CMR INSTITUTE OF TECHNOLOGY

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Internal Assessment Test II

SUBJECT: BASIC THERMODYNAMICS						Code:	15ME33
Date:	03/11/2016	Duration:	90 min	Max. Marks:	50	Sem:	03	Branch:	MECH

*Answer any **5** FULL questions. Each question carries equal marks.*

Q. No.		Question	Marks	OBE MAP	
				CO	RBT
1	a	A container of 3 m^3 capacity contains 10 kg of CO_2 at 27°C. Estimate the pressure exerted by CO_2 by using : (i) Perfect gas equation (ii) Vander Waals' equation given a = 362.85 kNm^4/(kg mol)^2 and b = 0.0423 m^3/kg mol	[4]	CO4, CO5	L2
	b	Explain the establishment of a thermodynamic temperature scale.	[6]	CO1, CO2	L4
2	a	Two identical blocks of mass m are available at temperatures T_1 and T_2. They can be used as source and sink to operate a heat engine. Determine the maximum amount of work that can be obtained if the specific heats of the blocks are C.	[7]	CO2	L3
	b	Define C_p and C_v in terms of entropy change.	[3]	CO4	L2
3	a	It is desired to compress air (an ideal gas with γ = 1.4) in a piston cylinder arrangement from 1 bar and 300 K to a pressure of 10 bar and the final temperature of the air is 300 K. The air interacts with the surroundings, also at 300 K. Determine the minimum amount of work to be done per kg of air.	[6]	CO2	L3
	b	Explain availability.	[4]	CO2	L4
4	a	What is meant by second law efficiency? Discuss the necessity of its introduction.	[5]	CO2	L2
	b	List the factors which contribute to the irreversibility of a process.	[5]	CO2	L1
5	a	Explain Classius inequality.	[6]	CO2	L4
	b	A Carnot cycle operates between source and sink temperatures of 250°C and −15°C. If the system receives 90 kJ from the source, calculate: (i) Efficiency of the system; (ii) The net work transfer; (iii) Heat rejected to sink.	[4]	CO2	L3
6	a	Prove that entropy is a property of the system.	[5]	CO2	L4
	b	An iron cube at a temperature of 400°C is dropped into an insulated bath containing 10 kg of water at 25°C. The water finally reaches a temperature of 50°C at steady state. Given that the specific heat of water is 4.187 kJ/kgK, determine the entropy changes for the iron cube and water. Is the process reversible? If so, why?	[5]	CO4	L3

Mapping of Course outcomes with Program Outcomes.

Course Outcomes		PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1:	Recall thermodynamic systems, properties, Zeroth law of thermodynamics, temperature scales and energy interactions.	3*											
CO2:	Explain the ideas of heat, work, internal energy, enthalpy for flow & non flow process using First and Second Law of Thermodynamics.	3											
CO3:	Interpret behavior of pure substances and its applications to practical problems.	3	2										
CO4:	Execute the ideas developed earlier to determine change in internal energy, change in enthalpy and change in entropy using TD relations for ideal gases		1										
CO5:	Implementing Thermodynamics properties of real gases at all ranges of pressure, temperatures using modified equation of state including Vander Waals equation, Redlich Wong equation and Beattie-Bridgeman equation.		1										

Relevance: 1 – Low, 2 – Medium, 3 - High
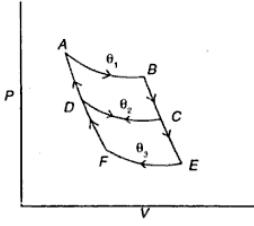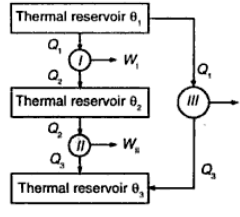
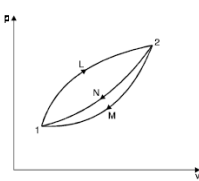| Cognitive level	KEYWORDS – Revised Bloom's Taxonomy (RBT)
L1	List, define, tell, describe, identify, show, label, collect, examine, tabulate, quote, name, who, when, where, etc.
L2	summarize, describe, interpret, contrast, predict, associate, distinguish, estimate, differentiate, discuss, extend
L3	Apply, demonstrate, calculate, complete, illustrate, show, solve, examine, modify, relate, change, classify, experiment, discover.
L4	Analyze, separate, order, explain, connect, classify, arrange, divide, compare, select, explain, infer.
L5	Assess, decide, rank, grade, test, measure, recommend, convince, select, judge, explain, discriminate, support, conclude, compare, summarize.

Program Outcomes:

PO1 - *Engineering knowledge*; **PO2** - *Problem analysis*; **PO3** - *Design/development of solutions*; **PO4** - *Conduct investigations of complex problems*; **PO5** - *Modern tool usage*; **PO6** - *The Engineer and society*; **PO7**- *Environment and sustainability*; **PO8** – *Ethics*; **PO9** - *Individual and team work*; **PO10** - *Communication*; **PO11** - *Project management and finance*; **PO12** - *Life-long learning*

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Internal Assessment Test 2

SUBJECT: BASIC THERMODYNAMICS							Code:	15ME33	
Date:	03/11/2016	Duration:	90 min	Max. Marks:	50	Sem:	03	Branch:	MECH

*Answer any **5** FULL questions. Each question carries equal marks.*

1	a	**A container of 3 m^3 capacity contains 10 kg of CO_2 at 27°C. Estimate the pressure exerted by CO_2 by using : (i) Perfect gas equation (ii) Vander Waals' equation given a = 362.85 kNm^4/(kg mol)^2 and b = 0.0423 m^3/kg mol**	2 + 2

Using perfect gas equation:

Characteristic gas constant, $R = \frac{8.314}{44} = 0.18895 \frac{kJ}{kg\,K}$

Using perfect gas equation,

$$pV = mRT, \quad p = 188.95 \, kPa$$

Using Vander Waals' equation :

$$\left(p + \frac{a}{v^2}\right)(v - b) = RT$$

$$p = \frac{RT}{(v-b)} - \frac{a}{v^2}$$

$$p = \frac{8.314}{\left(\frac{3}{10} * 44 - 0.0423\right)} - \frac{362.85}{\left(\frac{3}{10} * 44\right)^2} = 187.48 \, kPa$$

	b	**Explain the establishment of a thermodynamic temperature scale.**	1 + 1 + 4

Let θ denote the temperature as measured on the thermodynamic scale and consider three isotherms θ_1, θ_2 and θ_3 such that $\theta_1 > \theta_2 > \theta_3$. Let engine HE1 work between θ_1 and θ_2; HE2 between θ_2 and θ_3. Let the third engine HE3 work between θ_1 and θ_3 directly. Then the PV diagram appears as shown along.

$W_I = Q_1 - Q_2$ and
$W_{II} = Q_2 - Q_3$
$W_{III} = Q_1 - Q_3 = W_I + W_{II}$

$$\eta_I = 1 - \frac{Q_2}{Q_1} = f(\theta_1, \theta_2) \implies \frac{Q_1}{Q_2} = F(\theta_1, \theta_2)$$

Similarly,

$$\frac{Q_2}{Q_3} = F(\theta_2, \theta_3) \quad and \quad \frac{Q_1}{Q_3} = F(\theta_1, \theta_3)$$

Since $\frac{Q_1}{Q_2} = \frac{Q_1}{Q_3} \Big/ \frac{Q_2}{Q_3}$, $\quad F(\theta_1, \theta_2) = \frac{F(\theta_1, \theta_3)}{F(\theta_2, \theta_3)}$

As the left hand side is independent of θ_3, the right hand side must also be independent of θ_3.

Therefore, $F(\theta_1, \theta_2) = \frac{\varphi(\theta_1)}{\varphi(\theta_2)} = \frac{\theta_1}{\theta_2}$ in the simplest of the relations.

Thus, $\eta = 1 - \frac{\theta_1}{\theta_2}$

2	a	**Two identical blocks of mass m are available at temperatures T_1 and T_2. They can be used as source and sink to operate a heat engine. Determine the maximum amount of work that can be obtained if the specific heats of the blocks are C.**	1 +1 +1 +1 +1 +1 +1

For maximum work, the engine should be reversible. Let T be the final temperature.

$$\Delta s_{source} + \Delta s_{sink} = \Delta s_{uni}$$

$$\Delta s_{source} = \int_{T_1}^{T} \frac{\delta Q}{T} = \int_{T_1}^{T} \frac{mCdT}{T} = mC \ln\frac{T}{T_1}$$

$$\Delta s_{sink} = \int_{T_2}^{T} \frac{\delta Q}{T} = \int_{T_2}^{T} \frac{mCdT}{T} = mC \ln\frac{T}{T_2}$$

$$\Delta s_{uni} = mC \ln\frac{T}{T_1} + mC \ln\frac{T}{T_2} = mC \ln\frac{T^2}{T_1 T_2} = 0 \Rightarrow T = \sqrt{T_1 T_2}$$

$$W = mC(T_1 - T) - mC(T - T_2) = mC(T_1 + T_2 - 2T) = mC\left(\sqrt{T_1} - \sqrt{T_2}\right)^2$$

	b	**Define C_p and C_v in terms of entropy change.**	1 + 1 + 1

The specific heat of a substance is defined as

$$C_p = \left(\frac{\delta Q}{dT}\right)_p \ and \ C_v = \left(\frac{\delta Q}{dT}\right)_v$$

The second law od thermodynamics gives

$$ds = \left(\frac{\delta Q}{T}\right)_R \Rightarrow \delta Q = Tds$$

Therefore the specific heats are defined as

$$C_p = T\left(\frac{\partial s}{\partial T}\right)_p \ and \ C_v = T\left(\frac{\partial s}{\partial T}\right)_v$$

3	a	**It is desired to compress air (an ideal gas with γ = 1.4) in a piston cylinder arrangement from 1 bar and 300 K to a pressure of 10 bar and the final temperature of the air is 300 K. The air interacts with the surroundings, also at 300 K. Determine the minimum amount of work to be done per kg of air.**	2 + 1+ 1+ 1+ 1

$$W_{min} = \Delta F = (u_2 - T_2 s_2) - (u_1 - T_1 s_1)$$
$$T_2 = T_1 = T_0 = 300 \ K$$
$$\therefore W_{min} = -T_0(s_2 - s_1) = RT_0 \ln\frac{p_2}{p_1} = 5.74 \ kJ/kg$$

	b	**Explain availability.**	4

The availability of a system is defined as the maximum useful work that can be obtained in a process in which the system comes to equilibrium with the surroundings or attains the dead state.
Suppose a system is initially available at temperature T and pressure P while the surroundings are at T_0 and P_0. The system can undergo a process in which it reaches a state of thermal equilibrium with the surroundings and delivers some work. When the system is in equilibrium with the surroundings, there is no possibility of obtaining further work from such a system. The work done in such a dead state is the maximum. The maximum useful work is obtained by this work minus the work done in pushing the surrounding the atmosphere. This is called the availability of the system.

4	a	**What is meant by second law efficiency? Explain the necessity of its introduction.**	1 + 4

The second law efficiency of a system is defined as:

$$\eta_{II} = \frac{Exergy \ recovered}{Exergy \ supplied} = 1 - \frac{Exergy \ destroyed}{Exergy \ supplied}$$

The second law efficiency is intended to serve as a measure of approximation to reversible operation, and thus its value should range from zero in the worst case of complete destruction of exergy, to one in the best case of no destruction of exergy. The second law efficiency is sometimes referred to as the process effectiveness. It is the ratio of the thermal efficiency of an actual engine to the thermal efficiency of a reversible engine operating between the same temperature limits. The available energy is high if the energy as heat is available at a higher temperature. To take into account the quality of energy, the term second law efficiency is introduced. In the first law, there is no mention

		of the quality of energy leave alone the deterioration of energy. Thus, it becomes useful to measure the extent of irreversibility accompanying the process. This concept becomes useful while building a device or machine which would be thermo economically viable.	
	b	**List the factors which contribute to the irreversibility of a process.** The following is a list of spontaneous events which contribute to the irreversibility of processes. • Heat transfer through a finite temperature difference • Friction • Plastic deformation • Flow of electric current through a resistance • Magnetization or polarization with a hysteresis • Unrestrained expansion of fluids • Spontaneous chemical reactions • Spontaneous mixing of matter of varying composition/states	5*1
5	a	**Explain Classius inequality** For a system undergoing a cycle, from the first law, $\Sigma\,\delta Q = \Sigma\,\delta W$ Also, $\Sigma\,\delta W \le \Sigma\,\delta W_R$ where $\Sigma\,\delta W_R$ represents the work done by a reversible engine. $$\frac{\delta W_R}{\delta Q} = \frac{\delta Q_0 - \delta Q}{\delta Q} = \frac{T_0 - T}{T}$$ Combining, $\Sigma\,\frac{\delta Q}{T} \le 0$ since T_0 is not equal to zero. This is known as Clausius inequality. The equality sign holds good only when the system undergoes a reversible cycle.	1 + 1 + 1+ 1+ 1+ 1
	b	**A Carnot cycle operates between source and sink temperatures of 250°C and– 15°C. If the system receives 90 kJ from the source, find: (i) Efficiency of the system; (ii) The net work transfer; (iii) Heat rejected to sink.** $T_1 = 250 + 273 = 523$ K; $T_2 = -15 + 273 = 258$ K $$\eta = 1 - \frac{T_2}{T_1} = 0.5067$$ Net work done $W = \eta Q_1 = 45.6\ kJ$ Heat rejected $Q_2 = Q_1 - W = 44.4\ kJ$	1+ 1+ 1+ 1
6	a	**Prove that entropy is a property of the system.** Consider a system undergoing a reversible process from state 1 to state 2 along path *L* and then from state 2 to the original state 1 along path *M*. Applying the Clausius theorem to this reversible cyclic process, we have, for the reversible cycle, $\oint_R \frac{\delta Q}{T} = 0$ Hence when the system passes through the cycle 1-*L*-2-*M*-1, we have, $\int_{1L}^{2} \frac{\delta Q}{T} + \int_{2M}^{1} \frac{\delta Q}{T} = 0$ Now consider another reversible cycle in which the system changes from state 1 to state 2 along path *L*, but returns from state 2 to the original state 1 along a different path *N*. For this reversible cyclic process, we have $\int_{1L}^{2} \frac{\delta Q}{T} + \int_{2N}^{1} \frac{\delta Q}{T} = 0$ Equating, $\int_{2M}^{1} \frac{\delta Q}{T} = \int_{2N}^{1} \frac{\delta Q}{T}$. This implies that entropy is a property since the value remains unaltered irrespective of the considered.	1+ 1+ 1+ 1+ 1

b	**An iron cube at a temperature of 400C is dropped into an insulated bath containing 10 kg of water at 25C. The water finally reaches a temperature of 50C at steady state. Given that the specific heat of water is 4.187 kJ/kgK, find the entropy changes for the iron cube and water. Is the process reversible? If so, why?**	1+ 1+ 1+ 1+ 1

$$m_i c_{pi} \Delta T_i = m_w c_{pw} \Delta T_w \implies m_i c_{pi} = 10 * 4.187 * \frac{(323-298)}{(673-323)} = 3 \text{ kJ/K}$$

Entropy of iron at 673 K:
$$m_i c_{pi} \ln\left(\frac{673}{273}\right) = 3 \ln\left(\frac{673}{273}\right) = 2.71 \ kJ/K$$

Entropy of iron at 323 K
$$m_i c_{pi} \ln\left(\frac{323}{273}\right) = 3 \ln\left(\frac{323}{273}\right) = 0.505 \ \frac{kJ}{K}$$

Entropy of water at 323 K
$$m_w c_{pw} \ln\left(\frac{323}{273}\right) = 10 * 4.187 * \ln\left(\frac{323}{273}\right) = 7.04 \text{ kJ/K}$$

Entropy of water at 298 K
$$m_w c_{pw} \ln\left(\frac{298}{273}\right) = 10 * 4.187 * \ln\left(\frac{298}{273}\right) = 3.669 \text{ kJ/K}$$

Change in entropy of iron = 0.505 – 2.71 = - 2.205 kJ/K

Change in entropy of water = 7.04 – 3.669 = 3.401 kJ/K

Net change in entropy = 3.401 – 2.205 = 1.196 kJ/K > 0, irreversible