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**TECHNICAL UNIVERSITY OF MOMBASA**

*Faculty of Engineering & Technology*

DEPARTMENT OF MECHANICAL & AUTOMOTIVE ENGINEERING

**UNIVERSITY EXAMINATION FOR**  
THE DEGREE OF BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING  
(SCHOOL-BASED PROGRAMME)

**EMG 2308 ENGINEERING THERMODYNAMICS III**

**END OF SEMESTER EXAMINATIONS**

**SERIES: AUGUST 2017**

**TIME: 2 HOURS**

**INSTRUCTIONS TO CANDIDATES:**

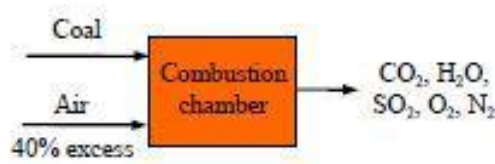
1. You should have **Answer Booklet** for this examination.
  2. This paper contains **FIVE** questions. Answer **ANY THREE** questions.
  3. All diagrams should be clearly drawn and labeled.
  4. This paper consists of **THREE** printed pages and Appendixes.
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**Question 1**

- (a) Prove that for a two-stage reciprocating compressor with complete inter-cooling, the stage pressure ratio equals to the square root of the overall pressure ratio for the required power to be minimum. State clearly any assumptions made. **(14 marks)**
- (b) A three-stage, single-acting compressor is required to compress  $135 \text{ m}^3$  of free air per hour from 1 bar to 64 bar. The mean piston speed is to be 140 m/min. The polytropic index for all compressions is 1.3. Neglect the effect of clearance volume. Calculate:
- (i) The power needed to run the compressor,
  - (ii) The piston areas. **(6 marks)**

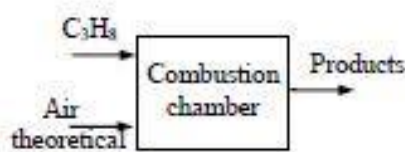
### Question 2

- (a) Coal has the following analysis on a mass basis: 67.4% carbon, 5.31% hydrogen, 15.11% oxygen, 1.44% nitrogen, 2.36% sulphur and 8.38% non-combustible ash. The coal is burned with 40 percent excess air. Determine,
- the air–fuel ratio and
  - the relative molecular weight of the product gas.
- (14 marks)**



**Figure Q(2a)**

- (b) Determine the lower and higher heating values in kJ/kg of liquid propane ( $C_3H_8$ ) in kJ/kg at 25°C, 1 atm.
- (6 marks)**



**Figure Q(2b)**

### Question 3

- (a) Derive an expression for the thermal efficiency of an air-standard Otto cycle.
- (10 marks)**
- (b) An ideal Otto cycle has a compression ratio of 8. At the beginning of the compression process air is at 95 kPa and 27°C and 750 kJ/kg of heat is transferred to air during the constant-volume heat addition process. Sketch the cycle on  $p-v$  and  $T-s$  diagrams. Taking into account the variation of specific heats with temperature, calculate:
- The pressure and temperature at the end of heat addition process.
  - The net work output.
  - The thermal efficiency.
  - The mean effective pressure (MEP), in kPa.
- (10 marks)**

#### **Question 4**

- (a) Derive an expression for the thermal efficiency of an air-standard Diesel cycle. **(10 marks)**
- (b) An air standard Diesel cycle has a compression ratio of 16 and a cutoff ratio of 2. At the beginning of the compression process, air is at 95 kPa and 27°C. Sketch the cycle on  $p$ - $v$  and  $T$ - $s$  diagrams. Accounting for the variation in specific heats with temperature, calculate:
- (i) The temperature after the heat addition process.
  - (ii) The thermal efficiency of the cycle.
  - (iii) The mean effective pressure (MEP), in kPa. **(10 marks)**

#### **Question 5**

- (a) Derive an expression for the thermal efficiency of an air-standard Brayton cycle. **(9 marks)**
- (b) A simple Brayton cycle using air as a working fluid has a pressure ratio of 10. The minimum and maximum temperatures in the cycle are 290 K and 1100 K. Sketch the cycle on  $p$ - $v$  and  $T$ - $s$  diagrams. Assuming an isentropic efficiency of 75 percent for the compressor and 82 percent for the turbine, calculate:
- (i) The air temperature at the compressor exit.
  - (ii) The back-work ratio.
  - (iii) The thermal efficiency of the cycle. **(11 marks)**

**TABLE A–26**

Enthalpy of formation, Gibbs function of formation, and absolute entropy at 25°C, 1 atm

Substance	Formula	$\bar{h}_f^\circ$ kJ/kmol	$\bar{g}_f^\circ$ kJ/kmol	$\bar{s}^\circ$ kJ/kmol · K
Carbon	C(s)	0	0	5.74
Hydrogen	H <sub>2</sub> (g)	0	0	130.68
Nitrogen	N <sub>2</sub> (g)	0	0	191.61
Oxygen	O <sub>2</sub> (g)	0	0	205.04
Carbon monoxide	CO(g)	–110,530	–137,150	197.65
Carbon dioxide	CO <sub>2</sub> (g)	–393,520	–394,360	213.80
Water vapor	H <sub>2</sub> O(g)	–241,820	–228,590	188.83
Water	H <sub>2</sub> O(l)	–285,830	–237,180	69.92
Hydrogen peroxide	H <sub>2</sub> O <sub>2</sub> (g)	–136,310	–105,600	232.63
Ammonia	NH <sub>3</sub> (g)	–46,190	–16,590	192.33
Methane	CH <sub>4</sub> (g)	–74,850	–50,790	186.16
Acetylene	C <sub>2</sub> H <sub>2</sub> (g)	+226,730	+209,170	200.85
Ethylene	C <sub>2</sub> H <sub>4</sub> (g)	+52,280	+68,120	219.83
Ethane	C <sub>2</sub> H <sub>6</sub> (g)	–84,680	–32,890	229.49
Propylene	C <sub>3</sub> H <sub>6</sub> (g)	+20,410	+62,720	266.94
Propane	C <sub>3</sub> H <sub>8</sub> (g)	–103,850	–23,490	269.91
<i>n</i> -Butane	C <sub>4</sub> H <sub>10</sub> (g)	–126,150	–15,710	310.12
<i>n</i> -Octane	C <sub>8</sub> H <sub>18</sub> (g)	–208,450	+16,530	466.73
<i>n</i> -Octane	C <sub>8</sub> H <sub>18</sub> (l)	–249,950	+6,610	360.79

Note: Enthalpy of formation has 2 values: 1. for vapor phase 2. for liquid phase -the difference = latent heat of vaporization

TABLE A-27

Properties of some common fuels and hydrocarbons

Fuel (phase)	Formula	Molar mass, kg/kmol	Density, <sup>1</sup> kg/L	Enthalpy of vaporization, <sup>2</sup> kJ/kg	Specific heat, <sup>1</sup> $c_p$ , kJ/kg · K	Higher heating value, <sup>3</sup> kJ/kg	Lower heating value, <sup>3</sup> kJ/kg
Carbon (s)	C	12.011	2	—	0.708	32,800	32,800
Hydrogen (g)	H <sub>2</sub>	2.016	—	—	14.4	141,800	120,000
Carbon monoxide (g)	CO	28.013	—	—	1.05	10,100	10,100
Methane (g)	CH <sub>4</sub>	16.043	—	509	2.20	55,530	50,050
Methanol (ℓ)	CH <sub>4</sub> O	32.042	0.790	1168	2.53	22,660	19,920
Acetylene (g)	C <sub>2</sub> H <sub>2</sub>	26.038	—	—	1.69	49,970	48,280
Ethane (g)	C <sub>2</sub> H <sub>6</sub>	30.070	—	172	1.75	51,900	47,520
Ethanol (ℓ)	C <sub>2</sub> H <sub>6</sub> O	46.069	0.790	919	2.44	29,670	26,810
Propane (ℓ)	C <sub>3</sub> H <sub>8</sub>	44.097	0.500	335	2.77	50,330	46,340
Butane (ℓ)	C <sub>4</sub> H <sub>10</sub>	58.123	0.579	362	2.42	49,150	45,370
1-Pentene (ℓ)	C <sub>5</sub> H <sub>10</sub>	70.134	0.641	363	2.20	47,760	44,630
Isopentane (ℓ)	C <sub>5</sub> H <sub>12</sub>	72.150	0.626	—	2.32	48,570	44,910
Benzene (ℓ)	C <sub>6</sub> H <sub>6</sub>	78.114	0.877	433	1.72	41,800	40,100
Hexene (ℓ)	C <sub>6</sub> H <sub>12</sub>	84.161	0.673	392	1.84	47,500	44,400
Hexane (ℓ)	C <sub>6</sub> H <sub>14</sub>	86.177	0.660	366	2.27	48,310	44,740
Toluene (ℓ)	C <sub>7</sub> H <sub>8</sub>	92.141	0.867	412	1.71	42,400	40,500
Heptane (ℓ)	C <sub>7</sub> H <sub>16</sub>	100.204	0.684	365	2.24	48,100	44,600
Octane (ℓ)	C <sub>8</sub> H <sub>18</sub>	114.231	0.703	363	2.23	47,890	44,430
Decane (ℓ)	C <sub>10</sub> H <sub>22</sub>	142.285	0.730	361	2.21	47,640	44,240
Gasoline (ℓ)	C <sub>n</sub> H <sub>1.87n</sub>	100–110	0.72–0.78	350	2.4	47,300	44,000
Light diesel (ℓ)	C <sub>n</sub> H <sub>1.8n</sub>	170	0.78–0.84	270	2.2	46,100	43,200
Heavy diesel (ℓ)	C <sub>n</sub> H <sub>1.7n</sub>	200	0.82–0.88	230	1.9	45,500	42,800
Natural gas (g)	C <sub>n</sub> H <sub>3.8n</sub> N <sub>0.1n</sub>	18	—	—	2	50,000	45,000

<sup>1</sup>At 1 atm and 20°C.<sup>2</sup>At 25°C for liquid fuels, and 1 atm and normal boiling temperature for gaseous fuels.<sup>3</sup>At 25°C. Multiply by molar mass to obtain heating values in kJ/kmol.



## Ideal gas properties of air

TABLE A-17

Ideal-gas properties of air

$T$ K	$h$ kJ/kg	$P_r$	$u$ kJ/kg	$v_r$	$s^\circ$ kJ/kg·K	$T$ K	$h$ kJ/kg	$P_r$	$u$ kJ/kg	$v_r$	$s^\circ$ kJ/kg·K
200	199.97	0.3363	142.56	1707.0	1.29559	580	586.04	14.38	419.55	115.7	2.37348
210	209.97	0.3987	149.69	1512.0	1.34444	590	596.52	15.31	427.15	110.6	2.39140
220	219.97	0.4690	156.82	1346.0	1.39105	600	607.02	16.28	434.78	105.8	2.40902
230	230.02	0.5477	164.00	1205.0	1.43557	610	617.53	17.30	442.42	101.2	2.42644
240	240.02	0.6355	171.13	1084.0	1.47824	620	628.07	18.36	450.09	96.92	2.44356
250	250.05	0.7329	178.28	979.0	1.51917	630	638.63	19.44	457.78	92.84	2.46048
260	260.09	0.8405	185.45	887.8	1.55848	640	649.22	20.64	465.50	88.99	2.47716
270	270.11	0.9590	192.60	808.0	1.59634	650	659.84	21.86	473.25	85.34	2.49364
280	280.13	1.0889	199.75	738.0	1.63279	660	670.47	23.13	481.01	81.89	2.50985
285	285.14	1.1584	203.33	706.1	1.65055	670	681.14	24.46	488.81	78.61	2.52589
290	290.16	1.2311	206.91	676.1	1.66802	680	691.82	25.85	496.62	75.50	2.54175
295	295.17	1.3068	210.49	647.9	1.68515	690	702.52	27.29	504.45	72.56	2.55731
298	298.18	1.3543	212.64	631.9	1.69528	700	713.27	28.80	512.33	69.76	2.57277
300	300.19	1.3860	214.07	621.2	1.70203	710	724.04	30.38	520.23	67.07	2.58810
305	305.22	1.4686	217.67	596.0	1.71865	720	734.82	32.02	528.14	64.53	2.60319
310	310.24	1.5546	221.25	572.3	1.73498	730	745.62	33.72	536.07	62.13	2.61803
315	315.27	1.6442	224.85	549.8	1.75106	740	756.44	35.50	544.02	59.82	2.63280
320	320.29	1.7375	228.42	528.6	1.76690	750	767.29	37.35	551.99	57.63	2.64737
325	325.31	1.8345	232.02	508.4	1.78249	760	778.18	39.27	560.01	55.54	2.66176
330	330.34	1.9352	235.61	489.4	1.79783	780	800.03	43.35	576.12	51.64	2.69013
340	340.42	2.149	242.82	454.1	1.82790	800	821.95	47.75	592.30	48.08	2.71787
350	350.49	2.379	250.02	422.2	1.85708	820	843.98	52.59	608.59	44.84	2.74504
360	360.58	2.626	257.24	393.4	1.88543	840	866.08	57.60	624.95	41.85	2.77170
370	370.67	2.892	264.46	367.2	1.91313	860	888.27	63.09	641.40	39.12	2.79783
380	380.77	3.176	271.69	343.4	1.94001	880	910.56	68.98	657.95	36.61	2.82344
390	390.88	3.481	278.93	321.5	1.96633	900	932.93	75.29	674.58	34.31	2.84856
400	400.98	3.806	286.16	301.6	1.99194	920	955.38	82.05	691.28	32.18	2.87324
410	411.12	4.153	293.43	283.3	2.01699	940	977.92	89.28	708.08	30.22	2.89748
420	421.26	4.522	300.69	266.6	2.04142	960	1000.55	97.00	725.02	28.40	2.92128
430	431.43	4.915	307.99	251.1	2.06533	980	1023.25	105.2	741.98	26.73	2.94468
440	441.61	5.332	315.30	236.8	2.08870	1000	1046.04	114.0	758.94	25.17	2.96770
450	451.80	5.775	322.62	223.6	2.11161	1020	1068.89	123.4	776.10	23.72	2.99034
460	462.02	6.245	329.97	211.4	2.13407	1040	1091.85	133.3	793.36	23.29	3.01260
470	472.24	6.742	337.32	200.1	2.15604	1060	1114.86	143.9	810.62	21.14	3.03449
480	482.49	7.268	344.70	189.5	2.17760	1080	1137.89	155.2	827.88	19.98	3.05608
490	492.74	7.824	352.08	179.7	2.19876	1100	1161.07	167.1	845.33	18.896	3.07732
500	503.02	8.411	359.49	170.6	2.21952	1120	1184.28	179.7	862.79	17.886	3.09825
510	513.32	9.031	366.92	162.1	2.23993	1140	1207.57	193.1	880.35	16.946	3.11883
520	523.63	9.684	374.36	154.1	2.25997	1160	1230.92	207.2	897.91	16.064	3.13916
530	533.98	10.37	381.84	146.7	2.27967	1180	1254.34	222.2	915.57	15.241	3.15916
540	544.35	11.10	389.34	139.7	2.29906	1200	1277.79	238.0	933.33	14.470	3.17888
550	555.74	11.86	396.86	133.1	2.31809	1220	1301.31	254.7	951.09	13.747	3.19834
560	565.17	12.66	404.42	127.0	2.33685	1240	1324.93	272.3	968.95	13.069	3.21751
570	575.59	13.50	411.97	121.2	2.35531						

**TABLE A-17**

Ideal-gas properties of air (*Concluded*)

<i>T</i> K	<i>h</i> kJ/kg	<i>P<sub>r</sub></i>	<i>u</i> kJ/kg	<i>v<sub>r</sub></i>	<i>s°</i> kJ/kg·K	<i>T</i> K	<i>h</i> kJ/kg	<i>P<sub>r</sub></i>	<i>u</i> kJ/kg	<i>v<sub>r</sub></i>	<i>s°</i> kJ/kg·K
1260	1348.55	290.8	986.90	12.435	3.23638	1600	1757.57	791.2	1298.30	5.804	3.52364
1280	1372.24	310.4	1004.76	11.835	3.25510	1620	1782.00	834.1	1316.96	5.574	3.53879
1300	1395.97	330.9	1022.82	11.275	3.27345	1640	1806.46	878.9	1335.72	5.355	3.55381
1320	1419.76	352.5	1040.88	10.747	3.29160	1660	1830.96	925.6	1354.48	5.147	3.56867
1340	1443.60	375.3	1058.94	10.247	3.30959	1680	1855.50	974.2	1373.24	4.949	3.58335
1360	1467.49	399.1	1077.10	9.780	3.32724	1700	1880.1	1025	1392.7	4.761	3.5979
1380	1491.44	424.2	1095.26	9.337	3.34474	1750	1941.6	1161	1439.8	4.328	3.6336
1400	1515.42	450.5	1113.52	8.919	3.36200	1800	2003.3	1310	1487.2	3.994	3.6684
1420	1539.44	478.0	1131.77	8.526	3.37901	1850	2065.3	1475	1534.9	3.601	3.7023
1440	1563.51	506.9	1150.13	8.153	3.39586	1900	2127.4	1655	1582.6	3.295	3.7354
1460	1587.63	537.1	1168.49	7.801	3.41247	1950	2189.7	1852	1630.6	3.022	3.7677
1480	1611.79	568.8	1186.95	7.468	3.42892	2000	2252.1	2068	1678.7	2.776	3.7994
1500	1635.97	601.9	1205.41	7.152	3.44516	2050	2314.6	2303	1726.8	2.555	3.8303
1520	1660.23	636.5	1223.87	6.854	3.46120	2100	2377.7	2559	1775.3	2.356	3.8605
1540	1684.51	672.8	1242.43	6.569	3.47712	2150	2440.3	2837	1823.8	2.175	3.8901
1560	1708.82	710.5	1260.99	6.301	3.49276	2200	2503.2	3138	1872.4	2.012	3.9191
1580	1733.17	750.0	1279.65	6.046	3.50829	2250	2566.4	3464	1921.3	1.864	3.9474

*Note:* The properties *P<sub>r</sub>* (relative pressure) and *v<sub>r</sub>* (relative specific volume) are dimensionless quantities used in the analysis of isentropic processes, and should not be confused with the properties pressure and specific volume.

*Source:* Kenneth Wark, *Thermodynamics*, 4th ed. (New York: McGraw-Hill, 1983), pp. 785–86, table A-5. Originally published in J. H. Keenan and J. Kaye, *Gas Tables* (New York: John Wiley & Sons, 1948).