Shirpur Education Society's
R. C. PATEL INSTITUTE OF TECHNOLOGY, SHIRPUR
An Autonomous Institute
(Affiliated to Dr. Babasaheb Ambedkar Technological University, Lonere)
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(स्वायत्त महाविद्यालय)

Programme: B.Tech in Mechanical Engineering

Year: II/Semester III (Exam Year: 2024-2025)

Subject: Applied Thermodynamics

Synoptic

Date: 09 Dec 2024

Time: 09:00 am - 11:00 am (02:00 Hrs.)

Max Marks: 60

FINAL EXAMINATION(2024-2025)

Instructions:

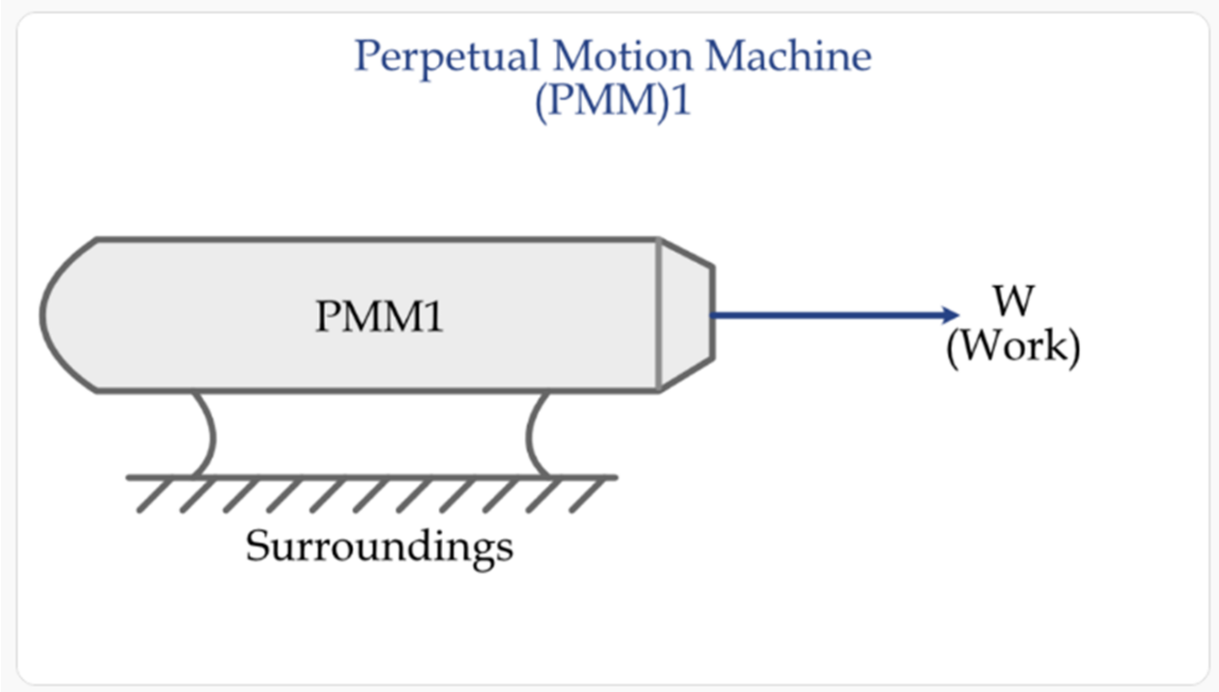
1. This Synoptic paper contains 10 pages
2. All Questions are Compulsory.
3. Answer to each new question to be started on a fresh page.
4. Figure in right hand side indicates full marks.
5. Use of steam table and Mollier diagram is permitted.

1. **15**

a. Answer: This type of machine produces work without any energy input, and does not obey the first law of thermodynamics. **5**

A perpetual motion machine of the first kind refers to a hypothetical machine that can operate indefinitely without an external energy source, essentially creating energy from nothing. This idea violates the First Law of Thermodynamics, also known as the law of conservation of energy, which states that energy cannot be created or destroyed, only transformed from one form to another.

In other words, for a perpetual motion machine of the first kind, the machine would need to produce more energy than it consumes, or operate without losing energy due to friction, heat, or other forms of energy dissipation. However, in reality, all machines encounter some form of energy loss, making it impossible to create a machine that runs forever without input.



Perpetual Motion Machine (PMM)1

b. Dry bulb temperature (tDB):Dry bulb temperature of air is the temperature recorded by ordinary thermometer and it is not affected by the moisture present in air. Wet bulb temperature (tws):Wet bulb temperature is the temperature recorded by thermometer when its bulb is covered with wet cloth (known as wick) and is exposed to air is known as wet bulb temperature. Dry air is the mixture of nitrogen and oxygen neglecting the water vapour and other gases. The volumetric composition of dry air is 77% nitrogen and 23% oxygen. Dry air does not contain any moisture. **5**

c. . **5**

1. x = 0.872 **5**

------------- OR -------------

2. Steam, the gaseous phase of water, is classified into three types based on its moisture content and temperature: wet steam, dry steam, and superheated steam. Wet steam is a mixture of water vapor and liquid water droplets. It contains moisture, which means it is not fully vaporized. Wet steam typically has a quality (or dryness fraction) between 0 and 1, where the quality represents the fraction of the steam mass that is vapor. Dry steam is steam that contains no water droplets and is completely vaporized. It has a dryness fraction of 1, meaning 100% of the steam is in the gaseous phase at the saturation temperature. Dry steam is often referred to as saturated steam because it is at the saturation temperature but has no liquid water content. Superheated steam is steam that has been heated beyond its saturation temperature without increasing its pressure. **5**

Unlike wet and dry steam, which exist at the saturation temperature, superheated steam exists at a higher temperature and is entirely in the vapor phase

2. **15**

a. . **7**

1. **7**

p1V1 =mRT1							
kg	m =	0.005046257					
bar	p1 =	1	T1 =	290	K		
bar	p2 =	10			cp	14.25	
	p3 =	5.155617649	R	4.1	cv	10.15	
m3	V1 =	0.06	γ	1.403941			
m3	V2 =	0.011637791					
	V3 =	0.011637791	T2 =	562.4932			
process		Q2-3 = ΔH2-3	T3 =	290			
adiabatic compression	W1-2 =	-13.95697008	Q1-2 =	0			
constant volume cooling	W2-3 =	0	Q2-3 =	-13.957			
isothermal expansion	W3-1 =	9.840521555	Q3-1 =	9.840522			
	Wtotal =	-4.116448521	Qtotal	-4.11645			
	ΔU2-3 =	-13.95697008					

------------- OR -------------

2. **7**

mdot (kg/s)	0.8
P1 (bar)	1
P1 (kPa)	100
v1 (m3/kg)	0.95
u1 (kJ/kg)	30
V1 (m/s)	10
P2 (bar)	8
P2 (kPa)	800
v2 (m3/kg)	0.2
u2 (kJ/kg)	124
V2 (m/s)	6
dQ/dt (kW) =	0
m(u1+p1v1 + V1^2/2)	100.04
m(u2+p2v2 + V2^2/2)	227.2144
dW/dt (kW) =	-127.174
d1 (m) =	0.311073
d2 (m) =	0.184264

b. . **8**

1. Dryness fraction = 0.766, Work ratio = 0.99, efficiency = 27 to 30 % **8**

------------ OR ------------

2. The Reheat Rankine Cycle is an advanced version of the basic Rankine cycle, often used in large power plants to enhance efficiency and performance. It is designed to address some limitations of the simple Rankine cycle, particularly with respect to efficiency and steam quality. Here's a more detailed breakdown of its components, process, and advantages: **8**

1. Components of the Reheat Rankine Cycle

The cycle involves the same primary components as a basic Rankine cycle but with an additional reheater:

Boiler (or steam generator): Generates high-pressure steam by transferring heat to water.

High-Pressure Turbine (HPT): Expands high-pressure, high-temperature steam to produce work.

Reheater: Reheats the steam after it exits the HPT, increasing its temperature at constant pressure.

Low-Pressure Turbine (LPT): Further expands the reheated steam to produce additional work.

Condenser: Condenses the expanded steam into water by transferring heat to a cooling medium, such as water or air.

Pump: Increases the pressure of the condensed water and sends it back to the boiler to complete the cycle.

2. Working Process of the Reheat Rankine Cycle

The Reheat Rankine cycle follows these steps, typically illustrated on a temperature-entropy (T-s) or pressure-enthalpy (P-h) diagram:

Step 1: Heating in the Boiler (1–2)

The feedwater enters the boiler at a high pressure after being pumped from the condenser.

Heat is added to the water in the boiler, turning it into superheated steam at a high temperature and pressure (State 2).

Step 2: Expansion in the High-Pressure Turbine (2–3)

The high-pressure steam enters the HPT, where it undergoes expansion, converting thermal energy into mechanical work.

As the steam expands, its pressure and temperature drop, and its moisture content increases (State 3).

Step 3: Reheating the Steam (3–4)
To prevent excessive moisture in the later stages of expansion and to improve efficiency, the partially expanded steam is sent back to the boiler for reheating.
The reheater raises the steam temperature (typically to nearly its initial temperature), keeping the pressure constant (State 4).
Step 4: Expansion in the Low-Pressure Turbine (4–5)
The reheated steam then enters the LPT, where it undergoes further expansion, generating additional work.
This process lowers the steam's pressure and temperature to near saturation conditions at the condenser's pressure (State 5).
Step 5: Condensation in the Condenser (5–6)
The expanded steam is condensed in the condenser, transforming into saturated water (State 6).
The heat released in the condenser is typically rejected to a cooling water system, like a river, lake, or cooling tower.
Step 6: Pressurizing the Condensate (6–1)
The condensed water is pressurized by a feedwater pump and sent back to the boiler to begin the cycle again.
3. Advantages of the Reheat Rankine Cycle
Increased Thermal Efficiency: Reheating increases the average temperature at which heat is added to the steam, improving the cycle's thermal efficiency.
Reduced Moisture Content in the Steam: Reheating helps maintain a higher quality of steam during the final stages of expansion, reducing the moisture content. This decreases the risk of erosion and damage to turbine blades, especially in the LPT.
Higher Work Output: Since the reheated steam has higher enthalpy, it allows more energy extraction in the LPT, increasing the overall work output.
4. Practical Considerations
Number of Reheating Stages: Some advanced plants use multiple reheating stages for even higher efficiency, although this adds complexity and cost.
Optimum Reheat Temperature and Pressure: The choice of reheat temperature and pressure is optimized to balance efficiency gains with equipment costs and materials that can withstand high temperatures and pressures.
Environmental Impact: Improved efficiency in the Reheat Rankine cycle means less fuel is required per unit of power produced, reducing emissions in fossil-fuel-based power plants

3. **15**

a. The First Law of Thermodynamics, which states that energy cannot be created or destroyed, only transformed, has limitations: **7**

• No Direction of Process: It only accounts for energy conservation but does not indicate the direction of energy transfer or the feasibility of a process. For example, it does not explain why heat flows from a hot object to a cold one and not the other way around.
• No Insight on Efficiency: It doesn’t provide information about the efficiency or quality of energy transfer. For instance, it doesn’t address the maximum achievable efficiency of heat engines or the practical limitations due to irreversibilities in real processes.
• No Account for Degradation of Energy Quality: While energy is conserved, its usability can decrease. The First Law does not consider the concept of entropy, which governs energy degradation in real-world processes.
The Second Law of Thermodynamics addresses these limitations by introducing entropy and providing a basis for the direction of processes and maximum efficiency.

Heat Engine, Heat Pump, and Refrigerator
Heat Engine
A heat engine is a device that converts heat energy into mechanical work by transferring heat from a high-temperature source to a low-temperature sink. Common examples include steam engines, internal combustion engines, and gas turbines.
• Working Principle: A heat engine absorbs heat QHQ_HQH from a high-temperature reservoir, converts part of it into work WWW, and rejects the remaining heat QLQ_LQL to a low-temperature reservoir.
2. Heat Pump
A heat pump transfers heat from a low-temperature reservoir to a high-temperature reservoir using work input. Heat pumps are commonly used for heating buildings in cold weather.
• Working Principle: A heat pump takes in heat QLQ_LQL from a cold reservoir, requires work WWW, and delivers heat QHQ_HQH to a hot reservoir.

b. 1. **8**

1. **8**

W1	3	T1 (K)	1500
W2	2	T2 (K)	T2
W3	1	T3 (K)	T3
W2/W1	0.66666667	T4 (K)	600
W3/W1	0.33333333		
2T1-2T2 = 3T2-3T3		5T2-3T3 = 2T1	3000
T1-T2 = 3T3-3T4		T2+3T3 = T1+3T4	3300
	adding	6T2=	6300
		T2 (K) =	1050
		T3 (K) =	750

------------- OR -------------

2. **8**

t1 (0C)	1250	1200	Q1	162.5152439
T1(K)	1523		Q2 (kJ)	35
t2 (0C)	55	50		
T2(K)	328			
t3 (0C)	55	50	Q3 (kJ)	403.5152439
T3(K)	328		Q4 (kJ)	276
t4 (0C)			η =	0.784635588
T4(K)			W (kJ)=	127.5152439
HE			COP	3.164447101
HP	COP= (T3/(T3-T4))		T4 (K)	224.3484016
			t4 (0C)	-48.65159838

4. **15**

a. Answer: **5**

The Clausius-Clapeyron equation describes the relationship between the temperature and pressure of a system in equilibrium during a phase transition, such as from liquid to gas. It is fundamental in thermodynamics for studying phase changes, especially vaporization and condensation. The equation is given by:

$$\frac{dP}{dT} = \frac{L}{T\Delta V}$$

where:

- P is the pressure,
- T is the temperature,
- L is the latent heat of the phase transition (e.g., heat of vaporization),
- ΔV is the change in volume between the two phases.

b. . **10**

1. **10**

	p1 (bar)	1		cp	1.05	
	p1 (kPa)	100		cv	0.75	
	T1 (K)	300		R =	0.3	
	T2 (K)	600		γ =	1.4	
	T3 (K)	1800				
				rk =	5.656854249	
				T4 (K)	900	
	Otto cycle			Q1 (kJ/kg)	900	
				Q2 (kJ/kg)	450	
				Wnet	450	
				η(%) =	50	

------------- OR -------------

2. **10**

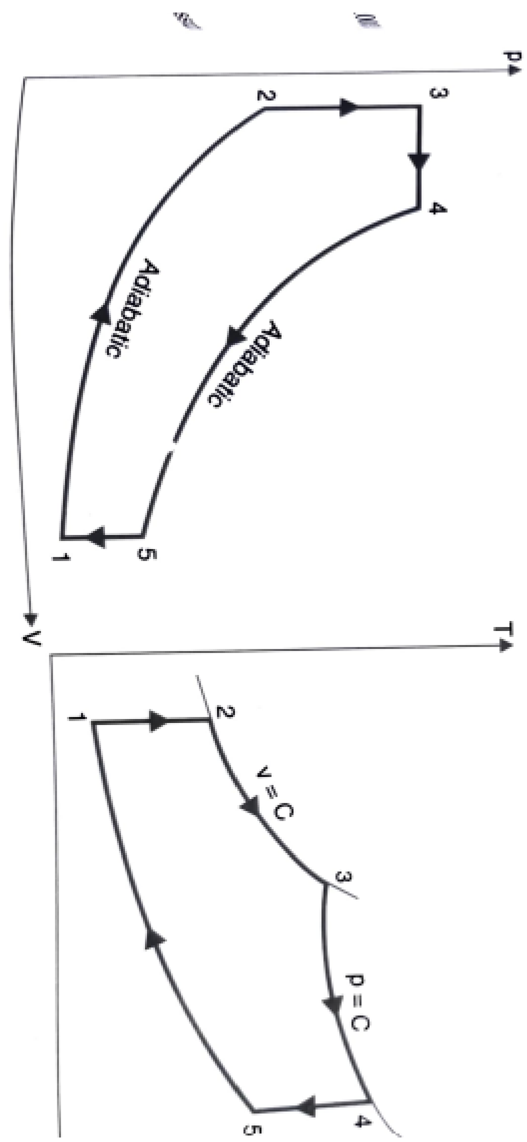


Fig. 13.19.

Putting the value of T_2 in eqn. (*ii*), we get

$$\frac{\frac{T_3}{\beta}}{T_1} = (r)^{\gamma - 1}$$

$$T_1 = \frac{T_3}{\beta} \cdot \frac{1}{(r)^{\gamma - 1}}$$

Now inserting the values of T_1, T_2, T_4 and T_5 in eqn. (*i*), we get

$$\eta_{dual} = 1 - \frac{\left[\rho . T_3 \left(\frac{\rho}{r}\right)^{\gamma - 1} - \frac{T_3}{\beta} \cdot \frac{1}{(r)^{\gamma - 1}}\right]}{\left[\left(T_3 - \frac{T_3}{\beta}\right) + \gamma(\rho T_3 - T_3)\right]} = 1 - \frac{\frac{1}{(r)^{\gamma - 1}}\left(\rho^{\gamma} - \frac{1}{\beta}\right)}{\left(1 - \frac{1}{\beta}\right) + \gamma(\rho - 1)}$$

i.e.,

$$\eta_{dual} = 1 - \frac{1}{(r)^{\gamma - 1}} \cdot \frac{(\beta . \rho^{\gamma} - 1)}{[(\beta - 1) + \beta\gamma(\rho - 1)]} \quad \text{...(13.10)}$$

Work done is given by,

$$W = p_3(v_4 - v_3) + \frac{p_4 v_4 - p_5 v_5}{\gamma - 1} - \frac{p_2 v_2 - p_1 v_1}{\gamma - 1}$$

$$= p_3 v_3(\rho - 1) + \frac{(p_4 \rho v_3 - p_5 r v_3) - (p_2 v_3 - p_1 r v_3)}{\gamma - 1}$$

$$= \frac{p_3 v_3 (\rho - 1)(\gamma - 1) + p_4 v_3 \left(\rho - \frac{p_5}{p_4} r\right) - p_2 v_3 \left(1 - \frac{p_1}{p_2} r\right)}{\gamma - 1}$$

Also $\quad \frac{p_5}{p_4} = \left(\frac{v_4}{v_5}\right)^{\gamma} = \left(\frac{\rho}{r}\right)^{\gamma}$ and $\frac{p_2}{p_1} = \left(\frac{v_1}{v_2}\right)^{\gamma} = r^{\gamma}$

Also, $\quad p_3 = p_4$, $v_2 = v_3$, $v_5 = v_1$

$$\therefore \quad W = \frac{v_3[p_3(\rho - 1)(\gamma - 1) + p_3(\rho - \rho^{\gamma} r^{1 - \gamma}) - p_2(1 - r^{1 - \gamma})]}{(\gamma - 1)}$$

$$= \frac{p_2 v_2[\beta(\rho - 1)(\gamma - 1) + \beta(\rho - \rho^{\gamma} r^{1 - \gamma}) - (1 - r^{1 - \gamma})]}{(\gamma - 1)}$$

$$= \frac{p_1 (r)^{\gamma} v_1 / r[\beta\gamma(\rho - 1) + (\beta - 1) - r^{1 - \gamma}(\beta\rho^{\gamma} - 1)]}{\gamma - 1}$$

$$= \frac{p_1 v_1 r^{\gamma - 1}[\beta\gamma(\rho - 1) + (\beta - 1) - r^{\gamma - 1}(\beta\rho^{\gamma} - 1)]}{\gamma - 1} \quad \text{...(13.11)}$$