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

Study Programme	Master of Energy Management (MEM)
Name of the Examination	Final Examination
Course Code and Title	**DMX9402 Thermal Energy Utilities (TEU)**
Academic Year	2020
Date	15th August 2020 (Saturday)
Time	13.30 h– 16.30 h **(IST)**
Duration	**03 hours**

General Instructions

1. Read all instructions carefully before answering the questions.
2. This question paper consists of **Five (5)** questions. **Answer all questions.**
3. All questions carry equal marks
4. **Answer for each question should commence from a new page.**
5. **Relevant data/ charts/ codes are provided.**
6. This is a Closed Book Test (CBT).
7. Answers should be in clear handwriting.
8. Do not use Red color pen.

QUESTION 01 (20 marks)

(a) Briefly explain the direct method of calculating boiler efficiency. **(3 marks)**

(b) As an energy Manager in a factory you are supposed to take a decision on replacing the existing boiler with a new boiler of 84% efficiency. The cost of new boiler is Rs. 4 million. The following information is available related to the existing boiler.

Average steam generation: 5000 kg/hr
Fuel used: furnace oil
Enthalpy gained by the steam in the boiler: 600 kcal/kg of steam
Cost of furnace oil: Rs. 100/ kg
Gross calorific value of the fuel: 9650 kcal/kg
Annual operating hours: 6000 h
Boiler efficiency: 80%

Evaluate the given information and indicate your decision with reasons. **(7 marks)**

(c) Distinguish between topping cycle and bottoming cycle in co-generation plant and give two examples for a specific industry.

(4 marks)

(d) Briefly explain the four main sizing methods of the co-generation plants.

(6 marks)

QUESTION 02 (20 marks)

(a) What is a furnace? Explain the main components of a furnace.

(3 marks)

(b) Explain why furnace efficiencies are lower than boiler efficiencies. List down four energy conservation opportunities in furnaces.

(4 marks)

(c) An energy audit was conducted in a process industry and the details of operating parameters of reheating furnace, observed during the audit are given below.

(7 marks)

Furnace output: 10 TPH (Tons per Hour).
Temperature range of billet heating: from 50 °C to 1200 °C.
Oil Consumption rate: 700 liters/hr.
Specific gravity of fuel: 0.95
Net calorific value (NVC) of fuel: 9650 kCal/kg
Specific heat of billet: 0.12 kcal/ kg°C.
Annual furnace operating hours: 7000 hrs

Find out the thermal efficiency of the furnace on NCV basis.

(d) It is proposed to replace the above oil fired furnace by an electric furnace considering environmental pollution. Estimate the annual savings or loss with this replacement considering the following data:

(6 marks)

Efficiency of proposed electrical furnace: 75%
Electrical energy consumption: 5 MWh/batch
Number of batches: 5000 batches / year
Cost of electricity: Rs. 20 per kWh
Cost of furnace oil: Rs. 100 per kg

Note: Annual operating capacities of both furnaces are same

QUESTION 03 (20 marks)

(a) Discuss the advantages and disadvantages of Shell and tube Heat Exchangers Vs Plate and frame Heat Exchangers. **(4 marks)**

(b) The showers in the changing rooms of a gymnasium will need a continuous supply of 1 ton/min of hot water. One way of doing this is to heat city water from 10 ^{0}C to 90 ^{0}C in a heat exchanger where water flows through the tubes while waste saturated steam at 1 atm condenses in the shell, leaving as liquid at 100 ^{0}C. If the overall heat transfer coefficient, U is, 500 W/m^2 K, Calculate,

(i) Amount of steam needed (in kg/h). **(4 marks)**

(ii) Area of heat exchanger needed **(8 marks)**

Assume Countercurrent configuration
Latent heat of condensation = 2.29 x 10^6 J/kg, Cp for water = 4,184 J/kg K

(c) Briefly describe the core idea of the pinch technology. **(4 marks)**

QUESTION 04 (20 marks)

(a) Briefly explain what will happen to consumption of saturated steam for a given heating process when dryness fraction of steam is increased. **(1 mark)**

(b) In a process heating steam plant, why steam needs to be distributed at highest possible pressure and used at lowest possible pressure in an indirect heating process? **(4 marks)**

(c) Estimate the steam carrying capacity of a 100 NB Sch. 40 pipe at 7 barg and 14 barg saturated steam for **long steam pipe**. What happens to steam carrying capacity of the pipe with increased pressure of steam? **(5 marks)**
(Refer to Table 10.2.4)

(d) In a section of a steam plant, there is a 300 m (equivalent length) long pipe line carrying 800 kg/h saturated steam at inlet pressure 7 barg and outlet pressure 6.5 barg of pipe line. Find out the line size suitable for these parameters. Comment on actual pressure drop through the selected pipe. **(10 marks)**

$$PDF = \frac{F_1 - F_2}{L}$$

Where:
PDF = Pressure Drop Factor (**Ref: Table 10.2.6 for pipe selection**)
F_1 = Pressure factor at inlet pressure (**Ref: Table 10.2.5**)
F_2 = Pressure factor at pressure at a distance of L meters (**Ref: Table 10.2.5**)
L = Equivalent length of pipe (**m**)

QUESTION 05 (20 marks)

(a) What are the three main groups of steam traps? **(3 marks)**

(b) In a steam plant, two indirect heating process equipment are used as given below.

Equipment 1 - operating at rated 7 barg pressure (Steam consumption 1000 kg/h)
Equipment 2 - operating at rated 3 barg pressure (Steam consumption 200 kg/h)

With given data, suggest the major energy saving option for combined system operating at the same time. Assume operating pressures are fixed.
You are not required to do calculations. **(4 marks)**

(c) i) What is the economical thickness of insulation? Show on a graph. **(2 marks)**

ii) What is the purpose of having air bubbles inside insulation material? **(1 mark)**

(d) i) In a freeze dryer, what will happen when solid ice is maintained at a pressure below the triple point and then heated? **(2 marks)**

ii) State first three stages of freeze drying. **(3 marks)**

iii) List down five (5) energy saving measures in industrial dryers. **(5 marks)**

Table 10.2.4
Saturated steam pipeline capacities in kg/h for different velocities (Schedule 40 pipe)

Pressure bar g	Velocity m/s	Pipe size (nominal)										
		15	20	25	32	40	50	65	80	100	125	150
		Actual inside pipe diameter Schedule 40										
		15.80	20.93	26.64	35.04	40.90	52.50	62.70	77.92	102.26	128.20	154.05
		Pipeline capacity kg/h										
0.4	15	9	15	25	43	58	95	136	210	362	569	822
	25	14	25	41	71	97	159	227	350	603	948	1 369
	40	23	40	66	113	154	254	363	561	965	1 517	2 191
0.7	15	10	18	29	51	69	114	163	251	433	681	983
	25	17	30	49	85	115	190	271	419	722	1 135	1 638
	40	28	48	78	136	185	304	434	671	1 155	1 815	2 621
1	15	12	21	34	59	81	133	189	292	503	791	1 142
	25	20	35	57	99	134	221	315	487	839	1 319	1 904
	40	32	56	91	158	215	354	505	779	1342	2 110	3 046
2	15	18	31	50	86	118	194	277	427	735	1 156	1 669
	25	29	51	83	144	196	323	461	712	1 226	1 927	2 782
	40	47	92	133	230	314	517	737	1 139	1 961	3 083	4 451
3	15	23	40	65	113	154	254	362	559	962	1 512	2 183
	25	38	67	109	188	256	423	603	931	1 603	2 520	3 639
	40	61	107	174	301	410	676	964	1 490	2 565	4 032	5 822
4	15	28	50	80	139	190	313	446	689	1 186	1 864	2 691
	25	47	83	134	232	316	521	743	1 148	1 976	3 106	4 485
	40	75	132	215	371	506	833	1 189	1 836	3 162	4 970	7 176
5	15	34	59	96	165	225	371	529	817	1 408	2 213	3 195
	25	56	98	159	276	375	619	882	1 362	2 347	3 688	5 325
	40	90	157	255	441	601	990	1 411	2 180	3 755	5 901	8 521
6	15	39	68	111	191	261	430	613	947	1 631	2 563	3 700
	25	65	114	184	319	435	716	1 022	1 578	2 718	4 271	6 167
	40	104	182	295	511	696	1 146	1 635	2 525	4 348	6 834	9 867
7	15	44	77	125	217	296	487	695	1 073	1 848	2 904	4 194
	25	74	129	209	362	493	812	1 158	1 788	3 080	4 841	6 989
	40	118	206	334	579	788	1 299	1 853	2 861	4 928	7 745	11 183
8	15	49	86	140	242	330	544	775	1 198	2 063	3 242	4 681
	25	82	144	233	404	550	906	1 292	1 996	3 438	5 403	7 802
	40	131	230	373	646	880	1 450	2 068	3 194	5 501	8 645	12 484
10	15	60	105	170	294	401	660	942	1 455	2 506	3 938	5 686
	25	100	175	283	490	668	1 101	1 570	2 425	4 176	6 563	9 477
	40	160	280	453	785	1 069	1 761	2 512	3 880	6 682	10 502	15 164
14	15	80	141	228	394	537	886	1 263	1 951	3 360	5 281	7 625
	25	134	235	380	657	896	1 476	2 105	3 251	5 600	8 801	12 708
	40	214	375	608	1 052	1 433	2 362	3 368	5 202	8 960	14 082	20 333

Table 10.2.5 Pressure factor (F) table

Pressure bar a	Pressure factor (F)
0.05	0.0301
0.10	0.0115
0.15	0.0253
0.20	0.0442
0.25	0.0681
0.30	0.0970
0.35	0.1308
0.40	0.1694
0.45	0.2128
0.50	0.2610
0.55	0.3140
0.60	0.3716
0.65	0.4340
0.70	0.5010
0.75	0.5727
0.80	0.6489
0.85	0.7298
0.90	0.8153
0.95	0.9053
1.013	1.0250

Pressure bar g	Pressure factor (F)
0	1.025
0.05	1.126
0.10	1.230
0.15	1.339
0.20	1.453
0.25	1.572
0.30	1.694
0.35	1.822
0.40	1.953
0.45	2.090
0.50	2.230
0.55	2.375
0.60	2.525
0.65	2.679
0.70	2.837
0.75	2.999
0.80	3.166
0.85	3.338
0.90	3.514
0.95	3.694
1.00	3.878
1.05	4.067
1.10	4.260
1.15	4.458
1.20	4.660
1.25	4.866

Pressure bar g	Pressure factor (F)
1.30	5.076
1.35	5.291
1.40	5.510
1.45	5.734
1.50	5.961
1.55	6.193
1.60	6.429
1.65	6.670
1.70	6.915
1.75	7.164
1.80	7.417
1.85	7.675
1.90	7.937
1.95	8.203
2.00	8.473
2.05	8.748
2.10	9.026
2.15	9.309
2.20	9.597
2.25	9.888
2.30	10.18
2.35	10.48
2.40	10.79
2.45	11.40
2.50	11.41
2.55	11.72
2.60	12.05
2.65	12.37
2.70	12.70
2.75	13.03
2.80	13.37
2.85	13.71
2.90	14.06
2.95	14.41
3.00	14.76
3.10	15.48
3.20	16.22
3.30	16.98
3.40	17.75
3.50	18.54
3.60	19.34
3.70	20.16
3.80	21.00
3.90	21.85
4.00	22.72
4.10	23.61
4.20	24.51
4.30	25.43
4.40	26.36

Pressure bar g	Pressure factor (F)
4.50	27.32
4.60	28.28
4.70	29.27
4.80	30.27
4.90	31.29
5.00	32.32
5.10	33.37
5.20	34.44
5.30	35.52
5.40	36.62
5.50	37.73
5.60	38.86
5.70	40.01
5.80	41.17
5.90	42.35
6.00	43.54
6.10	44.76
6.20	45.98
6.30	47.23
6.40	48.48
6.50	49.76
6.60	51.05
6.70	52.36
6.80	53.68
6.90	55.02
7.00	56.38
7.10	57.75
7.20	59.13
7.30	60.54
7.40	61.96
7.50	63.39
7.60	64.84
7.70	66.31
7.80	67.79
7.90	69.29
8.00	70.80
8.10	72.33
8.20	73.88
8.30	75.44
8.40	77.02
8.50	78.61
8.60	80.22
8.70	81.84
8.80	83.49
8.90	85.14
9.00	86.81
9.10	88.50
9.20	90.20
9.30	91.92

Pressure bar g	Pressure factor (F)
9.40	93.66
9.50	95.41
9.60	97.18
9.70	98.96
9.80	100.75
9.90	102.57
10.00	104.40
10.20	108.10
10.40	111.87
10.60	115.70
10.80	119.59
11.00	123.54
11.20	127.56
11.40	131.64
11.60	135.78
11.80	139.98
12.00	144.25
12.20	148.57
12.40	152.96
12.60	157.41
12.80	161.92
13.00	166.50
13.20	171.13
13.40	175.83
13.60	180.58
13.80	185.40
14.00	190.29
14.20	195.23
14.40	200.23
14.60	205.30
14.80	210.42
15.00	215.61
15.20	220.86
15.40	226.17
15.60	231.50
15.80	236.97
16.00	242.46
16.20	248.01
16.40	253.62
16.60	259.30
16.80	265.03
17.00	270.83
17.20	276.69
17.40	282.60
17.60	288.58
17.80	294.52
18.00	300.72

Table 10.2.6 Pipeline capacity from pressure drop factor

Pressure drop factor (PDF)	Pipe size (mm)												
	15	20	25	32	40	50	65	80	100	150	200	250	300
	Capacity (kg/h)												
0.00016						30.40	55.41	90.72	199.1	598.2	1 275	2 329	3 800
0.00020					16.18	34.32	62.77	103.0	225.6	662.0	1 437	2 623	4 276
0.00025				10.84	17.92	38.19	69.31	113.2	249.9	735.5	1 678	2 904	4 715
0.00030				11.95	19.31	41.83	75.86	124.1	271.2	804.5	1 733	3 172	5 149
0.00035			6.86	12.44	20.59	43.76	80.24	130.0	285.3	845.3	1 823	3 346	5 530
0.00045		3.62	7.94	14.56	23.39	50.75	92.68	150.9	333.2	979.7	2 118	3 884	6 267
0.00055		4.04	8.99	16.18	26.52	57.09	103.8	170.8	373.1	1 101	2 382	4 338	7 057
0.00065		4.46	9.56	17.76	29.14	62.38	113.8	186.7	409.6	1 207	2 595	4 781	7 741
0.00075		4.87	10.57	19.31	31.72	68.04	124.1	203.2	445.9	1 315	2 836	5 172	8 367
0.00085		5.52	11.98	21.88	35.95	77.11	140.7	230.2	505.4	1 490	3 215	5 861	9 482
0.00100	1.96	5.84	12.75	23.50	38.25	81.89	148.6	245.2	539.4	1 579	3 383	6 226	10 052
0.00125	2.10	6.26	13.57	24.96	40.72	87.57	159.8	261.8	577.9	1 699	3 634	6 655	10 639
0.00150	2.39	7.35	15.17	28.04	45.97	98.84	179.3	295.1	652.8	1 908	4 091	7 493	11 999
0.00175	2.48	7.51	16.30	29.61	49.34	103.4	188.8	311.1	686.5	2 017	4 291	7 852	13 087
0.0020	2.84	8.58	18.63	33.83	56.39	118.2	215.8	355.5	784.6	2 305	4 904	8 974	14 956
0.0025	3.16	9.48	20.75	37.25	61.30	132.0	240.5	391.3	881.7	2 456	5 422	10 090	16 503
0.0030	3.44	10.34	22.5	40.45	66.66	143.4	262.0	429.8	924.4	2 767	6 068	11 033	18 021
0.0040	4.17	12.50	26.97	48.55	80.91	173.1	313.8	514.9	1 128	3 330	7 208	13 240	21 625
0.0050	4.71	14.12	30.40	54.92	90.23	196.1	354.0	578.6	1 275	3 727	8 189	14 858	24 469
0.0060	5.25	15.69	35.80	60.31	99.05	215.8	392.3	647.3	1 412	4 148	9 072	16 476	26 970
0.0080	6.08	18.34	39.23	70.12	116.2	251.5	456.0	750.3	1 648	4 879	10 543	19 173	31 384
0.0100	6.86	20.64	44.13	79.44	130.4	283.9	514.9	845.9	1 863	5 492	11 867	21 576	35 307
0.0125	7.35	22.20	47.28	81.00	140.1	302.1	547.3	901.9	1 983	5 867	12 697	23 074	37 785
0.0150	8.27	25.00	53.33	95.62	157.2	342.0	620.6	1 020	2 230	6 620	14 251	25 974	42 616
0.0175	8.58	26.39	55.78	100.4	165.6	360.4	665.1	1 073	2 360	6 994	15 017	27 461	44 194
0.0200	9.80	30.16	63.75	114.7	189.3	411.9	760.1	1 226	2 697	7 993	17 163	31 384	50 508
0.0250	10.99	33.48	70.73	127.3	209.8	459.7	834.6	1 367	2 970	8 817	19 332	34 750	56 581
0.0300	12.00	36.78	77.23	137.9	229.9	501.1	919.4	1 480	3 264	9 792	20 917	37 697	62 522
0.0400	14.46	44.16	93.17	169.2	279.5	600.7	1 093	1 790	3 923	11 622	25 254	45 604	75 026
0.0500	16.43	49.53	104.4	191.2	313.8	676.7	1 231	2 020	4 413	13 044	28 441	51 489	85 324
0.060	18.14	52.96	115.7	210.8	343.2	750.3	1 373	2 231	4 855	14 368	31 384	57 373	
0.080	21.06	62.28	134.8	245.2	402.1	872.8	1 594	2 599	5 688	16 672	36 532		
0.100	24.03	70.12	152.0	277.0	456.0	980.7	1 804	2 942	6 424	18 879			
0.120	25.99	77.48	167.7	306.5	500.2	1 079	1 986	3 236	7 110	20 841			
0.150	28.50	84.13	183.9	334.2	551.7	1 195	2 161	3 494	7 769				
0.200	34.32	102.0	220.7	402.1	622.0	1 427	2 599	4 217	9 317				
0.250	37.72	112.7	245.2	447.9	735.5	1 565	2 876	4 668					
0.300	41.37	122.7	266.6	487.3	804.5	1 710	3 126	5 057					
0.350	43.34	128.7	283.2	514.9	841.0	1 802	3 261						
0.400	49.93	147.1	323.6	588.4	961.1	2 059	3 727						
0.450	50.31	150.0	326.6	600.2	979.9	2 083							
0.500	55.90	166.7	362.9	666.9	1 089	2 314							
0.600	62.28	185.3	402.1	735.5	1 201								
0.700	63.07	188.8	407.6	750.9									
0.800	72.08	215.8	465.3	858.1									
0.900	73.28	218.4	476.6										