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The Open University of Sri Lanka
Faculty of Engineering Technology
Department of Mechanical Engineering

Study Programme	:	Bachelor of Technology Honours in Engineering
Name of the Examination	:	Final Examination
Course Code and Title	:	**MEX5231/DMX5531 Applied Thermodynamics**
Academic Year	:	2017/18
Date	:	3rd February 2019
Time	:	0930 h-1230 h
Duration	:	**3 hours**

General instructions

1. Read all instructions carefully before answering the questions.
2. This question paper consists of **Eight (8)** questions in **Five (5)** pages.
3. Answer any **Five (5) questions** only. All questions carry equal marks.
4. Answer for each question should commence from a new page.
5. This is a Closed Book Test (CBT).
6. Answers should be in clear hand writing.
7. Do not use red colour pen.
8. h-s chart and extract of steam table are provided.

Q1 (a) List four advantages of reheat cycle over the simple Rankine cycle used in steam power plant.

(b) Details of two designs of steam turbine power plant are given below.

Design 01 : Consists of one turbine

Boiler pressure = 40 bar

Condenser pressure = 0.035 bar

Temperature of steam at turbine inlet = 450°C

Isentropic efficiency of turbine = 0.92

Isentropic efficiency of feed pump = 1

Design 02 : Consists of two turbines with reheating stage

Boiler pressure = 40 bar

Condenser pressure = 0.035 bar

Isentropic efficiency of HP turbine = 1

Isentropic efficiency of LP turbine = 0.92

Isentropic efficiency of feed pump = 1

The super-heated steam at 450°C is expanded isentropically till it is dry-saturated in the first turbine. The steam is then reheated to the original superheat temperature of 450°C and is expanded through the second turbine.

Determine the expected thermal efficiency and the specific fuel consumption for the two designs. Which design would give better performance? Justify your answer.

(Take saturated liquid enthalpy at 0.035 bar as 112 kJ/kgK)

Q2 (a) What is the basic difference between axial flow and radial flow turbines?

(b) How does a steam turbine convert energy in steam to shaft work?

(c) In an impulse turbine (with a single raw wheel) the mean diameter of the rotor is 1m and its speed is 3000 rev/min. The nozzle angle is 20° and the ratio of blade speed to steam speed is 0.4. The ratio of relative velocity at outlet from the blades to that at inlet is 0.9. The outlet angle of the blade is 4° less than the inlet angle. The steam flow rate is 10 kg/s.

(i) Draw the velocity diagram for the blades and name velocity components.

(ii) Calculate the tangential thrust and the axial thrust on the blades.

(iii) Calculate the diagram efficiency.

Q3 (a) When selecting a refrigerant for a certain application, what qualities would you look for in the refrigerant?

(b) Refrigerant 134a is the working fluid in an ideal vapour-compression refrigeration cycle that communicates thermally with a cold region at 0°C and a warm region at 26°C. Saturated vapour enters the compressor at 0°C and saturated liquid leaves the condenser at 26°C. The mass flow rate of the refrigerant is 0.08 kg/s.

(i) Show the cycle on T-S diagram.

(ii) Calculate the compressor power in kW

(iii) Determine the refrigeration capacity in tons.

(iv) Determine the coefficient of performance.

(v) Calculate the coefficient of performance of a Carnot refrigeration cycle operating between same warm and cold regions and compare results.

Some properties of R134a at specified temperatures are given below.

Temp °C	Sat. pressure (bar)	Enthalpy (kJ/kg)	
		liquid	vapour
0	3	-	247.23
26	6.85	85.75	-

Enthalpy at the end of compression process is 264.7 kJ/kg

Q4 An electric cable of 10 mm outer diameter has a copper wire of 4 mm diameter inside it, with insulation covering it all around. The insulation material has thermal conductivity of 0.16 W/mK. Cable is exposed in the surroundings at a temperature of 50°C and has heat transfer coefficient of 15 W/m²K. Cable carries a current of 6A. There is a voltage drop of 18 V along the 6 m length of the cable.

(i) Calculate the rate of heat generation due to flow of electrical current.

(ii) Calculate the thermal resistance due to conduction across the plastic interface.

(iii) Calculate the thermal resistance due to convection between surrounding and cable outer surface.

(iv) Determine the temperature at copper wire and insulation interface.

(v) Find out the critical radius of insulation and hence decide whether doubling the insulation thickness would increase or decrease the temperature at the copper wire and insulation interface.

Q5 (a) For a specified pressure ratio, why does multistage compression with intercooling decrease the compressor work, and multistage expansion with reheating increase the turbine work?

(b) In an open cycle gas turbine plant, two stage compression with inter-cooling and one reheating stage are employed. Air is drawn in at a pressure and temperature of 1 bar and 31°C. The overall pressure ratio of compression is 8:1. Temperature of the gases at inlet to the High Pressure (HP) turbine is 577°C and the gases are reheated to 577°C after expansion and then fed in to the Low Pressure (LP) turbine. The HP turbine drives the compressors and the LP turbine drives the alternator.

(i) Calculate the exit temperature and pressure of HP Turbine.

(ii) Determine the reheat pressure.

(iii) Find the temperature of LP turbine exhaust gas.

(iv) Determine the thermal efficiency of the plant.

(v) How would you improve the thermal efficiency of the gas turbine plant further? Explain with reasons.

- Neglect mass of fuel
- Assume perfect intercooling between compression stages
- Assume isentropic expansions and compressions.
- Take Cp as = 1.005 kJ/kgK throughout the cycle

Q6 As shown in Figure Q6 (a) and Q6 (b), steam enters a converging–diverging nozzle at 2 MPa and 400°C with a negligible velocity and a mass flow rate of 2.5 kg/s, and it exits at a pressure of 300 kPa. The flow is isentropic between the nozzle entrance and throat, and the overall nozzle efficiency is 93 percent.

Take specific heat ratio γ as 1.3 for superheated steam.

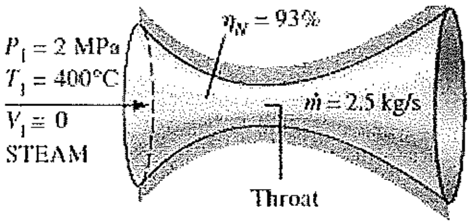


Figure Q6(a)

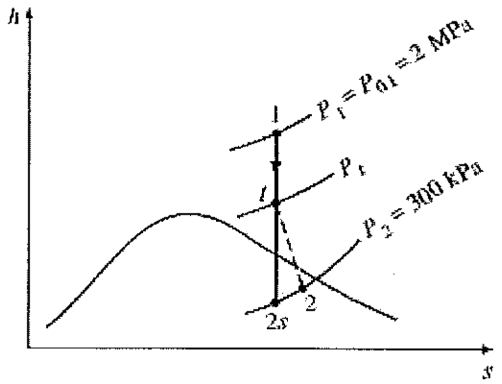


Figure Q6(b)

(i) Determine the pressure at throat.

(ii) Find the enthalpy at inlet and throat.

(iii) What is the velocity at throat?

(iv) If the specific volume of steam at throat is 0.2419 m³/kg, determine the throat area.

(v) Write an expression for nozzle efficiency; hence find actual enthalpy at exit.

(vi) If the specific volume of steam at exit is 0.6776 m³/kg, calculate the exit area.

Q7 (a) Define dew point temperature.

(b) What is enthalpy of combustion? How does it differ from the enthalpy of reaction?

(c) What is enthalpy of formation?

(d) What are the higher and the lower heating values of a fuel? How do they differ?

(e) Propylene (C_3H_6) is burned with 50 percent excess air during a combustion process. Assume complete combustion and a total pressure of products is 105 kPa.

(i) Write down the balanced combustion equation.

(ii) Determine the air–fuel ratio.

(iii) Estimate the dew point temperature.

(Extract of steam table is attached)

Q8 (a) Define Nusselt, Reynolds, and Prandtl numbers with their usual notations and identify each term.

(b) As shown in Figure Q8 an electrically heated thin foil of length 30 mm and width 10 mm is to be used as a wind speed meter. Wind with a temperature T_∞ and velocity U_∞ blows parallel to the longest side. The foil is internally heated by an electric heater dissipating heat (Q average) of 0.32 Watts from both sides and it is to be operated in air with T_∞ = 27°C. The surface temperature Ts of the foil is to be measured at the trailing edge but can be assumed to be constant.

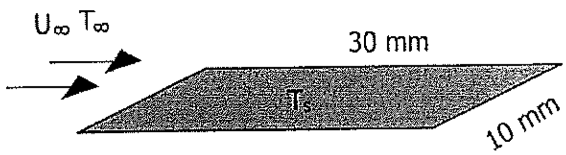


Figure Q 8

(i) Calculate the convective heat transfer coefficient when Ts is 37°C.

(ii) Determine the Nusselt number and Reynolds number. If the critical Reynolds number is 3×10^5, justify that the air flow is laminar.

(iii) Estimate the wind sped at this condition.

Properties of air at 1atm and at the mean film temperature are:

$\nu = 1.522 \times 10^{-5}$ m²/s, k= 0.0253 W/mK

Following data with usual notations can be used

$$Nu = 0.662\,(Re)^{0.5}\,(Pr)^{0.3}$$

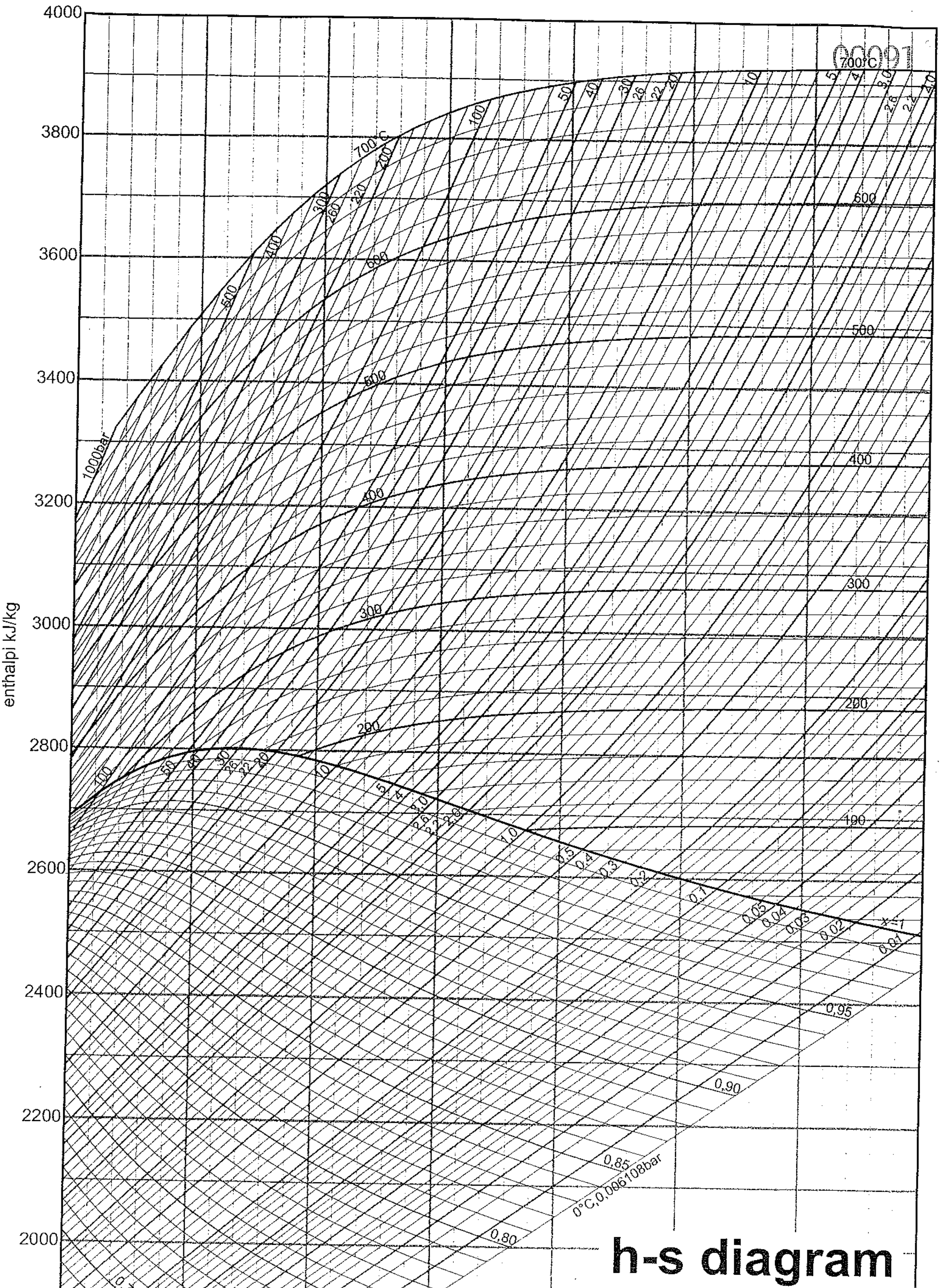
where P_r - Prandtl number = 0.72

Saturated Water and Steam

p [bar]	t_s [°C]	v_g [m³/kg]	u_f [kJ/kg]	u_g	h_f [kJ/kg]	h_{fg}	h_g	s_f [kJ/kg K]	s_{fg}	s_g
0.006112	0.01	206.1	0†	2375	0*	2501	2501	0†	9.155	9.155
0.010	7.0	129.2	29	2385	29	2485	2514	0.106	8.868	8.974
0.015	13.0	87.98	55	2393	55	2470	2525	0.196	8.631	8.827
0.020	17.5	67.01	73	2399	73	2460	2533	0.261	8.462	8.723
0.025	21.1	54.26	88	2403	88	2451	2539	0.312	8.330	8.642
0.030	24.1	45.67	101	2408	101	2444	2545	0.354	8.222	8.576
0.035	26.7	39.48	112	2412	112	2438	2550	0.391	8.130	8.521
0.040	29.0	34.80	121	2415	121	2433	2554	0.422	8.051	8.473
0.045	31.0	31.14	130	2418	130	2428	2558	0.451	7.980	8.431
0.050	32.9	28.20	138	2420	138	2423	2561	0.476	7.918	8.394
0.055	34.6	25.77	145	2422	145	2419	2564	0.500	7.860	8.360
0.060	36.2	23.74	152	2425	152	2415	2567	0.521	7.808	8.329
0.065	37.7	22.02	158	2427	158	2412	2570	0.541	7.760	8.301
0.070	39.0	20.53	163	2428	163	2409	2572	0.559	7.715	8.274
0.075	40.3	19.24	169	2430	169	2405	2574	0.576	7.674	8.250
0.080	41.5	18.10	174	2432	174	2402	2576	0.593	7.634	8.227
0.085	42.7	17.10	179	2434	179	2400	2579	0.608	7.598	8.206
0.090	43.8	16.20	183	2435	183	2397	2580	0.622	7.564	8.186
0.095	44.8	15.40	188	2436	188	2394	2582	0.636	7.531	8.167
0.100	45.8	14.67	192	2437	192	2392	2584	0.649	7.500	8.149
0.12	49.4	12.36	207	2442	207	2383	2590	0.696	7.389	8.085
0.14	52.6	10.69	220	2446	220	2376	2596	0.737	7.294	8.031
0.16	55.3	9.432	232	2450	232	2369	2601	0.772	7.213	7.985
0.18	57.8	8.444	242	2453	242	2363	2605	0.804	7.140	7.944
0.20	60.1	7.648	251	2456	251	2358	2609	0.832	7.075	7.907
0.22	62.2	6.994	260	2459	260	2353	2613	0.858	7.016	7.874
0.24	64.1	6.445	268	2461	268	2348	2616	0.882	6.962	7.844
0.26	65.9	5.979	276	2464	276	2343	2619	0.904	6.913	7.817
0.28	67.5	5.578	283	2466	283	2339	2622	0.925	6.866	7.791
0.30	69.1	5.228	289	2468	289	2336	2625	0.944	6.823	7.767
0.32	70.6	4.921	295	2470	295	2332	2627	0.962	6.783	7.745
0.34	72.0	4.649	302	2472	302	2328	2630	0.980	6.745	7.725
0.36	73.4	4.407	307	2473	307	2325	2632	0.996	6.709	7.705
0.38	74.7	4.189	312	2475	312	2322	2634	1.011	6.675	7.686
0.40	75.9	3.992	318	2476	318	2318	2636	1.026	6.643	7.669
0.42	77.1	3.814	323	2478	323	2315	2638	1.040	6.612	7.652
0.44	78.2	3.651	327	2479	327	2313	2640	1.054	6.582	7.636
0.46	79.3	3.502	332	2481	332	2310	2642	1.067	6.554	7.621
0.48	80.3	3.366	336	2482	336	2308	2644	1.079	6.528	7.607
0.50	81.3	3.239	340	2483	340	2305	2645	1.091	6.502	7.593
0.55	83.7	2.964	351	2486	351	2298	2649	1.119	6.442	7.561
0.60	86.0	2.731	360	2489	360	2293	2653	1.145	6.386	7.531
0.65	88.0	2.535	369	2492	369	2288	2657	1.169	6.335	7.504
0.70	90.0	2.364	377	2494	377	2283	2660	1.192	6.286	7.478
0.75	91.8	2.217	384	2496	384	2278	2662	1.213	6.243	7.456
0.80	93.5	2.087	392	2498	392	2273	2665	1.233	6.201	7.434
0.85	95.2	1.972	399	2500	399	2269	2668	1.252	6.162	7.414
0.90	96.7	1.869	405	2502	405	2266	2671	1.270	6.124	7.394
0.95	98.2	1.777	411	2504	411	2262	2673	1.287	6.089	7.376
1.00	99.6	1.694	417	2506	417	2258	2675	1.303	6.056	7.359

* $\dfrac{h_f}{[\mathrm{kJ/kg}]} = \dfrac{pv_f}{[\mathrm{kJ/kg}]} = \dfrac{p}{[\mathrm{bar}]} \times \dfrac{10^5[\mathrm{N}]}{[\mathrm{m}^2]} \times \dfrac{v_f}{[\mathrm{m^3/kg}]} \times \left[\dfrac{\mathrm{m}^3}{\mathrm{kg}}\right] \times \dfrac{[\mathrm{kJ}]}{10^3[\mathrm{N\,m}]} \times \dfrac{1}{[\mathrm{kJ/kg}]}$

$$= \frac{p}{[\mathrm{bar}]} \times \frac{v_f}{[\mathrm{m^3/kg}]} \times 10^2 = 0.006112 \times 0.0010002 \times 10^2 = 0.0006112$$



h-s diagram
enthalpi kJ/kg
entropi kJ kg⁻¹ K⁻¹
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
5,5
6,0
6,5
7,0
7,5
8,0
8,5
9,0
1000bar
700°C
600
500
400
300
200
100
x=1
0,95
0,90
0,85
0,80
0,75
0,70
0°C,0,006108bar