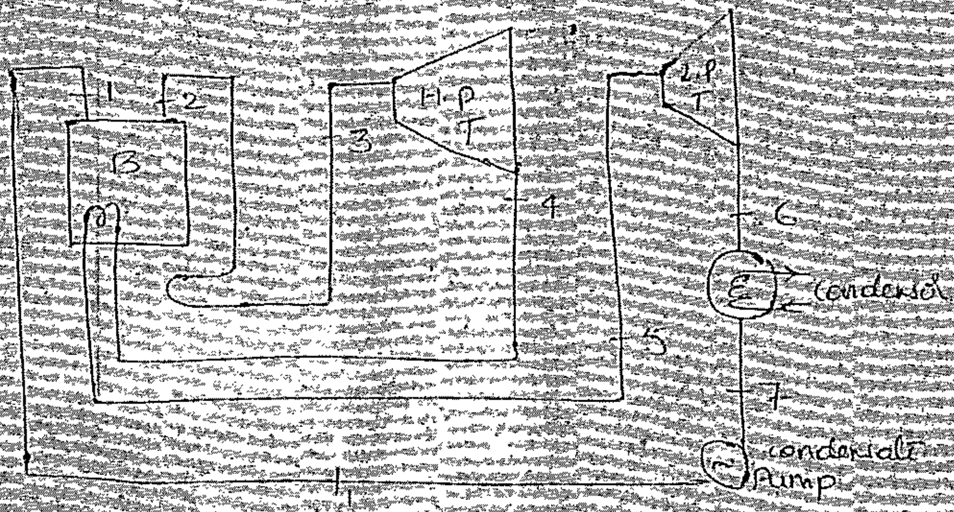
$W_P = (h_{w1} - h_{w5})$

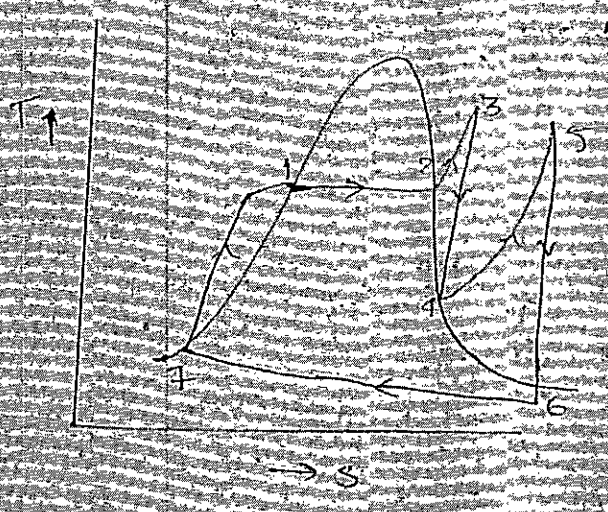
$$\eta_{th} = \frac{W_{net}}{Q_s}$$

$$\eta_{th} = \frac{W_T - W_P}{Q_s} \qquad (\because W_P = 0)$$

$$\boxed{\eta_{th} = \frac{h_3 - h_4}{h_3 - h_{w_1}}}$$

2 Reheat Rankine cycle :





$$\eta_{th} = \frac{W_{net}}{Q_s} \times 100$$

$$= \frac{(W_{H.P.T} + W_{L.P.T}) - W_P}{Q_B + Q_R} \times 100$$

$$W_{HPT} = (h_3 - h_4)$$

$$W_{LPT} = (h_5 - h_6)$$

$$W_P = (h_1 - h_7) = v_7 (P_1 - P_7)$$

$$Q_B = (h_2 - h_{w1})$$

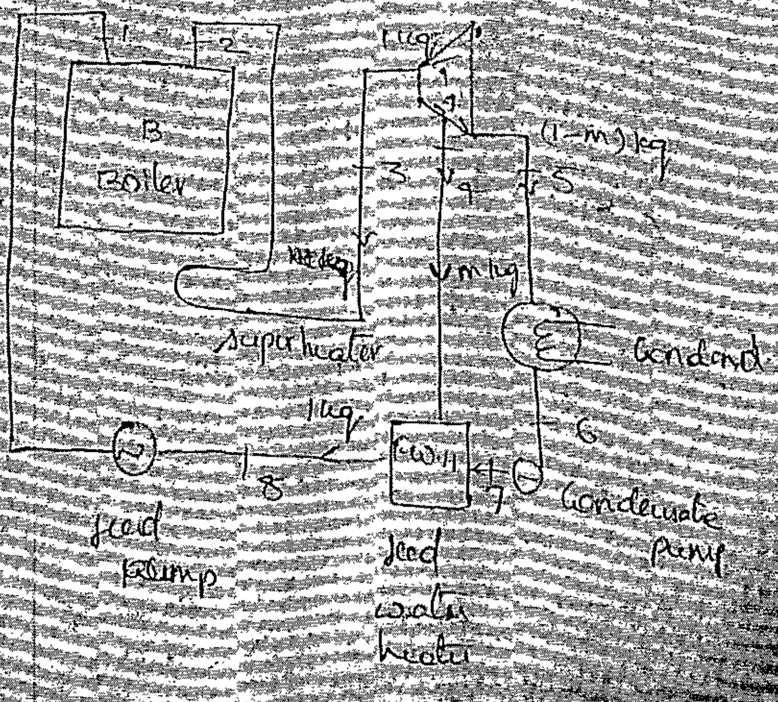
$$Q_R = (h_5 - h_4)$$

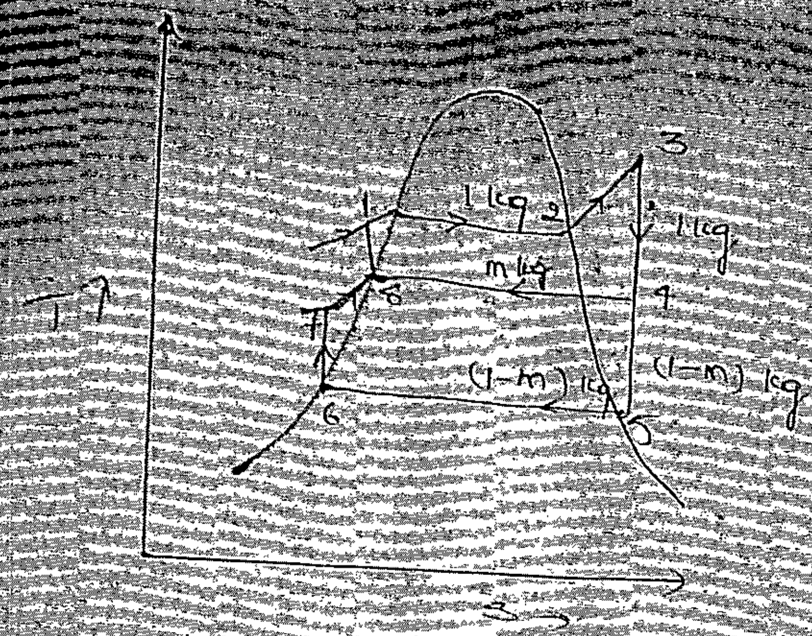
$$\eta_{th} = \frac{\left[(h_3 - h_4) + (h_5 - h_6)\right] - (h_1 - h_7)}{(h_2 - h_{w1}) + (h_5 - h_4)}$$

Specific steam consumption

$$S.S.C = \frac{3600}{W_{net}} \text{ kg/kW.h}$$

3. Regenerative cycle with single feed water heater





$$\eta_{th} = \frac{W_{net}}{Q_s} \times 100$$

$$= \frac{W_T - (W_{cpt} + W_{FP})}{(h_3 - h_{w_1})} \times 100$$

$$W_T = 1(h_3 - h_4) + (1-m)(h_4 - h_5)$$

$$W_{cp} = (h_7 - h_6) = v_6 (P_7 - P_6)$$

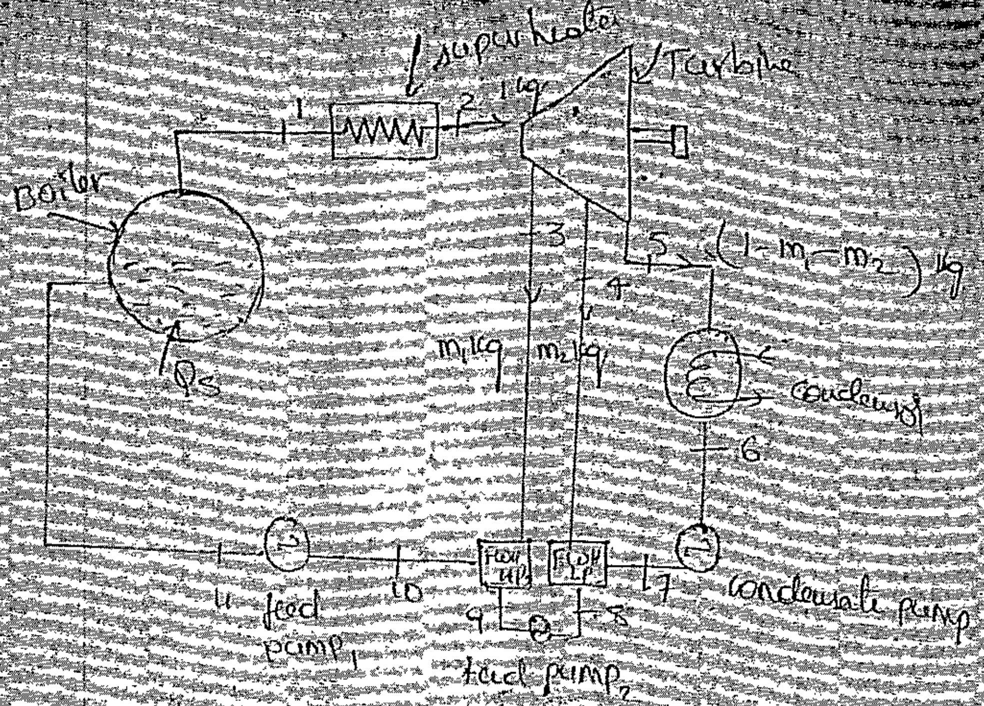
$$W_{FP} = (h_1 - h_8) = v_8 (P_1 - P_8)$$

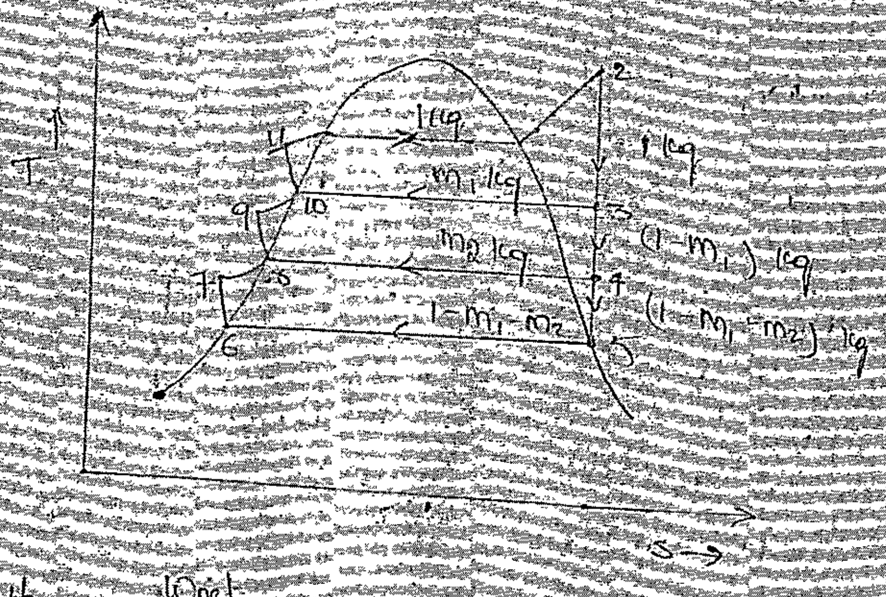
$$\eta_{th} = \frac{[(h_3 - h_4) + (1-m)(h_4 - h_5)] - [(h_7 - h_6) + (h_1 - h_8)]}{(h_3 - h_{w_1})}$$

specific steam consumption

$$S.S.C = \frac{3600}{W_{net}} \text{ kg/kWh}$$

Regenerative ranking cycle with double feed water heater





$$\eta_{th} = \frac{W_{net}}{Q_S} \times 100 = \frac{W_T - W_P}{Q_S} \times 100$$

$$W_T = 1(h_2 - h_3) + (1-m_1)(h_3 - h_4) + (1-m_1-m_2)(h_4 - h_5)$$

$$W_P = W_{CP} + W_{FP_1} + W_{FP_2}$$

$$= (h_7 - h_6) + (h_9 - h_8) + (h_{11} - h_{10})$$

heat supplied $Q_s = (h_2 - h_{11})$

$$\eta_{th} = \frac{\left[1(h_2-h_3)+(1-m_1)(h_3-h_4)+(1-m_1-m_2)(h_4-h_5)\right] - \left((h_7-h_6)+(h_9-h_8)+(h_{11}-h_{10})\right)}{h_2-h_{11}}$$

Specific steam consumption.

$$S.S.C = \frac{3600}{W_{net}} \text{ kg/kwh}$$

→ mass of the steam extracted for H.P feed water heater (m_1)

consider energy balance of H.P. FWH.

$$m_1 h_3 + (1-m_1) h_{w9} = 1 \times h_{w10}$$

$$m_1 h_3 + h_{w9} - m_1 h_{w9} = h_{w10}$$

$$m_1 (h_3 - h_{w9}) = h_{w10} - h_{w9}$$

$$\boxed{m_1 = \frac{h_{w10} - h_{w9}}{h_3 - h_{w9}}}$$

→ mass of the steam extracted for LP feed water (m_2).

consider energy balanced for LP FWH.

$$m_2 h_4 + (1-m_1-m_2) h_{w7} = (1-m_1) h_{w8}$$

$$m_2 h_4 + h_{w7} - m_1 h_{w9} - m_2 h_{w7} = (1-m_1) h_{w8}$$

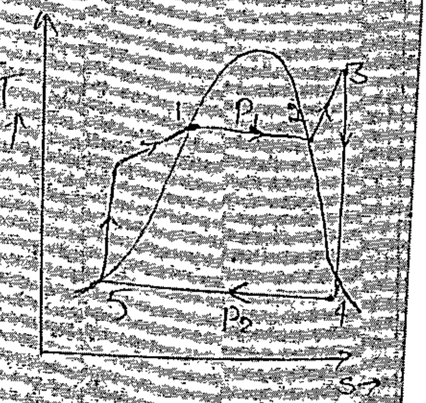
$$m_2 h_4 + h_{w7} - m_1 h_{w7} - m_2 h_{w7} = h_{w8} - m_1 h_{w8}$$

$$m_2 (h_4 - h_{w7}) + h_{w7} - m_1 h_{w7} = h_{w8} - m_1 h_{w8}$$

$$m_2 = \frac{h_{w8} - m_1 h_{w8} - h_{w7} + m_1 h_{w7}}{h_4 - h_{w7}}$$

1. In a steam turbine steam at 20 bar, 360c is expanded to 0.~~0~~8 bar. It is then enters into condensd where it is condensate to saturated liquid water the pump feed back to water into the boiler Assume ideal process find per kg of steam the net work & cycle η.

sd Given data



$P_1 = 20$ bar

$P_2 = 0.08$ bar

$T_1 = 360°C$

$t_s \rightarrow 212.4°C$

find Wnet ?

$\eta_{cycle} = ?$

$P_1 = P_2 = P_3 = 20$ bar

$P_4 = P_5 = 0.08$ bar

enthalpy of super heated steam

$$h_3 = h_{sup_3} = h_{s_3} + C_p (t_{sup} - t_s)$$

$$= 2792.2 + 2.1 (360 - 212.4)$$

$$= 3107.1 \ kJ/kg$$

$\phi_3 = \phi_4$

$\phi_{sup_3} = \phi_{wet_4}$

$$\phi_{s3} + c_p \ln\left[\frac{T_{sup_3}}{T_{s3}}\right] = \phi_{w4} + x_4 \phi_{e4}$$

$$6.337 + 2.1 \ln\left[\frac{360 + 273}{212.4 + 273}\right] = 0.593 + x_4 \times 7.637$$

$x_4 = 0.82.$

Enthalpy of wet exhaust steam

$h_4 = h_{wet_4} = h_{w4} + x_4 L_4$

$= 173.9 + 0.82 \times 2403.2$

$= 2144.52$ kJ/kg.

$W_{net} = W_T - W_P$

$W_T = (h_3 - h_4)$

$= 3107.1 - 2144.52$

$= 962.5$ kJ/kg.

$W_P = (h_{w1} - h_{w5}) = v_5 (P_1 - P_5)$

$= 0.00100^5 (20 - 0.08) \times 100$

$= 2$ kJ/kg

$W_{net} = W_T - W_P$

$= 962.5 - 2.00$

$= 960.5$ kJ/kg

$W_p = h_{w1} - h_{w5} = 2$

$h_{w1} = 2 + 173.9$

$h_{w1} = 175.9$ kJ/kg

$Q_s = (h_3 - h_{w1})$

$= 3107.1 - 175.9$

$= 2931.2$ kJ/kg

$\eta_{cycle} = \frac{W_{net}}{Q_s} \times 100$

$= \frac{960.5}{2931.2} \times 100$

$= 32.76\%$

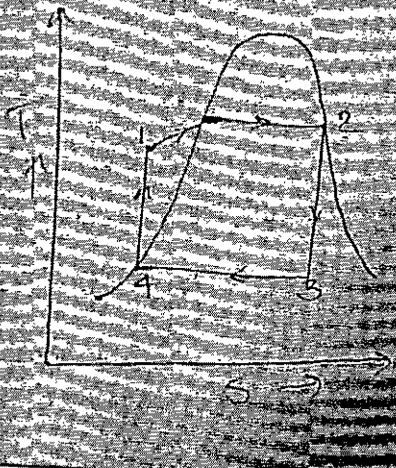
2. In a rankine cycle, the steam at inlet to the turbine is saturated at a pressure of 35 bar at exhaust pressure is 0.2 bar. Determine pump work, turbine work, η rankine, condenser heat flow, dryness of the end of the expansion. Assume flow rate is 9.5 kg/sec

sol $P_1 = P_2 = 35$ bar

$P_3 = P_4 = 0.2$ bar

$x_2 = 1$

$x_3 = ?$



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$h_2 = h_{s2} = 2802$ kJ/kg

$\phi_2 = \phi_3$

$\phi_{s2} = \phi_{wet\,3}$

$6.123 = \phi_{w3} + x_3 \phi_{e3}$

$6.123 = 0.832 + x_3(7.077)$

$x_3 = 0.74 < 1$

enthalpy of exhaust steam

$h_3 = h_{wet\,3} = h_{w3} + x_3 L_3$

$= 251.5 + 0.74 \times 2358.4$

$= 1996.71$ kJ/kg

$h_4 = h_{w4} = 251.5$ kJ/kg

→ Pump work $w_P = v_4 (P_1 - P_4) \times 100$

$= 0.001017 (35 - 0.2) \times 100$

$= 3.5$ kJ/kg

$w_P = (h_{w_1} - h_{w4}) = 3.5$

$h_{w_1} = 3.5 + 251.5$

$= 255$ kJ/kg

→ turbine work $w_T = (h_2 - h_3)$

$m (h_2 - h_3)$

$= 9.5 (2802 - 1996.71)$

$= 7652$ kw

BOILER MOUNTINGS

INTODUCTION TO BOILER

Definition:

- ✓ A boiler is a closed vessel in which water is converted in to steam by burning of fuel in presence of air at desired temperature, pressure and at desired mass flow rate.
- ✓ According to the Indian Boiler Act 1923, a boiler is a closed pressure vessel with capacity more than 23 liters and used for generating steam under pressure and includes all the mountings fitted to a closed vessel.
- ✓ According to American society of Mechanical Engineers (A.S.M.E.), a steam generator or a boiler is defined as "a combination of apparatus for producing, finishing or recovering heat together with the apparatus for transferring the heat so made available to the fluid being heated and vaporized.

PRINCIPAL OF WORKING

In case of boiler, any type of fuel burn in presence of air and form flue gases which are at very high temperature (hot fluid). The feed water at atmospheric pressure and temperature enters the system from other side (cold fluid). Because of exchanges of heat between hot and cold fluid (water) temperature raises and it form steam. The flue gases (hot fluid) temperature decreases and at lower temperature hot fluid is thrown in to the atmosphere via stack/chimney.

FUNCTION OF A BOILER

The steam generated is employed for the following purposes:

- ➤ Used in steam turbines to develop electrical energy. ✓
- ➤ Used to run steam engines.
- ➤ In the textile industries, sugar mills or in chemical industries as a cogeneration plant.
- ➤ Heating the buildings in cold weather.
- ➤ Producing hot water for hot water supply.

IBR AND NON-IBR BOILERS

- ✓ Boiler generating steam at working pressure below 10 bar and having water storage capacity less than 22.75 liters are called non-IBR boilers. (INDIAN BOILER REGULATION).
- ✓ Boilers outside these limits are covered by the IBR and have to observe certain specified conditions before being operated.

CLASSIFICATION OF BOILERS

The different ways to classify the boilers are as follows

1. According to location of boiler shell axis

- Horizontal (Lancashire boiler, Locomotive boiler, Babcock and Wilcox etc.)
- Vertical (Cochran boiler, vertical boiler etc.)
- Inclined boilers

When the axis of the boiler shell is horizontal the boiler is called horizontal boiler. If the axis is vertical, the boiler is called vertical boiler and if the axis of the boiler is inclined it is known as inclined boiler.

2. According to the flow medium inside the tubes

- Fire tube (Lancashire, Locomotive, Cochran and Cornish boiler.)
- Water tube boilers (Simple vertical boiler, Babcock and Wilcox boiler.)

The boiler in which hot flue gases are inside the tubes and water is surrounding the tubes is called fire tube boiler. When water is inside the tubes and the hot gases are outside the boiler is called water tube boiler.

3. According to boiler pressure

According to pressure of the steam raised the boilers are classified as follows

- Low pressure (Below 80 bar) [Cochran and Cornish boiler, Lancashire and locomotive boiler]
- High pressure boilers (> 80 bar) [Babcock and Wilcox boiler]

4. According to the draft used:

- Natural draft (Simple vertical boiler, Lancashire boiler.)
- Artificial draft boilers (Babcock and Wilcox boiler, Locomotive boiler.)

Boilers need supply of air for combustion of fuel. If the circulation of air is provided with the help of a chimney, the boiler is known as natural draft boiler. When either a forced draft fan or an induced draft fan or both are used to provide the flow of air in the boiler is called artificial draft boiler.

5. According to method of water circulation:

- Natural circulation (Babcock and Wilcox boiler, Lancashire boiler.)
- Forced circulation (Velox boiler, Lamont boiler, Loffler boiler.)

If the circulation of water takes place due to difference in density caused by temperature of water, the boiler is called natural circulation boiler. When the circulation is done with the help of a pump the boiler is known as forced circulation boiler.

6. According to furnace position:

- Internally fired (Simple vertical boiler Lancashire boiler, Cochran boiler.)
- Externally fired boilers (Babcock and Wilcox boiler.)

When the furnace of the boiler is inside its drum or shell, the boiler is called internally fired boiler. If the furnace is outside the drum the boiler is called externally fire boiler.

7. According to Fuel Used.

- Solid
- Liquid
- Gaseous
- Electrical
- Nuclear energy fuel boilers

The boiler in which heat energy is obtained by the combustion of solid fuel like coal or lignite is known as solid fuel boiler. A boiler using liquid or gaseous fuel for burning is known as liquid or gaseous fuel boiler. Boilers in which electrical or nuclear energy is used for generation of heat are respectively called as electrical energy headed boilers and nuclear energy heated boiler.

8. According to number of tubes

- Single tube (Cornish boiler, Vertical boiler.)
- Multi-tube boiler (Lancashire boiler, Locomotive boiler, Babcock and Wilcox.)

A boiler having only one fire tube or water tube is called a single tube boiler. The boiler having two or more, fire or water tubes is called multi-tube boiler.

9. According to boiler mobility

- Stationary (Lancashire, Babcock and Wilcox boiler, Vertical boiler.)
- Portable (Locomotive boiler, Marine boiler)
- Marine boilers

When the boiler is fixed at one location and cannot be transported easily it is known as stationary boiler. If the boiler can be moved from one location to another it is known as portable boiler. The boiler which work on surface of water are called marine boilers.

FACTORS AFFECTING THE SELECTION OF A BOILER

One has to send the technical details to the manufacturer to purchase a boiler. The technical details that are used to give information about a particular boiler include the following things:

- Size of drum (Diameter and Length)
- Rate of steam generation (kg/hr)
- Heating surface (Square meters)
- Working pressure(Bar)
- Number of tubes /drum
- Type of boiler
- Manufacture of boiler
- Initial cost
- Quality of steam
- Repair and inspection facility

BOILER MOUNTINGS

The boiler mountings are the different fittings and devices which are mounted on a boiler shell for proper functioning and safety.

(A) Mountings for safety

1. Safety valve (02 Nos.)
2. High pressure and low water safety valve on Lancashire and Cornish boiler (01 each)
3. Water level indicator (02 Nos.)
4. Fusible plug (01 No.)

(B) Mountings for controls

1. Pressure gauge (01 No.)
2. Steam stop valve (01 No.)
3. Feed check valve (01 No.)
4. Blow off cock (01 No.)
5. Man hole (01 No.)
6. Mud box (01 No.)

SAFETY VALVE

Safety valve is located on the top of the boiler. They guard the boiler against the excessive high pressure of steam inside the drum. If pressure exceeds the working pressure then the safety valve allows to blow off a certain quantity of steam to the atmosphere, and the pressure falls in the drum.

There are four types of safety valves.

1. Dead-weight safety valves

Figure 01 shows the schematic of a dead weight safety valve. It is similar to dead weight (whistle) loaded on a pressure cooker and functions in a similar way. A gunmetal valve rests on gunmetal seat. The gunmetal seat is mounted on a steel steam pipe. The valve is fastened to a weight carrier. The dead weight is in the form of cylindrical discs are placed on the carrier so it acts downward. When the force due to steam pressure exceeds the total dead weight acting downward, the valve lifts up from the seat and some quantity of steam left the atmosphere, thus reducing the steam pressure in the boiler shell, and the valve is again closed. The dead weight safety valve is used on stationary boilers.

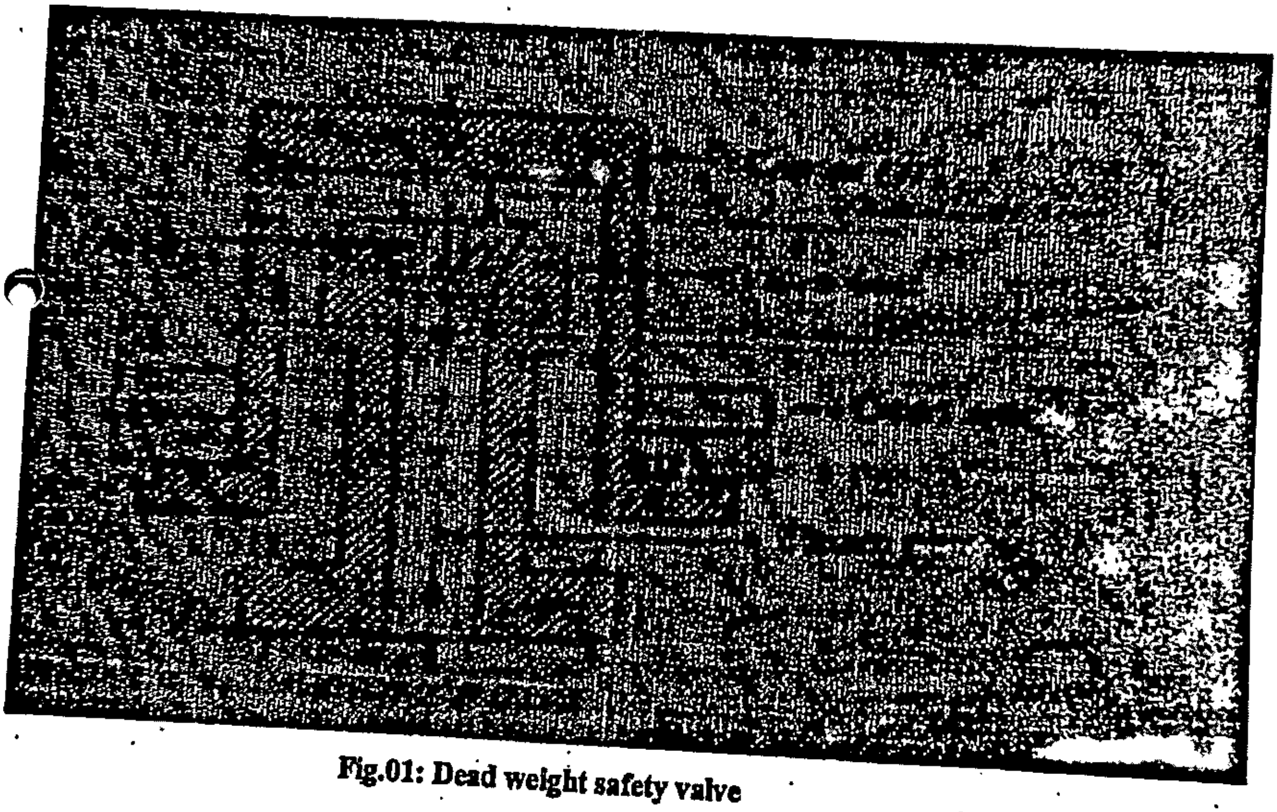


Fig.01: Dead weight safety valve

2. Spring- loaded safety valve

The dead weight safety valve cannot be used on locomotive and marine boilers. The spring loaded safety valve is used on locomotive marines and on high –pressure valve. Fig shows the valve close the steam passages under the action of a central helical spring. When the upward force of steam exceeds the down ward spring tension, the valves open and some steam escape to the atmosphere. Thus lower the steam pressure in the boiler and the valves are closed again under the spring force.

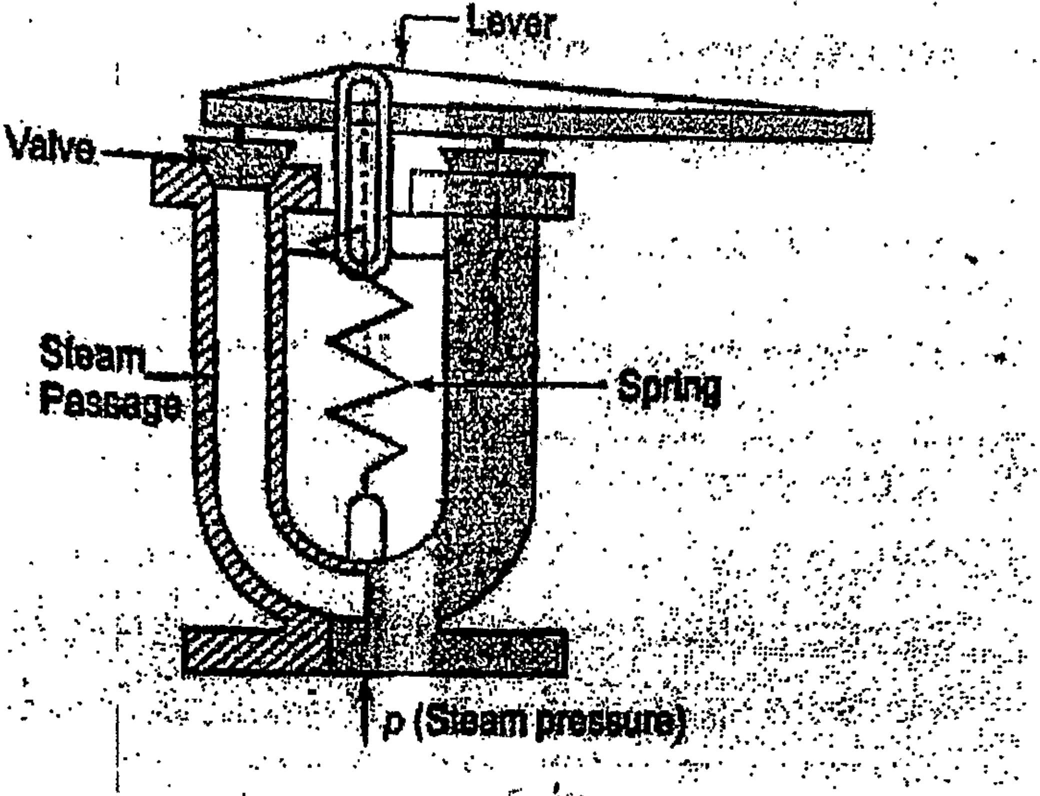


Fig.02: Spring –loaded safety valve

3. Lever-loaded safety valve

The fig. shows the lever- loaded spring safety valve, the body of valve is fastened on the top of the boiler shell. A gunmetal valve is placed on the steam passage formed in the casing. A cast iron lever attached to a fulcrum on one end and loaded by weight on the other end keeps the valve on the seat in a closed position.

When the upward force due to steam pressure exceeds the load on the valve, the valve opens, and allows some quantity of steam to escape. The pressure of steam in the boiler falls and the valve again rests on the seat.

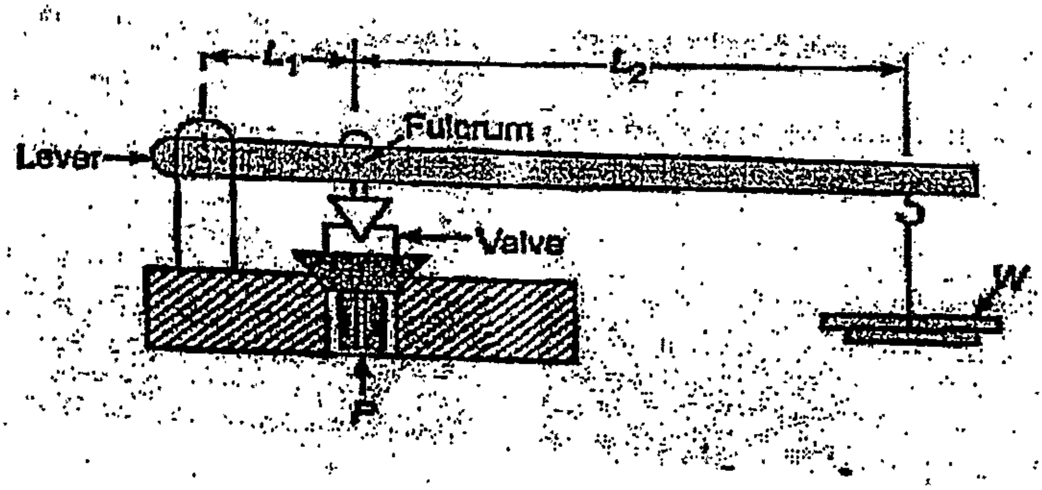


Fig.03: Lever-loaded safety valve

4. High steam and low water safety valve

This valve is combination of two valves as shown in fig 4. It is used in Cornish and Lancashire boilers. One of the valves is lever loaded and is operated when steam pressure in the boiler exceeds the working pressure. The second valve operates and blows off steam with a louder noise, when water level in the boiler falls below the normal level.

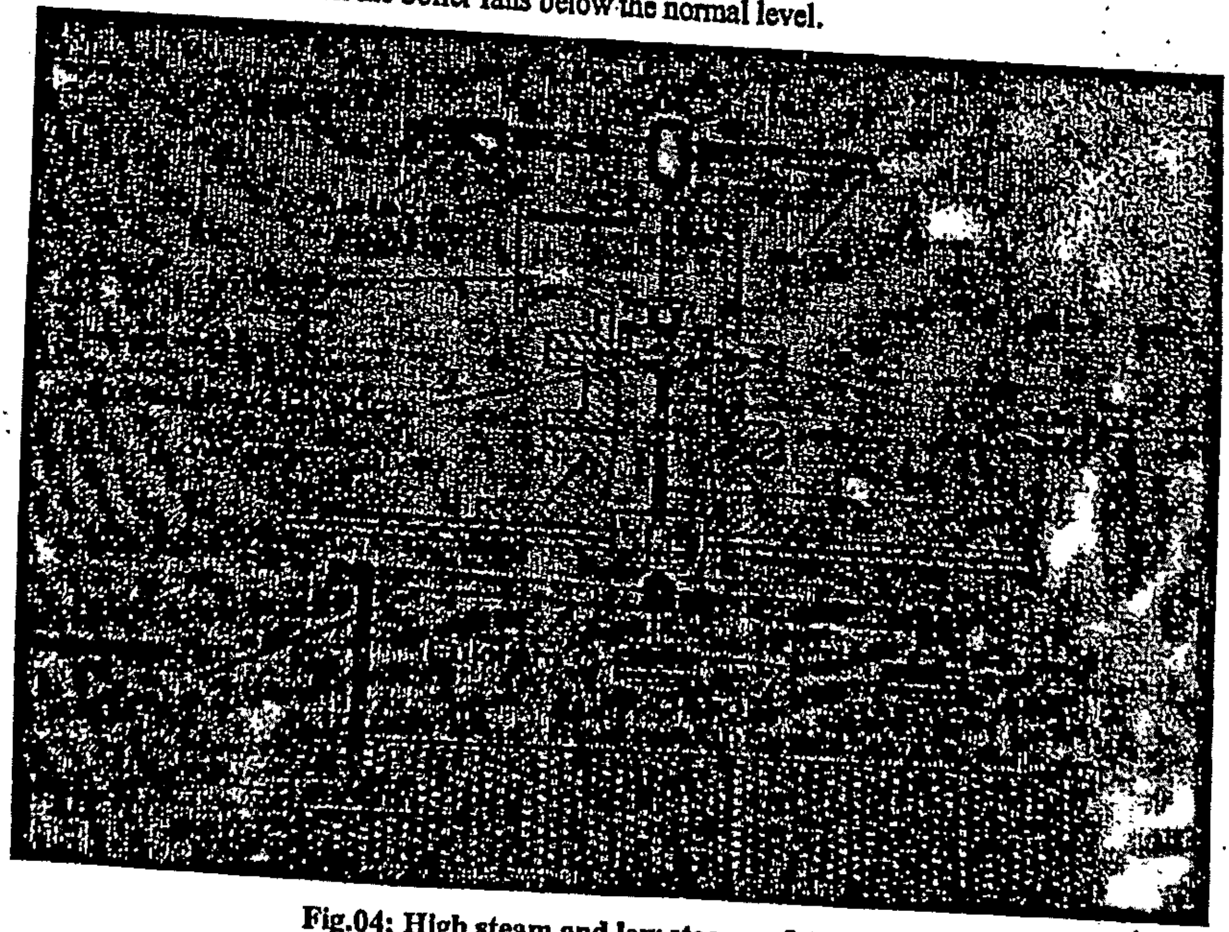


Fig.04: High steam and low steam safety valve

WATER LEVEL INDICATOR

The water level indicator is located in front of the boiler in such a position that the level of water can easily be seen by the attendant. Two water level indicators are used on all boilers. A water level indicator consists of a metal tube and a strong glass tube with markings. The upper and lower ends are connected to two gunmetal hollow pipes. The drain cock is to ensure the water and steam cock are clear. During operation steam cock and water cock remains open while the drain cock remains close. During the normal operation, the two balls provided inside the gunmetal pipe remains in position as shown in figure, hence the water can reach the glass gauge and its level can be seen.

In case the glass gauge breaks accidently, the water and steam simultaneously rush out through the gunmetal pipes. The force is exerted on two balls and they are carried away by water and steam and the passage are closed. The water and the steam cocks are then closed and the glass gauge is replaced.

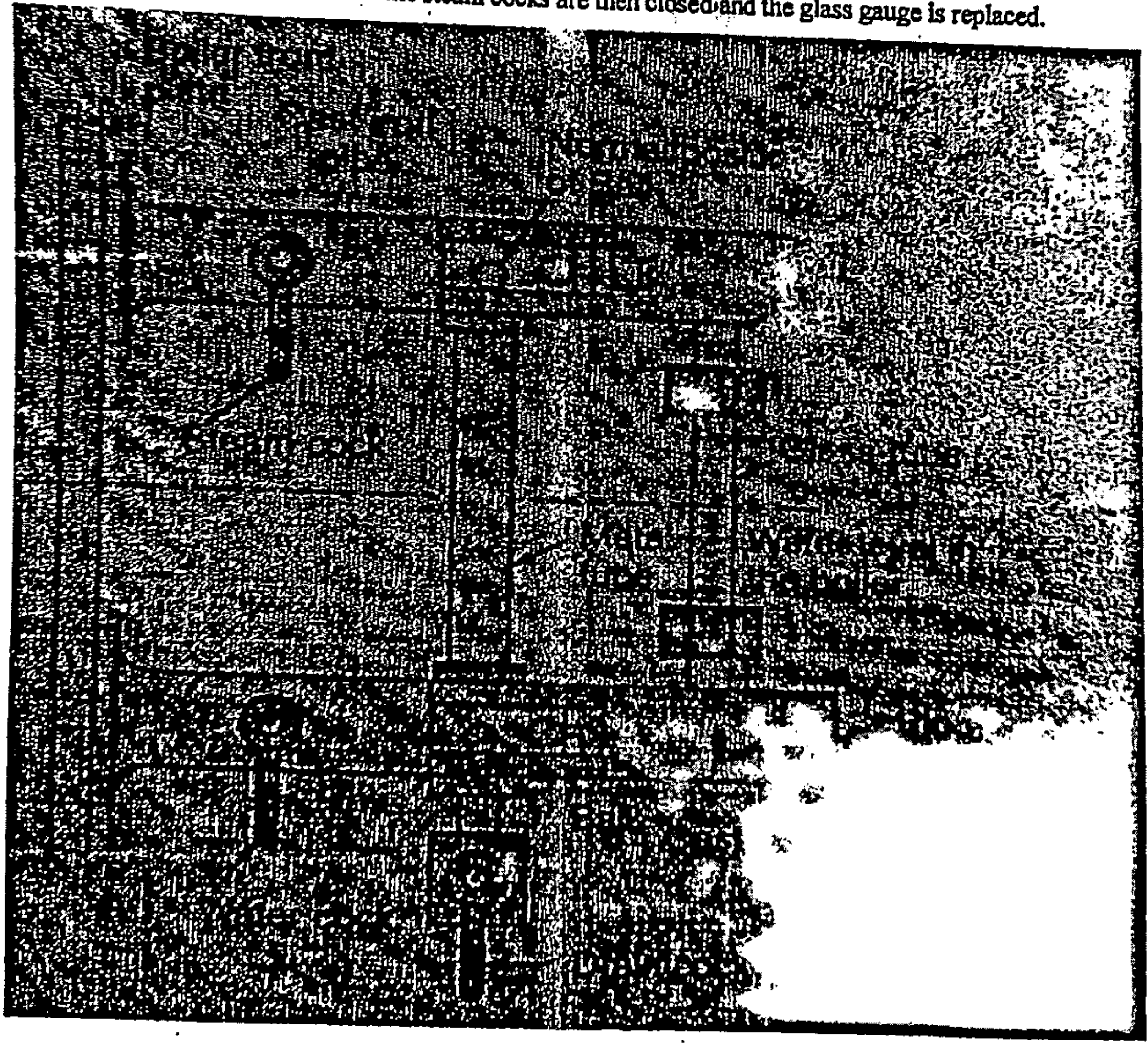


Fig.05: Water level indicator.

PRESSURE GAUGE

A pressure gauge is fitted in front of the boiler in such a position that the operator can conveniently read it. It read the pressure of steam in the boiler and is connected to the steam space by a siphon tube.

The most commonly used gauge is the bourdon pressure gauge. Fig 6. Illustrates the bourdon pressure gauge. It consists of an elliptical spring bourdon tube. One end of the tube is connected to the siphon tube and other end is connected by levers and gears to pointer.

When fluid pressure acts on the bourdon tube, it tries to make its cross section change from elliptical to circular. In this process, the lever end of the tube moves out as indicated by an arrow. The tube movement is magnified by the mechanism and given to pointer to move over a circular scale indicating the pressure.

The siphon tube is shown in Fig.07. It connects the steam space of the boiler to the bourdon gauge is filled with water in order to avoid the effect of high temperature steam on the gauge components. The steam pressure is transferred by water to the bourdon gauge.

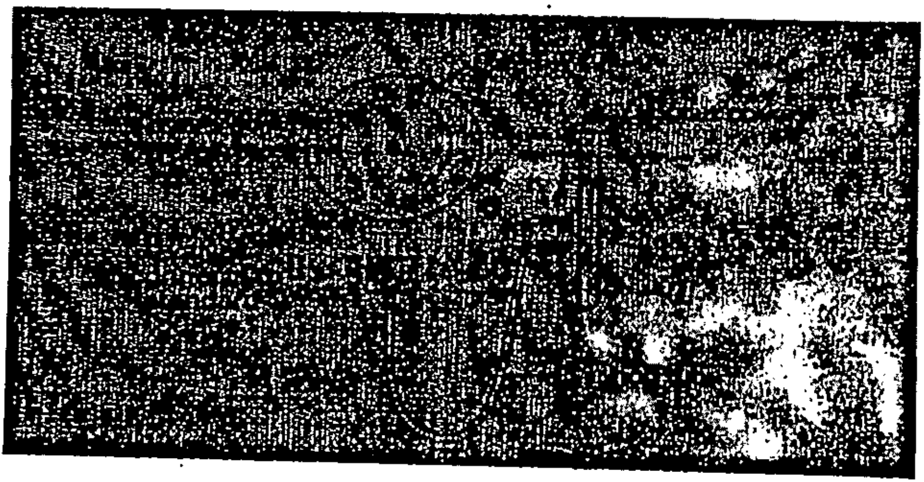


Fig.06: Bourdon pressure gauge

Fig.07: pressure gauge with siphon tube.

Unit - IV

M

Reaction turbines

The reaction turbines which are used. these days are really impulse - reaction turbine. pure reaction turbines are not in general use. The expansion of steam and heat drop occur both fixed and moving blades.

Mech-A

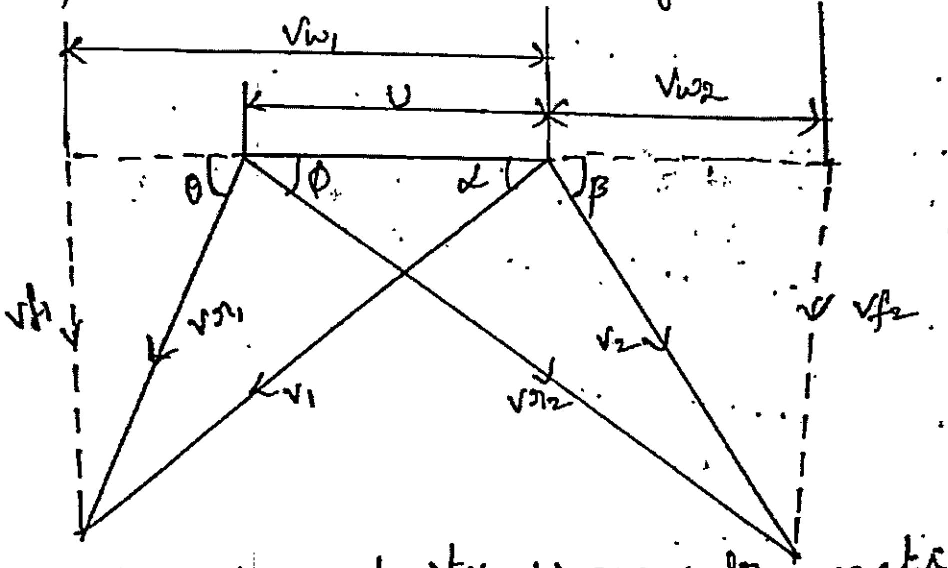
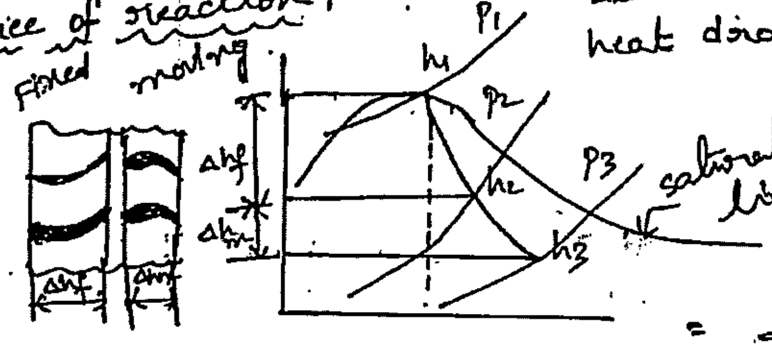


Fig. shows the velocity diagram for reaction turbine blade Incase of an impulse turbine blade the relative velocity of steam either remains constant. As the steam glides over the blades Vr is reduced slightly due to friction In reaction turbine blades, the steam continuously expands as it flows over the blades. The effect of the continuous expansion of steam during the flow over the blade is to increase the relative velocity velocity of steam for reaction turbines.

$V_{r2} > V_{r1}$ for reaction turbines.

Degree of reaction :- It is the ratio of reaction heat drop over moving blades to the total heat drop in the stage.



$$= \frac{\Delta h_m}{\Delta h_f + \Delta h_m}$$

The total heat drop in the stage is equal to the workdone by steam in the stage.

$$\Delta h_f + \Delta h_m = u(V_{w_1} + V_{w_2})$$

$$\Delta h_m = \frac{V_{r_2}^2 - V_{r_1}^2}{2}$$

$$(R_d) = \frac{V_{r_2}^2 - V_{r_1}^2}{2u(V_{w_1} + V_{w_2})},$$

So

$V_{r_2} = V_{f_2} \operatorname{cosec}\phi$

$V_{r_1} = V_{f_1} \operatorname{cosec}\theta$

$V_{w_1} + V_{w_2} = V_{f_1} \cot\theta + V_{f_2} \cot\phi$

$V_{f_1} = V_{f_2} = V_f$

$$(R_d) = \frac{V_f^2(\operatorname{cosec}^2\phi - \operatorname{cosec}^2\theta)}{2uV_f(\cot\theta + \cot\phi)}$$

$$= \frac{V_f}{2u}\left[\frac{(\cot^2\phi + 1) - (\cot^2\theta + 1)}{\cot\theta + \cot\phi}\right]$$

$$= \frac{V_f}{2u}\left[\frac{\cot^2\phi - \cot^2\theta}{\cot\phi + \cot\theta}\right]$$

$$= \frac{V_f}{2u}\left[\cot\phi - \cot\theta\right]$$

If turbine is 50% reaction turbine $\Delta h_f = \Delta h_m$

$$\frac{1}{2} = \frac{V_f}{2u}\left[\cot\phi - \cot\theta\right]$$

$$u = V_f\left[\cot\phi - \cot\theta\right]$$

$$u = V_f\left[\cot\phi - \cot\beta\right]$$

$$u = V_f\left[\cot\alpha - \cot\theta\right]$$

When comparing the above equations

$$\theta = \beta, \quad \phi = \alpha$$

which means that moving blade and fixed blade must have the same shape if the degree of reaction is 50%. This condition gives symmetrical velocity diagrams. This type of turbine is known as parson's reaction turbine.

The blades are symmetrical means exit angle of the fixed blade ~~and~~ equal to the ~~inlet~~ exit angle of moving blade the inlet angle of moving blade is equal to the inlet angle of fixed blade. Since the blades are symmetrical the velocity diagram also symmetrical In such a case the degree of reaction is 50%. Applying the steady flow energy equation to the fixed blades and assuming that the velocity of steam leaving the previous moving row

$$\Delta h_f = \frac{V_1^2 - V_2^2}{2}, \quad \Delta h_m = \frac{V_r^2 - V_1^2}{2}, \quad \begin{matrix} V_1 = V_{r2} \\ V_2 = V_{r1} \end{matrix}, \quad \Delta h_f = \Delta h_m$$

$$\text{Degree of reaction} = \frac{\Delta h_m}{\Delta h_f + \Delta h_m} = \frac{1}{2}$$

Condition for maximum efficiency :- The following assumptions.

1. Degree of reaction is 50%.
2. The moving blades and fixed blades are symmetrical.

workdone / kg of steam

$$w = u(V_{w1} + V_{w2}) = u[V_1\cos\alpha + (V_{r2}\cos\phi - u)]$$

$\phi = \alpha$, $V_{r2} = V_{r1}$ as per the assumptions

$$w = u[2V_1\cos\alpha - u] \qquad \rho = \frac{u}{V_1}$$

$$w = V_1^2\left[\frac{2uV_1\cos\alpha}{V_1^2} - \frac{u^2}{V_1^2}\right]$$

$$= V_1^2[2\rho\cos\alpha - \rho^2]$$

K.E supplied to fixed blade $= \frac{V_1^2}{2g}$

" " " moving blade $= \frac{V_{r2}^2 - V_{r1}^2}{2}$

Total energy supplied to stage $= \Delta h_f + \Delta h_m$

$$= \frac{V_1^2}{2} + \frac{V_{r2}^2 - V_{r1}^2}{2}$$

$$V_{r2} = V_1 \Rightarrow \Delta h = \frac{V_1^2}{2} + \frac{V_1^2 - V_{r1}^2}{2}$$

$$= V_1^2 - \frac{V_{r1}^2}{2}$$

But $V_{r1}^2 = V_1^2 + u^2 - 2V_1 \cdot u\cos\alpha$ [from fig of velocity diagram]

substitute the value of V_{r1}^2 value in above equation

Total energy supplied to the stage

$$\Delta h = V_1^2 - (V_1^2 + u^2 - 2V_1 u \cos\alpha)/2$$
$$= (V_1^2 + 2V_1 u\cos\alpha - u^2)/2$$
$$= \frac{V_1^2}{2}\left[1 + \frac{2u}{V_1}\cos\alpha - \left(\frac{u}{V_1}\right)^2\right]$$
$$= \frac{V_1^2}{2}\left[1 + 2\rho\cos\alpha - \rho^2\right]$$

Blade efficiency of reaction turbine is given by

$$\eta_{bl} = \frac{W}{\Delta h}$$

substitute W and Δh values in above equation.

$$\eta_{bl} = \frac{V_1^2[2\rho\cos\alpha - \rho^2]}{\frac{V_1^2}{2}[1 + 2\rho\cos\alpha - \rho^2]}$$

$$= \frac{2(2\rho\cos\alpha - \rho^2)}{(1 + 2\rho\cos\alpha - \rho^2)} = \frac{2\rho(2\cos\alpha - \rho)}{(1 + 2\rho\cos\alpha - \rho^2)}$$

$$= \frac{2(1 + 2\rho\cos\alpha - \rho^2) - 2}{(1 + 2\rho\cos\alpha - \rho^2)} = 2 - \frac{2}{1 + 2\rho\cos\alpha - \rho^2}$$

when $1 + 2\rho\cos\alpha - \rho^2$ becomes maximum the efficiency will maximum.

The required equation is

$$\frac{d}{d\rho}(1 + 2\rho\cos\alpha - \rho^2) = 0$$
$$2\cos\alpha - 2\rho = 0$$
$$\rho = \cos\alpha$$

substitute ρ value in blade efficiancioncy formula

$$\eta_b = 2 - \frac{2}{1 + 2\cos^2\alpha - \cos^2\alpha}$$

$$= 2\left[1 - \frac{1}{1 + \cos^2\alpha}\right)$$

$$= \frac{2\cos^2\alpha}{1 + \cos^2\alpha}$$

$$\boxed{(\eta)_{max} = \frac{2\cos^2\alpha}{1 + \cos^2\alpha}}$$

Blade or diagram efficiency :- It is the ratio of workdone on the blade/sec to the energy entering the blade/second.

Stage efficiency :- $$\frac{\text{Net workdone on shaft / stage / kg of steam}}{\text{Adiabatic heat drop / stage.}}$$

Internal efficiency :- $$\frac{\text{Heat converted into useful work}}{\text{Total adiabatic heat drop}}$$

Overall efficiency :- $$\frac{\text{work delivered at the turbine coupling}}{\text{Total adiabatic heat drop.}}$$

Net efficiency :- $$\frac{\text{Heat converted into useful work}}{\text{Total adiabatic heat drop.}}$$

Adiabatic power :- It is the power based on the total internal steam flow and adiabatic heat drop.

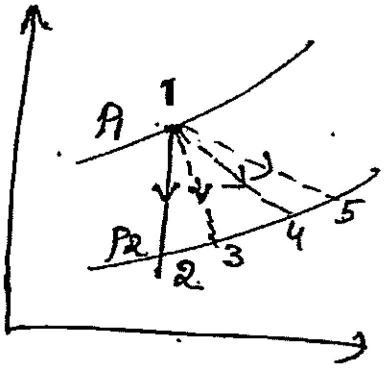
Shaft power :- It is the actual power transmitted by the turbine.

$m_s(h_1 - h_5)$

Rim power :- It is the power developed at the rim. It is also called blade power.

$m_s(h_1 - h_4)$

$A.P = m_s(h_1 - h_2)$



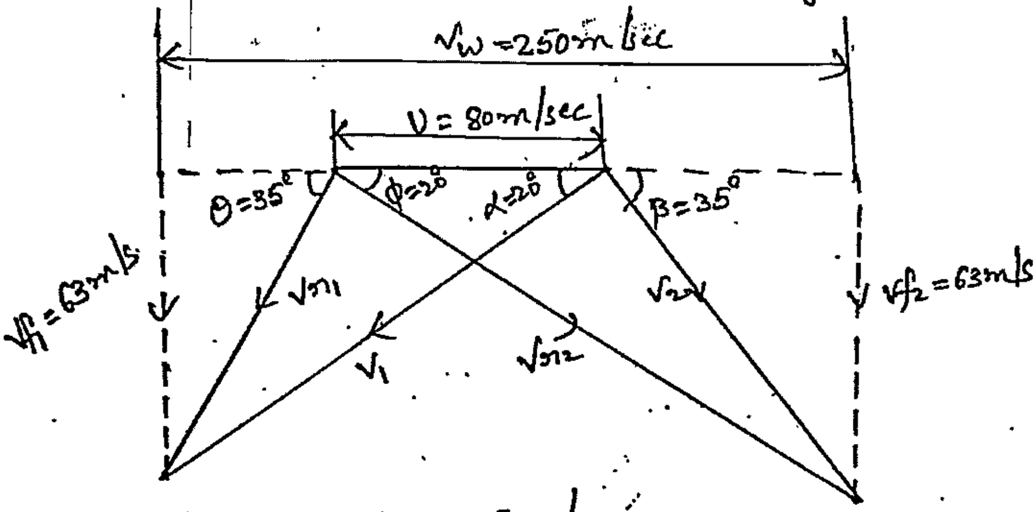
In one stage of reaction steam turbine both the fixed and moving blades have inlet and outlet blade tip angles of 35° and 20° respectively. The mean blade speed is 80m/s and the steam consumption is 22500 kg/hr. Determine power developed and stage efficiency if the isentropic heat drops in both fixed and moving rows is 23.5 KJ/kg in the pair.

Given :- Inlet blade angle $\theta = 35° = \beta$
Outlet " " $\phi = 20° = \alpha$

Blade Speed $(u) = 80 m/s$

mass of steam consumption $(m_s) = \frac{22500}{3600}$

$= 6.25$ kg/sec



From the diagram $V_w = 250$ m/sec

power $(P) = \frac{m(V_w)u}{1000}$

$= \frac{6.25(250)80}{1000} = 125$ kw

stage efficiency $(\eta_{stage}) = \frac{(V_w)u}{1000 \times \Delta h} = \frac{250 \times 80}{1000 \times 23.5}$

$= 85.1\%$

Height of Blades of a reaction turbine:-

h = height of blades

In reaction turbines, the steam enters the moving blades over the whole circumference. So the area of steam flow is full of steam

D = Diameter of rotor drum

$V_{f1} = V_f = V_{f2}$ = Velocity of flow

Area of steam flow $= \pi(D+h)h$

D+h = mean diameter of blade

$m = \frac{\text{Area of steam flow} \times \text{velocity of flow}}{\text{specific volume of steam}}$

$= \frac{(\pi(D+h)h)V_f}{v}$

$v = v_g$ = dry steam

$v = xv_g$ = wet "

unit-6

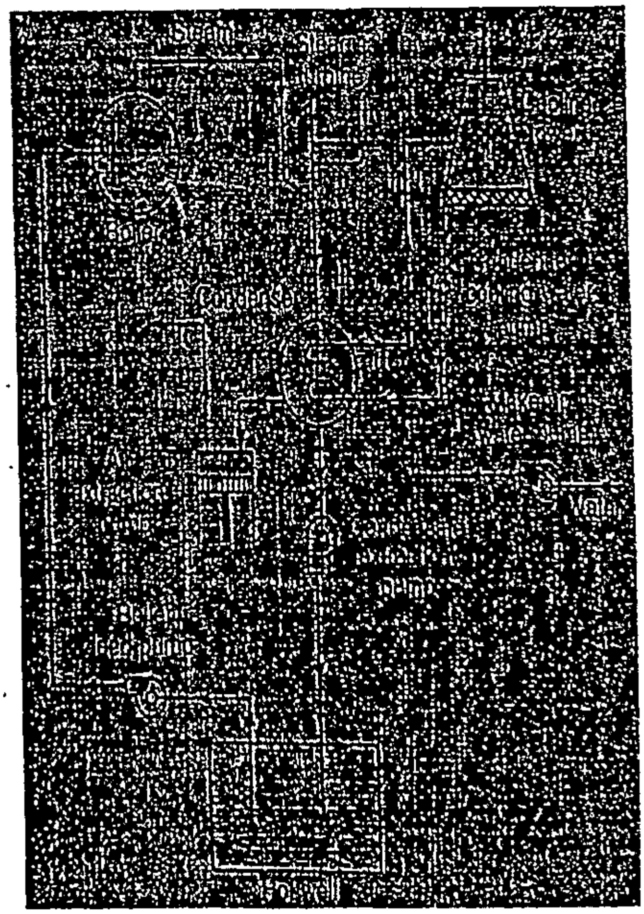
UNIT – 6 *Steam Condensers*

Elements of a condensing plant, Types of condensers, Comparison of jet and surface condensers, Condenser vacuum, Sources of air leakage & its disadvantages, Vacuum efficiency, Condenser efficiency

- **Steam Condenser:** It is a device or an appliance in which steam condenses and heat released by steam is absorbed by water.

- **Elements of a steam condensing plant:**

1. **Condense:** It is a closed vessel is which steam is condensed. The steam gives up heat energy to coolant (which is water) during the process of condensation.
2. **Condensate pump:** It is a pump, which removes condensate (i.e. condensed steam) from the condenser to the hot well.
3. **Hot well:** It is a sump between the condenser and boiler, which receives condensate pumped by the condensate pump.
4. **Boiler feed pump:** It is a pump, which pumps the condensate from the hot well to the , boiler. This is done by increasing the pressure of condensate above the boiler pressure.
5. **Air extraction pump:** It is a pump which extracts (i.e. removes) air from the condenser.
6. **Cooling tower:** It is a tower used for cooling the water which is discharged from the condenser.
7. **Cooling water pump:** It is a pump, which circulates the cooling water through the condenser.

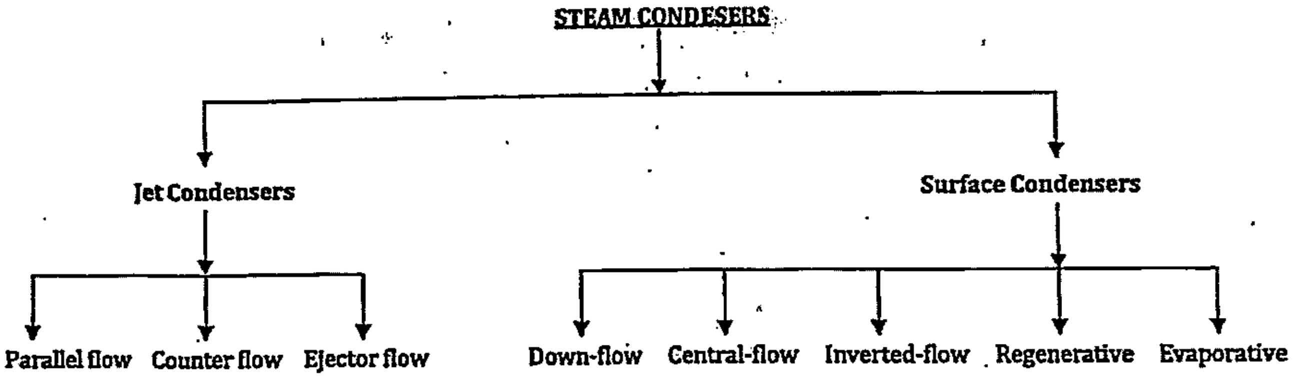


➢ Classification of Condensers

- Jet condensers
- Surface condenser

✓ Jet Condensers: The exhaust steam and water come in direct contact with each other and temperature of the condensate is the same as that of cooling water leaving the condenser. The cooling water is usually sprayed into the exhaust steam to cause, rapid condensation.

✓ Surface Condensers: The exhaust steam and water do not come into direct contact. The steam passes over the outer surface of tubes through which a supply of cooling water is maintained.



1. Parallel- Flow Type of Jet Condenser: The exhaust steam and cooling water find their entry at the top of the condenser and then flow downwards and condensate and water are finally collected at the bottom.

2. Counter- Flow Type jet Condenser: The steam and cooling water enter the condenser from opposite directions. Generally, the exhaust steam travels in upward direction and meets the cooling water which flows downwards.

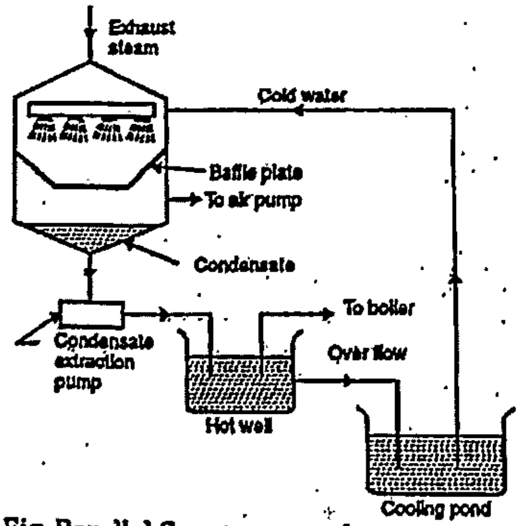


Fig. Parallel flow type condenser

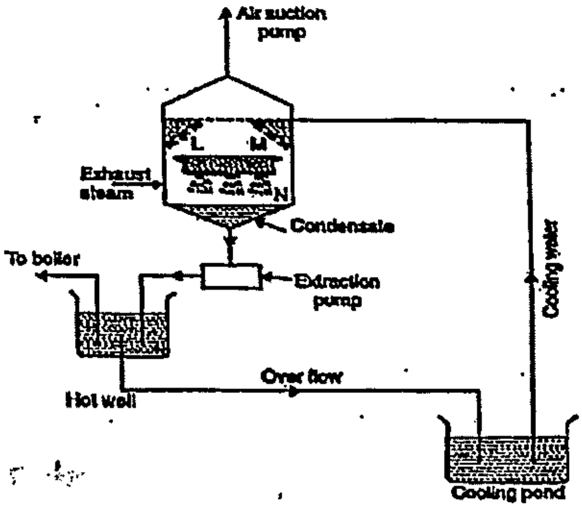


Fig. Low level counter flow type condenser

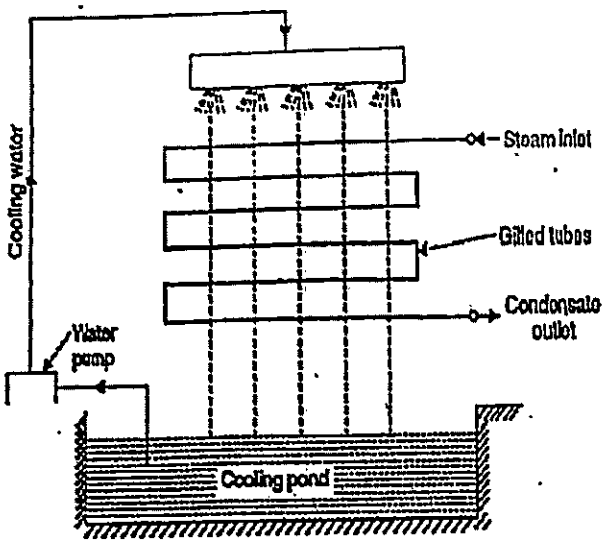


Fig. Evaporative Type

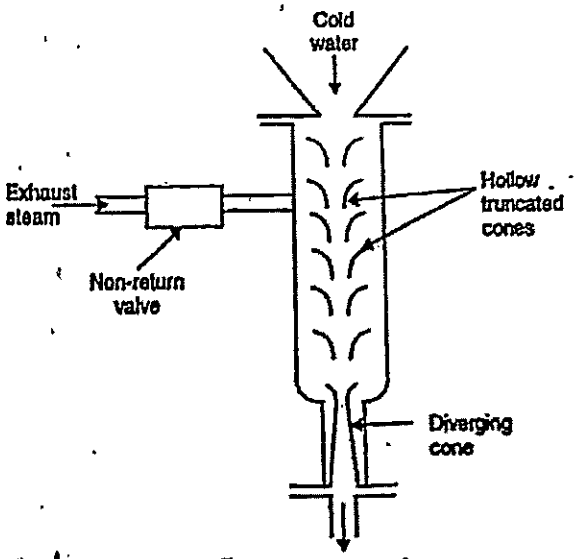


Fig. Ejector flow type condenser

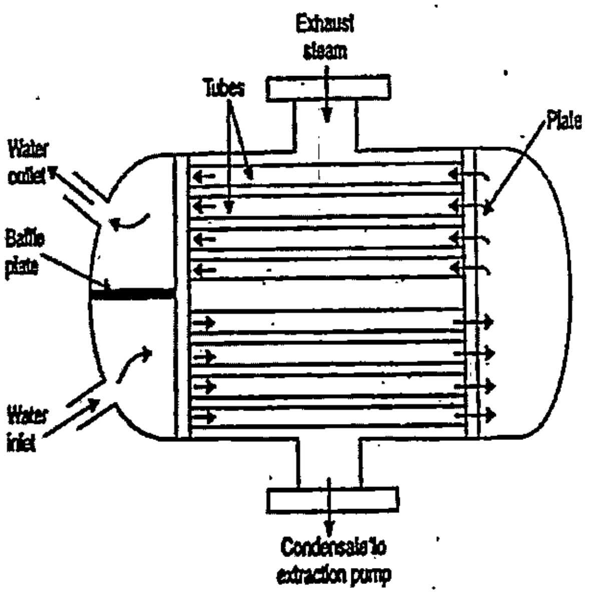


Fig. Down-Flow Type

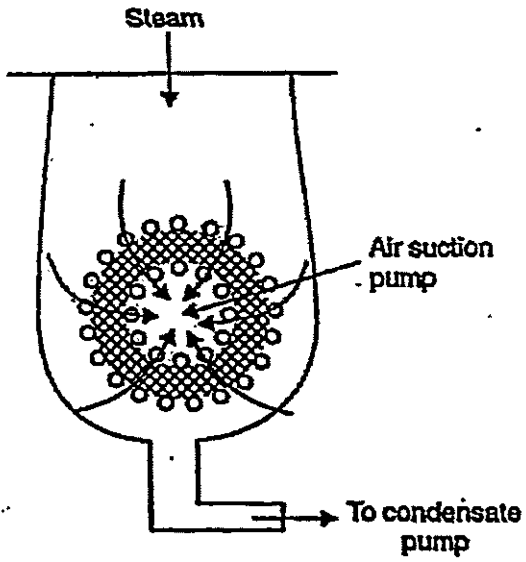


Fig. Central Flow Type

7. **Inverted Flow Type:** This type of condenser has the air suction at the top; the steam after entering at the bottom rises up and then again flows down to the bottom of the condenser, by following a path near the outer surface of the condenser. The condensate extraction pump is at the bottom.

8. **Regenerative Type:** This type is applied to condensers adopting a regenerative method of heating of the condensate. After leaving the tube nest, the condensate is passed through the entering exhaust steam from the steam engine or turbine thus raising the temperature of the condensate, for use as feed water for the boiler.

- **Low Level Jet Condenser (Counter-Flow Type Jet Condenser):** Figure Shows, L, M and N are the perforated trays which break up water into jets. The steam moving upwards comes in contact with water and gets condensed.

  The condensate and water mixture is sent to the hot well by means of an extraction pump and the air is removed by an air suction pump provided at the top of the condenser.

- **High Level Jet Condenser (Counter-Flow Type Jet Condenser):** It is also called barometric condenser. In this type the shell is placed at a height about 10.363 meters above hot well and thus the necessity of providing an extraction pump can be obviated. However provision of own injection pump has to be made if water under pressure is not available.

3. **Ejector Condenser Flow Type Jet Condenser:** Here the exhaust steam and cooling water mix in hollow truncated cones. Due to this decreased pressure exhaust steam along with associated air is drawn through the truncated cones and finally lead to diverging cone.

   In the diverging cone, a portion of kinetic energy gets converted into pressure energy which is more than the atmospheric so that condensate consisting of condensed steam, cooling water and air is discharged into the hot well. The exhaust steam inlet is provided with a non-return valve which does not allow the water from hot well to rush back to the engine in case a failure of cooling water supply to condenser.

4. **Down-Flow Type:** The cooling water enters the shell at the lower half section and after traveling through the upper half section comes out through the outlet. The exhaust steam entering shell from the top flows down over the tubes and gets condensed and is finally removed by an extraction pump. Due to the fact that steam flows in a direction right angle to the direction of flow of water, it is also called cross-surface condenser.

5. **Central Flow Type:** In this type of condenser, the suction pipe of the air extraction pump is located in the centre of the tubes which results in radial flow of the steam. The better contact between the outer surface of the tubes and steam is ensured; due to large passages the pressure drop of steam is reduced.

6. **Evaporative Type:** The principle of this condenser is that when a limited quantity of water is available, its quantity needed to condense the steam can be reduced by causing the circulating water to evaporate under a small partial pressure.

   The exhaust steam enters at the top through gilled pipes. The water pump sprays water on the pipes and descending water condenses the steam. The water which is not evaporated falls into the open tank (cooling pond) under the condenser from which it can be drawn by circulating water pump and used over again.

   The evaporative condenser is placed in open air and finds its application in small size plants.

- **Vacuum Efficiency:** The minimum absolute pressure (also called ideal pressure) at the steam inlet of a condenser is the pressure corresponding to the temperature of the condensed steam. The corresponding vacuum (called ideal vacuum) is the maximum vacuum that can be obtained in a condensing plant, with no air present at that temperature. The pressure in the actual condenser is greater than the ideal pressure by an amount equal to the pressure of air present in the condenser. The ratio of the actual vacuum to the ideal vacuum is known as vacuum efficiency. Mathematically, vacuum efficiency

$$\eta = \text{Actual Vacuum} / \text{Ideal Vacuum}$$

Where, η = Vacuum efficiency

Actual vacuum = Barometric pressure - Actual pressure

And Ideal vacuum = Barometric pressure - Ideal pressure

- **Condenser Efficiency**

It is defined as the ratio of the difference between the outlet and inlet temperatures of cooling water to the difference between the temperature corresponding to the vacuum in the condenser and inlet temperature of cooling water, i.e.,

$$\text{Condenser efficiency} = \frac{\text{Rise in temperature of cooling water}}{\left[\begin{array}{c}\text{Temp. corresponding to vacuum}\\ \text{in the condenser}\end{array}\right] - \left[\begin{array}{c}\text{Inlet temp. of}\\ \text{cooling water}\end{array}\right]}$$

$$= \frac{\text{Rise in temperature of cooling water}}{\left[\begin{array}{c}\text{Temp. corresponding to the absolute}\\ \text{pressure in the condenser}\end{array}\right] - \left[\begin{array}{c}\text{Inlet temp. of}\\ \text{cooling water}\end{array}\right]}$$

- **Sources of air into the condensers:**

1. The dissolved air in the feed water enters into the boiler, which in turn enters into the condenser with the exhaust steam.
2. The air leaks into the condenser, through various joints, due to high vacuum pressure in the condenser.
3. In case of jet condensers, dissolved air with the injection water enters into the condenser.

- **Effects of Air Leakage:**

1. It reduces the vacuum pressure in the condenser.
2. Since air is a poor heat conductor, particularly at low densities, it reduces the rate of heat transmission.
3. It requires a larger air pump. Moreover, an increased power is required to drive the pump.

Comparison Between Jet And Surface Condensers

	Jet Condenser	Surface Condenser
1.	Cooling water and steam are mixed up.	Cooling water and steam are not mixed up.
2.	Low manufacturing cost.	High manufacturing cost.
3.	Lower up keep.	Higher upkeep.
4.	Requires small floor space.	Requires large floor space.
5.	The condensate cannot be used as feed water in the boilers unless the cooling water is free from impurities.	Condensate can be reused as feed water as it does not mix with the cooling water.
6.	More power is required for air pump.	Less power is needed for air pump.
7.	Less power is required for water pumping.	More power is required for water pumping.
8.	It requires less quantity of cooling water.	It requires large quantity of cooling water.
9.	The condensing plant is simple.	The condensing plant is complicated.
10.	Less suitable for high capacity plants due to low vacuum efficiency.	More suitable for high capacity plants as vacuum efficiency is high.

Mixture of Air and Steam (Dalton's Law of Partial Pressures):

It states "The pressure of the mixture of air and steam is equal to the sum of the pressures, which each constituent would exert, if it occupied the same space by itself" Mathematically, pressure in the condenser containing mixture of air and steam,

$$P_c = P_a + P_s$$

Where,
P_c = Pressure in condenser
P_a = Partial pressure of air and,
P_s = Partial pressure of steam

Measurement of Vacuum in a Condenser:

- **Vacuum**: The difference between the atmospheric pressure and the absolute pressure.

In the study of condensers, the vacuum is generally converted to correspond with a standard atmospheric pressure, which is taken as the barometric pressure of 760 mm of mercury (Hg). Mathematically, vacuum gauge reading corrected to standard barometer or in other words:

Corrected vacuum in the condenser = 760 - (Barometer reading - Vacuum gauge reading)

Note: We know that; Atmospheric pressure = 760 mm of Hg = 1.013 bar

$\therefore$ 1 mm of Hg = 1.013/760 = 0.00133 bar = 133 N/m^2 ($\because$ 1 bar = 10^5 N/m^2)

Cooling Towers

In a cooling tower water is made to trickle down drop by drop so that it comes in contact with the air moving in the opposite direction. As a result of this some water is evaporated and is taken away with air. In evaporation, the heat is taken away from the bulk of water, which is thus cooled.

Types of Cooling Tower

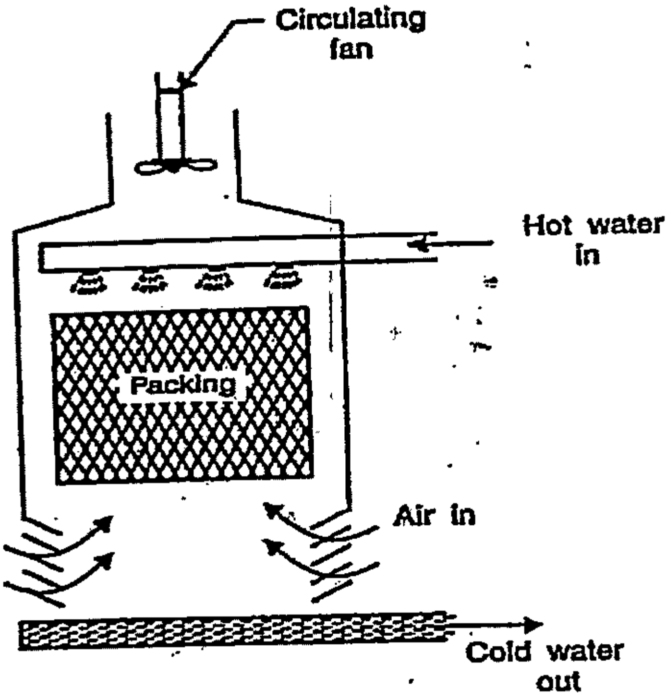


Fig. Natural draught cooling tower

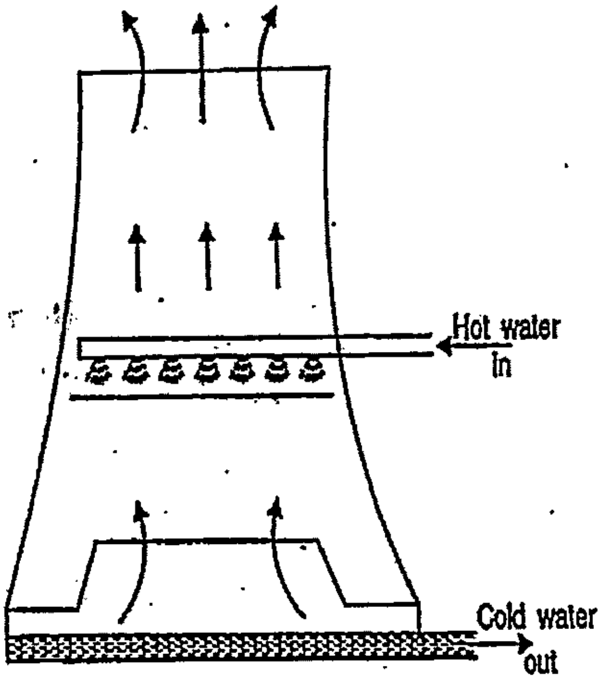


Fig. Forced draught cooling tower

Student Notes:

The following observations were recorded during a test on a steam condenser

Barometer reading = 765 mm of Hg
condenser vaccum = 710 mm of Hg
mean condenser temperature = $35^{\circ}c$
condensate temperature = $28^{\circ}c$,
condensate collected/hour = 2 tonnes
Quantity of cooling water/hour = 60 tonnes
Temperature of cooling water at inlet = $10^{\circ}c$
" " " outlet = $25^{\circ}c$

Find vaccum corrected to the standard barometer reading, vaccum efficiency, undercooling of the condensate, condenser efficiency, Quality of steam entering in the condenser volume, mass of air/kg of mass of air/m^3 of condenser volume, mass of air/kg of uncondensed steam

Barometer reading = 765 mm of Hg, $T = 35^{\circ}c \Rightarrow 308K$
condenser vaccum = 710 mm of Hg, $t_c = 28^{\circ}c$, $m_s = 2000 kg/h$
$m_w = 60{,}000\ kg/h$, $t_i = 10^{\circ}c$, $t_o = 25^{\circ}c$

Absolute pressure in the condenser
= 765 - 710 = 55 mm of Hg

standard barometer reading vaccum corrected = 760 mm of Hg
= 760 - 55 = 705 mm of Hg

From the steam table corresponding mean temperature of 35°,

$$P_S = 0.0562\ bar = \frac{0.0562}{0.00133} = 42.2\ mm\ of\ Hg$$

$$\text{Ideal vaccum} = \underset{765\ -\ 42.2}{(B.P - (I.P))} = 722.8\ mm\ of\ Hg$$

$$\eta_v = \frac{\text{Actual vaccum}}{\text{Ideal vaccum}} = \frac{710}{722.8} = 98.2\%$$

undercooling the condensate = Mean condenser temp - condensate temp
= 35 - 28 = $7^{\circ}c$

pressure in the condenser = (P_c) = 765 - 710 = 55 mm of Hg
= 55×0.00133
= 0.073 bar

from steam tables at 0.073 bar $(t_v) = 39.83°c$

$$\eta_c = \frac{\text{Temp. rise of cooling water}}{\text{vaccum temp} - \text{Inlet cooling temp}}$$

$$= \frac{t_o - t_i}{t_v - t_i}$$

$$= \frac{25-10}{39.83-10} = 50.3\%$$

at 0.073 bar

$h_f = 166.7$ KJ/kg, $h_{fg} = 24074$ KJ/kg

$$h = h_f + x h_{fg}$$

$$h = 166.7 + x(24074) \text{ KJ/kg}$$

mass of cooling water

$$60{,}000 = \frac{m_s(h - h_{f})}{C_w(t_o - t_i)} = \frac{2000(166.7 + x \times 24074 - 117.3)}{4.2(25-10)}$$

$x = 0.76$

From Dalton's law

$$P_a = P_c - P_s = 0.073 - 0.0562$$

$$= 0.0168 \text{ bar}$$

$$= 1680 \text{ N/m}^2$$

$$m_a = \frac{P_a V}{RT} = \frac{1680 \times 1}{287 \times 308} = 0.019 \text{ Kg}$$

at mean temperature $35°c$, $v_g = 25.245 \text{ m}^3/\text{kg}$

$$m_g = \frac{P_a v_g}{RT} = \frac{1680 \times 25.245}{287 \times 308}$$

$$= 0.48 \text{ kg}$$

The air leakage into a surface condenser operating with a steam turbine is estimated as 84 kg/h. The vaccum near the inlet of air pump is 70mm of Hg when barometer reads 760mm of Hg. The temperature at inlet of vaccum pump 20°c calculate. The minimum capacity of the air pump m3/h, The dimensions of the recipro cating air pump to remove air if it runs at 200 rpm Take L/D ratio = 1.5 and volumetric efficiency 100%, The mass of vapour extracted/min.

pressure in condenser = (P_c) = Barometer reading − condenser vaccum

$= 760 - 700 = 60$ mm of Hg

$= 60 \times 0.00133$

$= 0.0798$ bar

at mean temperature 20°c, the pressure of steam

$P_s = 0.0234$ bar

pressure of air = (P_a) = $P_c - P_s = 0.0798 - 0.0234$

$= 0.0564$ bar

$= 5640\ N/m^2$

minimum capacity of the air pump

$$V_a = \frac{m_a R T}{P_a} = \frac{84 \times 287 \times 293}{5640}$$

$= 1252.4\ m^3/h$

Dimensions of reciprocating pump:- Length of stroke $= 1.5D$

$\eta_{vol} = 100\% = 1$

N = Speed of rpm = 200 rpm

minimum capacity of air (V_a)

$$\frac{1252.4}{60} = \frac{\pi}{4} \times D^2 \times L \times N = \frac{\pi}{4} \times D^2 \times 1.5D \times 200 = 235.6D^3$$

$D^3 = 0.0886 \Rightarrow D = 0.446m$

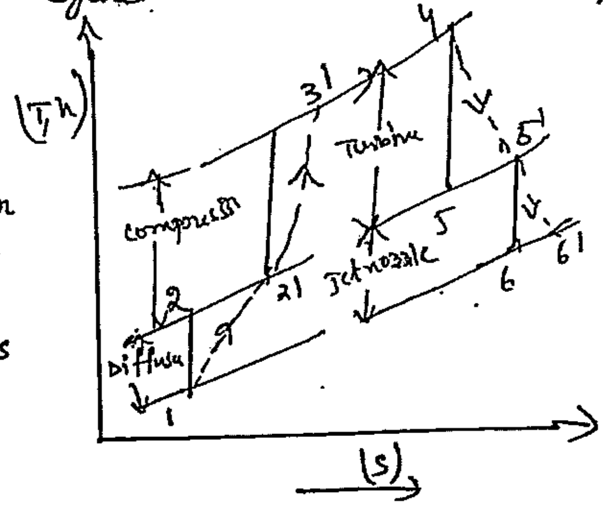
$L = 1.5D \Rightarrow 1.5 \times 0.446 = 0.669m$

mass of vapour extracted/min = $\frac{V_a}{v_g}$

at Tmean 20°C, $v_g = 57.84\ m^3/kg$

$$= \frac{1252.4}{60 \times 57.84} = 0.361\ kg/min$$

Turbo-jet engine :- The basic cycle for turbo jet engine is the Joule or Brayton cycle.



Process 1-2 :- The air entering from atmosphere is diffused isentropically from velocity C_a. This indicates that the diffuser has an efficiency of 100%. This is termed as ram compression.

process 2-3 :- 2'-3' process shows the actual compression of air

process 3-4 :- 3'-4 shows the actual addition of heat at constant process $P_3 = P_4$

process 4-5 :- 4'-5' shows actual expansion in the turbine

process 5-6 :- 5'-6' shows actual expansion of gas in the nozzle.

Diffuser :- $\frac{C_a^2}{2} + h_1 + Q_{1-2} = \frac{C_2^2}{2} + h_2 + W_{1-2}$

In an ideal diffuser $C_2 = Q_{1-2} = W_{1-2} = 0$

$\boxed{h = C_pT}$

$$h_2 = h_1 + \frac{C_a^2}{2}$$

$$T_2 - T_1 + \frac{C_a^2}{2C_p}$$

$$\eta_d = \frac{h_2 - h_1}{h_2' - h_1} \Rightarrow \frac{T_2' - T_1}{T_2' - T_1}$$

$$T_2' = T_1 + \frac{C_a^2}{2 \times C_p \times \eta_d}$$

Compressor :- Energy equation between states 2 and 3 gives

$$h_2 + \frac{C_2^2}{2} + Q_{2-3} + W_c = h_3 + \frac{C_3^2}{2}$$

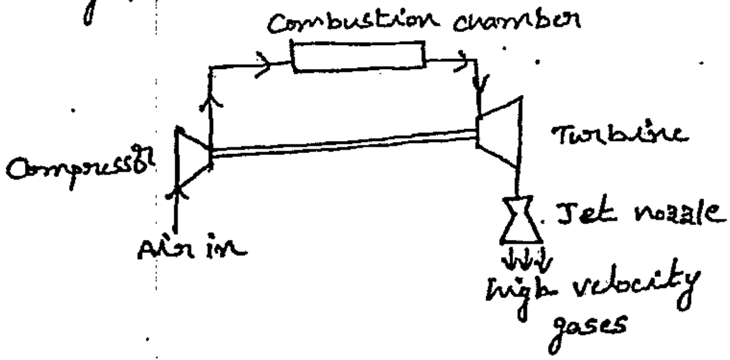
change in P.E and K.E negligable

$$W_c = h_3 - h_2 = C_p (T_3 - T_2)$$

actual work $= h_3' - h_2 = \frac{h_3 - h_2}{\eta_c} = \frac{C_p (T_3 - T_2)}{\eta_c}$

Jet propulsion :-

The working of Jet engines is based on Newtons laws of motion. In these units the energy of fuel is converted into Kinetic energy of a jet of gases. The propulsive forces is obtained from the reaction of the jet of gases which are discharged with a very high velocity from the rear side of the unit.

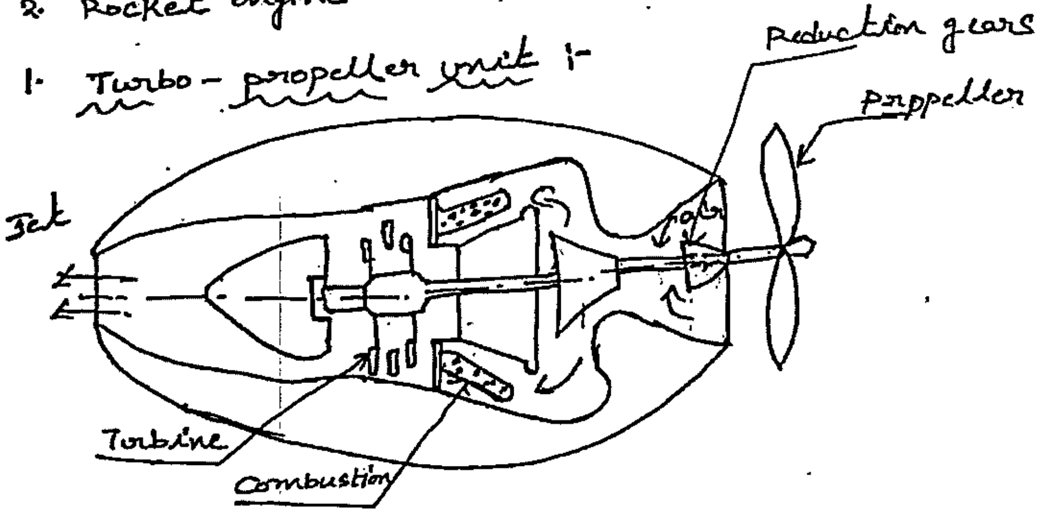


Types of Jet propulsion units :-

According to the method of operation all the jet engines.

1. Atmospheric jet engines
   a) Turbo - propeller units (engine)
   b) Turbo - Jet unit (engine)
   c) Ram jet engine
2. Rocket engine

1. Turbo - propeller unit :-

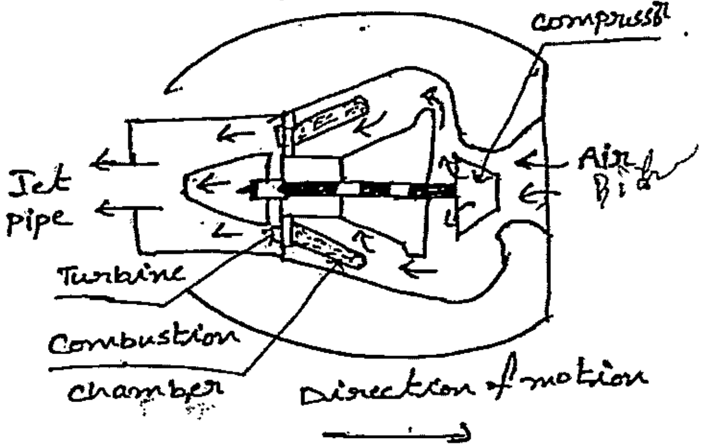


It consists of an open cycle gas turbine, compressor, Combustion chamber, turbine and a propeller added to the engine

Air enters into compressor where it is compressed to a high pressure. The compressed air is then entered into combustion chamber in which the combustion of fuel take place. The products of combustion are forced into the gas turbine. The power produced in the turbine is used to drive the compressor and propeller. A set of reduction gears is used to reduce the speed of rotation of the propeller. The Jet of exhaust gases leave the unit from its rear end. Approximately 80 to 90% of the thrust of the turboprop engine is produced by propeller and about 10 to 12% of the thrust is produced by the reaction of the jet at exit.

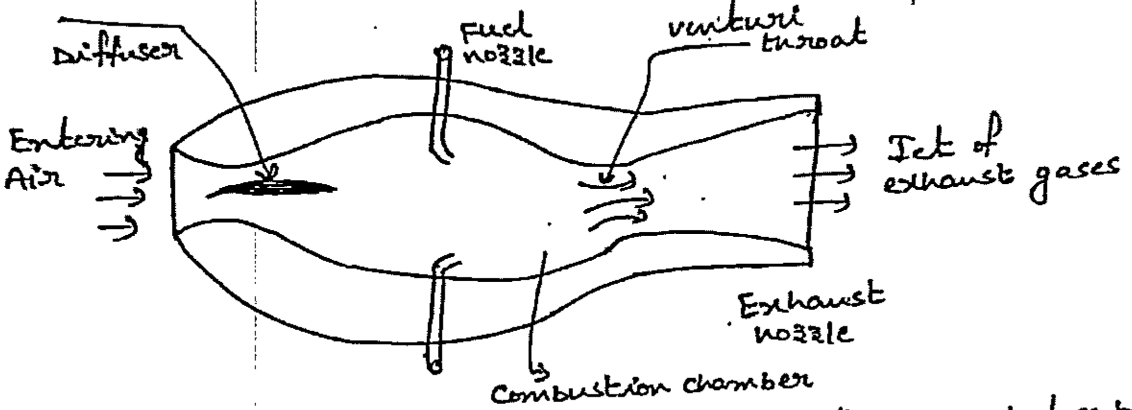
Turbo - Jet unit :- It consists of a open cycle gas turbine with a diffuser infront of the compressor and an exit nozzle added to the turbine end.

Air enters into compressor through a diffuser where it is compressed. Small pressure rise in the entering air is caused in the diffuser, but the major part of pressure rise is accomplished in the compressor which is driven by turbine. Compressed air passed into the combustion chamber in which fuel is injected at high pressure. Combustion of fuel takes place at constant pressure. Due to combustion temperature and volume of products of combustion increases considerable. High air fuel ratio limits the temperature of hot gases. The hot gases is then expanded through exit nozzle in which the thermal energy of the hot gases in converted into kinetic energy. The jet of gases is discharged out through the rear end of the unit. The reaction of the jet provides the thrust to move the unit in the direction opposite to that of the jet.



Ram Jet engine :- It consists of an inlet diffuser, a combustion chamber, and an exit nozzle. It has no compressor and turbine.

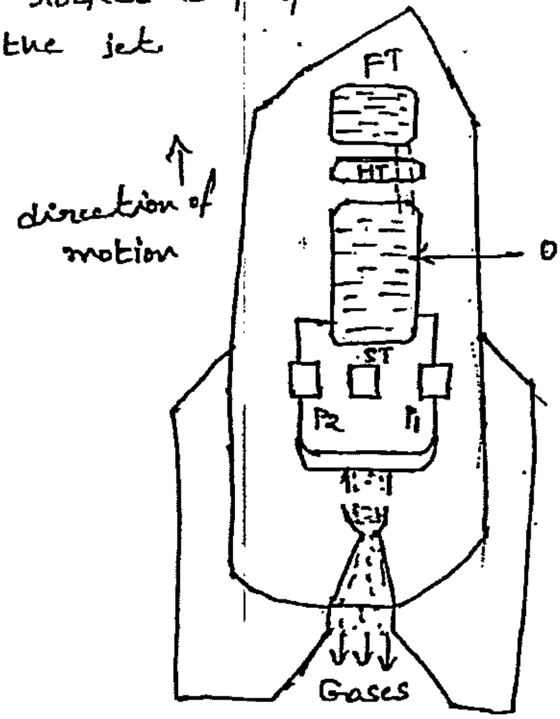
The velocity of air entering the diffuser is decreased and is acompained by an increase in pressure. This pressure rise due to decrease in velocity of incoming air is known as ram effect. The air at high pressure is passed into combustion chamber by fuel nozzle. The mixture is ignited by a spark plug. The temperature of combustion products is not limited as in the case of turbo jet engine. Air-fuel ratio of around 15 to 1 used. This produces exhaust gas temperatures in the range of 1950° to 2200°c. High pressure and temperature gases pass through the nozzle where the pressure energy is converted into kinetic energy. The high velocity jet leaving a nozzle exert a thrust to the ram jet engine



In ram jet engines, travelling at a speed less than Super sonic Speed the air enters through grid. Grid valves (shutter valves) are operated automatically by the pressure difference on either side of grid. If the pressure in combustion chamber is more, the valves are closed. The pressure in the combustion chamber decreases due to expansion of gases then the valves are automatically opened air flows into the diffuser.

Rocket engines :- It carries both the fuel and oxidising agent. As a result this type of engine is independent of the atmosphere. From this point of view rocket engines are most attractive and can be operated in the vaccum. however the propellant (oxidiser and fuel) consumption is very high.

Rocket consists two tanks one containing fuel (alcohol) and other oxidiser (liquid oxygen) two pumps (P_1 and P_2) a steam turbine (ST) and a combustion chamber. The fuel and oxidiser are supplied to the combustion chamber by the pumps. The pumps are driven by steam turbine. The steam required for turbine is produced by mixing a very concentrated hydrogen peroxide with calcium permanganace. The oxidiser and fuel burn in the combustion chamber producing high pressure gases. The high pressure gases are passed through the nozzle where pressure is converted into kinetic energy. The gas jet is ejected to the atmosphere at supersonic speed through a nozzle. The jet produce the thrust on the rocket engine and rocket is propelled into sky in the direction opposite to the jet



FT = Fuel tank
HT = Hydrogen peroxide tank
O = oxidiser tank
ST = steam turbine
P1, P2 = pumps
C.C = combustion chamber
HG = Hot gases
N = Nozzle

Fuels used in jet propulsion:-

1. petrol
2. avitation kerosine
3. Gasoline
4. paraffin
5. Alcohol
6. Natural gas

Combustion chamber :- Ideal heat Supplied / kg $= h_4 - h_3$

$= C_p (T_4 - T_3)$

Actual heat supplied $= \left(1 + \frac{m_f}{m_a}\right) h_4 - h_3'$

$= C_{pg} \left(1 + \frac{m_f}{m_a}\right) T_4 - C_{pa} T_3'$

Turbine :- The energy equation

$$h_4 + \frac{C_4^2}{2} + Q_{4-5} = h_5 + \frac{C_5^2}{2} + W_t$$

$$Q_{4-5} = 0 \qquad W_t = (h_4 - h_5) + \frac{C_4^2 - C_5^2}{2}$$

Change in K.E is neglected

$$W_t = (h_4 - h_5) \Rightarrow C_p (T_4 + T_5)$$

$$\text{Actual work} = C_p (T_4 - T_5') \eta_t$$

$$C_p (T_4 - T_5') = C_p (T_4 - T_5) \eta_t$$

Nozzle :-

$$h_5' + \frac{C_5^2}{2} = h_6' + \frac{C_6^2}{2}$$

$$h_5' = h_6' + \frac{C_6'^2}{2}$$

$$C_6' = \sqrt{2 \times \eta_n C_p (T_5' - T_6)}$$

Thermal efficiency :- $\dfrac{(h_4 - h_6') - (h_3' - h_1)}{(h_4 - h_3')}$

Thrust :- The atmospheric air to be still. the velocity of air relative to aircraft at entry to the air craft will be Ca. It is called velocity of approach of air.

Cj = velocity of jet relative to the exit nozzle

$\left(1 + \frac{m_f}{m_a}\right)$ = mass of products leaving the nozzle

change of momentum $= \left(1 + \frac{m_f}{m_a}\right)(C_j - C_a)$ N/kg of air/sec

neglecting the mass of fuel

$$T = (C_j - C_a)$$

Thrust power :- The rate at which work must be developed by the engine if the aircraft is to be kept moving at a constant velocity Ca against friction force

T.P = forward thrust × speed of aircraft

$= \left[\left(1 + \frac{m_f}{m_a}\right)(C_j - C_a)\right] C_a$ w/kg of air mass of fuel is neglected

$$= \frac{(C_j - C_a) C_a}{1000} \text{ kw/kg of air}$$

propulsive power:- The energy required to change the momentum of the mass flow of gas represents the propulsive power. It is expressed as the difference between the rate of kinetic energies of the entering air and exit gases

$$P.P = A.K.E = \frac{\left(1 + \frac{m_f}{m_a}\right) C_j^2}{2} - \frac{C_a^2}{2} \text{ w/kg}$$

$$= \frac{C_j^2 - C_a^2}{2} \text{ w/kg}$$

propulsive efficiency:- The ratio of thrust power to propulsive power is called the propulsive efficiency.

$$= \frac{\left[\left(1 + \frac{m_f}{m_a}\right)(C_j - C_a)\right] C_a}{\left[\frac{\left(1 + \frac{m_f}{m_a}\right) C_j^2}{2} - \frac{C_a^2}{2}\right]}$$

$$= \frac{2\left[\left(1 + \frac{m_f}{m_a}\right)(C_j - C_a)\right] C_a}{\left[\left(1 + \frac{m_f}{m_a}\right) C_j^2 - C_a^2\right]}$$

Neglecting mass of fuel.

$$\eta_{prop} = \frac{2(C_j - C_a) C_a}{C_j^2 - C_a^2} = \frac{2(C_j - C_a) C_a}{(C_j + C_a)(C_j - C_a)}$$

$$\eta_{prop} = \frac{2C_a}{C_j + C_a}$$

Thermal efficiency :- $\dfrac{\text{propulsive work}}{\text{Heat released by the combustion of fuel}}$

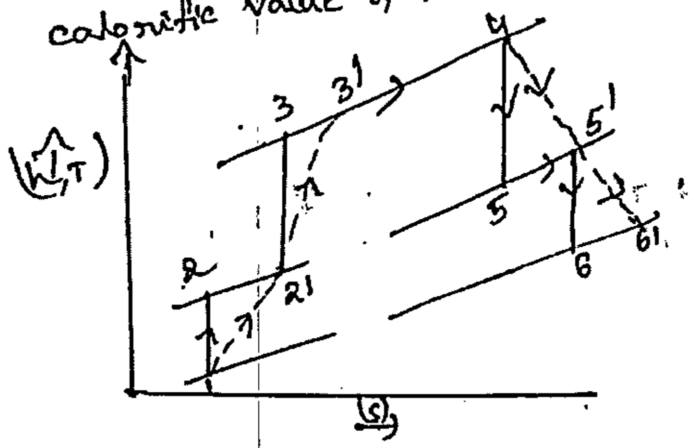
$$= \frac{\left(1+\frac{m_f}{m_a}\right) c_j^2 - c_a^2}{2\left(\frac{m_f}{m_a}\right) cv}$$

$$= \frac{c_j^2 - c_a^2}{2\left(\frac{m_f}{m_a}\right) cv}$$

overall efficiency :- $\eta_{th} \times \eta_{prop} = \dfrac{c_j^2 - c_a^2}{2\left(\frac{m_f}{m_a}\right) cv} \times \dfrac{2c_a}{c_j + c_a}$

$$= \frac{(c_j - c_a)\, c_a}{\left(\frac{m_f}{m_a}\right) cv}$$

A turbo jet engine travels at 216 m/s in air at 0.78 bar and -7.2°c. Air first enters diffuser in which it is brought to rest relative to the unit and it is then compressed in a compressor through a pressure ratio 5.8 and fed to a turbine at 1110°c. The gases expand through the turbine and then through the nozzle to atmospheric pressure. The effeciencies of diffuser, nozzle and compressor are each 90%. The effeciency of turbine 80%. pressure drop in the combustion chamber is 0.168 bar. Determine 1) Air-fuel ratio 2) Specific thrust of the unit 3) Total thrust, if the inlet c/s of diffuser is 0.12m² assume calorific value of fuel as 44150 kJ/kg of fuel



Speed of air craft $(C_a) = 216$ m/s

Intake air temp (T_1)

$= -7.2 + 273$

$= 265.8$ K.

Intake air pressure $(P_1) = 0.78$ bar

pressure ratio in the compressor = 5.8

Temperature of gases entering the gas turbine

$T_4 = 1110 + 273 = 1383K$

pressure drop in the Combustion chamber

$= 0.168$ bar

$\eta_d = \eta_n = \eta_c = 90\%;\ \eta_t = 80\%$

1. Diffuser:-

$h_2 = h_1 + \frac{Ca^2}{2}$

$\boxed{h_2 - h_1 = \frac{Ca^2}{2}}$

$\boxed{T_2 - T_1 = \frac{Ca^2}{2C_p}}$

$= 265.8 + \frac{(216)^2}{2 \times 1.005 \times 1000}$

$\boxed{T_2 = 289K}$

$T_2^1 = T_1 + \frac{Ca^2}{2C_p \eta_d}$

$= 265.8 + \frac{216^2}{2 \times 1.005 \times 1000 \times 0.9}$

$\boxed{T_2^1 = 291.6K.}$

$\Rightarrow \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$

$P_2 = (P_1)^{\frac{\gamma}{\gamma-1}} \times \left(\frac{T_2}{T_1}\right)$

$\boxed{P_2 = 1.044\,bar}$

$\Rightarrow \frac{T_3}{T_2^1} = (r_p)^{\frac{\gamma-1}{\gamma}}$

$T_3 = 291.6 \times 1.662 = 484.7K.$

$\eta_c = \frac{T_3 - T_2^1}{T_3^1 - T_2^1} =$

$\boxed{T_3^1 = 502.8K}$

Heat Supplied:-

$(m_f \times CV) = (m_a + m_f)C_p T_4 - m_a C_p T_3^1$

$m_a C_p (T_4 - T_3^1) = m_f (CV - C_p T_4)$

$\frac{m_a}{m_f} = \frac{CV - C_p T_4}{C_p (T_4 - T_3^1)}$

$\boxed{\frac{m_a}{m_f} = 48.34}$

$\Rightarrow$ Specific thrust of the unit

$P_4 = P_3 - 0.168 =$

$= 5.8 \times 1.044 - 0.168$

$\boxed{P_4 = 5.88\,bar}$

Assume turbine drives compressor only.

$C_p (T_3^1 - T_2^1) = C_p (T_4 - T_5^1)$

$(T_3^1 - T_2^1) = T_4 - T_5^1$

$T_5^1 = T_4 - (T_3^1 - T_2^1)$

$\boxed{T_5^1 = 1171.8K.}$

$\eta_t = \frac{T_4 - T_5^1}{T_4 - T_5}$

$T_5 = T_4 - \frac{T_4 - T_5^1}{\eta_t}$

$\boxed{T_5 = 1119K.}$

$\frac{T_4}{T_5} = \left(\frac{P_4}{P_5}\right)^{\frac{\gamma-1}{\gamma}}$

$\boxed{P_5 = 2.8\,bar.}$

$$\frac{T5^1}{T6} = \left(\frac{P5}{P6}\right)^{\frac{\gamma-1}{\gamma}} \qquad \boxed{P6 = P1}$$

$T_6 = 813.75K$

$$\eta_n = \frac{T5^1 - T6^1}{T5^1 - T6}$$

$T6^1 = 849.5K$

Velocity at the exit of nozzle

$C_j = 44.72\sqrt{h5^1 - h6^1}$

$= 44.72\sqrt{Cp(T5^1 - T6^1)}$

$= 804.8 m/s$

Special thrust $= (1 + mf)\, Cj$

$= \left(1 + \frac{1}{48.34}\right) 804.8$

$= 821.45$ N/kg of air/sec

Total thrust :-

volume of flowing air

$(V_1) = 0.12 \times 216$

$= 25.92 m^3/s$

$$ma = \frac{P_1V_1}{RT_1}$$

$$= \frac{0.78 \times 10^5 \times 25.92}{(0.287 \times 1000) 265.8}$$

$= 26.5$ kg/s

Total thrust

$= 26.5 \times 821.45$

$= 21768.4 N$

A turbo-jet engine consumes air at the rate of 60.2 kg/s when flying at a speed of 1000km/h calculate exit velocity of jet when the enthalaphy change for the nozzle is 230 KJ/kg and velocity co-effecient is 0.96. Fuel flow rate in kg/s when air fuel ratio is 70:1, thrust specific fuel consumption, Thermal efficiency of the plant when the combustion efficiency is 92% and the calorific value of fuel is used is 42000 KJ/kg. propulsive power, propulsive efficiency, overall efficiency.

Rate of air consumption

$(ma) = 60.2$ kg/s

Enthalaphy change for nozzle

$\Delta h = 230$ KJ/kg

velocity coefficient $= 0.96$

Air- fuel ratio $^{(3)} = 70:1$

$\eta_{combustion} = 92\%$

Calorific value $(cv) = 42000$ KJ/kg

Aircraft velocity (ca)

$$= \frac{1000 \times 1000}{3600}$$

$= 277.8 m/sec$

Exit velocity of jet

$c_j = 44.72\sqrt{}$

$c_j = 2\sqrt{2 \times \Delta h \times 1000}$

$= 0.96\sqrt{2 \times 1000 \times 230}$

$= 651 m/s.$

Fuel flow rate

$$mf = \frac{\text{Air Consumption}}{\text{Air- fuel ratio}}$$

$$= \frac{60.2}{70}$$

$= 0.86$ kg/sec

Thrust specific fuel consumption

$$= \frac{\text{fuel consumption}}{\text{Thrust}}$$

$$= \frac{0.86}{\text{Thrust}}$$

Thrust $= ma\,(Cj - Ca)$

$= 60.2\,(651 - 277.8)$

$= 22466.6N$

$$= \frac{0.86}{22466.6}$$

$= 3.823 \times 10^{-5}$ kg/N

$$\eta_{overall} = \frac{\text{Thrust work}}{\text{Heat supplied by fuel}}$$

$$= \frac{(Cj - Ca)Ca}{\left(\frac{mf}{ma}\right) cv \times \eta_{com}}$$

$$= \frac{(651 - 277.8)\,277.8}{\frac{1}{70} \times 42000 \times 0.92 \times 100}$$

$= 18.78\%$

$$\eta_{thermal} = \frac{\text{work output}}{\text{Heat supplied}}$$

$$= \frac{Cj^2 - Ca^2}{\left(\frac{mf}{ma}\right) cv \times \eta_{com} \times 1000}$$

$$= \frac{(651)^2 - (277.8)^2}{2 \times \frac{1}{70} \times 42000 \times 0.92 \times 1000}$$

$= 31.39\%$

propulsive power

$$= \frac{\text{Thrust power}}{\text{propulsive power}}$$

$$= \frac{2Ca}{cj + Ca} = \frac{2 \times 277.8}{651 + 277.8}$$

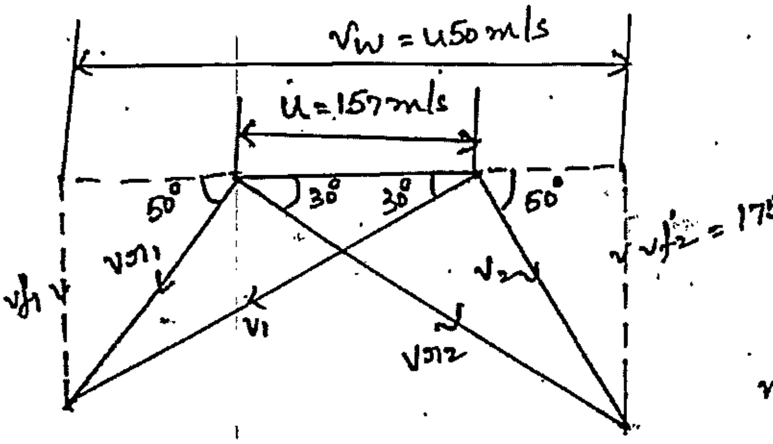
$= 59.8\%$

A 50% reaction turbine stage running at 3000 rpm the exit angles are 60° and the Inlet angles are 50°. The mean diameter is 1m. The steam flowrate is 10,000 kg/min stage efficiency is 85%, find the power developed and enthalaphy drop in a stage.

$u = \frac{\pi D N}{60}$

$= \frac{\pi \times 1 \times 3000}{60}$

$= 157 m/s$



$m = \frac{10,000}{60}$

$= 166.67 kg/s$

$\eta_{stage} = 0.85$

$V_w = 450 m/sec$

$P = \frac{m (V_w) u}{1000}$

$= \frac{166.67 \times 450 \times 157}{1000}$

$= 11,775 KW$

$\eta_{stage} = \frac{(V_w) u}{\Delta h \times 1000}$

$\Delta h = 83.12 kJ/kg$

The total tangential force on one ring of parsons turbine is 1200N when the blade speed is 100m/s. The mass flow rate is 8 kg/s the blade outlet angle is 20° determine the steam velocity at outlet from the blades. If the friction loss which occurs with pure Impulse are 30% of the kinetic energy and if the expansion losses are 15% of the heat drop in the blades, determine the heat drop / stage and stage efficiency.

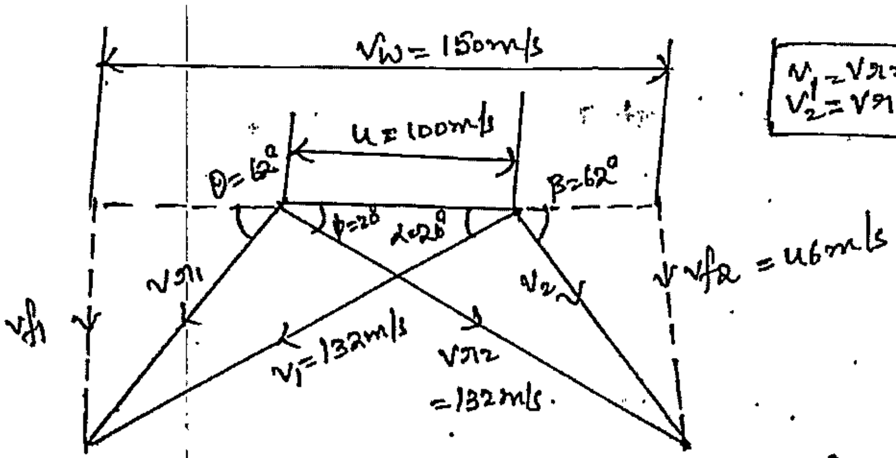
Tangential force = 1200N

Blade Speed (u) = 100 m/s

$m = 8 kg/s$, $\phi = 20°$

$F = \frac{m (V_w)}{}$

$V_w = \frac{T.F}{m} \Rightarrow \frac{1200}{8} = 150 m/s$



$V_1 = V_{r2}$
$V_2' = V_{r1}$

$\Delta h_f = \Delta h_m = \frac{V_1^2 - 0.7 V_2^2}{2 \times 1000} \Rightarrow \frac{132^2 - 0.7 (52)^2}{2 \times 1000 \times 0.85}$

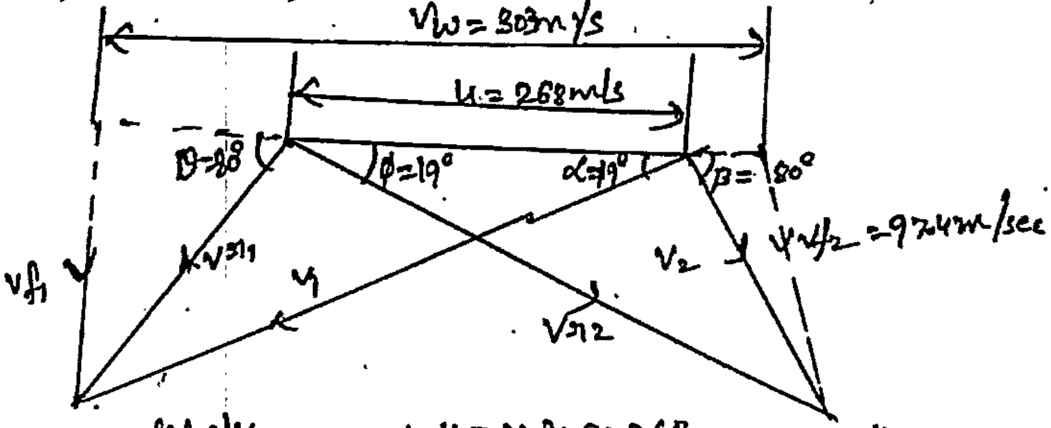
$= 9.14 \, kJ/kg$

Total heat drop = $\Delta h_f + \Delta h_m = 18.28 \, kJ/kg$.

$\eta_{stage} = \frac{V_w u}{1000 \times \Delta h} = 82.1\%$.

In a stage of impulse reaction turbine operating with 50% Degree of reaction the blades are identical in shape. The outlet angle of moving blades is 19° and the absolute discharge velocity of steam is 100m/s in direction at 100° to the motion of blades. If the rate of flow of steam through the turbine is 15000 kg/hr. calculate power developed by turbine.

$\phi = 19°$, $V_2 = 100m/s$, $\beta = 180 - 100 = 80°$, $m = \frac{15000}{3600} = 4.167 kg/s$



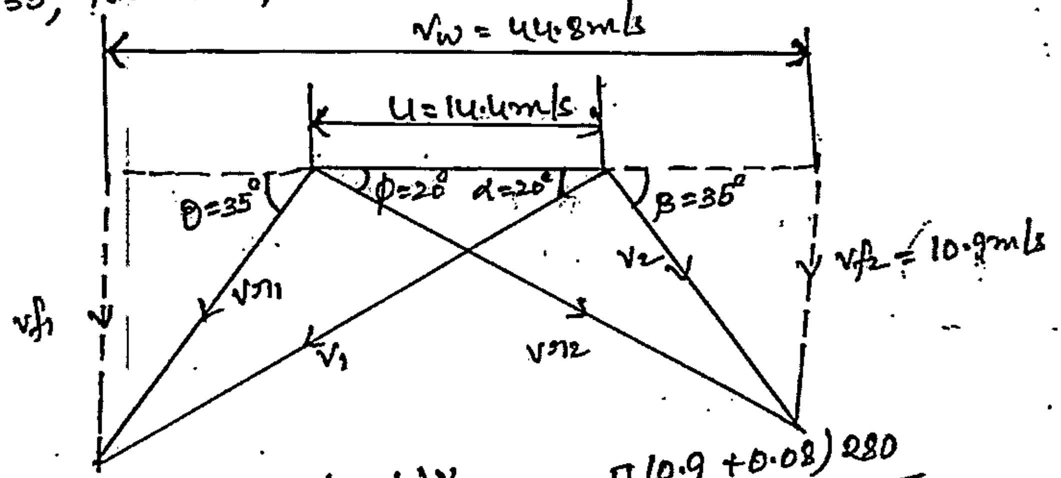
$P = \frac{m (V_w) u}{1000} = \frac{4.167 \times 303 \times 268}{1000} = 338.4 \, kW$

In a reaction turbine, the blade tip angles at inlet and exit are 35° and 20° respectively at a certain place in the turbine, the drawn diameter is 0.9m and the blades are 0.98m high At this place steam has a pressure of 1.7 bar and dryness fraction 0.935. If the speed of turbine is 280 rpm and the steam passess through the blades without shock find the mass of steam flow and the power developed in the ring of moving blades.

$D = 0.9m$, $h = 0.08m$, $p = 1.7 bar$

$\theta = \beta = 35^\circ$, $\phi = \alpha = 20^\circ$,

$x = 0.935$, $N = 280$ rpm.



$$\text{Blade Speed } (u) = \frac{\pi (D+h) N}{60} = \frac{\pi (0.9 + 0.08) 280}{60}$$

$$= 14.4 m/s$$

at pressure 1.7 bar, $v_g = 1.031\ m^3/kg$

$$\text{Sp. volume } v_g = x v_g \Rightarrow = 0.935 \times 1.031$$
$$= 0.964 m^3/kg$$

$$\dot{m} = \frac{\left[\pi (D+h) h\right] V_{f2}}{V_g}$$

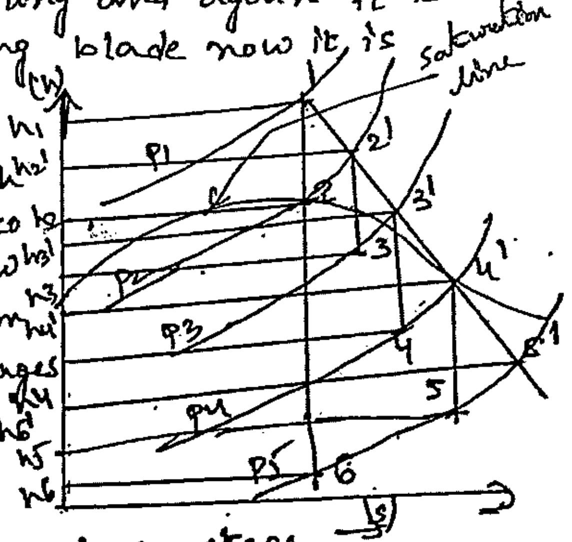
$$= \frac{\left[\pi (0.9 + 0.08) 0.08\right] 10.9}{0.964} = 2.78\ kg/s$$

$$\text{power } (P) = \frac{\dot{m} (V_w) u}{1000}$$

$$= \frac{2.78 (44.8) 14.4}{1000} = 1.8\ kW$$

State point locus and reheat factor:- In multi stage turbine steam leaving from the first moving blade is made to flow through fixed ring and again it is made to strike on second moving blade now it is completed 2 stages.

After leaving second moving blade it is again made to flow through fixed ring. and again it is made to strike on third moving blade. now it completes 3 stages. If the steam passes through many number of stages then the turbine is known as multistage turbine



○ Let

P_1 = Inlet pressure of steam entering first stage.

" " leaving. ~~Second~~ first "

P_2 = Exit " " " " ~~Third~~ Second "

P_3 = " " " " " ~~Fa~~third "

P_4 = " " " " " Fourth "

P_5 = " " " "

The locus passing through 1, 2', 3', 4' and 5' is known as state point locus

If the friction is neglected then (h_1-h_6) will represent the isentropic heat drop the sum of $(h_1-h_2) + (h_2'-h_3) + (h_3'-h_4) + (h_4'-h_5)$ is known as cumulative heat drop

○ The ratio of cumulative heat drop to the isentropic heat drop is known as reheat factor.

$$\text{Reheat factor} :- \frac{\text{Cumulative heat drop}}{\text{Isentropic heat drop}}$$

$$= \frac{(h_1-h_2) + (h_2'-h_3) + (h_3'-h_4) + (h_4'-h_5)}{(h_1-h_6)}$$

Gas turbines

Gas turbine is a rotary type of I.C engine. The cyclic events of gas turbine are similar to reciprocating type I.C engine. But each event in gas turbine is carried out in different devices. The simple gas turbine consists of rotary compressor, combustion chamber and turbine unit.

The air is first compressed in a rotary compressor before passing to a combustion chamber where the fuel is injected and ignited. The hot burnt gases expand through the blades of a turbine where the kinetic energy of burnt gases is utilised to produce power. Finally the gases are exhausted from the turbine unit.

Advantages :-

1. Comparatively small weight and size
2. The mechanical efficiency is higher.
3. Torque produced is uniform
4. poor quality of fuels can be used
5. small working pressures are involved.

Limitations :-

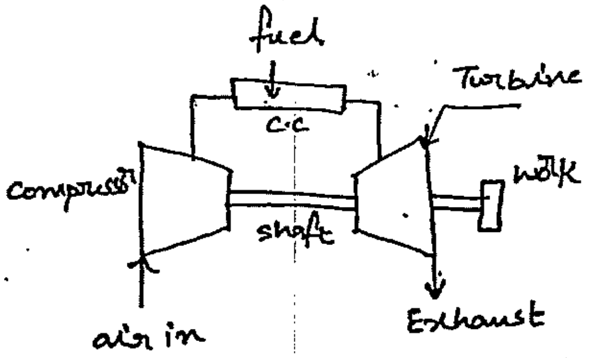
1. part of power produced is utilised for driving the compressor.
2. Not a self-starting unit
3. Relatively low overall efficiency
4. Requires costly reducing gears for normal industrial aplications.

classification of gas turbines:-

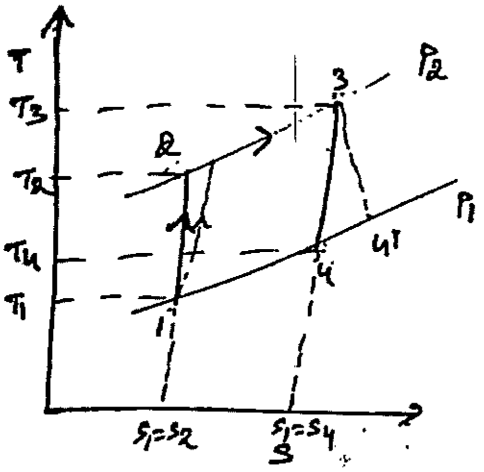
1. According to the path of working fluid
   a) open cycle gas turbine
   b) closed cycle gas turbine
   c) semi closed cycle gas turbine
2. According to the basis of combustion process
   a) Constant pressure

b) Constant volume

Open cycle gas turbine :-



The open cycle gas turbine in which a rotary compressor and a turbine are mounted on a common shaft. Air is drawn into the compressor and after compression passes a combustion chamber. Energy is supplied in the combustion chamber by spraying fuel into the air stream and resulting hot gases expand through the turbine to the atmosphere. In order to achieve network output from the unit, the turbine must develop more gross work output than is required to drive the compressor and to overcome mechanical lossess in drive. The products of combustion coming out from the turbine are exhaust to the atmosphere.



$1-2'$ = Adiabatic compression
$2'-3$ = constant pressure heat supply
$3-4'$ = Adiabatic expansion
$1-2$ = Ideal Isentropic Compression
$3-4$ = Ideal Isentropic expansion.

work input (compressor) = $c_p(T_2' - T_1)$
Heat supplied = $c_p(T_3 - T_2')$
work output (turbine) = $c_p(T_3 - T_4')$

Net workoutput = work output - work input

$$= c_p(T_3 - T_4') - c_p(T_2' - T_1)$$

$$\eta_{thermal} = \frac{\text{Network output}}{\text{Heat supplied}}$$

$$= \frac{c_p(T_3 - T_4') - c_p(T_2' - T_1)}{c_p(T_3 - T_2')}$$

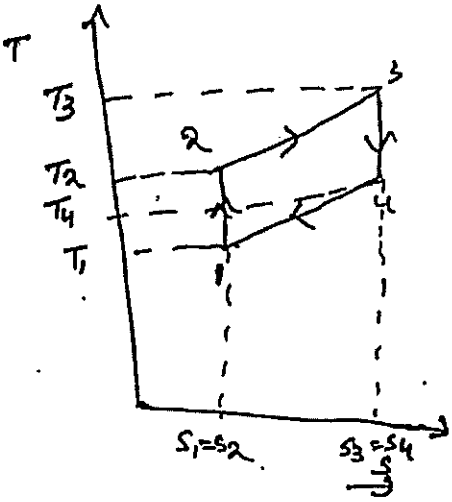
$$\eta_{compressor} = \frac{\text{work input required in Isentropic compression}}{\text{Actual work required.}}$$

$$= \frac{c_p(T_2 - T_1)}{c_p(T_2' - T_1)} = \frac{T_2 - T_1}{T_2' - T_1}$$

$$\eta_{\text{Turbine}} = \frac{\text{Actual work output}}{\text{Isentropic work output}}$$

$$= \frac{c_p(T_3 - T_4')}{c_p(T_3 - T_4)} = \frac{T_3 - T_4'}{T_3 - T_4}$$

1. The simple gas [illegible] has the pressure ratio 6 and the maximum and minimum temperatures of the cycle are 1000K and 288K respectively. Assuming an ideal cycle, calculate the efficiency and specific workout of the plant.



pressure ratio $\frac{P_2}{P_1} = \frac{P_3}{P_4} = 6$

Minimum temperature $(T_1) = 288K$

Maximum temperature $(T_3) = 1000K$

$\gamma = 1.4$ $C_p = 1.005\ kJ/kg\ K$

$$\eta = 1 - \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}} = 1 - \frac{1}{6^{\frac{1.4-1}{1.4}}} = 0.401$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = 6^{\frac{0.4}{1.4}} = 6^{0.2857}$$

$$T_2 = (288)(6^{0.2857}) = 480.53K$$

$T_4 = 1000 \times 0.599 = 599K$

Also $\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}}$ $= 1.005(1000-599) = 403\ kJ/kg$

Turbine work $= C_p(T_3 - T_4)$ $= 1.005(480.53 - 288) = 193.49\ kJ/kg$

Compressor work $= (W_C) = C_p(T_2 - T_1)$ $= 403 - 193.49 = 209.51\ kJ/kg$

Specific workoutput $= W_T - W_C$

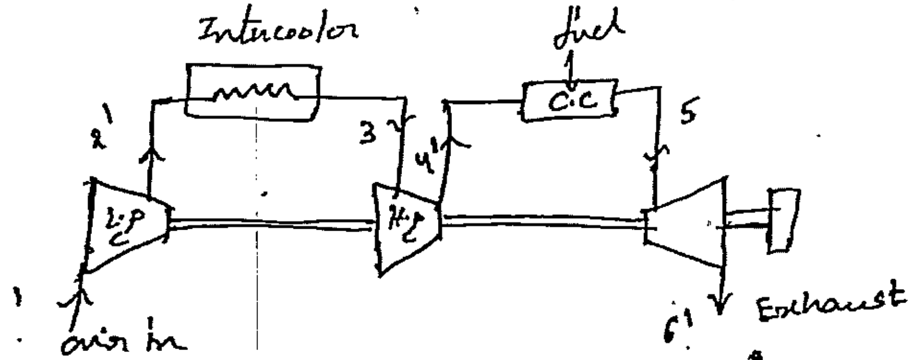
$$\eta = \frac{W}{Q_{sup}} = \frac{209.51}{1.005(1000-480.53)} = 0.401 = 40.1\%$$

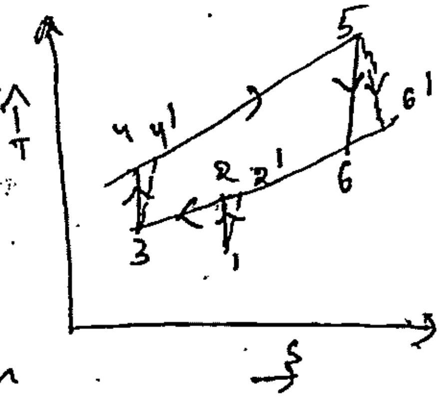
Methods for improvement of thermal efficiency of open cycle gas turbine plants:-

The following methods are employed to increase the specific output and thermal efficiency of plant.

1. Intercooling :- A compressor in a gas turbine cycle utilises the major percentage of power developed by the gas turbine. The work required by the compressor can be reduced by compressing the air in two stages and incorporating an intercooler between the two. The actual processes take place as follows.

1-2' = L.P compression, 3-4' = H.P compression, 5-6' = Turbine expansion.
2'-3 = Intercooling, 4'-5 = C.C heating,





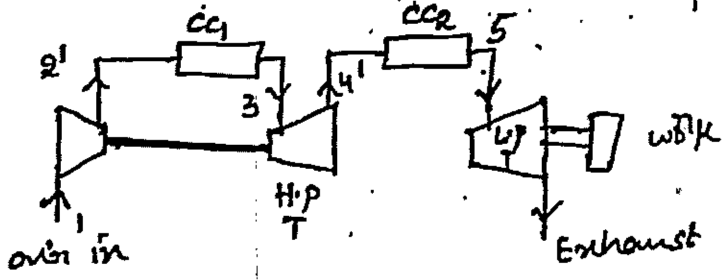
The ideal cycle for this arrangement is 1-2-3-4-5-6

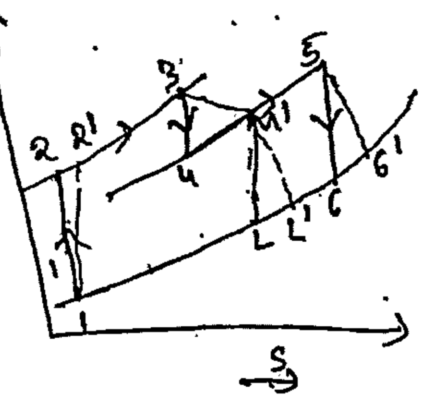
~~now the workoutput~~ (~~with intercooling~~)

∴ work ratio = $\frac{\text{Net work output}}{\text{Gross work output}}$

= $\frac{\text{work of expansion} - \text{work of compression}}{\text{work of expansion}}$

2. Reheating :- The workoutput of a gas turbine can be amply improved by expanding the gases in two stages with a reheater between the two as shown in fig. The Hp turbine drives the compressor and L.p turbine provides the useful power output





Neglecting mechanical losses the workoutput of the H.p turbine must be exactly equal to the work input required for the compressor.

$$c_{pa}(T_2'-T_1) = c_{pg}(T_3-T_4')$$

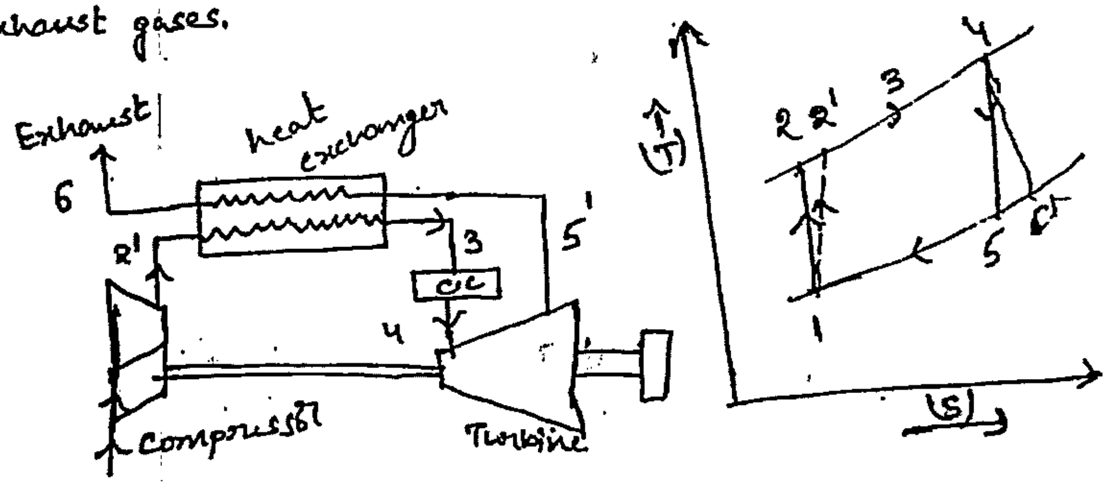
Net workoutput (with reheating) = $c_{pg}(T_5-T_6')$

" " (without ") = $c_{pg}(T_4'-T_L)$

From the T-S diagram temperature difference (T_5-T_6') is always greaterthan $(T_4'-T_L)$. so that reheating Increases the workoutput.

4.

3. Regeneration :- The exhaust gases from a gas turbine carry a large quantity of heat with them since their temperature is far above the ambient temperature. They can be used to heat the air coming from the compressor thereby reducing the mass of fuel supplied in the combustion chamber. In a figure 2'-3 ~~prep~~ represents the heat flow into the compressed air during its passage through the heat exchanger and 3-4 represents the heat taken from the combustion of fuel point 6 represents the temperature of exhaust gases at discharge from the heat exchanger. The maximum temperature to which the air could be heated in the heat exchanger is ideally that of exhaust gases.

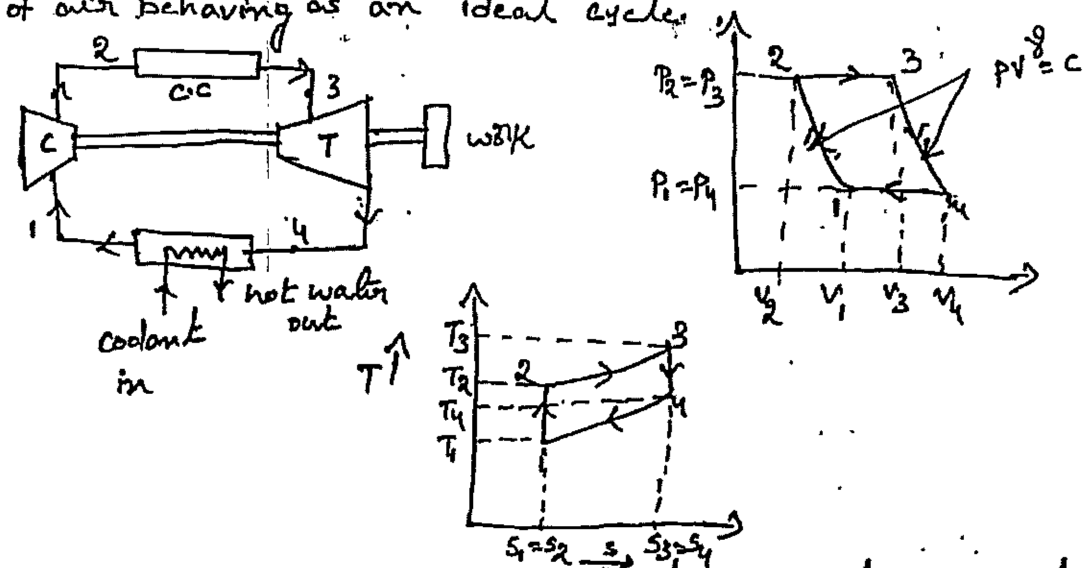


The effectiveness of heat exchanger is given by

$$= \frac{\text{Increase in enthalaphy / kg of air}}{\text{Available increase in enthalaphy / kg of air}}$$

$$= \frac{T_3-T_2'}{T_5'-T_2'}$$

Closed cycle gas turbine :- This cycle operates on a constant pressure cycle in which the closed system consists of air behaving as an ideal cycle.



1-2 :- The air is compressed isentropically from the lower pressure p_1 to upper pressure p_2, the temperature raising from T_1 to T_2. No heat flow occurs.

2-3 :- Heat flow into the system increasing volume from v_2 to v_3 and temperature from T_2 to T_3. whilst the pressure remains constant at p_2. Heat received $= mc_p(T_3-T_2)$

3-4 :- The air is expanded isentropically from p_2 to p_3. The temperature falling from T_3 to T_4. No heat flow occurs.

4-1 :- Heat is rejected from system as the volume decreases from v_4 to v_1 and the temperature from T_4 to T_1 whilst the pressure remains constant at p_1. Heat rejected $= mc_p(T_4-T_1)$

$$\eta_{\text{air-standard}} = \frac{\text{workdone}}{\text{Heat received}}$$

$$= \frac{\text{Heat supplied} - \text{Heat rejected}}{\text{Heat supplied}}$$

$$= \frac{mc_p(T_3-T_2) - mc_p(T_4-T_1)}{mc_p(T_3-T_2)}$$

$$= 1 - \frac{T_4-T_1}{T_3-T_2}$$

5.

From air 1-2 process:-

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow T_2 = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \times T_1$$

$P_2 = P_3 = r_p$
$P_1 = P_4 = r_p$

3-4 process:- $\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$ $T_3 = T_4 \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$

$$= T_4 (r_p)^{\frac{\gamma-1}{\gamma}}$$

$$\eta_{\text{air-standard}} = 1 - \frac{T_4 - T_1}{T_4 (r_p)^{\frac{\gamma-1}{\gamma}} - T_1 (r_p)^{\frac{\gamma-1}{\gamma}}}$$

$$= 1 - \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}$$

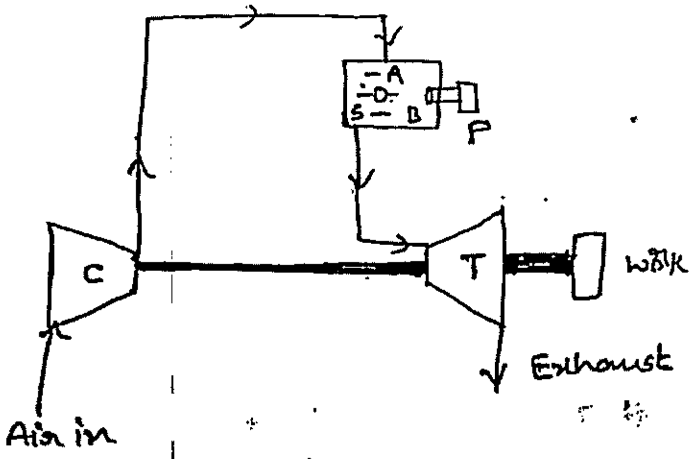
Merits of closed cycle:-

1. Higher thermal efficiency
2. Reduced size
3. No contamination
4. Improved part load efficiency
5. Greater output
6. Inexpensive fuel.

Demerits of closed cycle:-

1. Complexity
2. Dependent system
3. Requires the use of a very large air heater.

Constant volume combustion turbines:- The compressed air from an air compressor C is admitted into the C.C D through the valve A. When valve A is closed, the fuel is admitted into the chamber by means of a fuel pump P. Then the mixture is ignited by means of a spark plug S. The combustion take place at constant volume with increase of pressure. The valve B opens and the hot gases flow to the turbine T and finally they are discharged into atmosphere. The energy of hot gases is thereby converted into mechanical energy. For continuous running of the turbine these operations are repeated.



1. A gas turbine unit received air at 1 bar and 300k and compressess it adiabatically to 6.2 bar. The compressor efficiency is 88%. The fuel has a heating value of 44186 KJ/kg and the fuel air ratio is 0.017 KJ/kg of air. The turbine Internal efficiency is 90%. Calculate the work of turbine and compressor / kg of air compressed and thermal efficiency For products of combustion $C_p = 1.147$ KJ/kgK $\gamma = 1.4$.

$P_1 = P_4 = 1$ bar, $T_1 = 300$ K $P_2 = P_3 = 6.2$ bar, $\eta_{compressor} = 88\%$

$c = 44186$ KJ/kg, Fuel air ratio = 0.017 KJ/kg, $\eta_{turbine} = 90\%$

$C_p = 1.147$ KJ/kgK $\gamma = 1.4$

<u>1-2 process</u> :-
$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$
$$= 300 \left(\frac{6.2}{1}\right)^{\frac{1.4-1}{1.4}}$$
$$= 505.2 \text{ K}.$$

$$\eta_{com} = \frac{T_2 - T_1}{T_2' - T_1} \Rightarrow 0.88 = \frac{505.2 - 300}{T_2' - 300}$$
$$T_2' = 533.2 \text{ K}.$$

Heat supplied $= m\left(1 + \frac{m_f}{m_a}\right) c_p \left(T_3 - T_2'\right) = \frac{m_f}{m_a} \times c$
$$\left(1 + 0.017\right) 1.005 \left(T_3 - 533.2\right) = 0.017 \times 44186.$$
$$T_3 = 1268 \text{ K}.$$

$$\frac{T_3}{T_4} = \cancel{\frac{P_4}{P_3}} \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$$
$$T_4 = \frac{T_3}{\left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}} \Rightarrow 1268 \times 0.634 = 803.9 \text{K}.$$

$$\eta_{Turbine} = \frac{T_3 - T_4^{1}}{T_3 - T_4}$$

6.

$$T_4^{1} = 1268 - 0.9\,(1268 - 803.9) = 850.3\,K.$$

$$w_{compressor} = C_p\,(T_2^{1} - T_1) = 1.005\,(533.2 - 300) = 234.4\ KJ/kg$$

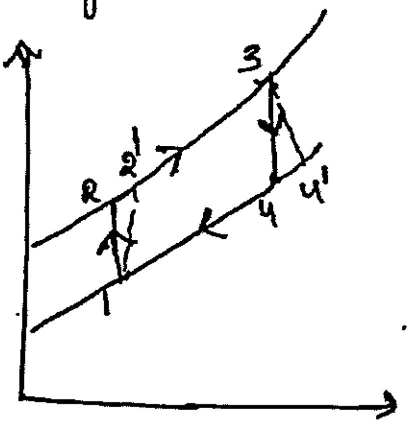
$$w_{turbine} = C_{pg}\,(T_3 - T_4^{1}) = 1.147\,(1268 - 850.3) = 479.1\ KJ/kg$$

$$\text{network} = w_{turbine} - w_{compressor} = 244.7\ KJ/kg$$

$$\text{Heat supplied / kg of air} = 0.017 \times 44186 = 751.2\ KJ/kg$$

$$\eta_{thermal} = \frac{\text{Network}}{\text{Heat supplied}} = \frac{244.7}{751.2} = 32.57\%$$

A Gas turbine unit receiver air at 1 bar and 300K and compressses it adiabatically to 6.2 bar. The Compressor efficiency is 88%. The fuel has heating value of 44186 KJ/kg and the air fuel ratio is 0.017 KJ/kg of air The turbine efficiency is 90%. calculate the work of turbine and compressor / kg of air compressed and thermal efficiency. for products of combustion $C_p = 1.147$ KJ/kgK $\gamma = 1.333$



Given:-

$P_1 = P_4 = 1$ bar, $T_1 = 300K$

$P_2 = P_3 = 6.2$ bar

$C = 44186$ KJ/kg

Fuel air ratio $= 0.017$ KJ/kg

$\eta_{turbine} = 90\%$

$C_p = 1.147$ KJ/kg K

$\gamma = 1.333$

$\gamma = 1.4$

From 1-2 process:-

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow \left(\frac{6.2}{1}\right)^{\frac{1.4-1}{1.4}} \Rightarrow$$

$$T_2 = 300 \times 1.684 = 505.2K.$$

$\gamma = 1.333$

$$\eta_{compressor} = \frac{T_2 - T_1}{T_2^1 - T_1}$$

$$0.88 = \frac{505.2 - 300}{T_2^1 - 300}$$

$T_2^1 = 533.2K.$

$$\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}}$$

$T_4 = 1268 \times 0.634 = 803.9K.$

$$\eta_{turbine} = \frac{T_3 - T_4^1}{T_3 - T_4}$$

$T_4^1 = 850.3K.$

Heat supplied :-

$(m_a + m_f) C_p (T_3 - T_2^1) = m_f \times C$

$\left(1 + \frac{m_f}{m_a}\right) C_p (T_3 - T_2^1) = \left(\frac{m_f}{m_a}\right) C$

$(1 + 0.017)\, 1.005\, (T_3 - 533.2) = 0.017 \times 44186$

$T_3 = 1268 K.$

$W_{compressor} = C_p (T_2^1 - T_1) = 1.005(533.2 - 300) = 234.4$ kJ/kg

$W_{Turbine} = C_{pg} (T_3 - T_4^1) = 1.147(1268 - 850.3) = 479.1$ kJ/kg

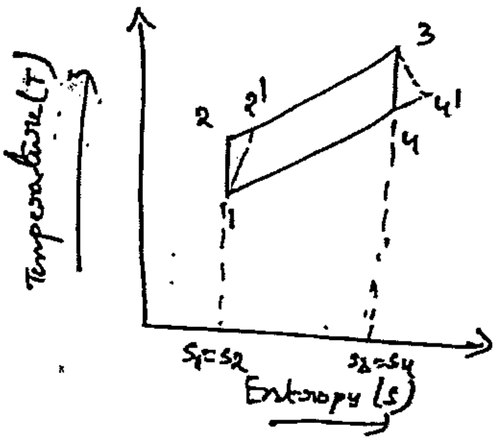
net work output $= W_{Turbine} - W_{compressor} = 479.1 - 234.4 = 244.7$ kJ/kg

Heat supplied / kg of air $= \left(\frac{m_f}{m_a}\right) CV = 0.017 \times 44186 = 751.2$ kJ/kg

$$\text{Thermal efficiency} = \frac{\text{Network}}{\text{heat supplied}} = \frac{244.7}{751.2} = 32.57\%.$$

Gas turbines

1. A gas turbine employs a heat exchanger with a thermal ratio of 72%. The turbine operates between the pressure of 1.01 bar and 0.04 bar and ambient temperature is 20c. Isentropic efficiencies of compressor and turbine are 80% and 85% respectively. The pressure drop on each side of the heat exchanger is 0.05 bar and in the combustion chamber 0.14 bar. Assume combustion efficiency to be unity and calorific value of the fuel to be 41800 kJ/kg. Calculate the increase in efficiency due to heat exchanger over that for simple cycle. $c_p = 1.024$ kJ/kgK. and assume $\gamma = 1.4$, air-fuel ratio = 90:1 and for the heat exchanger cycle the turbine entry temperature is the same as for a simple cycle.



1-2 process :-

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{4.40}{1.01}\right)^{\frac{1.4-1}{1.4}}$$

$$T_2 = (293)(1.486) = 435.4 \text{ K.}$$

$$\eta_{\text{compressor}} = \frac{T_2 - T_1}{T_2' - T_1}$$

$$0.8 = \frac{435.4 - 293}{T_2' - 293}$$

$$T_2' = 471 \text{ K}$$

$$(m_a + m_f) c_p (T_3 - T_2') = m_f \times c$$

$$T_3 = \frac{m_f \times c}{c_p (m_a + m_f)} + T_2' \Rightarrow \frac{1 \times 41800}{1.024 (90+1)} + 471 = 919.5 \text{K}$$

3-4 process :-

$$\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_4 = (T_3)\left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow 919.5\left(\frac{1.01}{3.9}\right)^{\frac{1.4-1}{1.4}}$$

$$T_4 = 625 \text{ K}$$

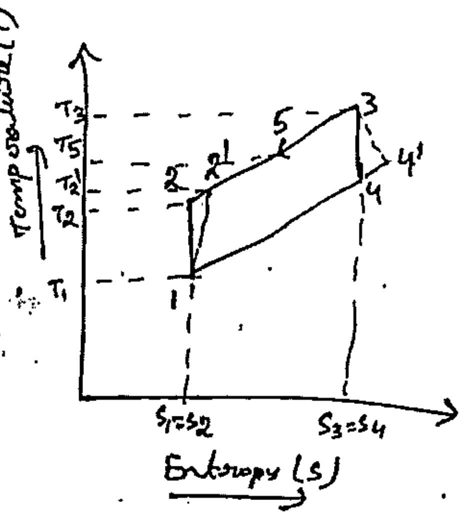
$$\eta_{\text{turbine}} = \frac{T_3 - T_4'}{T_3 - T_4} \Rightarrow T_4' = 919.5 - 0.85(919.5 - 625)$$

$$= 669 \text{ K}$$

$$\eta_{\text{thermal}} = \frac{(T_3 - T_4') - (T_2' - T_1)}{(T_3 - T_2')} = \frac{(919.5 - 669) - (471 - 293)}{(919.5 - 471)}$$

$$= 16.16\%.$$

Heat exchanger cycle :-



$P_3 = 4.04 - 0.14 - 0.05 = 3.86$ bar

$P_4 = 1.01 + 0.05 = 1.06$ bar

$$\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow \left(\frac{1.06}{3.85}\right)^{\frac{1.4-1}{1.4}} = 0.69$$

$T_4 = 919.5 \times 0.69 = 634K.$

$$\eta_{turbine} = \frac{T_3 - T_4'}{T_3 - T_4} \Rightarrow 0.85 = \frac{919.5 - T_4'}{919.5 - 634}$$

$T_4' = 677K$

Thermal ratio (Effectiveness)

$$\epsilon = \frac{T_5 - T_2'}{T_4' - T_2'} \Rightarrow 0.72 = \frac{T_5 - 471}{677 - 471}$$

$T_5 = 619 K$

$$\eta_{thermal} = \frac{(T_3 - T_4') - (T_2' - T_1)}{(T_3 - T_5)}$$

$$= \frac{(919.5 - 677) - (471 - 293)}{(919.5 - 619)}$$

$$\therefore \quad = \frac{64.5}{300.5} = 21.46\%$$

Increase in thermal efficiency = 21.46 - 16.16 = 5.3%

2. Air is drawn in a gas turbine unit at 15°c and 1.01 bar and pressure ratio is 7:1. The compressor is driven by the H.P turbine and L.p turbine drives a seperate power shaft. The isentropic efficiencies of compressor, and the H.p and L.p turbines are 0.82, 0.85 and 0.85 respectively. If the maximum cycle temperature is 610°c calculate

1. The pressure and temperature of gases entering the power turbine
2. The net power developed by the unit / Kg mass flow.
3. work ratio
4. Thermal efficiency of the unit. Neglect the mass of fuel and assume the following for compression process

$C_{pa} = 1.005$ KJ/kg K, $\gamma = 1.4$ $\quad C_{pg} = 1.15$ KJ/kg and $\gamma = 1.333$

Given :-

$T_1 = 15+273 = 288K$, $\eta_{compressor} = 0.85$, $\eta_{turbine\,(H.P)} = 0.85$ 8.

$P_1 = 1.01$ bar $\frac{P_2}{P_1} = 7$, $\eta_{turbine\,(LP)} = 0.85$, Maximum temperature $(T_3) = 610+273 = 883K$

1. 1-2 process :-

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = (7)^{\frac{1.4-1}{1.4}} = 1.745$$

$$T_2 = 1.745 \times 288 = 502.5K$$

$$\eta_{compressor} = \frac{T_2 - T_1}{T_2' - T_1} \Rightarrow T_2' = 549.6K$$

work of compressor $= C_{pa}\,(T_2' - T_1) = 1.005\,(549.6 - 288) = 262.9$ KJ/kg

work output of H.p turbine = work input to compressor.

$$C_{pg}\,(T_3 - T_4') = 262.9$$

$$1.15\,(883 - T_4') = 262.2 \Rightarrow T_4' = 654.4K$$

$$\eta_{turbine} = \frac{T_3 - T_4'}{T_3 - T_4}$$

$$0.85 = \frac{883 - 654.4}{883 - T_4} \Rightarrow T_4 = 614K.$$

2. 3-4 process :- (Isentropic expansion)

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$$

$$P_4 = \frac{P_3}{4.32} = 1.636 \text{ bar}$$

pressure of gases entering the L.p or power turbine = 1.636 bar

3) Net power developed / kg/s mass flow =

$$\boxed{\begin{matrix} P_2 = P_3 \\ P_1 = P_5 \end{matrix}}$$

pressure ratio $\frac{P_4}{P_5} \Rightarrow \frac{P_4}{P_3} \times \frac{P_3}{P_5}$

$$= \frac{P_4}{P_3} \times \frac{P_2}{P_5} = \frac{7}{4.32} = 1.62$$

Then

$$\frac{T_4'}{T_5} = \left(\frac{P_4}{P_5}\right)^{\frac{\gamma-1}{\gamma}} = (1.62)^{\frac{0.33}{1.33}} = 1.127$$

$$T_5 = \frac{T_4'}{1.127} = 580.6K$$

Efficiency of turbine (L.p turbine) $= \frac{T_4' - T_5'}{T_4' - T_5}$

$$0.85 = \frac{654.4 - T_5'}{654.4 - 580.6}$$

$T_5' = 654.4 - 0.85\,(654.4 - 580.6) = 591.7\,K$

work of L.P turbine $= C_{pg}\,(T_4' - T_5') = 1.15\,(654.4 - 591.7)$
$= 72.1$ KJ/kg

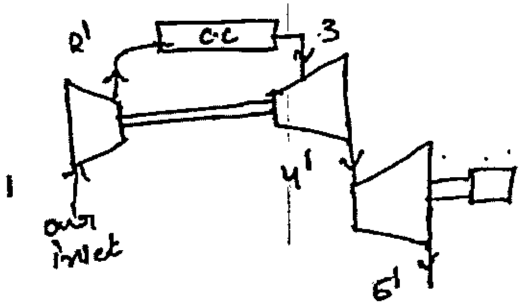
hence net power output = 72.1 KW

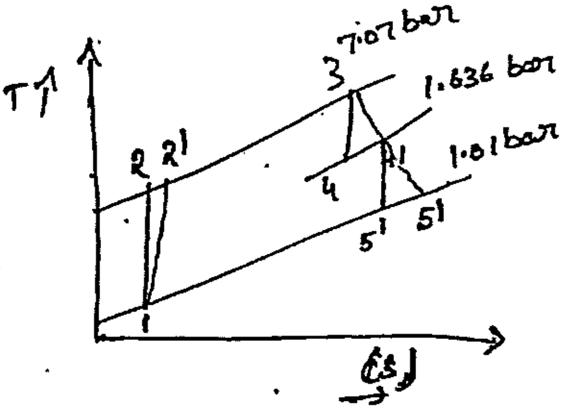
3) work ratio :- $\dfrac{\text{Net work output}}{\text{Gross work output}} = \dfrac{72.1}{72.1 + 262.9} = 0.215$

4) Thermal efficiency of the unit ($\eta_{thermal}$) :-

Heat supplied $= C_{pg}\,(T_3 - T_2') = 1.15\,(883 - 549.6)$
$= 383.4$ KJ/kg

$$\eta_{thermal} = \frac{\text{Network output}}{\text{Heat supplied}} = \frac{72.1}{383.4} = 18.8\%$$





3. The pressure ratio of an open-cycle gas turbine power plant is 5.6. Air is taken at 30°c and 1 bar The compression is carried out in two stages with perfect intercooling in between The maximum temperature of the cycle is limited to 700°c. Assuming isentropic efficiency of each compressor stage as 85% and that of turbine as 90%. Determine the power developed and the efficiency of power plant, if the air flow is 1.2 kg/s The mass of fuel may be neglected, and it may be assumed that $c_p = 1.02$ KJ/kgK and $\gamma = 1.41$

The pressure ratio of the open-cycle gas turbine = 5.6
Temperature of intake air (T_1) = 30°c = 30+273 = 303K
pressure of intake air (P_1) = 1 bar
Maximum temperature of cycle = (T_3) = 700+273 = 973 K
Isentropic efficiency of each compressor (η_{comp}) = 85%.
Isentropic efficiency of turbine ($\eta_{turbine}$) = 90%.

mass rate of flow $(m_a) = 1.2$ kg/s, $c_p = 1.02$ kJ/kg $\gamma = 1.4$,
power developed and efficiency of the power plant 9.

assume pressure ratio in each stage is same we have

$$\frac{P_2}{P_1} = \frac{P_4}{P_3} = \sqrt{\frac{P_4}{P_1}} = \sqrt{5.6} = 2.366.$$

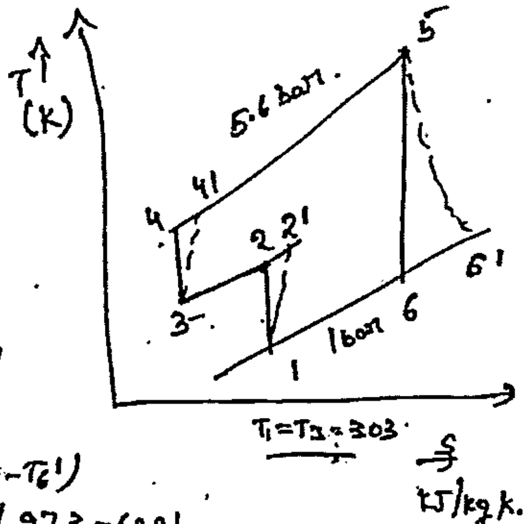
$\eta_{comp_1} = \eta_{comp_2}$ and $\frac{P_2}{P_1} = \frac{P_4}{P_3}$ so that work required for each compressor is same since both the compressors have the same inlet temperature $T_1 = T_3$, $T_2' = T_4'$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = (2.366)^{\frac{1.4-1}{1.4}} = T_2 = (303)(1.2846)$$
$$= 389.23 \text{ K}.$$

$$\eta_{comp} = \frac{T_2 - T_1}{T_2' - T_1} \Rightarrow T_2' = \frac{389.23 - 303}{0.85} + 303 = 404.44 \text{K},$$

$$\text{2-stage compressor} = 2 \times m \times c_p (T_2' - T_1) = 2 \times 1.2 \times 1.02 (404.44 - 303$$
$$= 248.32 \text{ kJ/s}$$

For turbine we have



$$\frac{T_5}{T_6} = \left(\frac{P_5}{P_6}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_6 = \frac{973}{1.65} = 589.7 \text{K}.$$

$$\eta_{turbine} = \frac{T_5 - T_6'}{T_5 - T_6} = 0.9 = \frac{973 - T_6'}{973 - 589.7}$$

$T_6' = 628$ K.

$$\text{work output of turbine} = m c_p (T_5 - T_6')$$
$$= 1.2 \times 1.02 (973 - 628)$$
$$= 422.28 \text{ kJ/sec.}$$

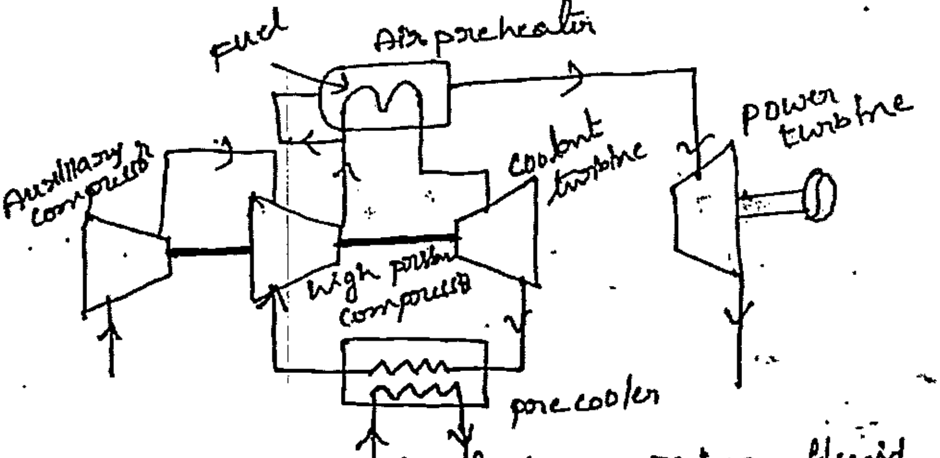
$$\text{Net work output} = w_{turbine} - w_{compressor}$$
$$= 422.28 - 248.32$$
$$= 173.96 \text{ kJ/sec.}$$

hence power developed = 173.9 kW

$$\text{heat supplied} \quad (Q_s) = m c_p (T_5 - T_4')$$
$$= 1.2 \times 1.02 (973 - 404.44)$$
$$= 695.92 \text{ kJ/sec.}$$

$$\eta_{efficiency} = \frac{W_{net}}{Q_s} = 0.25 = 25\%.$$

Semi closed cycle gas turbine :-



when some part of the working fluid is confined to the plant and another part flows into and from the atmosphere it is called semi cycle. It is basically a high pressure system and the component parts are smaller than an open cycle for the same power output.

The basic working medium is air. compressed air from auxillary compressor and exhaust air of turbine compressor, passing through the precooler enters the high pressure compressor and is compressed. The high pressure air before entering the air heater is in two parts one part serving the power turbine is used to intial combustion in the air heater and another ~~plant~~ part which does not mix with the fuel is heated by the heat of external combustion so that all the time this part of air may be circulated in a closed system. The exhaust of power turbine goes to atmosphere.

· The air entirs the compressor of an open ^{10} cycle plant pressure of 1 bar and timperature 20°c The pressiore of air after compression is 4 bar. The isentropic efficiency of compressor and turbine are 80% and 85% respectively The air fuel ratio used of 90:1. If the flow rate of air is 3.0 kg/s Find power developed, Thermal efficiency of cycle $C_p = 1.0$ KJ/kgK, $\gamma = 1.4$ for air and gases cv of fuel = 41800 KJ/kg

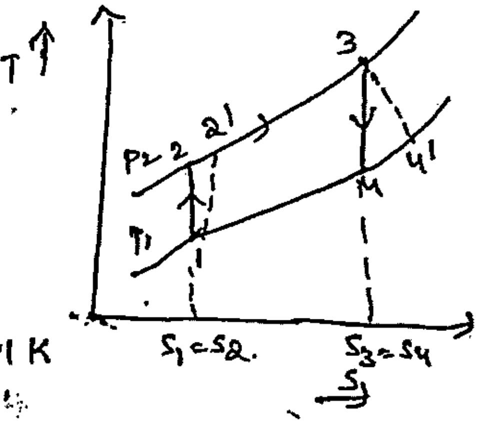
$P_1 = 1$ bar $\quad P_2 = 4$ bar, $\quad \eta_{compressor} = 0.8$, $\eta_t = 0.85$

$T_1 = 20+273 = 293K \quad A/F = 90/1, \quad m_a = 3.0$ kg/sec.

1-2 process:-

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow T_2 = (20+273)(1.486)$$

$$= 435.4 \text{ K.}$$



$$\eta_{compressor} = \frac{T_2 - T_1}{T_2' - T_1}$$

$$T_2' = \frac{435.4 - 293}{0.8} + 293 = 471 \text{ K}$$

3-4. process:- $T_3/T_4 = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$

$$T_4 = 12.68 \times 0.634 = 803.9K$$

Heat supplied by fuel = Heat taken by burning gases

$$m_f \times cv = (m_a + m_f)\, C_p (T_3 - T_2')$$

$$cv = \left(\frac{m_a}{m_f} + 1\right) C_p (T_3 - T_2')$$

$$41800 = (90+1)\, 1.0\, (T_3 - 471)$$

$$T_3 = 930 K$$

$$T_4 = 624.9 K$$

$$\eta_T = \frac{T_3 - T_4'}{T_3 - T_4}$$

$$T_4' = 930 - 0.85(930 - 624.9)$$

$$= 670.6K.$$

workdone by turbine $= (m_f + m_a)\, C_p (T_3 - T_4')$

$$= m_a\left(\frac{m_f}{m_a} + 1\right) C_p (T_3 - T_4')$$

$$= 1\left(\frac{1}{90} + 1\right) 1.0\, (930 - 670.6)$$

$= 262.28$ KJ/kg of air

$W_{compressor} = m_a C_p (T_2' - T_1)$

$= 1 \times 1.0 (471 - 293) = 178$ KJ/kg of air

$W_{net} = W_T - W_C$

$= 262.28 - 178 = 84.28$ KJ/kg of air

power = Wnet × mass of air

$= 84.28 \times 3 = 252.84$ KW/kg of air

$\eta_{thermal} = \frac{\text{workoutput}}{\text{Heat Supplied}}$

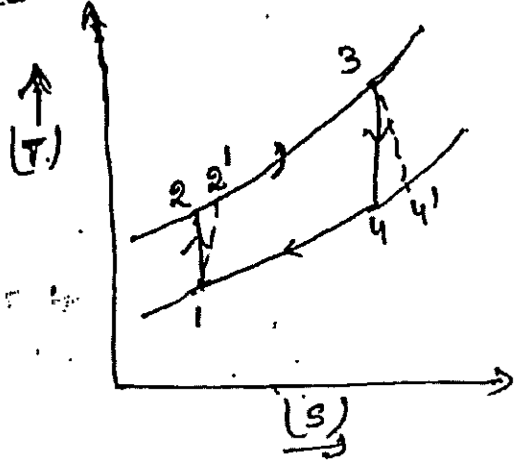
Heat supplied $= \left(\frac{m_f}{m_a}\right) CV$

$= \left(\frac{1}{90}\right) 41800 = 464.44$ KJ/kg of mls

$= \frac{84.28}{46444}$

$= 0.1814$ %

In a constant pressure open cycle gas turbine air enters at 1 bar and 20c and leaves the compressor at 5 bar - using the following data Temperature of gases entering the turbine 680c, pressure loss in the combustion chamber 0.1 bar, $\eta_c = 85\%$, $\eta_t = 80\%$, $\eta_{cc} = 85\%$, $\gamma = 1.4$ $c_p = 1.024$ KJ/kgK for the air and gas Find the quantity of air circulation if the plant develops 1065 KW, Heat supplied /kg of air circulation the thermal efficiency of cycle mass of fuel may be neglected.



Given :-

$P_1 = 1$ bar, $P_2 = 5$ bar

$P_3 = 5 - 0.1 = 4.9$ bar, $P_4 = 1$ bar

$T_1 = 20 + 273 = 293$ K.

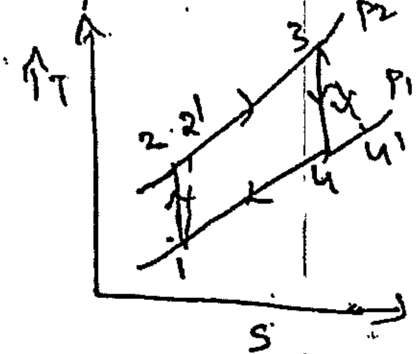
$T_3 = 680 + 273 = 953$ K.

$\eta_c = 0.85$ $\eta_T = 0.8$, $\eta_{cc} = 0.85$

$P = 1065$ KW, $C_p = 1.024$ KJ/kgK

$\gamma = 1.4$

A gas turbine unit has a pressure ratio of 6:1 and maximum cycle temperature of 610°C. The isentropic efficiencies of compressor and turbine are 0.8 and 0.82 Calculate power output when the air enters the compressor at 15°c at the rate of 16 kg/sec. Take $C_p = 1.005$ kJ/kgK $\gamma = 1.4$ for compression $C_p = 1.11$ kJ/kgK and $\gamma = 1.333$ for expansion process.



$T_1 = 15 + 273 = 288K$

$T_3 = 610 + 273 = 883 K$ $\quad \frac{P_2}{P_1} = \frac{6}{1}$

$\eta_c = 0.8, \quad \eta_T = 0.82$

Air flow rate 16 kg/sec.

$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow T_2 = 481 K.$

$\eta_c = \frac{T_2 - T_1}{T_2' - T_1} \Rightarrow T_2' = 529 K$

$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow T_4 = 664K$

$\eta_T = \frac{T_3 - T_4'}{T_3 - T_4} = 621.4 K$

Compressor work input

$= C_p (T_2' - T_1)$

$= 1.005 (529 - 288) = 242.2$ kJ/kg

Turbine work output

$= C_p (T_3 - T_4')$

$= 1.11 (883 - 621.4)$

$= 290.4$ kJ/kg

Network output $= W_T - W_c$

$= 290.4 - 242.2 = 48.2$ kJ/kg

power in kw $= 48.2 \times \overset{mass}{\textcircled{16}} = 771.2$ kw

$$\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{T_2}{T_1}\right)$$

$$\left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} = \frac{T_3}{T_4}$$

UNIT 5

JET PROPULSION & ROCKETS

Course Objective:

Applications and the principles of thermodynamics to components and systems.

Course Outcome:

Develop problem solving skills through the application of thermodynamics.

5

JET PROPULSION ENGINES

5.1 Introduction

Jet propulsion, similar to all means of propulsion, is based on Newton's Second and Third laws of motion.

The jet propulsion engine is used for the propulsion of aircraft, missile and submarine (for vehicles operating entirely in a fluid) by the reaction of jet of gases which are discharged rearward (behind) with a high velocity. As applied to vehicles operating entirely in a fluid, a momentum is imparted to a mass of fluid in such a manner that the reaction of the imparted momentum furnishes a propulsive force. The magnitude of this propulsive force is termed as thrust.

For efficient production of large power, fuel is burnt in an atmosphere of compressed air (combustion chamber), the products of combustion expanding first in a gas turbine which drives the air compressor and then in a nozzle from which the thrust is derived. Paraffin is usually adopted as the fuel because of its ease of atomisation and its low freezing point.

Jet propulsion was utilized in the flying Bomb, the initial compression of the air being due to a divergent inlet duct in which a small increase in pressure energy was obtained at the expense of kinetic energy of the air. Because of this very limited compression, the thermal efficiency of the unit was low, although huge power was obtained. In the normal type of jet propulsion unit a considerable improvement in efficiency is obtained by fitting a turbo–compressor which will give a compression ratio of at least 4 : 1.

5.2 Classification

Jet propulsion engines are classified basically as to their method of operation as shown in fig. 5–1. The two main catagories of jet propulsion systems are the *atmospheric jet engine* and *rocket*. Atmospheric jet engines require oxygen from the atmosperic air for combustion of fuel, *i.e.* they are dependent on atmospheric air for combustion.

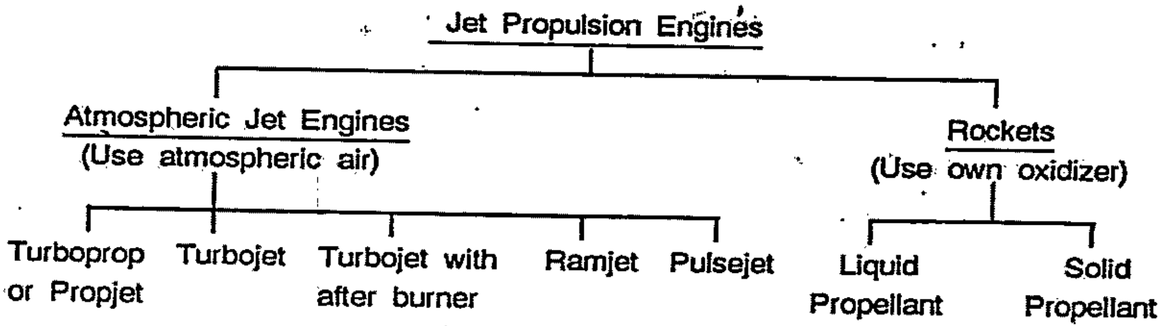
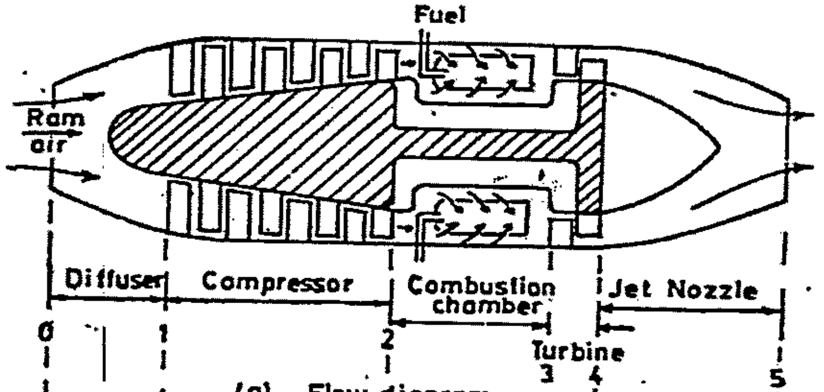


Fig. 5 – 1. Jet propulsion engines.

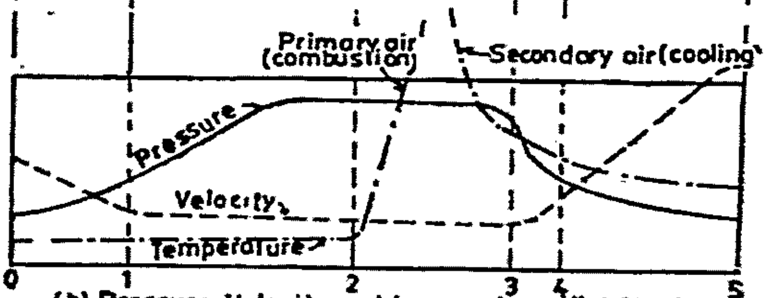
The rocket engine carries its own oxidizer for combustion of fuel and is, therefore, independent of the atmospheric air. Rocket engines are discussed in art. 5·6.

The turboprop, turbojet and turbojet with after burner are modified simple open cycle gas turbine engines. In turboprop thrust is not completely due to jet. Approximately 80 to 90 percent of the thrust in turboprop is produced by acceleration of the air outside the engine by the propeller (as in conventional aeroengines) and about 10 to 20 percent of the thrust is produced by the jet of the exhaust gases. In turbojet engine, the thrust is completely due to jet of exhaust gases. The turbojet with after burner is a turbojet engine with a reheater added to the engine so that the extended tail pipe acts as a combustion chamber.

The ramjet and pulsejet are aero-thermo-dynamic-ducts, i.e. a straight duct type of jet engine without compressor and turbine. The ramjet has the simplest construction of any propulsion engine, consisting essentially of an inlet diffuser, a combustion chamber and an exit nozzle of tail pipe. Since the ramjet has no compressor, it is dependent entirely upon ram compression.



(a) Flow diagram



(b) Pressure, Velocity and temperature distribution

Fig. 5-2 Turbojet engine.

The pulsejet is an intermittent combustion jet engine and it operates on a cycle similar to a reciprocating engine and may be better compared with an ideal Otto cycle rather than the Joule or Bryton cycle. From construction point of view, it is some what similar to a ramjet engine. The difference lies in provision of a mechanical valve arrangement to prevent the hot gases of combustion from going out through the diffuser.

5.3 Turbojet Engine

The turboject engine (fig..5–2) is similar to the simple open cycle constant pressure gas turbine plant (fig. 4–2) except that the exhaust gases are first partially expanded in the turbine to produce just sufficient power to drive the compressor. The exhaust gases leaving the turbine are then expanded to atmospheric pressure in a propelling (discharge) nozzle. The remaining energy of gases after leaving the turbine is used as a high speed jet from which the thrust is obtained for forward movement of the aircraft.

Thus, the essential *components* of a turbojet engine are :

- An entrance air diffuser (diverging duct) in front of the compressor, which causes rise in pressure in the entering air by slowing it down. This is known as *ram.* The pressure at entrance to the compressor is about 1·25 times the ambient pressure.
- A rotary compressor, which raises the pressure of air further to required value and delivers to the combustion chamber. The compressor is the radial or axial type and is driven by the turbine.
- The combustion chamber, in which paraffin (kerosene) is sprayed, as a result of this combustion takes place at constant pressure and the temperature of air is raised.
- The gas turbine into which products of combustion pass on leaving the combustion chamber. The products of combustion are partially expanded in the turbine to provide necessary power to drive the compressor.
- The discharge nozzle in which expansion of gases is completed, thus developing the forward thrust.

A Rolls–Royce Derwent jet engine employs a centrifugal compressor and turbine of the impulse–reaction type. The unit has 550 kg mass. The speed attained is 960 km/hour.

5.3.1 Working Cycle : Air from surrounding atmosphere is drawn in through the diffuser, in which air is compressed partially by ram effect. Then air enters the rotary compressor and major part of the pressure rise is accomplished here. The air is compressed to a pressure of about 4 atmospheres. From the compressor the air passes into the annular combustion chamber. The fuel is forced by the oil pump through the fuel nozzle into the combustion chamber. Here the fuel is burnt at constant pressure. This raises the temperature and volume of the mixture of air and products of combustion. The mass of air supplied is about 60 times the mass of the fuel burnt. This excess air produces sufficient mass for the propulsion jet, and at the same time prevents gas temperature from reaching values which are too high for the metal of the rotor blades.

The hot gases from the combustion chamber then pass through the turbine nozzle ring. The hot gases which partially expand in the turbine are then exhausted through the discharge (propelling nozzle) by which the remaining enthalpy is converted into kinetic energy. Thus, a high velocity propulsion jet is produced.

The oil pump ad compressor are mounted on the same shaft as the turbine rotor. The power developed by the turbine is spent in driving the compressor and the oil pump.

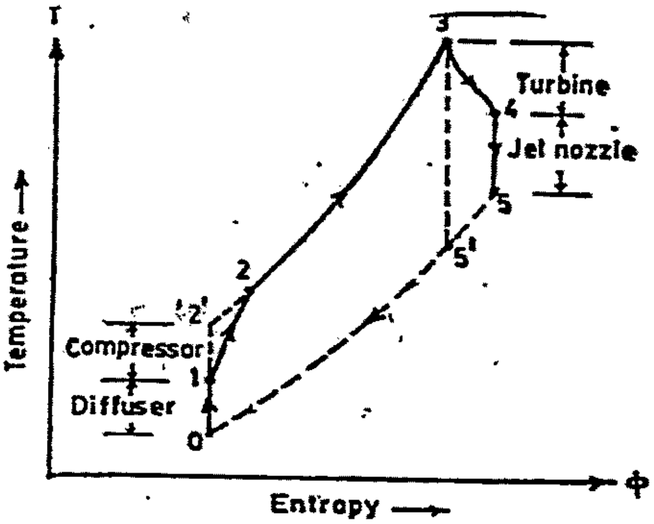


Fig. 5-3. A typical turbojet engine cycle on T – φ diagram.

Some starting device such as compressed air motor or electric motor, must be provided in the turbojet plant. Flight speeds upto 800 km per hour are obtained from this type of unit.

The basic thermodynamic cycle for the turbojet engine is the Joule or Brayton cycle as shown in $T - \Phi$ diagram of fig. 5–3. While drawing this cycle, following simplifying assumptions are made :

- There are no pressure losses in combustion chamber.
- Specific heat of working medium is constant.
- Diffuser has ram efficiency of 100 percent *i.e.*, the entering atmospheric air is diffused isentropically from velocity V_o to zero (V_o is the vehicle velocity through the air).
- Hot gases leaving the turbine are expanded isentropically in the exit nozzle *i.e.*, the efficiency of the exit nozzle is 100 percent.

5.3.2 Thrust Power and Propulsive Efficiency : The jet aircraft draws in air and expels it to the rear at a markedly increased velocity. The action of accelerating the mass of fluid in a given direction creates a reaction in the opposite direction in the form of a propulsive force. The magnitude of this propulsive force is defined as thrust. It is dependent upon the rate of change of momentum of the working medium i.e. air, as it passes through the engine.

The basis for comparison of jet engines is the thrust. The thrust, T of a turbojet engine can be expressed as,

$$T = m(V_j - V_o) \qquad \ldots (5.1)$$

where, m = mass flow rate of gases, kg/sec.,

V_j = exit jet velocity, m/sec., and,

V_o = vehicle velocity, m/sec.

The above equation is based upon the assumption that the mass of fuel is neglected. Since the atmospheric air is assumed to be at rest, the velocity of the air entering relative to the engine, is the velocity of the vehicle, V_o. The thrust can be increased by increasing the mass flow rate of gas or increasing the velocity of the exhaust jet for given V_o.

Thrust power is the time rate of development of the useful work achieved by the engine and it is obtained by the product of the thrust and the flight velocity of the vehicle. Thus, thrust power TP is given by

$$TP = T\,V_o = m(V_j - V_o)\,V_o \,\frac{\text{N·m}}{\text{sec.}} \qquad \ldots (5.2)$$

The kinetic energy imparted to the fluid or the energy required to change the momentum of the mass flow of air, is the difference between the rate of kinetic energy of entering air and the rate of kinetic energy of the exist gases and is called propulsive power. The propulsive power PP is given by

$$PP = \frac{m(V_j^2 - V_0^2)}{2} \text{ N.m/sec.} \qquad \ldots (5.3)$$

Propulsive efficiency is defined as the ratio of thrust power (TP) and propulsive power (PP) and is the measure of the effectiveness with which the kinetic energy imparted to the fluid is transformed or converted into useful work. Thus, propulsive efficiency η_p is given by

$$\eta_p = \frac{TP}{PP} = \frac{m(V_j - V_0)\,V_0}{1} \times \frac{2}{m(V_j^2 - V_0^2)}$$

$$\therefore \eta_p = \frac{2(V_j - V_o)V_o}{V_j^2 - V_o^2} = \frac{2V_o}{V_j + V_o} = \frac{2}{1 + \left(\frac{V_j}{V_o}\right)} \quad \ldots (5.4)$$

From the expression of n_p it may be seen that the propulsion system approaches maximum efficiency as the velocity of the vehicle approaches the velocity of the exhaust gases. But as this occurs, the thrust and the thrust power approach zero. Thus, the ratio of velocities for maximum propulsive efficiency and for maximum power are not the same. Alternatively, the propulsive efficiency can be expressed as

$$\eta_p = \frac{TP}{PP} = \frac{TP}{TP + K.E.\ \text{losses}} \quad \ldots (5.5)$$

Thermal efficiency of a propulsion is an indication of the degree of utilization of energy in fuel (heat supplied) in accelerating the fluid flow and is defined as the increase in the kinetic energy of the fluid (propulsive power) and the heat supplied. Thus,

$$\text{Thermal efficiency, } \eta_T = \frac{\text{Propulsive power}}{\text{Heat supplied}}$$

$$= \frac{\text{Propulsive power}}{\text{Fuel flow rate} \times \text{C.V. of fuel}} \quad \ldots (5.6)$$

The overall efficiency is the ratio of the thrust power and the heat supplied. Thus, overall efficiency is the product of propulsive efficiency and thermal efficiency. The propulsive and overall efficiencies of the turboject engine are comparable to the mechanical efficiency and brake thermal efficiency respectively, of the reciprocating engine.

Problem – 1 : *A jet propulsion unit, with turbojet engine, having a forward speed of 1,100 km/hr produces 14 kN of thrust and uses 40 kg of air per second. Find: (a) the relative exist jet velocity, (b) the thrust power, (c) the propulsive power, and (d) the propulsive efficiency.*

(a) Forward speed, $V_o = \frac{1{,}100 \times 1{,}000}{3{,}600} = 305{\cdot}55$ m/sec.

Using eqn. (5.1), thrust, $T = m(V_j - V_o)$

$$i.e.,\ 14{,}000 = 40(V_j - 305{\cdot}55)$$

$$\therefore V_j = \frac{14{,}000}{40} + 305{\cdot}55 = 350 + 305{\cdot}55 = 655{\cdot}55 \text{ m/sec.}$$

Thus relative exist jet velocity, V_j = **655·55 m/sec.**

(b) Using eqn. (5.2)

Thrust power, $TP = T \times V_o$

$= 14{,}000 \times 305{\cdot}55 = 42{,}77{,}700$ N.m/sec. or = **4,277.7 kN.m/sec.**

(c) Using eqn. (5.3),

$$\text{Propulsive power, } PP = \frac{m(V_2^2 - V_0^2)}{2}$$

$$= \frac{40[(655{\cdot}55)^2 - (305{\cdot}55)^2]}{2}$$

$= 6{,}727 \times 10^3$ N.m/sec = 6,727 KN.m/sec or **6,727 kW**

(d) Using eqn. (5.4),

is not effective and that there are pulsations created in the combustion chamber which affect the air flow in front of the diffuser.

Since the ram jet engine has no turbine, the temperature of the gases of combustion is not limited to a relatively low figure as in the turbojet engine. Air fuel ratios of around 15·1 are used. This produces exhaust temperatures in the range of 2000°C to 2200°C. Extensive research is being conducted on the development of hydrocarbon fuels that will give 30 percent more energy per unit volume than current aviation gasolines. Investigations are carried out to determine the possibility of using solid fuels in the ram jet and in the after burner of the turbojet engine. If powdered aluminium could be utilized as an aircraft fuel, it would deliver over 2·5 times as much heat per unit volume as aviation gasoline, while some other could deliver almost four times as much heat.

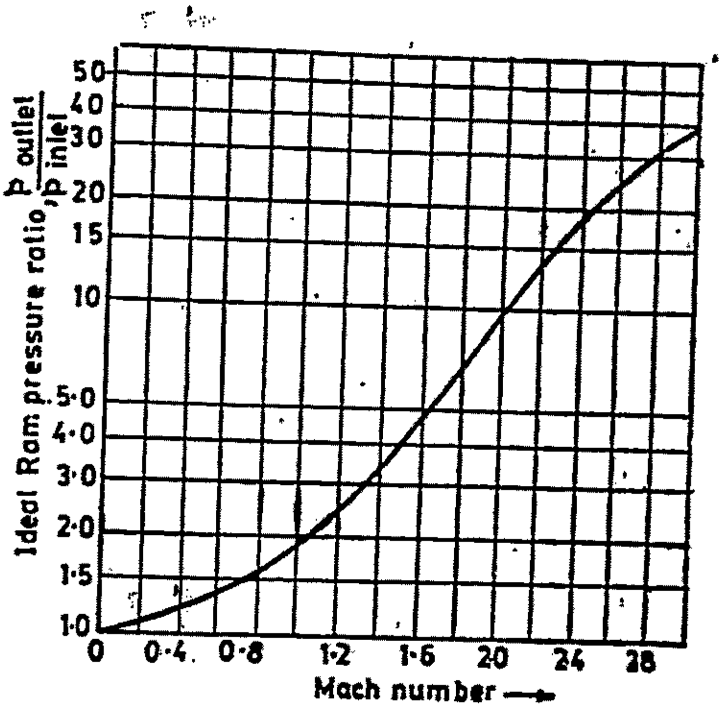


Fig. 5–5. Ram pressure ratio versus Mach number of vehicle for sea level condition.

The temperature, pressure and velocity of the air during its passage through a ram jet engine at supersonic flight are shown in fig. 5-4.

The cycle for an ideal ram jet, which has an isentropic entrance diffuser and exit nozzle, is the Joule cycle as shown by the dotted lines in fig. 5–6. The difference between the actual and ideal jet is due principally to losses actually encountered in the flow system. The sources of these losses are :

- Wall friction and flow separation in the subsonic diffuser and shock in the supersonic diffuser.
- Obstruction of the air stream by the burners which introduces eddy currents and turbulence in the air stream.
- Turbulence and eddy currents introduced in the flow during burning.
- Wall friction in the exit nozzle.

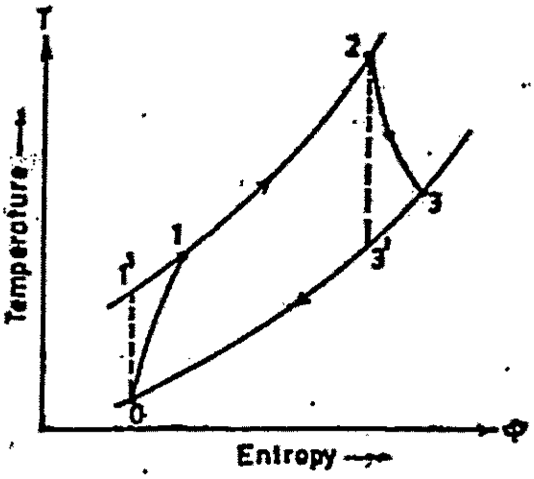


Fig. 5–6. T – φ diagram of Ram jet engine.

By far, the most critical component of the ram jet is the diffuser. Due to the peculiarities of steamline flow, a diffuser which is extremely engine weight than any other propulsion engine at supersonic speed with the exception of the rocket engine. The thrust per unit frontal area increases both with the efficiency and the air flow through the engine; therefore much greater thrust per unit area is obtainable at high supersonic speeds. General performance of a ram jet engine in the subsonic range would have a specific fuel consumption between 0.6 to 0·8 kg fuel per N thrust – hr and a specific weight between 0·01 to 0·02 kg per N thrust. The supersonic ram jet engine has a specific fuel consumption between 0·25 to 0·04 and a specific weight between 0·01 to 0·04. Thus, the best performance of the ram jet engine is obtained at flights speeds of 1500 to 3500 km/hr.

5.5 Pulse Jet Engine

The pulse jet engine is somewhat similar to a ram jet engine. The difference is that a mechanical valve arrangement is used to prevent the hot gases of combustion from flowing out through the diffuser in the pulse jet engine.

Paul Schmidt patented principles of the pulse jet engine in 1930. It was developed by Germany during World–War–II, and was used as the power plant for "buzz bomb".

The turbojet and ram jet engines are continuous in operation and are based on the constant pressure heat addition (Bryton) cycle. The pulse jet is an intermittent combusion engine and it operates on a cycle similar to a reciprocating engine and may be better compared with an ideal Otto cycle rather than the Joule or Bryton cycle.

The compression of incoming air is accomplished in a diffuser. The air passes through the spring valves and is mixed with fuel from a fuel spray located behind the valves. A spark plug is used to initiate combustion but once the engine is operating normally, the spark is turned off and residual flame in the combustion chamber is used for ignition. The engine walls also may get hot enough to initiate combustion.

The mechanical valves which were forced open by the entering air, are forced shut when the combustion process raises the pressure within the engine above the pressure in the diffuser. As the combustion products cannot expand forward, they move to the rear at high velocity. The combustion products cannot expand forward, they move to the rear at high velocity. When the combustion products leave, the pressure in the combustion chamber drops and the high pressure air in the diffuser forces the valves open and fresh air enters the engine.

Since the products of combustion leave at a high velocity there is certain scavenging of the engine caused by the decrease in pressure occasioned by the exit gases. There is a stable cycle set up in which alternate waves of high and low pressure travel down the engine. The alternating cycles of combustion, exhaust, induction, combustion, etc. are related to the acoustical velocity at the temperature prevailing in the engine. Since the temperature varies continually, the actual process is complicated, but a workable assumption is that the tube is acting similar to a quarter wave length organ pipe. The series of pressure and rarefaction waves move down it at the speed of sound for an assumed average temperatures.

The frequency of the combustion cycle may be calculated from the following expression:

$$f = \frac{a}{4L} \text{ cycles/sec.} \qquad \ldots (5.7)$$

where, $a = \sqrt{\gamma RT}$ = sound velocity in the medium at temperature, T, and

L = length of engine (from valves to exit).

efficient at a given speed may be quite inadequate at another velocity.

Because of the simplicity of the engine, the ram jet develops greater thrust per unit engine weight than any other propulsion engine at supersonic speed with the exception of the rocket engine. The thrust per unit frontal area increases both with the efficiency and the air flow through the engine; therefore much greater thrust per unit area is obtainable at high supersonic speeds. General performance of a ram jet engine in the subsonic range would have a specific fuel consumption between 0.6 to 0*8 kg fuel per N thrust - hr and a specific weight between 0*01 to 0*02 kg per N thrust. The supersonic ram jet engine has a specific fuel consumption between 0*25 to 0-04 and a specific weight between 0-01 to 0-04. Thus, the best performance of the ram jet engine is obtained at flights speeds of 1500 to 3500 km/hr.

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The turbojet and ram jet engines are continuous in operation and are based on the constant pressure heat addition (Bryton) cycle. The pulse jet is an intermittent combusion engine and it operates on a cycle similar to a reciprocating engine and may be better compared with an ideal Otto cycle rather than the Joule or Bryton cycle.

The compression of incoming air is accomplished in a diffuser. The air passes through the spring valves and is mixed with fuel from a fuel spray located behind the valves. A spark plug is used to initiate combustion but once the engine is operating normally, the spark is turned off and residual flame in the combustion chamber is used for ignition, line engine walls also may get hot enough to initiate combustion.

The mechanical valves which were forced open by the entering air, are forced shut when the combustion process raises the pressure within the engine above the pressure in the diffuser. As the combustion products cannot expand forward, they move to the rear at high velocity. The combustion products cannot expand forward, they move to the rear at high velocity. When the combustion produ-pf~ leave, the pressure in the combustion chamber drops and the high pressure air in the c.flbser Tbrces the valves open and fresh air enters the engine.

Since the products of combustion leave at a high velocity there is certain scavenging of the engine caused by the decrease in pressure occasioned by the exit gases. There is a stable cycle set up in which alternate waves of high and low pressure travel down the engine. The alternating cycles of combustion, exhaust, induction, combustion, etc. are related to the acoustical velocity at the temperature prevailing in the engine. Since the temperature varies continually, the actual process is*complicated, but a workable assumption is that the tube is acting similar to a quarter wave length organ pipe. The series of pressure and rarefaction waves move down it at the speed of sound for an assumed average temperatures.

The frequency of the combustion cycle may be calculated from the following expression:

^= 4 l cvc*es/sec-

where, a = VfTTT = sound velocity in the medium at temperature, *T*, and
L = length of engine (from valves to exit).

A serious limitation placed upon pulse jet engine is the mechanical valve arrangement. Unfortunately, the valves used have resonant frequencies of their own, and under certain conditions, the valve will be forced into resonant vibration and will be operating when they should be shutting. This limitation of valves also limits the engine because the gas goes out of the diffuser when it should go out of the tail pipe.

Despite the apparent noise and the valve limitation, pulse jet engines have several *advantages* when compared to other thermal jet engines.

- The pluse jet is very inexpensive when compared to a turbojet.
- The pulse jet produces static thrust and produces thrust in excess of drag at much lower speed than a ram jet.
- The potential of the pulse jet is quite considerable and its development and research may well bring about a wide range of application.

5.6 Rocket Motors

The jet propulsion action of the rocket has been recognised for long. Since the early beginning, the use of rockets has been in war time as a weapon and in peace time as a signaling or pyrotechnic displays. Although, the rocket was employed only to an insignificant extent in World War–I, marked advances were made by the research that was undertaken at that time. In World War–II, the rocket became a major offensive weapon employed by all warring powers. Rockets and rocket powered weapons have advanced to a point where they are used effectively in military operations.

Rocket type engine differs from the atmospheric jet engine in that the entire mass of the jet is generated from the propellant carried within the engine i.e. the rocket motor carries both the fuel and the oxidizing agent. As a result, this type of engine is independent of the atmospheric air that other thermal jet engines must rely upon. From this point of view rocket motors are most attractive. There are, however, other operational features that make rocket less useful. Here, the fundamentals of rocket motor theory and its applications are discussed.

Rocket engines are classified as to the type of propellant used in them. Accordingly, there are two major groups:

One type belonging to the group that utilizes liquid type propellants and other group that uses solid type propellants.

The basic theory governing the operation of rocket motor is applied, equally to both the liquid and the solid propellant rocket.

Rocket propulsion, at this time, would not be regarded as a competitor of existing means for propelling airplanes, but as a source of power for reaching objectives unattainable by other methods. The rocket motors are under active development programmes for an increasing number of applications. Some of these *applications* are :

- Artillery barrage rockets,
- Anti–tank rockets,
- All types of guided missiles,
- Aircraft launched rockets,
- Jets assisted take–off for airplanes,
- Engines for long range, high speed guided missiles and pilotless aircrafts, and
- Main and auxiliary propulsion engines on transonic airplanes.

It will be repeated again that the rocket engine differs from the other jet propulsion engines in that the entire mass of the gases in the jet is generated from the propellants carried within the engine. Therefore, it is not dependent on the atmospheric air to furnish the oxygen for combustion. However, since the rocket carries its own oxidiser, the propellant consumption is very high.

The particular advantages of the rocket are :

- Its thrust is practically independent of its environments.
- It requires no atmospheric oxygen for its operation.
- It can function even in a vacuum.
- It appear to be the simplest means for converting the themochemical energy of a propellant combination (fuel plus oxidizer) into kinetic energy associated with a jet flow gases.

Despite its apparent simplicity, the development of a reliable rocket system must be light in weight and the rocket motor must be capable of sustained operation in contact with gases at temperature above 2800° C and at appreciable pressures.The problem of materials in consequently a major one. Furthermore, owing to the enormous energy releases involved, problem of ignition, smooth start up, thrust control, cooling etc. arise.

A major problem of development of rocket is selection of suitable propellant to give maximum energy per premium total weight (propellant plus containing vessels) and convenience factors such as a safety in handling, dependability, corrosive tendencies, cost; availability and storage problems. In general, it can be stated that there is a wide variety of fuels that are satisfactory for rocket purpose, but choice of oxidizers is at present distinctly limited.

5.6.1 Basic Theory : Figure 5–7 shows a schematic diagram of a liquid bi-propellant rocket engine. It consists of an injection system, a combustion chamber, and an exit nozzle. The oxidizer and fuel burnt, in the combustion chamber produces a high pressure. The pressure produced is governed by

- Mass rate of flow of the propellants,
- Chemicals characteristics of the propellants, and
- Cross-section area of the nozzle throat.

The gases are ejected to the atmosphere at supersonic speeds through the nozzle. The enthalpy of high pressure gases is converted into kinetic energy. The reaction to the ejection of the high velocity, produces the thrust on the rocket engine.

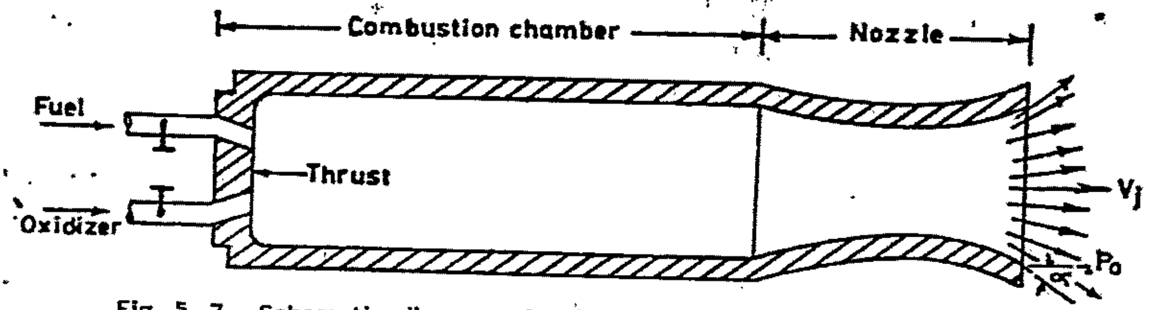


Fig. 5-7. Schematic diagram of a liquid bi-propellant uncooled rocket motor.

The *thrust* developed is a resultant of the pressure forces acting upon the inner and the outer surface of the rocket engine. The resultant internal force acting on the engine is given by

Resultant force $= m_p\ V_j + p_j\ A_j\ N$

where, m_p = Mass rate of propellant consumption, kg/sec,

V_j = Jet velocity relative to nozzle, m/sec,

V_{xj} = Average value of the x–component of the velocity of gases crossing, A_j,

p_j = Exist static pressure, N/m^2, and

A_j = Exit area of nozzle, m^2.

The resultant external forces acting on the rocket engine are p_oA_o, where p_o is the atmospheric pressure in N/m^2. The thrust which is a resultant of the total pressure forces becomes

$$T = m_p V_{xj} + A_j(p_j - p_o) N \quad \ldots (5.8)$$

Let V_j = the exit velocity of the rocket gases, assumed constant and let $V_{xj} = \lambda V_j$. Then, eqn. (5.8) becomes

$$T = \lambda m_p V_j + A_j(p_j - p_o) N \quad \ldots (5.9)$$

The coefficient λ is the correction factor for the divergence angle *a* of the exit conical section of the nozzle. λ is given by.

$$\lambda = \frac{1 - \cos 2\alpha}{4(1 - \cos\alpha)} = \frac{1}{2}(1 + \cos\alpha) \quad \ldots (5.10)$$

Equation (5.8) shows that thrust of a rocket engine increases as the atmospheric pressure decreases. Therefore, maximum thrust will be obtained when P_o= 0, *i.e., rocket engine produces maximum thrust when operating in a vacuum.*

In testing a rocket engine, thrust and propellant consumption for a given time are readily measured. It is convenient then, to express the thrust in terms of the mass rate of flow of propellant and an effective jet velocity, V_{ej}

i.e., Thrust, $T = m_p \times V_{ej}$ . . . (5.11)

The *effective jet exit velocity* is a hypothetical velocity and for convenience in test work it is defined from eqns. (5.9) and (5.11) as under :

$$V_{ej} = \lambda V_j + \frac{A_j}{m_p}(p_j - p_o) \text{ m/sec.} \quad \ldots (5.12)$$

The effective jet exit velocity has become an important parameter in rocket motor performance.

The *thrust power, TP* developed by a rocket motor is defined as the thrust multiplied by the flight velocity, V_o.

$$TP = TV_o = m_p \cdot V_{ej} \cdot V_o \text{ N.m/sec.} \quad \ldots (5.13)$$

The *propulsive efficiency*, η_p is the ratio of the thrust power to propulsive power supplied. The propulsive power is the thrust power plus the kinetic energy lost in the exhaust,

i.e., K.E. Loss $= \frac{1}{2} m_p (V_{ej} - V_o)^2$ N.m/sec.

Therefore, the propulsive efficiency may be expressed as

$$\eta_p = \frac{TP}{TP + \text{K.E. Loss}} = \frac{m_p V_{ej} V_o}{m_p V_{ej} V_o + \frac{1}{2} m_p (V_{ej} - V_o)^2}$$

$$\therefore \eta_p = \frac{2 (V_o/V_{ej})}{1 + (V_o/V_{ej})^2} \quad \ldots (5.14)$$

Specific Impulse, I_{sp} has become an important parameter in rocket motor performance and is defined as the thrust produced per unit mass rate of propellant consumption.

$$I_{sp} = \frac{T}{m_p} = \frac{m_p \cdot V_{ej}}{m_p} = V_{ej} \quad \ldots (5.15)$$

Specific impulse, with the units, Newtons of thrust produced per kg of propellant burned per second, gives a direct comparison as to the effectiveness among propellants. It is desirable to use propellants with the greatest possible specific impulse, since, this allows a greater useful load to be carried for a given overall rocket weight.

5.6.2. Types of Rocket Motors : The propellant employed in a rocket motor may be a solid, two liquids (fuel plus oxidizer), or materials containing an adequate supply of available oxygen in their chemical composition (monopropellant). Solid propellants are used for rockets which are to operate for relatively short periods, upto possibly 45 seconds. Their main application is to projectiles, guided missiles, and the assisted take-off aircraft.

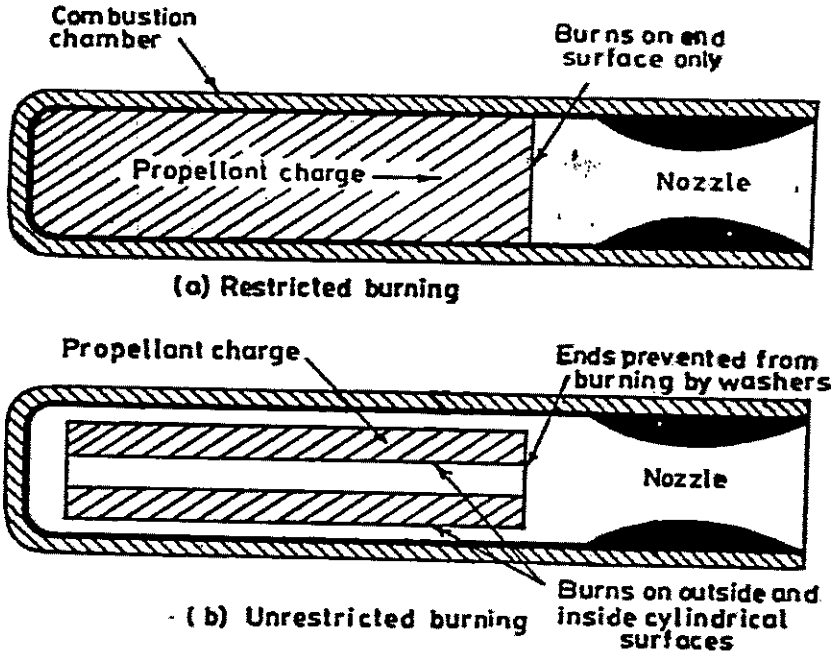


Fig. 5-8 Schematic diagram of a solid propellant rocket.

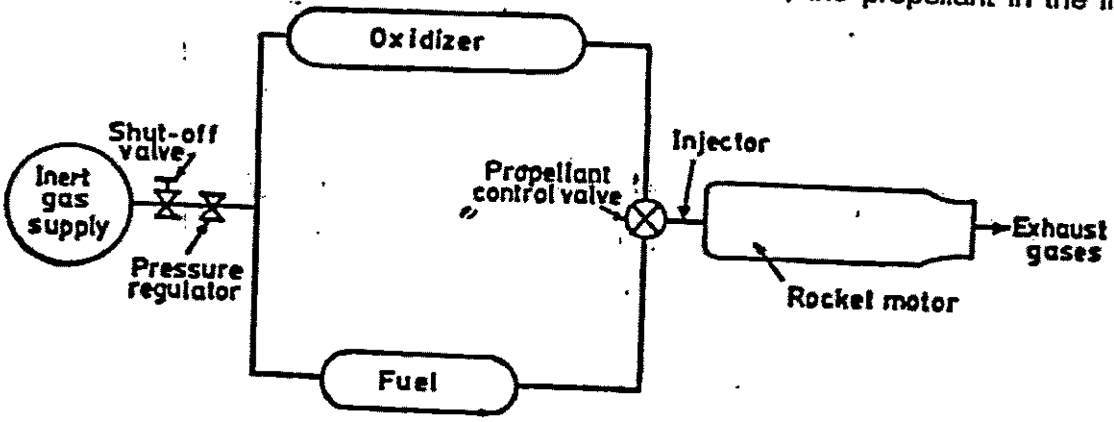
Solid propellant rockets (fig. 5-8) have been of two basic types :

- Unrestricted burning types for projectiles and launching rockets; and
- Restricted burning types for assisted take-off of aircraft and for propelling missiles.

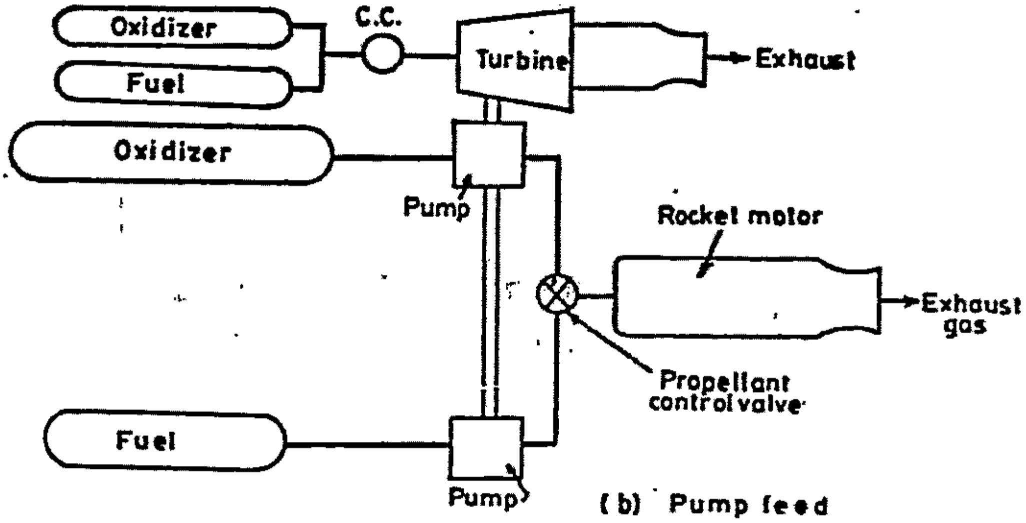
In the unrestricted burning rocket [fig. 5-8(a)] all surfaces of the propellant grain except the ends are ignited; in restricted burning rockets [fig. 5-8(b)] only one surface of the propellant is permitted to burn. Liquid propellant rockets utilizes liquid propellants which are stored in the containers outside the combustion chamber. The basic theory of operation of this type of rocket is same as that for solid propellant rocket. Liquid propellant rockets were developed in order to overcome some of the undesirable features of the

which ar

solid propellant rockets such as short duration of thrust, and no provisions for adequate cooling or control of the burning after combustion starts. Here, the propellant in the liquid state is injected into a combustion chamber, burned and exhausted at a high velocity through the nozzle. The liquid propellant is also used to cool the rocket motor by circulation of fuels around the walls of the combustion chamber and around the nozzle. Certain liquid fuel, however, such as hydrogen peroxide, burn at such temperatures that no cooling is necessary. Figure 5-9 shows schematic diagrams of pressure feed and pump feed liquid bipropellant rocket systems.



(a) Pressure feed



(b) Pump feed

Fig. 5-9. Schematic diagrams of bi-propellant rocket system.

Problem-2 : *The effective exit jet velocity of a rocket is 3000 m/sec, the forward flight velocity is 1500 m/sec and the propellant consumption is 70 kg per sec. Calculate : (a) Thrust, (b) Thrust power, (c) Specific impulse, (d) Specific propellant consumption, and (e) Propulsive efficiency of the rocket.*

(a) Using eqn. (5.11),

Thrust, $T = m_p \times V_{ej} = 70 \times 3{,}000 = 2{,}10{,}000$ N or **210 kN**

(b) Using eqn. (5.13),

Thrust power, $TP = T\ V_o = 2{,}10{,}000 \times 1{,}500 = 315 \times 10^6$ **N.m/s**

(c) Using eqn. (5.14),

Specific impluse, $I_{sp} = \frac{T}{m_p} = \frac{m_p \cdot V_{ej}}{m_p} = V_{ej} = $ 3,000 N.s/kg

(d) Specific propellant consumption $= \frac{m_p}{T} = \frac{m_p}{m_p V_{ej}} = \frac{1}{V_{ej}} = \frac{1}{3,000}$

$= 3{\cdot}3 \times 10^{-4}$ kg/N.s

(e) Using eqn. (5.14),

Propulsive efficiency, $\eta_p = \frac{2(V_o/V_{ej})}{1 + (V_o/V_{ej})^2}$

$= \frac{2(1500/3000)}{1 + (1500/3000)^2} = 0{\cdot}8$ i.e., 80%

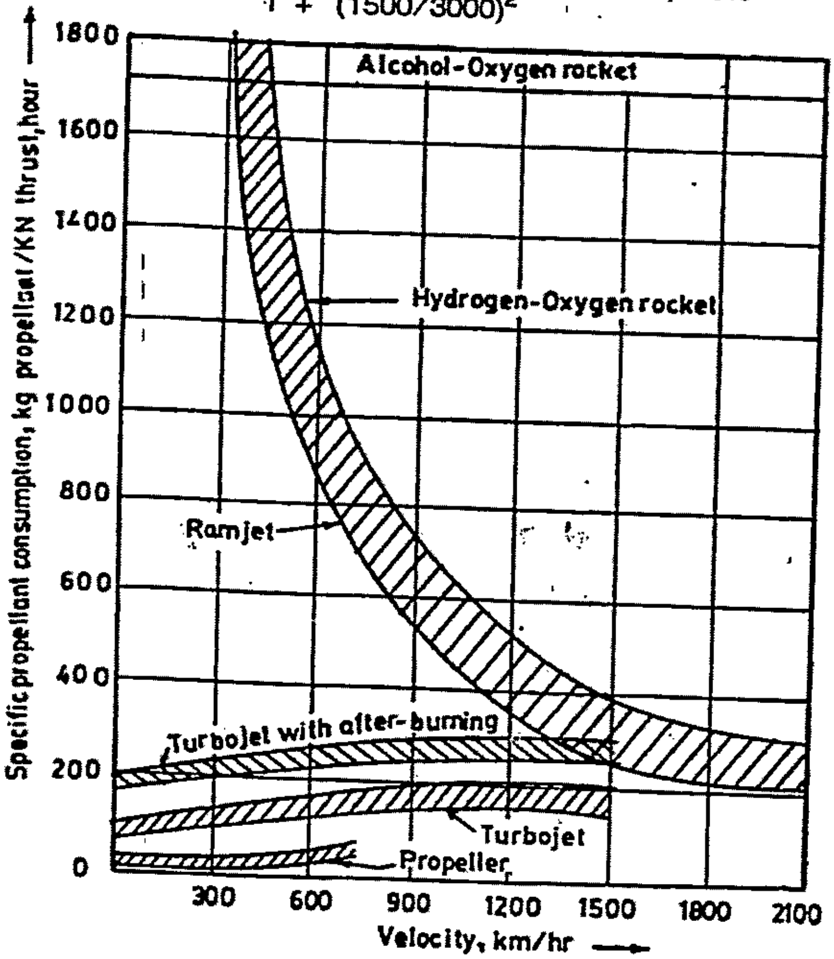


Fig. 5–10. Propellant or fuel consumption versus flight speed for different propulsion systems.

5.7 Comparison of the Various Propulsion Systems

Figure 5–10 shows the specific propellant consumption in kg per kN thrust versus speed for different engines. The curves in this figure indicate that the use of rocket engines to power air planes, as we know them today, is not feasible because of their high fuel consumption. Also, the use of ram jet engines is not economical at lower than 1500 km/hr vehicle speeds.

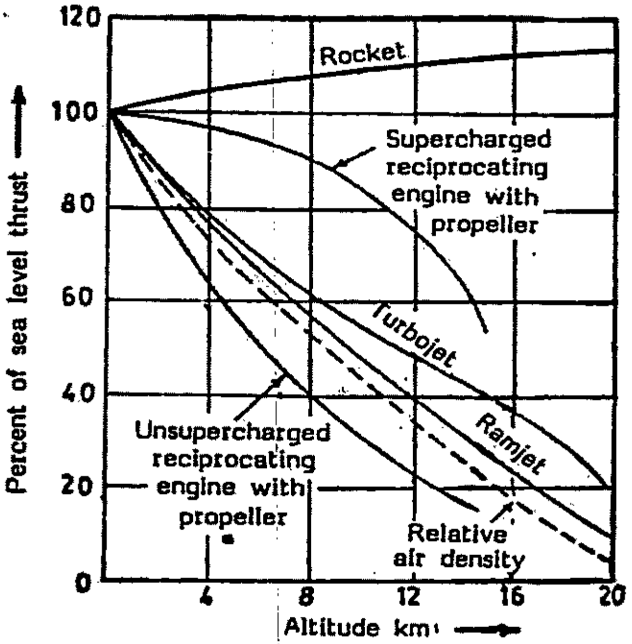


Fig. 5-11 Variation of thrust with altitude for different propulsion systems.

Figure 5-11 shows variation of thrust with altitude for different propulsion systems. It may be noted that the thrust of rocket motor increases with altitude while the thrust of other types of vehicles decreases with altitude.

Figure 5-12 gives relative picture of the probable operating envelope of the various propulsion systems.

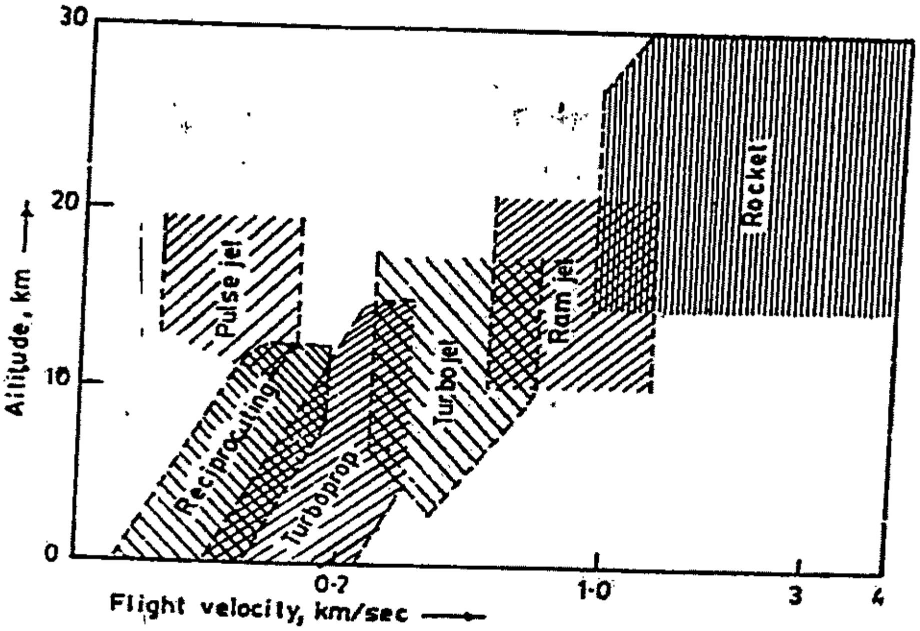


Fig. 5-12 Comparison of probable best performance for various propulsion engines.

INDUSTRIAL APPLICATIONS

INDUSTRIAL APPLICATIONS

- IN AIRCRAFT- Fighter plane, Missiles, Rocket, Airplane.
- Jet propulsion, land and sea transport, racing car.
- The first use of the jet engine was to power military aircraft.
- The General electric company used a "turboprop" jet engine to run an electric generator.
- The jet engine is not only used on aircraft but on boats, where water jets are used to propel the boat forward.
- Normal type of jet engine is used for domestic purpose i.e. Traveling, carrying goods etc.

An aircraft using this type of jet engine could dramatically reduce the time which it takes to travel from one place to another, potentially putting any place on Earth within a 90-minute flight.

Scramjet vehicle has been proposed for a single stage to tether vehicle, where a Mach 12 spinning orbital tether would pick up a payload from a vehicle at around 100 km and carry it to orbit

Rocket applications

1. Satellites in space serve air communication
2. Spacecraft
3. Missiles
4. Jet assisted air planes
5. Pilotless aircraft

TUTORIAL QUESTIONS

Theory Questions:

1. What are the different rocket propulsion systems? Brief the working differences between the propeller-jet, turbojet and turbo-prop.
2. With a neat diagram explain the working of rocket engine
3. Describe briefly about thrust augmentation method used in propulsion.
4. With a neat sketch, explain the working of turbo jet engine.
5. Differentiate between solid propellant and liquid propellant rocket engines.
6. What are the applications of pulse jet engines
7. Give the difference between ramjet and pulse jet engines
8. What are composite and homogeneous solid propellants? How do they work? State their merits and demerits.
9. What is the essential difference between rocket propulsion and turbo-jet propulsion?
10. Write a detailed classification of rockets. Explain liquid propellant rocket with a neat sketch Define and explain the terms:
    i. Thrust
    ii. Thrust power,
    iii. Effective jet exit velocity,
    iv. Propulsive efficiency related to turbojet engines.
11. What are the various applications of rockets?
12. Explain the advantages and disadvantages of bipropellants used in rocket engines over monopropellants.
2. Derive expressions for the thrust and propulsion efficiency of rockets and compare with those of turbojet

Numerical Problems:

1. A jet propulsion system has to create a thrust of 100 tones to move the system at a velocity of 700 km/hr. If the gas flow rate throtgh the system is restricted to a maximum of 30 kg/s. find the exit gas velocity and propulsive efficiency.

2. In a jet propulsion unit, initial pressure and temperature to the compressor are 1.0 bar and 100C. The speed of the unit is 200m/s. The pressure and temperature of the gases before entering the turbine are 7500 C and 3 bar. Isentropic efficiencies of compressor and turbine are 85% and 80%. The static back pressure of the nozzle is 0.5 bar and efficiency of the nozzle is 90%. Determine (a) Power consumed by compressor per kg of air. (b)Air-fuel ratio if calorific value of fuel is 35,000 kJ/kg. Cp of gases=1.12 kJ/kg K, _ =1.32 for gases.
3. A turbo-jet engine flying at a speed of 960 km/h consumes air at the rate of 54.5 kg/s. calculate i). Exit velocity of the jet when the enthalpy change for the nozzle is 200 KJ/kg and velocity coefficient is 0.97. ii).fuel flow rate in kg/s when air fuel ratio is 75:1 iii). Thrust specific fuel consumption iv). Propulsive power v). Propulsive efficiency.
4. A simple turbine jet unit was tested when stationary and the ambient conditions were 1bar and 150C. The pressure ratio for the compressor was 4:1. A fuel consumption of 0.37kg/s was obtained for an air flow of 23kg/s. Calculate the thrust produced if the exhaust gases from the turbine were expanded to atmospheric pressure in a convergent nozzle. Assume the following data:

   Isentropic efficiency of compressor-80% Isentropic efficiency of turbine-85%

   Efficiency of nozzle-93% Transmission efficiency-98%

   Calorific value of fuel-42000kJ/kg Assuming working fluid to be air throughout.

5. In a turbojet, air is compressed in an axial compressor at inlet conditions of 1 bar and 1000C

   3.5 bar. The final temperature is 1.25 times that for isentropic compression. The temperature of gases at inlet to turbine is 4800C. The exhaust gases from turbine are expanded in a velocity of approach is negligible and expansion may be taken to be isentropic in both turbine and nozzle. Value of gas constant R and index r are same for air and flue gases.

   Determine

   i) Power required to drive the compressor per kg of air/sec

   ii) Air-fuel ratio if the calorific value of fuel is 42,000 kJ/kg

   iii) Thrust developed / kg of air / sec.

ASSIGNMENT QUESTIONS

ASSIGNMENT QUESTIONS

1. Why is thrust augmentation necessary? What are the methods for thrust augmentation in a turbojet engine?
2. A turbo-jet engine flying at a speed of 960 km/h consumes air at the rate of 54.5 kg/s. calculate i). Exit velocity of the jet when the enthalpy change for the nozzle is 200 KJ/kg and velocity coefficient is 0.97. ii).fuel flow rate in kg/s when air fuel ratio is 75:1 iii). Thrust specific fuel consumption iv). Propulsive power v). Propulsive efficiency.
3. With a neat diagram explain the working of rocket engine
4. What is turbine and classify them?

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MID & ASSIGNMENT EXAMINATION QUESTION PAPERS WITH SCHEME AND SOLUTIONS

NARASARAOPET ENGINEERING COLLEGE (AUTONOMOUS): NARASARAOPET

DEPARTMENT OF MECHANICAL ENGINEERING

III B.TECH I - SEMESTER ASSIGNMENT TEST – II, OCTOBER- 2022

SUBJECT: HEAT POWER ENGINEERING	**DATE:** 11-10-2022
DURATION: 30 MIN	**MAX MARKS:** 10

Q. No	Questions	Course Outcome (CO)	Knowledge Level as Per Bloom's Taxonomy	Marks
1	**Explain** the classification and working principle of a nozzle.	3	Apply (K3)	2
2	Steam from nozzle enters into a single stage impulse turbine at 300 m/s absolute velocity. The nozzle angle=25°. The blade rotor mean diameter is 100cm and rotating at a speed of 2000 rpm. Find the blade angles if the axial thrust is zero. **Find** the power developed when the steam flow rate is 600 kg/min. Take blade velocity coefficient=0.9.	3	Analyze (K4)	3
3	**Derive** an expression for maximum mass flow per unit area of flow through a convergent-divergent nozzle when steam expands isentropic ally from rest.	3	Analyze (K4)	3
4	**Explain** the fundamental difference between the operation of impulse and reaction turbines?	4	Apply (K3)	2
5	**Draw** the velocity diagram for Pressure compounding of turbines.	4	Apply (K3)	2
6	A stage of impulse-reaction turbine is provided with single row wheel whose mean diameter is 100cm and it is rotating at 50 rps. The nozzle angle=20° and the velocity of steam coming out of the turbine is 350 m/sec. **Determine** the power developed if the axial thrust on the end bearings is limited to 118N. Take blade friction factor=0.8. Assume the blades are equi-angular.	4	Analyze (K4)	3

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DEPARTMENT OF MECHANICAL ENGINEERING
III B. TECH I-SEMESTER II-MID EXAMINATION

SUBJECT: Heat Power Engineering	DATE:18/11/2022
DURATION: 90 min	**MAX MARKS:** 25

Answer all questions

Q.no	Questions	CO	Knowledge Level
1.	Dry saturated steam at 10 bar (abs) is expanded in a steam nozzle 0. 4 bar (abs). The throat area is 7 cm^2, while the inlet velocity is negligible. Calculate, **(i)** The mass flow rate of steam, and **(ii)** The exit area. Assuming isentropic flow. Take index of expansion to be n=1.135, for dry saturated steam. [5M]	3	Applying (K3)
2.	**a)** Illustrate the principle of Reaction turbine [4M] **b)** In a simple impulse turbine, the steam enters the wheel through a nozzle with a velocity of 500 m/s and at an angle of 20° to the direction of motion of the blade. The blade speed is 200 m/s and the exit angle of the moving blade is 25°. Find the inlet angle of the moving blade, exit velocity of steam and its direction and work done per kg steam. [6M]	4	Applying (K3)
3.	**a)** Classify the different types of gas turbines and explain the gas turbine with reheating or gas turbine with intercooler. [6M] **b)** Write short notes on liquid propellant engines [4M]	5	Applying (K3)

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DEPARTMENT OF MECHANICAL ENGINEERING
III B. TECH I-SEMESTER II-MID EXAMINATION

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1.	Dry saturated steam at 10 bar (abs) is expanded in a steam nozzle 0. 4 bar (abs). The throat area is 7 cm^2, while the inlet velocity is negligible. Calculate, **(i)** The mass flow rate of steam, and **(ii)** The exit area. Assuming isentropic flow. Take index of expansion to be n=1.135, for dry saturated steam. [5M]	3	Applying (K3)
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3.	**a)** Classify the different types of gas turbines and explain the gas turbine with reheating or gas turbine with intercooler. [6M] **b)** Write short notes on liquid propellant engines [4M]	5	Applying (K3)

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UNIT WISE IMPORTANT QUESTIONS

UNIT WISE SAMPLE ASSESSMENT QUESTIONS

COURSE OUTCOMES:

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

CO1: Illustrate the various types of efficiency improvements of Rankine cycle
CO2: Describe the various boilers, mountings and accessories.
CO3: Identify different types of nozzles used in steam turbines.
CO4: Classify different turbines based on utility and applications.
CO5: Discuss gas turbines, jet propulsion and rocket propulsion.

S NO	QUESTION	KNOWLEDGE LEVEL	CO
UNIT I			
1	Explain working principle of Rankine cycle?	K3	CO1
2	In a Rankine cycle, the steam at inlet to Turbine is saturated at a pressure of 35bar and the exhaust pressure is 0.2bar. solve i)the pump work ii) Turbine work iii) Rankine efficiency iv) Condenser heat flow v) the dryness at the end of expansion. Assume flow rate of 9.5kg/sec	K3	CO1
3	The following is the ultimate analysis of a sample of petrol by weight: Carbon =85%, Hydrogen=15%. Computes the ratio of air to petrol consumption by weight if the volumetric analysis of dry exhaust gas is CO_2=11.5%,CO=1.2%,O_2=0.9% and N_2=86%. Also find percentage excess air.	K3	CO1
UNIT 2			
1	Differentiate following boilers? i) Externally fired and internally fired boilers. ii)Forced circulation and natural circulation	K2	CO2
2	Explain with neat sketches any three of the following mountings? i) water level indicator ii) Pressure gauge iii) Feed check valve	K2	CO2
3	Compare forced and induced draft, enumerate merits of induced draft over forced draught	K3	CO2
4	Compute Height of chimney for maximum discharge condition.	K3	CO2
UNIT 3			
1	Computes an expression for maximum mass flow per unit area of flow through a convergent- divergent nozzle when steam expands isentropic ally from rest.	K3	CO3
2	What do you mean by compounding of steam turbine? Discuss various methods of Compounding steam turbines with merits and demerits?	K2	CO3
3	Dry air at a pressure of 12 bar and 300°C is expanded isentropically through a nozzle at a pressure of 2 bar. Computes the maximum discharge through the nozzle of 150mm^2 area.	K3	CO3

UNIT 4			
1	Distinguishes between impulse and reaction turbines.	K2	CO4
2	Explain the Governing of steam Turbines	K2	CO4
3	In a De-lavel turbine, the steam enters the wheel through a nozzle with a velocity of 500 m/s and at an angle of 20° to thedirection of motion of the blade. The blade speed is 200 m/s and the exit angle of the moving blade is 25°. Estimates the inlet angle of the moving blade exit velocity of steam and its direction and work done per kg of steam.	K2	CO4
UNIT 5			
1	Explain closed cycle gas turbine and calculate woke done.	K3	CO5
2	Distinguishes of Closed Cycle and Open Cycle Gas Turbines.	K3	CO5
3	Explain the working principle of Ram-Jet with diagram	K3	CO5

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DEPARTMENT OF MECHANICAL ENGINEERING

PREVIOUS QUESTION PAPERS

NARASARAOPETA ENGINEERING COLLEGE
(AUTONOMOUS)

Subject Code: R20ME3102

III B.Tech. - I Semester Regular Examinations, November-2022
HEAT POWER ENGINEERING
(ME)

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

Note: Answer All FIVE Questions.
All Questions Carry Equal Marks (5 X 14 =70M)

QNo		Questions	KL	CO	Marks
		Unit-I			
1	a	Describe the schematic layout of Rankine cycle. Explain the effect of Boiler and Condenser pressure on cycle efficiency.	KL2	CO1	7M
		Explain the adiabatic flame temperature. Does "adiabatic flame temperature" assume 100% combustion? Justify.	KL3	CO1	7M
		OR			
	b	Represent schematic of regenerative and reheat cycles and plot the variations at salient point on P-V and T-S chart.	KL1	CO1	7M
		Explain the working of Orsat apparatus analysis.	KL2	CO1	7M
		Unit-II			
2	a	Mention the list of Boiler mountings and accessories. Explain their function briefly.	KL2	CO2	7M
		A chimney 30 m high is discharging hot gases at 300°C, when the outside air temperature is 20°C. The quantity of air supplied per kg of fuel is 20kg. Determine (a) Draught produced in mm of water column (b) efficiency of the chimney, if the minimum temperature of artificial draught is 150°C. The mean specific heat of the gases is 1.005 kJ/kg K.	KL3	CO2	7M
		OR			
	b	Describe and explain the working of Babcock and Wilcox water tube boiler.	KL2	CO2	7M
		What are the functions of a boiler chimney. Define efficiency of chimney.	KL2	CO2	7M
		Unit-III			
3	a	Derive an expression for maximum discharge through a convergent divergent nozzle.	KL3	CO3	7M
		A group of convergent divergent nozzle expands 6 kg/sec of steam from 13 bar dry saturated to 1.5 bar with a nozzle efficiency of 90%. Velocity at throat is 3% less than the theoretical. If throat section diameter of each nozzle is about 1.28 cm^2, find number of nozzles and area at throat and exit	KL3	CO3	7M
		OR			
	b	Discuss the function of convergent portion, throat and divergent portion of a convergent divergent nozzle with reference to flow of steam.	KL2	CO3	7M
		Inlet pressure and temperature of steam nozzle are 10 bar and 200^{0}c respectively. Back pressure is 0.5 bar. Calculate the mass flow rate of steam if throat diameter is 12 mm.	KL3	CO3	7M
4		**Unit-IV**			
	a	Describe pressure-velocity compounding in an impulse turbine.	KL2	CO4	7M
		Find the condition for maximum blade efficiency in a single stage impulse turbine.	KL3	CO4	7M

		OR			
	b	In a De Laval turbine, the steam issues from the nozzles with a velocity of 850 m/sec. The nozzle angle is 20°.Mean blade speed is 350 m/sec. The blades are symmetrical. The mass flow rate is 1000 kg/min. Friction factor is 0.8. Determine (i) Blade angles (ii) axial thrust on the bearings (iii) Power developed in KW (iv) blade efficiency (v) Stage efficiency if nozzle efficiency is 93%.	KL3	CO4	14M
		Unit-V			
5	a	What are the various methods which are used to improve the efficiency of a gas turbine? Explain in detail	KL2	CO5	7M
		Air enters the compressor of gas turbine plant operating a Brayton cycle at 102 KPa, 27°C. The pressure ratio in the cycle is 6. Calculate the maximum temperature in the cycle and the cycle efficiency. Assume W_T=2.5 W_C where W_T and W_C are the turbine work and compressor work respectively. γ= 1.4.	KL3	CO5	7M
		OR			
	b	Classify the jet propulsive engines. Explain working principle of any one engine with schematic diagrams and representation on T-S diagram.	KL2	CO5	7M
		Explain working of Turbo jet engine.	KL2	CO5	7M

KL: Blooms Taxonomy Knowledge Level CO: Course Outcome M:Marks

HEAT POWER ENGINEERING

III B.TECH I SEM REGULAR NOV 2022

1 a i)

From steam tables we have

At 30 bar 400°C : $h_1 = 323.9$ kJ/kg, $s_1 = 6.921$ kJ/kg.K $= s_2 = s_3$

At 5 bar : $s_f = 1.8604$ kJ/kg.K, $s_g = 6.8192$ kJ/kg.K, $h_f = 640.1$ kJ/kg

Since $s_2 > s_g$, the state 2 lie in the superheated region.

From the table for superheated steam,

$t_2 = 172$°C, $h_2 = 2796$ kJ/kg.

At 0.1 bar: $s_f = 0.649$ kJ/kg.K, $s_{fg} = 7.501$ kJ/kg.K, $h_f = 191.8$ kJ/kg, $h_{fg} = 2392.8$ kJ/hg

Now

$$s_2 = s_3$$

$$6.921 = S_{f3} + x_3 S_{fg3} = 0.\ 649 + x_3 \times 7.501$$

$$x_3 = 0.836$$

$$h_3 = h_{f3} + x_3\, h_{fg3} = 191.8 + 0.836 \times 2392.8 = 2192.2 \text{ kJ/kg}$$

Since pump work is neglected,

$h_{f4} = h_{f5} = 191.8$ kJ/ kg

$h_{f6} = h_{f7} = 640.1$ kJ/kg

Energy balance for heater gives,

$$m(h_2 - h_{f6}) = (1 - m)\,(h_{f6} - h_{f5})$$

$$m\,(2796 - 640.1) = (1 - m)\,(640.1 - 191.8)$$

$$m = 0.172 \text{ kg}$$

Turbine work, $w_t = (h_1 - h_2) + (1 - m)\,(h_2 - h_3)$

$= (3230.9 - 2796) + (1 - 0.172)\,(2796 - 2192.2)$

Heat supplied = $Q_1 = h_1 - h_{f6} = 3230.9 - 640.1 = 2590.8$ kJ/kg

$$W_T \text{(without regeneration)} = h_1 - h_3$$

$$= 3230.9 - 2192.2 = 1038.7 \text{ kJ/kg}$$

$$\text{Steam rate (without regeneration)} = \frac{3600}{1038.7} = 3.46 \text{ kg/kW h}$$

∴ Increase in steam rate due to regeneration

$$= 3.93 - 3.46 = 0.47 \text{ kg/kW h}$$

$$\eta_{\text{cycle}} \text{(without regeneration)} = \frac{h_1 - h_3}{h_1 - h_4} = \frac{1038.7}{3039.07}$$

$$= 0.3418 \text{ or } 34.18\%$$

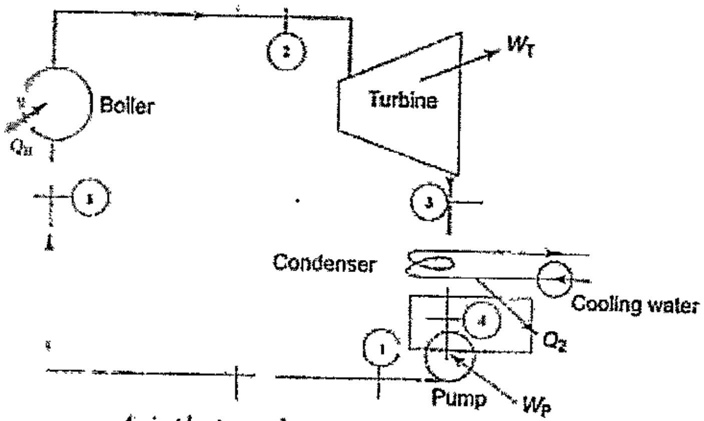
∴ Increase in cycle efficiency due to regeneration

$$= 35.36 - 34.18 = 1.18\%$$

ii)

Vapour power cycles are used in steam power plants. In a power cycle heat energy (released by the burning of fuel) is converted into work (shaft work), in which a working fluid repeatedly performs a succession of processes. In a vapour power cycle, the working fluid is water, which undergoes a change of phase

The simplest way of overcoming the inherent practical difficulties of the Carnot cycle without deviating too much from it is to keep the processes 1-2 and 2-3 of the latter unchanged and to continue the process 3-4 in the condenser until all the vapour has been converted into liquid water. Water is then pumped into the boiler upto the pressure corresponding to the state 1 and the cycle is completed. Such a cycle is known as the Rankine cycle. This theoretical cycle is free of all the practical limitations of the Carnot cycle.

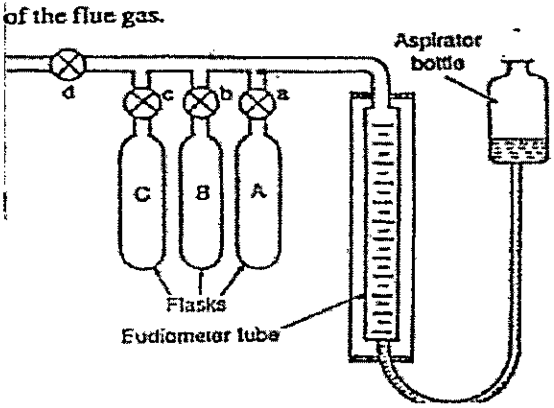


A simple steam plant

B i)

To check the combustion efficiency of boilers, it is considered essential to determine the constituents of the flue gases. Such an analysis is carried out with the help of Orsat apparatus as shown in Fig. 12.1.

It consists of a graduated measuring glass tube (known as eudiometer tube) and three flasks *A*, *B* and *C*, each containing different chemicals for absorbing carbon dioxide, carbon monoxide and oxygen. An aspirator bottle containing water is connected to the bottom of the eudiometer tube by means of a rubber tube. It can be moved up and down, at will, for producing a suction or pressure effect on the sample of the flue gas.



ii)

Solution. Steam supply pressure, $p_1 = 15$ bar, $x_1 = 1$

Condenser pressure, $p_2 = 0.4$ bar

Carnot and Rankine efficiencies :

From steam tables :

At 15 bar : $t_s = 198.3°\text{C}$, $h_g = 2789.9$ kJ/kg, $s_g = 6.4406$ kJ/kg K

At 0.4 bar : $t_s = 75.9°\text{C}$, $h_f = 317.7$ kJ/kg, $h_{fg} = 2319.2$ kJ/kg,

$s_f = 1.0261$ kJ/kg K, $s_{fg} = 6.6448$ kJ/kg K

$$T_1 = 198.3 + 273 = 471.3 \text{ K}$$

$$T_2 = 75.9 + 273 = 348.9 \text{ K}$$

$$\therefore \quad \eta_{\text{carnot}} = \frac{T_1 - T_2}{T_1} = \frac{471.3 - 348.9}{471.3}$$

$$= \mathbf{0.259 \text{ or } 25.9\%. \text{ (Ans.)}}$$

$$\eta_{\text{Rankine}} = \frac{\text{Adiabatic or isentropic heat drop}}{\text{Heat supplied}} = \frac{h_1 - h_2}{h_1 - h_{f_2}}$$

where $h_2 = h_{f_2} + x_2\, h_{fg_2} = 317.7 + x_2 \times 2319.2$ ...(*i*)

Value of x_2 :

As the steam expands isentropically,

$$\therefore \quad s_1 = s_2$$

$$6.4406 = s_{f_2} + x_2\, s_{fg_2} = 1.0261 + x_2 \times 6.6448$$

$$\therefore \quad x_2 = \frac{6.4406 - 1.0261}{6.6448} = 0.815$$

$$\therefore \quad h_2 = 317.7 + 0.815 \times 2319.2 = 2207.8 \text{ kJ/kg}$$ [From eqn. (*i*)]

Hence, $\eta_{\text{Rankine}} = \dfrac{2789.9 - 2207.8}{2789.9 - 317.7} = 0.2354$ or 23.54%. **(Ans.)**

2 a

Boiler Accessories

Boiler accessories are the components which are attached to the boiler (Not mounted on it) and are essentially for working of boiler and for increasing its efficiency. Various boiler accessories are discussed as below

Feed pump

Feed pump is placed nearby the boiler and is used to feed water to boiler working at a high pressure. The job of feed pump is not just put the water in the boiler but as boiler is working at high pressure, discharge pressure of feed pump must be sufficiently higher than this to push the water inside the boiler.

Construction & working

The feed pump used in boiler is of two types (i) Reciprocating type (ii) Rotary type. Both these types are positive displacement type to discharge against high pressure. The discharge pressure of a single stage centrifugal pump is not high enough to overcome the high pressure of boiler so multistage centrifugal pump is used as a boiler feed pump.

Construction & working

Economizers are of two types as (i) External type (ii) Internal type. The external type economizer is constructed and installed apart from the boiler and the flue gases from the boiler are directed to flow through it before escaping through chimney. A vertical tube external economizer is shown in fig

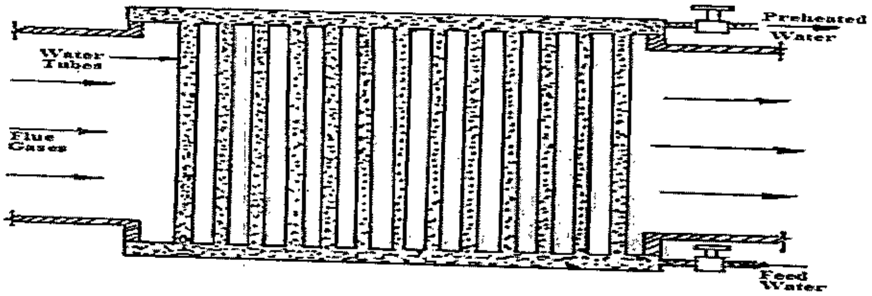


Fig: Economise

Air Pre-heater

It is a plate type or tubular type or storage heat exchanger, in which flue gases pass through the tubes on one side of plate and air pass on other side. In storage type a rotor fitted with mesh or matrix alternatively come in the passage of flue gases and air thus exchanging heat. A tubular type air-heater is as shown in fig

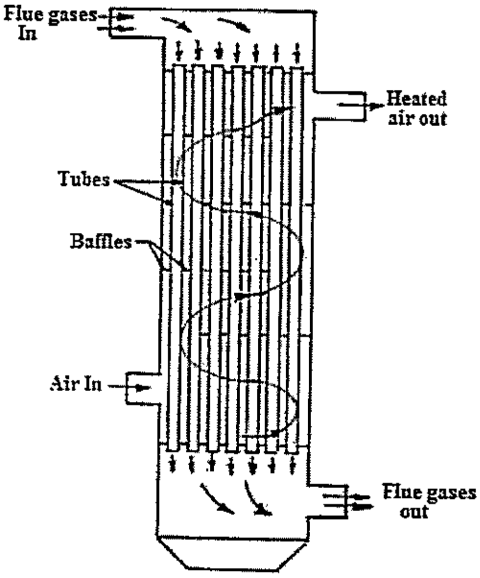


Fig: Air Preheater

i) Draught

It is an improved type of draught, and is a combination of induced and forced draught. It is Produced by running both induced and forced draught fans simultaneously.

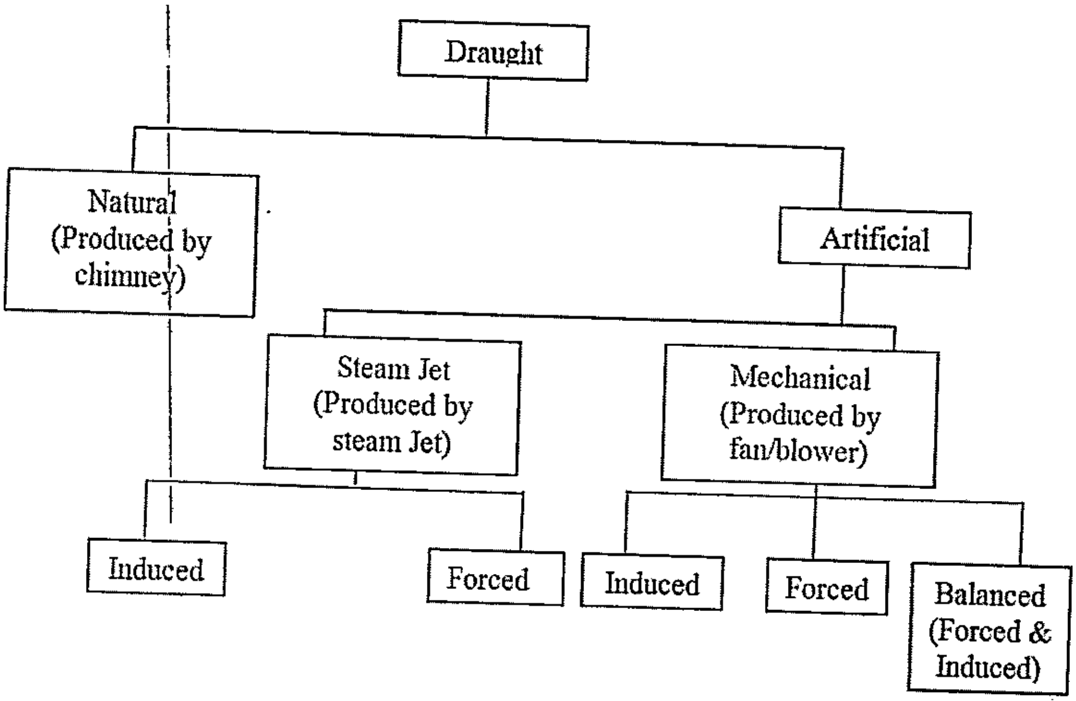
1. Natural draught. It is the draught produced by a chimney due to the difference of densities Between the hot gases inside the chimney and atmospheric air outside it.

2. Artificial draught. The artificial draught may be a mechanical draught or a steam jet draught.

The draught produced by a fan or blower is known as mechanical or fan draught

Whereas the draught Produced by a steam jet is called steam jet draught.

The artificial draught is provided, when natural Draught is not sufficient. It may be induced or forced.



The draught is one of the most essential systems of thermal power plant which supplies required quantity of air for combustion and removes the burnt products from the system

To move the air through the fuel bed and to produce a flow of hot gases through the boiler, economizer, preheater and chimney require a difference of pressure.

b ii) Advantages over natural draught:

It is better in control and more economical than natural draught.

The rate of combustion is high.

The air flow can be regulated according to the requirement.

It prevents the formation of smoke as complete combustion is possible

Limitations of Artificial Draught:-

The major disadvantage of the artificial draught is the high capital cost required and high running and maintenance costs

Importance: - For the proper and the optimized heat transfer from the flue gases to the boiler tubes draft holds a relatively high amount of significance.

The combustion rate of the flue gases and the amount of heat transfer to the boiler are both dependent on the movement and motion of the flue gases.

A boiler equipped with a combustion chamber which has a strong current of air (draft) through the fuel bed will increase the rate of combustion.

3 a i)

A nozzle is, normally, designed for maximum discharge by designing a certain throat pressure which produces this condition.

Let

p_1 = Initial pressure of steam in N/m²,

p_2 = Pressure of steam at throat in N/m²,

v_1 = Volume of 1 kg of steam at pressure (p_1) in m³,

v_2 = Volume of 1 kg of steam at pressure (p_2) in m³, and

A = Cross-sectional area of nozzle at throat, in m².

We have derived an equation in the previous article that the mass of steam discharged through nozzle,

$$m = A\sqrt{\frac{2n}{n-1}\times\frac{p_1}{v_1}\left[\left(\frac{p_2}{p_1}\right)^{\frac{2}{n}}-\left(\frac{p_2}{p_1}\right)^{\frac{n+1}{n}}\right]} \qquad \ldots (i)$$

There is only one value of the ratio p_2/p_1, which produces maximum discharge from the nozzle. This ratio p_2/p_1, is obtained by differentiating the right hand side of the equation. We see from this equation that except p_2/p_1, all other values are constant. Therefore, only that portion of the equation which contains p_2/p_1, is differentiated and equated to zero for maximum discharge.

$$\therefore \qquad \frac{d}{d\left(\frac{p_2}{p_1}\right)}\left[\left(\frac{p_2}{p_1}\right)^{\frac{2}{n}}-\left(\frac{p_2}{p_1}\right)^{\frac{n+1}{n}}\right]=0$$

or

$$\frac{2}{n}\left(\frac{p_2}{p_1}\right)^{\frac{2}{n}-1}-\frac{n+1}{n}\left(\frac{p_2}{p_1}\right)^{\frac{n+1}{n}-1}=0$$

$$\frac{2}{n}\left(\frac{p_2}{p_1}\right)^{\frac{2-n}{n}}=\frac{n+1}{n}\left(\frac{p_2}{p_1}\right)^{\frac{1}{n}}$$

$$\left(\frac{p_2}{p_1}\right)^{\frac{2-n}{n}-\frac{1}{n}}=\frac{n+1}{2}$$

$$\left(\frac{p_2}{p_1}\right)^{\frac{1-n}{n}}=\frac{n+1}{2}$$

$$\frac{p_2}{p_1}=\left(\frac{n+1}{2}\right)^{\frac{n}{1-n}}=\left(\frac{n+1}{2}\right)^{\frac{-n}{-(1-n)}}$$

$$=\left(\frac{2}{n+1}\right)^{\frac{n}{n-1}}$$

The ratio p2 /p1 is known as critical pressure ratio, and the pressure p2 at the throat's known as critical pressure.

ii)

Solution. Given : $p_1 = 12$ bar ; $T_1 = 220°C$; $p_3 = 1.2$ bar ; Power developed = 220 kW ; $m_s = 13.5$ kg/kWh ; $d_2 = 7$ mm

We know that for superheated steam, pressure of steam at throat,

$$p_2 = 0.546\, p_1 = 0.546 \times 12 = 6.552 \text{ bar}$$

The Mollier diagram for the expansion of steam through the nozzle is shown in Fig. 21.6.

From the Mollier diagram, we find that enthalpy of steam at entrance (*i.e.* at 12 bar and 220° C),

$$h_1 = 2860 \text{ kJ/kg}$$

Enthalpy of steam at throat (*i.e.* at pressure 6.552 bar),

$$h_2 = 2750 \text{ kJ/kg}$$

and dryness fraction of steam at throat,

$$x_2 = 0.992$$

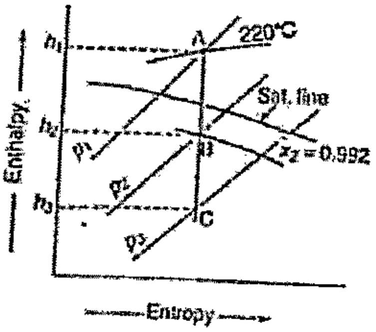


Fig. 21.6

From steam tables, we find that specific volume of dry saturated steam at throat (*i.e.* at pressure 6.552 bar),

$$v_{g2} = 0.29 \text{ m}^3\text{/kg}$$

We know that heat drop from entrance to throat,

$$h_{d2} = h_1 - h_2 = 2860 - 2750 = 110 \text{ kJ/kg}$$

∴ Velocity of steam at throat,

$$V_2 = 44.72\sqrt{h_{d2}} = 44.72\sqrt{110} = 470 \text{ m/s}$$

Area of nozzle at throat,

$$A_2 = \frac{\pi}{4}(d_2)^2 = \frac{\pi}{4} \times 7^2 = 38.5 \text{ mm}^2 = 38.5 \times 10^{-6} \text{ m}^2$$

∴ Mass flow rate per nozzle,

$$m = \frac{A_2 V_2}{v_2} = \frac{A_2 V_2}{x_2 v_{g2}} = \frac{38.5 \times 10^{-6} \times 470}{0.992 \times 0.29} = 0.063 \text{ kg/s}$$

We know that total mass flow rate

$$= 13.5 \times 220 = 2970 \text{ kg/h} = 0.825 \text{ kg/s}$$

∴ Number of nozzles $\dfrac{\text{Total mass flow rate}}{\text{Mass flow rate per nozzle}} = \dfrac{0.825}{0.063} = 13.1$ say 14 **Ans.**

B i) The maximum value of the discharge per second is obtained by

$$\therefore \text{Maximum discharge, } \dot{m}_{max} = A\sqrt{\frac{2n}{n-1}\times\frac{p_1}{v_1}\left[\left(\frac{2}{n+1}\right)^{\frac{2}{n-1}}-\left(\frac{2}{n+1}\right)^{\frac{n+1}{n-1}}\right]}$$

$$= A\sqrt{\frac{2n}{n-1}\times\frac{p_1}{v_1}\left(\frac{2}{n+1}\right)^{\frac{2}{n-1}}\left[1-\left(\frac{2}{n+1}\right)^{\frac{n+1}{n-1}-\frac{2}{n-1}}\right]}$$

$$= A\sqrt{\frac{2n}{n-1}\times\frac{p_1}{v_1}\left(\frac{2}{n+1}\right)^{\frac{2}{n-1}}\left[1-\left(\frac{2}{n+1}\right)\right]}$$

$$= A\sqrt{\frac{2n}{n-1}\times\frac{p_1}{v_1}\left(\frac{2}{n+1}\right)^{\frac{2}{n-1}}\left[\frac{n-1}{n+1}\right]}$$

$$= A\sqrt{\frac{2n}{n+1}\times\frac{p_1}{v_1}\left(\frac{2}{n+1}\right)^{\frac{2}{n-1}}}$$

ii)

Solution. Steam pressure at entry to the nozzle, $p_1 = 4$ bar, 200°C
Steam pressure at exit from the nozzle, $p_2 = 1$ bar
Initial velocity of steam, $C_1 = 60$ m/s
Nozzle efficiency, $\eta_{nozzle} = 92\%$
Exit velocity, C_2 :
Using steam tables only :

At $p_1 = 4$ bar, 200°C : $h_1 = 2860.5$ kJ/kg, $s_1 = 7.171$ kJ/kg

At $p_2 = 1$ bar : $h_{f_2} = 417.5$ kJ/kg, $h_{fg_2} = 2257.9$ kJ/kg,

$s_{f_2} = 1.3027$ kJ/kg K $s_{fg_2} = 6.0571$ kJ/kg K

(Refer Fig. 18.9.)

Now,

$$s_1 = s_2$$

$$= 7.171 = s_{f_2} + x_2\, s_{fg_2}$$

$$= 1.3027 + x_2 \times 6.0571$$

$$\therefore \quad x_2 = \frac{7.171 - 1.3027}{6.0571} = 0.969$$

∴ $h_2 = h_{f_2} + x_2 h_{fg_2} = 417.5 + 0.969 \times 2257.9 = 2605.4$ kJ/kg

Enthalpy drop (isentropic) $= h_1 - h_2 = 2860.5 - 2605.4 = 255.1$ kJ/kg

Using Mollier chart :

Refer Fig. 18.9.

$h_1 = 2860$ kJ/kg

$h_2 = 2605$ kJ/kg

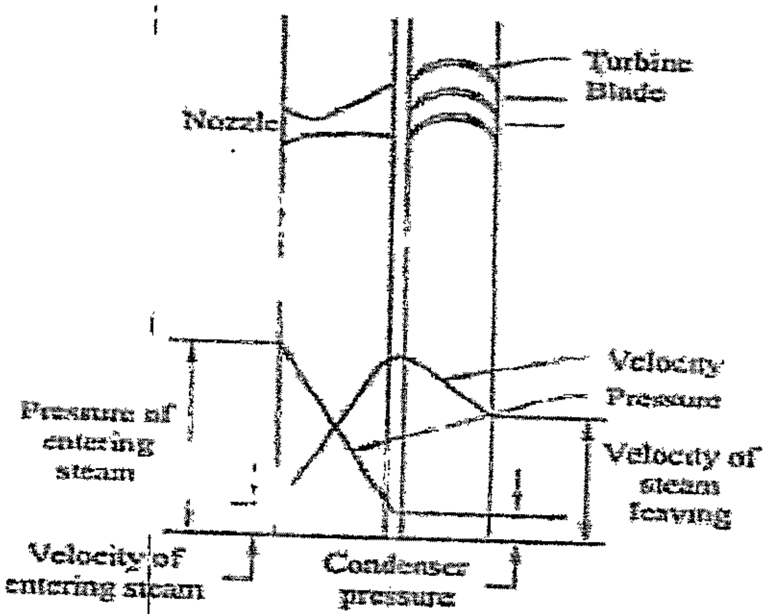
Enthalpy drop (isentropic) $= h_1 - h_2 = 2860 - 2605 = 255$ kJ/kg

Actual enthalpy drop $= \eta_{nozzle} \times (h_1 - h_2)$

$= 0.92 \times 255.1 = 234.69$ kJ/kg

4 a

In the impulse turbine, the steam is expanded within the nozzle and there is no any change in the steam pressure as it passes over the blades.



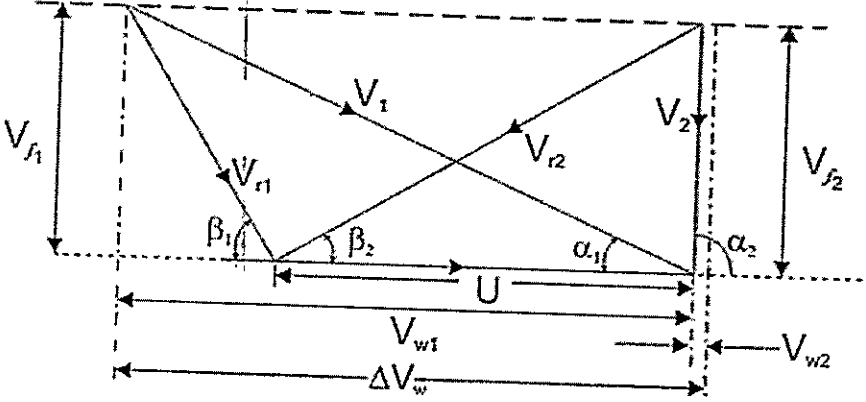


Diagram efficiency

We know that diagram efficiency,

$$\eta_b = \frac{2\,(V_w + V_{w1})\,V_b}{V^2}$$

b

In order to reduce the rotor speed, various methods are employed. All of these methods consist of a multiple system of rotors, in series, keyed to a common shaft and the steam pressure or the jet velocity is absorbed in stages as it flows over the rotor blades. This process is known as compounding. following three methods are commonly employed for reducing the rotor speed:

I. Velocity compounding

2. Pressure compounding, and

3. Pressure-velocity compounding.

1.

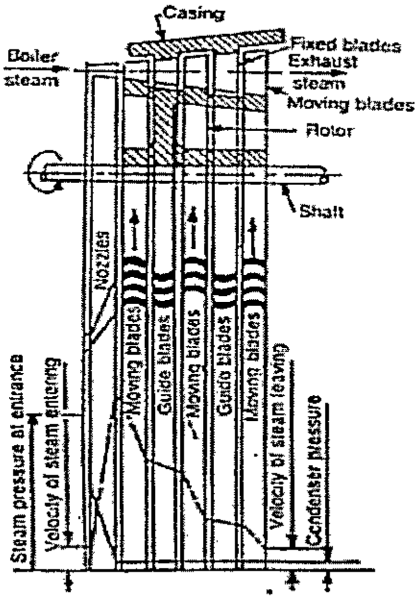
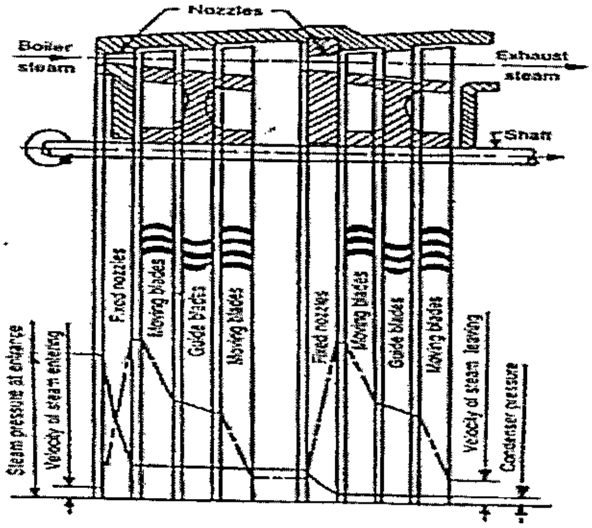


Fig. 24 17 Velocity compounding.

In velocity compounding of an impulse turbine, the expansion of steam takes place in a nozzle or a Set of nozzles from the boiler pressure to the condenser pressure. The impulse wheel carries two or three rows of moving blades

In a pressure compounding of an impulse turbine, the rings of the moving blades, each having a ring of fixed nozzles, are keyed to the turbine shaft in series, as shown in Fig. 24.18. The total pressure drop, of the steam, does not take place in the first nozzle ring, but is divided equally among all the nozzle rings



Ina pressure-velocity compounding of an impulse turbine, both the previous two methods are utilised. The total pressure drop of the steam is divided into stages, and velocity obtained in each stage is also compounded. A little consideration will show, that a pressure velocity compounded impulse turbine allows a bigger pressure drop, and hence less number of stages are required.

5 a i) Gas Turbine with Intercooling

The major portion of the power developed by the gas turbine is utilised by the compressor. It can be reduced by compressing the air in two stages with an intercooler between the two. This improves the efficiency of the gas turbine. The schematic arrangement of a closed cycle gas turbine with an intercooler is shown in Fig.

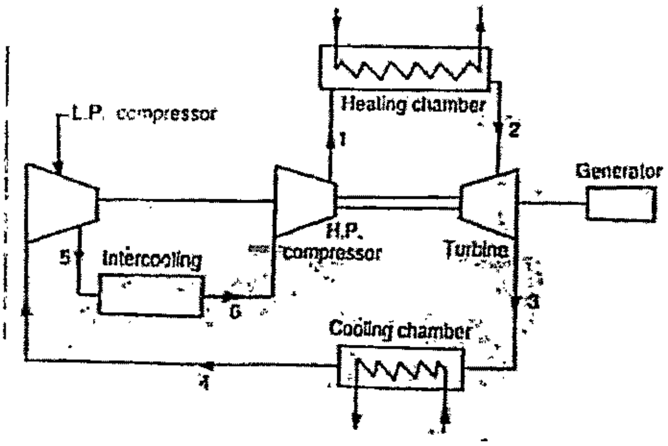


Fig. 32.4. Schematic arrangement of a closed cycle gas turbine with intercooler.

The process of intercooling the air in two stages of compression is shown on T-s diagram in Fig. The process 1-2 shows heating of I the air in heating chamber at Entropy constant pressure. The process 2-3 shows isentropic expansion of air in the turbine. The process 3-4 shows cooling of the air in the cooling chamber at constant pressure. The Fig. shows process 4-5 shows compression of air in the

L.P. compressor. The process 5-6 shows cooling of the air in the intercooler at constant pressure. Finally, the process 6-l shows compression of air in the H.P. compressor

∴ Work done by the compressor per kg of air,

$$W_T = c_p (T_2 - T_3)$$

and work done by the compressor per kg of air,

$$W_C = c_p [(T_1 - T_6) + (T_5 - T_4)]$$

Now the net work available,

$$W = W_T - W_C$$

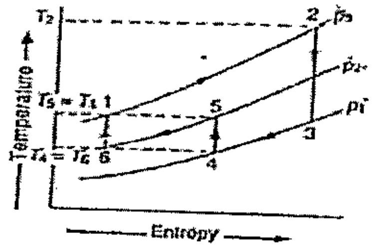


Fig. 32.5. T-s diagram for intercooling.

ii)

Let us first consider the Brayton cycle without the regenerator:

$$\frac{T_{02s}}{T_{01}} = \left(\frac{P_{02}}{P_{01}}\right)^{(\gamma-1)/\gamma} = \frac{T_{03}}{T_{04s}} = 6^{0.4/1.4} = 1.668$$

$$T_{02s} = 303 \times 1.669 = 505K$$

$$T_{04s} = \frac{1173}{1.668} = 705K$$

From the definition of isentropic efficiency of a compressor,

From the definition of isentropic efficiency of a compressor,

$$T_{02} - T_{01} = \frac{T_{02s} - T_{01}}{\eta_C} = \frac{505 - 303}{0.8} = 252K$$

For a turbine we have,

$$T_{03}-T_{04}=\eta_t(T_{03}-T_{04s})=0.8(1173-705)=375K$$

Therefore,

$$w_t=h_{03}-h_{04}=c_p(T_{03}-T_{04})=1.005\times 375=376.88\,\text{kJ/kg}$$

$$w_c=h_{02}-h_{01}=c_p(T_{02}-T_{01})=1.005\times 252=253.26\,\text{kJ/kg}$$

Now, $T_{02}=252+303=555K$

Hence, $Q_1=h_{03}-h_{02}=1.005\times(1173-555)$

$=621.09$ kJ/kg

$$\therefore \eta=\frac{w_t-w_c}{Q_1}=\frac{376.88-253.26}{621.09}=19.9\%$$

Let us now consider the regenerator :

$$T_{04}=T_{03}-375=1173-375=798K$$

$$\text{Regenerator effectiveness}=\frac{T_{06}-T_{02}}{T_{04}-T_{02}}=0.75$$

$$\therefore T_{06}-555=0.75(798-555)$$

$$or, T_{06}=737.3K$$

Now, $Q_1=h_{03}-h_{06}=c_p(T_{03}-T_{06})$

$=1.005(1173-737.3)=437.88$ kJ/kg

Since w_{net} remains the same,

$$\eta=\frac{w_{net}}{Q_1}=\frac{123.62}{437.9}=0.2837\ or\ 28.37\%$$

The percentage increase due to regeneration :

$$=\frac{0.2837\text{-}0.199}{0.199}=0.4256\ or\ 42.56\%$$

b

In solid propellant rocket motors the propellant to be burned is contained within the combustion chamber or case. The solid propellant charge is called the grain and it contains all the chemical elements for complete burning. Once ignited, it usually burns smoothly at a predetermined rate on all the exposed internal surfaces of the grain. Initial burning takes place at the internal surfaces of the cylinder perforation and the four slots. The internal cavity grows as propellant is burned and consumed. The resulting hot gas flows through the supersonic nozzle to impart thrust. Once ignited, the motor combustion proceeds in an orderly manner until essentially all the propellant has been consumed. There are no feed systems or valves

Liquid propellant rocket engines use liquid propellants that are fed under pressure from tanks into a thrust chamber.* A typical pressure-fed liquid propellant rocket engine system. The liquid bipropellant consists of a liquid oxidizer (e.g., liquid oxygen) and a liquid fuel (e.g., kerosene). A monopropellant is a single liquid that contains both oxidizing and fuel species; it decomposes into hot gas when properly catalyzed. A large turbopump-fed liquid propellant rocket engine. Gas pressure feed systems are used mostly on low thrust, low total energy propulsion systems, such as those used for attitude control of flying vehicles, often with more than one thrust chamber per engine. Pump-fed liquid rocket systems are used typically in applications with larger amounts of propellants and higher thrusts, such as in space launch vehicles.

Hybrid propellant rocket propulsion systems use both a liquid and a solid propellant. For example, if a liquid oxidizing agent is injected into a combustion chamber filled with solid carbonaceous fuel grain, the chemical reaction produces hot combustion gases.

APPLICATIONS OF ROCKET PROPULSION

1. Space Launch Vehicles
2. Spacecraft
3. Missiles and Other Applications

NARASARAOPETA
NEC ENGINEERING COLLEGE
(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

CO-POs & CO-PSOs ATTAINMENT

NARASARAOPETA ENGINEERING COLLEGE::NARASARAOPET
(AUTONOMOUS)
(R20) 2020 BATCH III B.TECH I SEMESTER FINAL INTERNAL MARKS - DEC- 2022

BRANCH - ME-A			HEAT POWER ENGINEERING (R20ME3102)								
SL.NO.	H.T.NO.	STUDENT NAME	A1	D1	Q1	CYCLE-1	A2	D2	Q2	CYCLE-2	TOTAL
1	20471A0301	ALAVALA ADITHYA VARA PRASAD	4	9	5	18	4	11	8	23	22
2	20471A0302	BATTULA RAJESH	A	10	3	13	3	14	8	25	23
3	20471A0303	BHIMAVARAPU HEMANTH KUMAR	A	A	A	0	3	11	5	19	16
4	20471A0304	BONAM JAYA PRAKASH	A	8	6	14	A	A	A	0	12
5	20471A0305	BOYAPATI PAVAN KUMAR	A	5	5	10	A	4	6	10	10
6	20471A0306	DADDANALA VEERANJIREDDY	5	7	5	17	5	14	8	27	25
7	20471A0307	DERANGILA PARDHU GANESH	5	9	5	19	4	11	9	24	23
8	20471A0308	DOPPALAPUDI S S NAGA RAVITEJA	4	12	5	21	5	15	10	30	29
9	20471A0309	EEDARA MOHON SAI	4	9	6	19	3	14	9	26	25
10	20471A0310	GANESH SAI PAVAN	5	6	7	18	A	11	10	21	21
11	20471A0311	GANGARAPU VENKATA REDDY	A	A	A	0	A	A	A	0	0
12	20471A0312	GERA KOTESWARA RAO	4	8	5	17	5	14	7	26	25
13	20471A0313	KARASALA PRASANTH	4	6	2	12	5	11	9	25	23
14	20471A0314	KARASANI PAVAN KUMAR REDDY	5	A	6	11	4	11	7	22	20
15	20471A0315	KATTA MAHESWAR	4	14	7	25	5	15	6	26	26
16	20471A0317	KESARI DHANUNJAYA REDDY	4	10	3	17	4	11	3	18	18
17	20471A0318	KOMARAGIRI SASIKUMAR	5	14	3	22	4	9	3	16	21
18	20471A0319	KOMERA SIVA NAGARAJU	A	A	A	0	2	9	A	11	9
19	20471A0320	KOTHA GOPI	5	15	5	25	5	15	6	26	26
20	20471A0321	KUNDURTHI NAVEEN	5	12	4	21	5	13	5	23	23
21	20471A0323	MADANU JOSEPH VINAY KUMAR	5	11	5	21	4	15	4	23	23
22	20471A0324	MADDUMALA RAMAKRISHNA	A	7	1	8	4	13	A	17	16
23	20471A0325	MAGANTI SASI PAVAN	5	A	A	5	5	15	6	26	22
24	20471A0326	MAKKENA SAMBASIVA RAO	A	12	5	17	5	14	9	28	26
25	20471A0327	MIRIYALA SASHANK	5	14	4	23	5	14	4	23	23
26	20471A0328	NALLA ABHIRAM CHOWDARY	5	8	4	17	A	A	A	0	14
27	20471A0329	NUTHAKKI RAKESH	A	9	3	12	2	14	6	22	20
28	20471A0330	ARAVAPALLI SAI SRINIVAS	5	11	3	19	5	A	8	13	18
29	20471A0331	PALETI JOHN HOSANNA	A	A	A	0	2	15	6	23	19
30	20471A0332	PERUMAALLA SRIKANTH	4	14	4	22	A	13	7	20	22
31	20471A0333	POLURI KRISHNA CHAITHANYA	4	14	6	24	5	14	9	28	28
32	20471A0334	PONNAGANTI CHANDU HARSHA VARDHAN	4	9	7	20	2	11	9	22	22
33	20471A0336	PATHAN MEERA VALI	4	A	5	9	A	A	A	0	8
34	20471A0337	POTTIMURTHI PURNA CHANDRA RAO	5	14	7	26	5	14	8	27	27
35	20471A0338	PRUDHVI DURGA BHARATH CHANDAN	A	10	3	13	A	12	8	20	19
36	20471A0339	RAMAVATHU BADDUNAIK	A	A	2	2	5	12	9	26	22
37	20471A0341	SHAIK APPAPURAM MAHABOOB SUBHANI	5	8	3	16	4	11	3	18	18
38	20471A0342	SHAIK ASIF	4	A	A	4	A	A	A	0	4

39	20471A0343	SHAIK GANGARAM ABDUL RAHAMAN	A	9	2	11	4	14	10	28	25
40	20471A0344	SHAIK GULLAPALLI NAGURVALI	A	9	3	12	A	10	10	20	19
41	20471A0345	SHAIK LAL AHAMAD BASHA	4	8	3	15	2	14	4	20	19
42	20471A0346	SHAIK MAHAMMAD FAREED	4	8	4	16	5	15	6	26	24
43	20471A0347	SHAIK MAHAMMAD YUNUS	4	A	A	4	3	A	A	3	4
44	20471A0348	SHAIK MANISHA	4	13	5	22	5	15	8	28	27
45	20471A0349	SHAIK PARVEZ	5	11	5	21	4	15	7	26	25
46	20471A0350	SHAIK SADHIK	4	10	6	20	4	12	6	22	22
47	20471A0351	SHAIK SALMAN	3	A	A	3	A	A	A	0	3
48	20471A0352	TIPPIREDDY AMARNATHREDDY	4	8	5	17	5	12	10	27	25
49	20471A0353	VADLAVALLI GANESH	A	6	4	10	4	14	2	20	18
50	20471A0354	VEERAGANDHAM VENKATA MANIKANTA	5	13	6	24	A	14	9	23	24
51	20471A0356	ADAKA GOPIRAJU	5	13	3	21	5	14	5	24	24

NAME OF THE STAFF MEMBER

SIGNATURE OF THE STAFF MEMBER

SIGNATURE OF THE HOD

NARASARAOPETA ENGINEERING COLLEGE::NARASARAOPET

(AUTONOMOUS)

(R20) 2020 BATCH III B.TECH I SEMESTER FINAL INTERNAL MARKS - DEC- 2022

BRANCH - ME-B			HEAT POWER ENGINEERING (R20ME3102)								
SL.NO.	H.T.NO.	STUDENT NAME	A1	D1	Q1	CYCLE-1	A2	D2	Q2	CYCLE-2	TOTAL
1	20471A0357	ATCHYUTHA PAVAN KUMAR	5	8	4	17	5	14	9	28	26
2	20471A0358	BALLE RAMANJANEYULU	4	11	5	20	5	15	8	28	27
3	20471A0359	BANDARU SAI GANESH	4	8	4	16	2	14	9	25	24
4	20471A0360	BERAM NARENDRA REDDY	3	6	3	12	A	13	9	22	20
5	20471A0361	CHEBROLU MANIKANTA SAI NITHIN	A	8	3	11	5	12	8	25	23
6	20471A0362	CHENNAMSETTY GOPI	5	11	4	20	3	15	8	26	25
7	20471A0363	GANGULA SUNNY	5	10	5	20	5	15	6	26	25
8	20471A0364	GANJI HANUMA KOTI GANESH	5	8	3	16	5	15	6	26	24
9	20471A0365	GANNNAVARAPU JAYA SRIKANTH	3	5	4	12	2	A	A	2	10
10	20471A0366	GUTTIKONDA AYYAPPA REDDY	5	12	1	18	4	10	10	24	23
11	20471A0367	MADDINENI AJAY	A	9	3	12	5	15	5	25	23
12	20471A0368	MANNEPALLI VEERA NARASIMHA	4	8	4	16	2	10	4	16	16
13	20471A0369	MARAGANI NAGA THIRUMALA RAO	A	10	4	14	3	10	7	20	19
14	20471A0370	PARELLA BALA GURAVAIAH	4	6	3	13	3	12	5	20	19
15	20471A0371	SETLAM RANENDRA VAMSHI	5	11	4	20	5	13	8	26	25
16	20471A0372	SHAIK GUTHIKONDA SALIM	5	11	4	20	5	15	8	28	27
17	20471A0373	SHAIK JAKIR	5	5	5	15	5	9	6	20	19
18	20471A0374	SHAIK MOHAMMAD TAHEER	5	8	5	18	2	A	A	2	15
19	20471A0375	THOTA SRIVAMSI NADH	5	6	3	14	A	10	8	18	18
20	20471A0376	YAKKANTI SAI KIRAN REDDY	5	8	3	16	A	6	9	15	16
21	21475A0301	PALLAPOTHU SAIKIRAN YADAV	5	15	7	27	5	15	8	28	28
22	21475A0302	SYED SARDAR VALI	5	13	5	23	5	15	10	30	29
23	21475A0303	DERANGULA GOPI KRISHNA	4	12	4	20	2	15	8	25	24
24	21475A0304	VADDANI RAKESH	A	A	A	0	A	9	6	15	12
25	21475A0305	SHAIK ADIL	5	10	5	20	4	14	10	28	27
26	21475A0306	JANAPAREDDI PRASAD	5	14	7	26	5	15	10	30	30
27	21475A0307	REPALLE YASHWANTH	A	10	4	14	A	14	8	22	21
28	21475A0308	RAMAVATHU PAVAN KUMAR NAIK	5	11	6	22	2	12	5	19	22
29	21475A0309	NELAVALLI VIKAS	4	12	5	21	2	15	7	24	24
30	21475A0310	DUDDU JOSEPH	A	12	6	18	5	13	9	27	26
31	21475A0311	MUNIKOLA SANTHOSH KUMAR	5	9	4	18	5	12	8	25	24
32	21475A0312	MORAPAKULA CHARAN TEJA	5	11	4	20	2	14	8	24	24
33	21475A0313	GODA SANDEEP	4	9	5	18	2	15	4	21	21
34	21475A0314	MOGILI PRAKASH	4	9	5	18	2	13	4	19	19
35	21475A0315	SHAIK MABU SUBHANI	5	11	5	21	2	A	A	2	18
36	21475A0316	DAGGUPATI VENKATA PRADEEP	5	12	6	23	5	14	8	27	27
37	21475A0317	NAGASURENDRA CHARI UPPALAPATI	5	12	7	24	5	14	9	28	28
38	21475A0318	NALLURI NAVEEN	5	12	5	22	3	15	10	28	27
39	21475A0319	ORCHU VENKATA RAVINDRA	5	12	5	22	A	14	9	23	23
40	21475A0320	NELLURI YASWANTH	5	14	5	24	5	15	10	30	29
41	21475A0321	PENUMALA PAVAN KUMAR	5	14	3	22	5	15	9	29	28

BRANCH - ME-B			HEAT POWER ENGINEERING (R20ME3102)								
SL.NO.	H.T.NO.	STUDENT NAME	A1	D1	Q1	CYCLE-1	A2	D2	Q2	CYCLE-2	TOTAL
42	21475A0322	BAANANA PRADEEP KUMAR	5	12	5	22	5	15	9	29	28
43	21475A0323	BOJANKI DEMUDU BABU	5	12	7	24	4	14	10	28	28
44	21475A0324	DATTI CHANDU	5	15	6	26	5	15	9	29	29
45	21475A0325	BORUGADDA NITHIN	4	14	5	23	A	9	6	15	22
46	21475A0326	VARIKUTI KARTHIK VENKATA RAM	A	13	7	20	5	14	8	27	26
47	21475A0327	GOLLA SUNDARA SAMRAJYA SUGNAN	4	12	6	22	2	15	8	25	25
48	21475A0328	CHATTA VENKATRAMAIAH	4	12	8	24	2	15	9	26	26
49	21475A0329	KSHATRIYA JITHENDRA SINGH	5	12	5	22	2	14	10	26	26
50	21475A0330	BOMMALI BALA SIVA YOGENDRA SAI NANDU	5	13	6	24	4	15	9	28	28
51	21475A0331	REVALLA SAI	5	13	5	23	5	14	10	29	28
52	21475A0332	BANDI SRINIVAS	5	12	5	22	5	14	10	29	28
53	21475A0333	GURRAM SIVA GANESH	5	15	3	23	1	15	9	25	25
54	21475A0334	EMANI LEELA SHANKAR	4	15	5	24	5	14	10	29	28
55	21475A0335	KUPPALA SRINU	4	13	3	20	2	14	3	19	20

NAME [illegible] THE STAFF MEMBER

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SIGNATURE OF THE HOD

Narasaraopeta Engineering College (Autonomous)
Department of Mechanical Engineering

Subject Name: HEAT POWER ENGINEERING
Faculty Name: P.Srinivasarao/J. Pavanu Sai

TERMINOLOGY

1. **Back work**: Work input to feed pump
2. **Back work ratio**: Ratio of pump work input to the work developed by the turbine
3. **Work ratio**: Ratio of the network output to the work developed by the turbine
4. **Steam rate:** Amount of steam required to produce 1KWh(3600kj) of power
5. **Heat Rate**: Amount of heat required by a power plant to produce 1kwh of power
6. **Reheating**: Heating of wet steam after its expansion in one stage for next stage
7. **Reheat factor**: Ratio of cumulative isentropic enthalpy drop to isentropic enthalpy from initial pressure to final pressure
8. **Fuel:** A combustible substance which burns in the presence of oxygen and releases heat energy
9. **Combustion**: An exothermic reaction with oxygen , in which heat energy is released
10. **Reactants:** The components of fuel that exist before the combustion reaction
11. **Products**: The components that exist after combustion reaction
12. **Ignition temperature:** Lowest temperature at which a fuel starts burning
13. **Air fuel ratio**: Ratio of mass of the air to the mass of the fuel
14. **Stoichiometric air:** Minimum amount of air for the complete combustion of fuel elements
15. **Boiler draught**: A small pressure difference between air outside the boiler and gases with in the furnace or chimney
16. **Natural draught**: The draught obtained by use of a chimney
17. **Artificial draught:** The draught produced artificially by a fan or a blower
18. **Steam jet draught:** Draught produced by steam jet
19. **Evaporation rate:** Mass of steam generated per hour
20. **Equivalent evaporation**: Amount of steam generated from and at 100^0 C
21. **Critical pressure**: Pressure of steam at the throat
22. **Critical velocity**: velocity of steam at throat corresponds to maximum discharge condition
23. **Super saturation**: Existence of fluid in super-heated state in wet region
24. **Meta stable state:** Super saturation state of a fluid
25. **Degree of super cooling**: difference between saturation temperature and temperature of super saturated vapor.
26. **Turbine:** A Rota dynamic machine
27. **Impulse turbine**: Steam expands in nozzles only and blades spin due to change in momentum of steam

28. **Reaction turbine**: steam expands in fixed and moving blades thus reactive force acts on blades to cause them to rotate
29. **Stage:** A set of fixed blades and moving blades
30. **Stage efficiency** : Ratio of work done on blade to energy supplied per stage
31. **Blade speed ratio**: Ratio of blade velocity to absolute steam velocity
32. **Condenser:** A device in which vapor condenses to liquid at saturation temperature and constant pressure.
33. **Jet condensers**: A device in which the exhaust steam and cooling water come in direct contact and mix-up together
34. **Surface condenser:** Exhaust steam and cooling water interact indirectly for heat transfer
35. **Condenser efficiency:** ratio of actual temperature rise to the maximum possible temperature rise of cooling water
36. **Vacuum** : The pressure below the atmospheric pressure
37. **Vacuum efficiency**: Ratio of the actual vacuum to the maximum possible steam
38. **Gas turbine:** An IC rotary engine using combustion gases as working fluid
39. **Regenerator:** A counter flow heat exchanger. Which transfers heat from hot gases air
40. **Regeneration**: Process of heat transfer from hot gases to air
41. **Reheating**: Heating of gases after one stage expansion in turbine by burning of additional fuel
42. **Intercooling** : Process of cooling of compressed air between stages of compression
43. **Back work:** The work input to compressor is called back work
44. **Jet propulsion**: Propelling of a vehicle due to thrust produced by fast moving gases at rear end
45. **Ramjet engine**: An engine which uses engines forward motion to compress the incoming air
46. **Pulse jest engine**: An IC jet engine in which combustion occurs in pulses.
47. **Turbo jet engine**: an engine in which thrust is produced due to acceleration of hot combustion gases through the exhausts nozzle
48. **Turbo prop engine:** A turbo jet engine in which a propeller is coupled to the turbo jet.engine.

Concepts:

1. Steam is most commonly used in vapor power cycle. It is alternately vaporized and condensed during cyclic process.
2. Thermal efficiency is the ratio of network output to heat input
3. Work ratio is the Ratio of network output to gross output.
4. In spite of high thermal efficiency, the Carnot cycle is not a practical cycle because isothermal heat addition in super-heated region is most difficult to achieve. Rankine cycle is the practical cycle in which the condensation process is complete i.e., exhaust steam is completely converted to saturated water.
5. Efficiency of Rankine cycle =$[(h_1-h_2)-W_p] / (h_1-h_{f4})$

   Neglecting pump work, $\eta = [h_1-h_2] /[h_1-h_{f3}]$, $h_{f4}=h_{f3}$
6. The efficiency of Rankine cycle may be improved by
   - i. Superheating the steam
   - ii. Reheating the steam
   - iii. Regenerating feed heating
7. Fuel is a substance that can be burned to release heat energy.
8. Combustion is chemical reaction in which a fuel is oxidized and large quantity of heat energy is released.
9. The components that exist before reaction are called reactants and the components that exist after the reaction are called products.
10. The ratio of the mass of air to the mass of fuel during a combustion process is called air - fuel ratio.
11. The heat of reaction is defined as $q_r = h_p - h_r$

    Where h_p = enthalpy of the products and h_r =enthalpy of the reactants
12. The calorific value is defined as the amount of heat released when a unit quantity of fuel is burnt completely in a study flow process.
13. The temperature of products will reach maximum and is called adiabatic flame temperature.
14. Boiler is closed steel shell in which steam is generated.
15. In fire tube boiler, the hot gases pass through the tubes surrounded by water.
16. In water tube boiler water is made to pass through the tubes over which the hot gases flow.
17. Devices fitted on boiler for safety and proper operation is called mountings.
18. Devices installed with the boiler for proper operation and to increase the efficiency are called accessories.
19. Equivalent evaporation ,

    $m_e = m_s[(h_2-hf_1) / h_{fg\ 100}]$

    the term $[(h_2-hf_1) / h_{fg\ 100}]$ is called factor of evaporation
20. Thermal efficiency of boiler $\eta_b = [m_s(h_2-h_{f1}) / m_f \text{ x } CV]$

21. Boiler HP = $[m_s(h_2-h_{f1}) / 2256.9 \text{ x } 15.653]$

    where h_2 = enthalpy of steam produced, Kj/ Kg

h_{fl} = enthalpy of feed water, Kj/Kg
m_s = mass of steam generated Kg/hr
m_f= mass of fuel burnt, Kj/hr
CV = calorific value of fuel, Kj/Kg

22. Draught: the pressure difference causing the air or gas flow is called draught.
23. Draught in terms of mm of water

$$h = 353H [1/T_a - (m+ 1) / mT_g] \text{ mm of water}$$

24. Draught in terms of column of hot gases

$$H' = H [(m/m+ 1) T_g/T_a - 1] \text{ meters}$$

25. The velocity of flue gases through chimney

$$V = \sqrt{2gH'} = 4.42\sqrt{H'} \text{ m/ s}$$

Where m = mass of air supplied / kg of fuel
T_a= absolute temperature of air outside the chimney
T_g= absolute temperature of flue gases in the chimney
H = height of chimney in meter
H' = height of hot gases in meters which would produce the draught.

26. Steam nozzle

Passage of varying cross section through which steam expands and enthalpy drop is converted into kinetic energy.

- The velocity at exit, $V = 44.72\sqrt{K(h1 - h2)}$ m/s
  Where K = friction factor
- For maximum discharge, $(p_2/p_1) = (2/ n+1)^{n/,n-1}$
  Where p_2 = throat pressure
  n= index of expansion
- For maximum discharge, m= AV/v Kg/s
  Where A = area of cross section, m^2
  V = velocity, m/s
  v = specific volume, m^3/Kg

27. Steam turbine : It is a prime mover in which heat energy of steam is transfer to kinetic energy and later it is utilized of rotation of the turbine shaft
28. Classification : According to the action of steam the turbines may be classified as
    i. Impulse turbine ii. Reaction turbine iii. Impulse-reaction turbine.
29. Difference between impulse and reaction turbines: In impulse turbine expansion of steam takes place only in the nozzle and pressure remains constant over the blades, where as in reaction turbine expansion of steam takes place in fixed end moving blades i.e., pressure drops continuously throughout the stages.
30. Compounding: Method to reduce the turbine speed to a practical limit is called compounding.
31. Methods of compounding:

    i. Velocity compounding ii. Pressure compounding iii. Velocity pressure compounding

    In reaction turbine the speed is reduced by incorporating the number of stages.

32. Governing; It is the process of maintain the constant speed irrespective of variation of load on the turbine.

33. Methods of governing:

i. Throttle governing ii. Nozzle control governing iii. By pass gioverning
iv. Combined governing

34. Performance of steam turbines :

Tangential force = m($v_{w1} \pm v_{w2}$) N
Power developed = m($v_{w1} \pm v_{w2}$) u W
Axial thrust = m($v_{f1} - v_{f2}$) N

35. Efficiencies:

Blade (diagram) η = ($v_{w1} \pm v_{w2}$) $2u / v_1^2$

Nozzle efficiency = $\frac{V_1^2}{2\Delta H}$

Stage efficiency = ($v_{w1} \pm v_{w2}$) u / ΔH = blade efficiency x nozzle efficiency

36. Degree of reaction : It is the ratio of enthalpy drop in moving blades to enthalpy drop in stage

= $(v_{r2}^2 - v_{r1}^2)/2u(v_{w1} \pm v_{w2})$

37. Condenser: A device in which steam is condensed to water at a pressure less than atmosphere.

38. Functions of condenser:

i. To decrease the exhaust pressure below the atmosphere
ii. To provide hot feed water to the boiler

39. Types of condensers

i. Jet condensers: cooling water is in direct contact with exhaust steam
ii. Surface condensers: cooling water and exhaust steam don't mix together

40. Condenser efficiency = (t_2-t_1)/ (t_g-t_1)

Where t_1 = inlet temperature of water
t_2=outlet temperature of water
t_g= saturation temperature at condenser pressure

41. Vacuum efficiency = p_{bar} –p/p_{bar}-p_s

Where p = absolute pressure in the condensate temperature
p_s = partial pressure of steam at condensate temperature
p_{bar} = atmospheric pressure recorded by barometer

42. Cooling water : heat gained by water = heat lost by exhaust steam

m.c (t_2-t_1) = m.s [xh_{fg}+(h_f-h_{f1})]
where h_f= enthalpy of water at condenser pressure
h_{f1} = enthyalpy of condensate
x = dryness fraction of steam
h_{fg} = latent heat of exhaust steam
(t_2-t_1) = rise in temperature of cooling water

43. Gas turbine is a rotary type of IC engine. It has the following components
    i. Air compressor ii. Combustion chamber iii. Turbine

44. Classification :
    i. Depending on the path of working fluid
        a. Open cycle gas turbine
        b. Closed cycle gas turbine
        c. Semi-closed cycle gas turbine
    ii. Depending on the basis of combustion process
        a. Constant pressure gas turbine
        b. Constant volume gas turbine

45. Efficiency of ideal gas turbine cycle, $\eta = 1- 1/ r_p^{(\gamma-1)/\gamma}$
    Where r_p = pressure ratio
    γ = index of compression

46. Condition for maximum work, $W_p = (T_3/T_1)^{\gamma/2(\gamma-1)}$
    Where T_1= minimum temperature
    T_3 = maximum temperature

47. Methods to improve the efficiency of gas turbine
    i. Multi stage compression with inter cool
    ii. Reheating
    iii. Regenerating

48. The jet propulsion is based on newton's laws of motion

49. Based on operation jet propulsion engines are classified as Jet propulsion engine
    i. Air breath engine(jet engine)
    ii. Non –air breath engine (rocket engine)

50. Jet engines are further classified into
    i. Study combustion system engines
        a. Turbo jet engine
        b. Turbo prop engine
        c. Ram jet engine
    ii. Intermittent combustion system(pulse jest engine)

51. The atmospheric jet engine obtained the required oxygen from the atmosphere where as rocket engines carrying their own oxidiser for combustion.

52. Types of rockets
    i. Solid propellant rockets
    ii. Liquid propellant rockets

53. The following methods are used for thrust augmentation
    i. Reheat or after burning
    ii. Water-methanol injection
    iii. Bleed - burn

NARASARAOPET ENGINEERING COLLEGE: NARASARAOPET
DEPARTMENT OF MECHANICAL ENGINEERING
III B. TECH II-SEMESTER II-MID EXAMINATION

SUBJECT: Heat Power Engineering	
DURATION:90 min	DATE:22/12/2020
	MAX MARKS: 30

Answer all questions

Q.no	Questions	CO	Knowledge Level
1.	a) Draw the layout of Rankine cycle with reheating [5M] b) A Steam turbine receives steam at a pressure of 20 bar and superheated to 88.6^{0} with exhaust pressure of 0. 07 bar and expansion of steam takes place isentropically. using the steam table calculate the following(i) heat supplied in the boiler (ii) heat rejected in the condenser(iii) network done (iv) thermal efficiency [5M]	1	Understanding (K2)
2.	a) What do you understand by boiler draught [5M] b) Write the detailed classification of boilers, explain construction and working of Babcock and Willcox boiler. [5M]	2	Understanding (K2)
3.	a) What is steam nozzle? Derive expression for velocity of steam through the nozzle [5M] b) Dry saturated steam at 10 bar (abs) is expanded in a steam nozzle 0. 4 bar (abs). The throat area is 7 cm^2, while the inlet velocity is negligible. Calculate, (i) the mass flow rate of steam, and(ii) the exit area. Assuming isentropic flow. Take index of expansion to be n=1.135, for dry saturated steam. [5M]	3	Applying (K3)

NARASARAOPET ENGINEERING COLLEGE: NARASARAOPET
DEPARTMENT OF MECHANICAL ENGINEERING
III B. TECH II-SEMESTER II-MID EXAMINATION

SUBJECT: Heat Power Engineering
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NARASARAOPET ENGINEERING COLLEGE: NARASARAOPET
DEPARTMENT OF MECHANICAL ENGINEERING
III B. TECH I-SEMESTER II-MID EXAMINATION

SUBJECT: Heat Power Engineering	
DURATION:90 min	DATE:22/12/2020
	MAX MARKS: 30

Answer all questions

Q.no	**Questions**	**CO**	**Knowledge Level**
1.	**a)** Illustrate the principle of Reaction turbine [4M] **b)** In a simple impulse turbine, the steam enters the wheel through a nozzle with a velocity of 500 m/s and at an angle of 20° to the direction of motion of the blade. The blade speed is 200 m/s and the exit angle of the moving blade is 25°. Find the inlet angle of the moving blade, exit velocity of steam and its direction and work done per kg steam. [6M]	4	Understanding (K2)
2.	a) Explain the working of a steam condenser in steam power plant. [4M] b) A Surface condenser is designed to handle 10000 kg of steam per hour, the steam enters at 0.08 bar and 0.9 dry and condensate leaves at the corresponding temperature, the pressure is constant throughout the condenser, Estimate the cooling water flow per hour, if the cooling water temperature is limited to 10°C [6M]	5	Understanding (K2)
3.	**a)** Classify the different types of gas turbines and explain the gas turbine with reheating or gas turbine with intercooler. [4M] **b)** Dry saturated steam at 10 bar (abs) is expanded in a steam nozzle 0. 4 bar (abs). The throat area is 7 cm², while the inlet velocity is negligible. Calculate, (i) the mass flow rate of steam, and(ii) the exit area. Assuming isentropic flow. Take index of expansion to be n=1.135, for dry saturated steam. [5M]	6	Applying (K3)

NARASARAOPET ENGINEERING COLLEGE: NARASARAOPET
DEPARTMENT OF MECHANICAL ENGINEERING
III B. TECH II-SEMESTER II-MID EXAMINATION

SUBJECT: Heat Power Engineering	
DURATION:90 min	DATE:22/12/2020
	MAX MARKS: 30

Answer all questions

Q.no	**Questions**	**CO**	**Knowledge Level**
1.	**a)** Draw the layout of Rankine cycle with reheating [5M] **b)** A Steam turbine receives steam at a pressure of 20 bar and superheated to 88.6° with exhaust pressure of 0. 07 bar and expansion of steam takes place isentropically. using the steam table calculate the following(i) heat supplied in the boiler (ii) heat rejected in the condenser(iii) network done (iv) thermal efficiency [5M]	1	Understanding (K2)
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Narasaraopeta Engineering College (Autonomous)

Kotappakonda Road, Yellamanda (P.O), Narasaraopet- 522601, Guntur District, AP.

Subject Code: R16ME3102

III B.Tech I Semester Regular Examinations, Nov – 2018

HEAT POWER ENGINEERING

(ME)

Time: 3 hours **Max Marks: 60**

Question Paper Consists of **Part-A** and **Part-B.**

Answering the question in **Part-A** is Compulsory & Four Questions should be answered from Part-B

All questions carry equal marks of 12.

PART-A

1. (a) What are the methods to improve performance of Rankine cycle?

(b) Enumerate the differences between Natural and artificial draught.

(c) What is critical pressure ration in Nozzles?

(d) Explain principle of Reaction turbine

(e) What are the functions of steam condensers in steam power plant?

(f) What are different operating variables affect the thermal efficiency of gas turbine power plant?

[2+2+2+2+2+2]

PART-B

2. (a) What are the methods to improve performance of Rankine cycle? Explain reheating in detail.

(b) A steam turbine consumes 9 kg/kW-hr when steam is supplied at a pressure of 10 bar and at 400^0 C. The exhaust takes place at 0.1bar. Compare the efficiency of the engine with the Rankine efficiency.

[4M+8M]

3. (a) Write detailed classification of boilers, Explain Construction and Working of Cochran boiler.

(b) What are Boiler Accessories and Mountings Explain with neat figures? [8M+4M]

4. (a) Derive the equation for mass discharge through a nozzle.

(b) Steam having pressure of 10.5 bar and 0.95 dryness is expanded through a convergent divergent nozzle and the pressure of steam leaving the nozzle is 0.85 bar. Find the velocity at the throat for maximum discharge conditions. Index of expansion may be assumed as 1.135 bar. Calculate mass rate of flow of steam through the nozzle.

[4M+8M]

5. In an impulse turbine, mean diameter of blades is 1.05m and the speed is 3000 rpm. The nozzle angle is 18^0, the ratio of blade speed to steam speed is 0.42 and blade velocity coefficient is 0.85. The outlet blade angle is 3^0 less than that of the inlet blade angle. Steam flow rate is 20kg/sec. Obtain: i) Tangential thrust on blades ii) Axial thrust on blades iii) Resultant thrust iv) Power developed v) Blade efficiency

[12M]

6. (a) Classify the condensers and explain anyone surface condenser with neat sketch.

(b) A surface condenser is designed to handle 10000 kg of steam per hour. The steam enters at 0.08 bar abs, and 0.9dryness and the condensate leaves at the corresponding saturation temperature. The pressure is constant throughout the condenser, Estimate the cooling water flow per hour, if the cooling water temperature rise is limited to 10 °C **[4M+8M]**

7. A gas turbine unit receives the air at100KPa and 300K, and compresses it adiabatically to 620KPa with efficiency of the compressor 88% . The fuel has heating value of 44,180KJ/kg and the fuel/air ratio is 0.017kg fuel/kg air. The turbine efficiency is 90%. Calculate the compressor work, turbine work and thermal efficiency. **[12M]**

***

Department of Mechanical Engineering

Vision and Mission of the Department

Vision:

To strive for making competent **mechanical engineering Professionals** to cater the real time needs of Industry and **Research** Organizations of high repute with **entrepreneurial skills and ethical values.**

Mission:

Mission 1: To train the students with **state of art infrastructure** to make them industry ready professionals and to promote them for higher studies and **research.**

Mission 2: To employ committed **faculty** for developing competent mechanical engineering graduates to deal with **complex** problems.

Mission 3: To support the students in developing professionalism and make them **socially** committed mechanical engineers with morals and **ethical values.**

Program Specific Objectives (PSOs)

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

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

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

Program Educational Objectives (PEOs)

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

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

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

Program Outcomes

Engineering Graduates will have

PO1: Ability to use basic knowledge in mathematics, science and engineering and apply them to solve problems specific to mechanical engineering.

PO2: Ability to design and conduct experiments, interprets and analyzes data, and reports the results.

PO3: Ability to design a system to meet desired needs within environmental, economic, political, ethical, health, safety, manufacturability, management knowledge and techniques to estimate time and resources to complete a project (Practical engineering analysis skills).

PO4: Ability to identify, formulate and solve mechanical engineering problems of a complex nature.

PO5: Familiarity in applying software methods and modern computer tools to analyze mechanical engineering problems.

PO6: An open mind and have an understanding of the impact of engineering on society and can create awareness of contemporary issues.

PO7: Ability to understand the impact of the profession engineering solutions in social and environmental contexts and demonstrate the knowledge of and need for sustainable development.

PO8: An understanding of their professional and ethical responsibilities, and use technology for the benefit of mankind.

PO9: An ability of demonstration to function as a coherent unit in multidisciplinary design teams through a collaborative research.

PO10: An ability to communicate effectively in both verbal and written forms.

PO11: An ability to design a system to meet desired needs with economic, management knowledge and techniques to estimate time and resources to complete a project.

PO12: An ability of self-education and can clearly understand the need of continuous and life-long learning.

NARASARAOPET ENGINEERING COLLEGE (AUTONOMOUS): NARASARAOPET

DEPARTMENT OF MECHANICAL ENGINEERING

III B.TECH I - SEMESTER ASSIGNMENT TEST – II, DEC - 2020

SUBJECT: HEAT POWER ENGINEERING	**DATE:** 22-12-2020
DURATION: 30 MIN	**MAX MARKS:** 10

Q. No	Questions	Course Outcome (CO)	Knowledge Level as Per Bloom's Taxonomy	Marks
1	Write the detailed classification of boilers and explain Cochran boiler with help of neat sketch.	2	Remembering (K1)	10
2	A.Write the difference between (i) Fire tube boiler and water tube boiler (ii) Low pressure boilers and high pressure boilers	2	Understanding (K2)	5
(a)	B. Draw the neat diagram backcombed and Wilcox boiler and indicate the parts.			5
3	What are boiler mountings and explain the working of different safety valves used in boilers.	2	Understanding (K2)	10
4	What are boiler accessories and explain the working of the economizer and super heater with help of diagrams.	2	Understanding (K2)	10
5	A.Define boiler draught and write down the classification of draught	2	Understanding & Applying (K2)	5
	B.Derive an expression for pressure difference created by Chimney in terms its height.	2	Understanding (K2)	5

1	Write the detailed classification of boilers and explain Cochran boiler with help of neat sketch.	2	Remembering (K1)	10
2 (b)	A.Write the difference between (i) Fire tube boiler and water tube boiler (ii) Low pressure boilers and high pressure boilers B. Draw the neat diagram backcombed and Wilcox boiler and indicate the parts.	2	Understanding (K2)	5 5
3	What are boiler mountings and explain the working of different safety valves used in boilers.	2	Understanding (K2)	10
4	What are boiler accessories and explain the working of the economizer and super heater with help of diagrams.	2	Understanding (K2)	10
5	A.Define boiler draught and write down the classification of draught B.Derive an expression for pressure difference created by Chimney in terms its height.	2	Understanding & Applying (K2) Understanding (K2)	5 5

III B.TECH-I-SEMESTER	L	T	P	INTERNAL MARKS	EXTERNAL MARKS	TOTAL MARKS	CREDITS
	3	1	-	40	60	100	3

HEAT POWER ENGINEERING
(Use of steam tables and Mollier chart is allowed)

COURSE OUTCOMES:

CO1: Interpret the steam power plant cycles
CO2: Demonstrate the basics of combustion
CO3: Identify different types of nozzles used in steam turbines
CO4: Classify different turbines based on utility and applications
CO5: List different types of steam condensers
CO6: Report different features of gas turbines and jet engines

UNIT – I:

RANKINE CYCLE: Schematic layout, thermodynamic analysis, methods to improve cycle performance, regeneration & reheating.

COMBUSTION: Fuels and combustion, concepts of heat reaction, adiabatic flame temperature, flue gas analysis.

UNIT - II:

BOILERS: Classification, working principles of L.P & H.P boilers, mountings and accessories, working principles, boiler horsepower, equivalent evaporation, efficiency.

DRAUGHT: Classification, Natural and Artificial draught, induced and forced draught, height of chimney for given draught and discharge, condition for maximum discharge, efficiency of chimney.

UNIT – III:

STEAM NOZZLES: Function of a nozzle, applications, types, flow through nozzles, thermodynamic analysis, assumptions, velocity of fluid at nozzle exit, Ideal and actual expansion in a nozzle, velocity coefficient, condition for maximum discharge, critical pressure ratio, nozzle design, Super saturated flow, its effects, degree of super saturation and degree of under cooling, Wilson line.

UNIT - IV:

STEAM TURBINES: Construction & working of steam turbines, Impulse & reaction principles, inlet & outlet velocity diagrams. Work output & efficiencies. Pressure & velocity compounding, regenerative feed water heating, reheat cycles, reheat factor, governing of turbine, back pressure & pass out turbine.

UNIT - V:

STEAM INSTRUMENTATION AND CONTROLS: Steam flow measurement, water and steam pressure measurements, superheated steam temperature control, steam pressure control, smoke detectors, and pollution monitoring instruments.

STEAM CONDENSERS: Types, cooling water requirement, air leakage and air pump capacity, vacuum and condenser efficiencies, steam ejectors, spray pond, cooling tower.

UNIT – VI:

GAS TURBINES: Simple gas turbine plant, ideal cycle, essential components, parameters of performance, actual cycle, regeneration, inter-cooling and reheating, closed and semi-closed cycles, merits and demerits and types of combustion chambers.

JET PROPULSION: Working principle, thrust power, propulsive force and efficiency.