

23CGC053**Process Economics and Project Management**

Semester 1 2023/24

In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **2 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

Attempt **THREE** questions in total. Each question carries 25 marks.

Candidates should show full working for all calculations and derivations.

A table of the Normal distribution is provided at the end of the paper.

1. The final appraisal is being made by a chemicals company for a proposed new plant in the UK. Values for the initial capital cost ($C = \text{£}10 \text{ M}$) and annual fixed costs ($F = \text{£}1.5 \text{ M/y}$) are known to a high degree of confidence, but there is some considerable uncertainty in the sales volume (S), sales price (p) and variable operating costs (v). Estimates of these are provided in Table Q1-1, where pessimistic and optimistic values are regarded as estimates six standard deviations apart. The company uses a Gross Return on Investment of 30% per annum as a minimum benchmark when making investment decisions.

Table Q1-1

	Most likely value	Pessimistic value	Optimistic value
Average sales (S)	9 000 te/y	6 000 te/y	10 500 te/y
Average sales price (p)	£1 000 /te	£550 /te	£1 150 /te
Variable costs (v)	£500 /te	£740 /te	£260 /te

- (a) Show that the Gross Return on Investment (GROI or R) for the project based on the most likely values just meets the company benchmark criterion of 30% per annum. [3 marks]
- (b) By also taking into account the pessimistic and optimistic values in Table Q1-1, calculate:
- (i) the expected GROI, [4 marks]
 - (ii) the standard deviation of the GROI, [10 marks]
 - (iii) the probability of the project meeting a GROI of 30% p.a. [4 marks]
- (c) Comment on the result. [2 marks]
- (d) State any assumptions that you made (or are implicit) in the analysis performed for part (b). [2 marks]

2. (a) Give an outline proof of the relationship:

$$NPV = P \left(\frac{1 - (1 + i)^{-n}}{i} \right) - C$$

Eq Q2

taking care to explain the assumptions made in the proof and the meanings of the symbols. [5 marks]

(b) An obsolete refrigeration plant is rated at 15 kW and runs for 50% of the time under thermostatic control. A proposed replacement is rated at 10 kW and would run for 25% of the time. Electricity costs can be taken as a constant 22p per kWh and the replacement plant is to be formally appraised over 10 years' life. Assume there are always 365 days in a year.

- (i) What is the maximum capital that should be invested in the replacement if a discounted cash flow rate of return (DCFRR) of 15% p.a. is required? [6 marks]
- (ii) What is the maximum capital that should be invested if a pay-back period of 4 years is required? [2 marks]
- (iii) What maximum DCF rates of return are achievable for each of the capital investments in (i) and (ii) if the new refrigeration plant continues to work indefinitely (theoretically, for an infinite number of years)? [4 marks]
- (iv) What do the numbers calculated in (b) (iii) also represent? [2 marks]
- (v) What project life would render the maximum acceptable payback period of 4 years and the minimum acceptable DCFRR of 15% p.a. compatible? [6 marks]

3. A gas absorption column system is to be installed in a chemical plant. The system comprises a gas feed blower, an external heat exchanger to cool the gases fed to the absorption column, the absorption column, and a process control unit.

The project is broken up into several jobs as shown in Table Q3-1. Each job has been assigned a normal (most likely) time for completion, plus optimistic and pessimistic times outside which completion is very unlikely to fall (probabilities of the order of 0.1%).

Table Q3-1 – Jobs and timing to install gas absorption column system.

		Normal time (days)	Optimistic time (days)	Pessimistic time (days)
A	Prepare location for installation	22	14	45
B	Install process and service lines ready for connection	12	10	17
C	Install gas feed blower on foundation	3	1	5
D	Install external heat exchanger	5	3	7
E	Mount absorption column	7	4	10
*F	Install control module	2	1	3
G	Connect gas blower, heat exchanger and absorption column with pipeline	9	5	13
H	Connect process and service lines	5	4	9
I	Connect controls	7	6	14
J	Insulate plant	10	8	15
K	Test and commission plant	15	11	28

*The control unit should be installed after all heavy units have been installed.

- (a) Draw a fully labelled activity-on-arrow diagram for the project considering the safety of the operations. Explain, with a short narrative, the logic used in drawing the diagram. Label each activity with the activity code letters given and the corresponding duration. Label each node with a node number, the Earliest Event Time (EET) and the Latest Event Time (LET). [13 marks]
- (b) Estimate the time within which the project is 95% certain of completion. [12 marks]

4. The source temperatures, target temperatures and stream heat capacities of four process streams in a chemical plant are shown in Table Q4-1.

Table Q4-1. Source temperatures, target temperatures and stream heat capacities of process streams.

Stream	Source temperature, (°C)	Target temperature (°C)	Stream heat capacity (kW/°C)
1 Hot	250	120	3
2 Hot	240	60	3
3 Cold	120	190	5
4 Cold	40	200	2.5

The temperature-enthalpy diagram for this heat exchanger network is shown in Fig Q4-1.

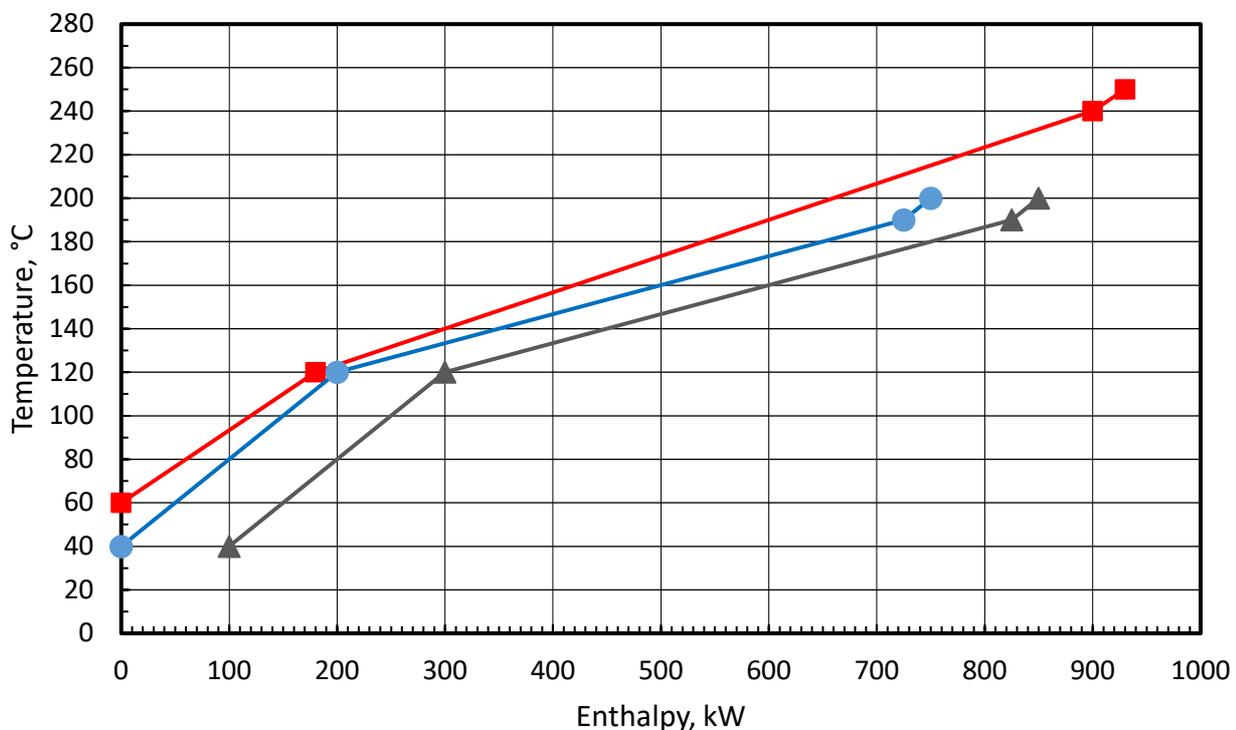


Fig Q4-1. Temperature-enthalpy diagram showing the hot line (squares), the cold line (circles) and the cold line shifted by 100 kW (triangles).

- (a) Attempt an efficient “common sense” design (a design that makes no reference to the Temperature-Enthalpy diagram). Show this design as a fully labelled heat exchanger network diagram, showing the temperatures of each stream across the network, the power requirement of each heat exchanger, heater or cooler, and all the checks over the temperatures across the heat exchangers. [9 marks]

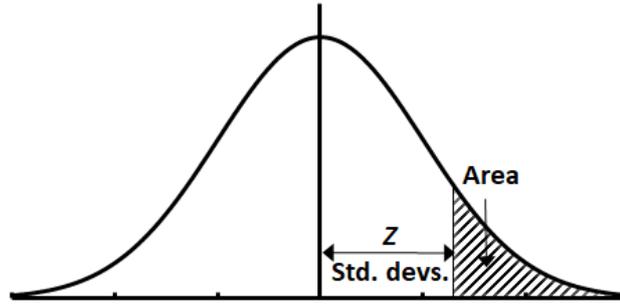
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Q4 Continued/...

- (b) Draw a fully labelled heat exchanger network that maximises heat recovery and minimises utilities consumptions, considering a minimum approach temperature of 20°C. Check that the basic rules for this “pinch” design are satisfied across the network, taking appropriate design actions in case the rules are not met. [12 marks]
- (c) Critically compare the “common sense” and the “pinch” design, highlighting the advantages and disadvantages of each design. [4 marks]

NORMAL DISTRIBUTION

Z, Standard deviations from mean



	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.50000	.49601	.49202	.48803	.48405	.48006	.47608	.47210	.46812	.46414
0.1	.46017	.45621	.45224	.44828	.44433	.44038	.43644	.43251	.42858	.42466
0.2	.42074	.41683	.41294	.40905	.40517	.40129	.49743	.49358	.48974	.48591
0.3	.38209	.37828	.37448	.37070	.36693	.36317	.35942	.35569	.35197	.34827
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0.6	.27425	.27093	.26763	.26435	.26109	.25785	.25463	.25143	.24824	.24510
0.7	.24196	.23885	.23576	.23270	.22965	.22663	.22363	.22065	.21760	.21476
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1.4	.08076	.07927	.07780	.07636	.07503	.07353	.07214	.07078	.06944	.06811
1.5	.06681	.06652	.06426	.06301	.06178	.06057	.05938	.05821	.05705	.05592
1.6	.05480	.05370	.05262	.05155	.05050	.04947	.04846	.04756	.04648	.04551
1.7	.04457	.04363	.04272	.04182	.04093	.04006	.03920	.03836	.03754	.03673
1.8	.03593	.03515	.03438	.03363	.03288	.03216	.03144	.03074	.03005	.02938
1.9	.02872	.02807	.02743	.02680	.02619	.02559	.02500	.02442	.02385	.02330
2.0	.02275	.02222	.02169	.02118	.02068	.02018	.01970	.01923	.01876	.01831
2.1	.01786	.01743	.01700	.01659	.01618	.01578	.01539	.01500	.01463	.01426
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2.3	.01072	.01044	.01017	.00990	.00964	.00939	.00914	.00889	.00866	.00842
2.4	.00820	.00798	.00776	.00755	.00734	.00714	.00695	.00676	.00657	.00639
2.5	.00621	.00604	.00587	.00570	.00554	.00539	.00523	.00508	.00494	.00480
2.6	.00466	.00453	.00440	.00427	.00415	.00402	.00391	.00379	.00368	.00357
2.7	.00347	.00336	.00326	.00317	.00307	.00298	.00289	.00281	.00272	.00264
2.8	.00256	.00248	.00241	.00233	.00226	.00219	.00212	.00205	.00199	.00193
2.9	.00187	.00181	.00175	.00169	.00164	.00159	.00154	.00149	.00144	.00139
3.0	.00135	.00131	.00126	.00122	.00118	.00114	.00111	.00107	.00103	.00100
3.1	.00097	.00094	.00090	.00087	.00084	.00082	.00079	.00076	.00074	.00071
3.2	.00069	.00066	.00064	.00062	.00060	.00058	.00056	.00054	.00052	.00050
3.3	.00048	.00047	.00045	.00043	.00042	.00040	.00039	.00038	.00036	.00035
3.4	.00034	.00032	.00031	.00030	.00029	.00028	.00027	.00026	.00025	.00024
3.5	.00023	.00022	.00022	.00020	.00020	.00019	.00019	.00018	.00017	.00017
3.6	.00016	.00015	.00015	.00014	.00014	.00013	.00013	.00012	.00012	.00011
3.7	.00011	.00010	.00010	.00010	.00009	.00009	.00009	.00008	.00008	.00008
3.8	.00007	.00007	.00007	.00006	.00006	.00006	.00006	.00005	.00005	.00005
3.9	.00005	.00005	.00005	.00004	.00004	.00004	.00004	.00004	.00003	.00003
4.0	.00003	.00003	.00003	.00003	.00003	.00003	.00002	.00002	.00002	.00002
4.1	.00002	.00002	.00002	.00002	.00002	.00002	.00002	.00002	.00002	.00002
4.2	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001
4.3	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001
4.4	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001

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