NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OF INDUSTRIAL TECHNOLOGY

DEPARTMENT OF CHEMICAL ENGINEERING

CHEMICAL ENGINEERING THERMODYNAMICS 1A

ECE/TCE 2104

Final Examination Paper

August 2024

This examination paper consists of 4 pages

Time Allowed: 3 hours

Total Marks: 100

Special Requirements: Chemical Engineering Thermodynamics Tables

INSTRUCTIONS

1. Answer ALL QUESTIONS.
2. Each question carries 25 marks
3. Use of calculators is permissible

MARK ALLOCATION

QUESTION	MARKS
1.	**25**
2.	**25**
3.	**25**
4.	**25**
TOTAL ATTAINABLE MARKS	**100**

SECTION A

Answer all questions

QUESTION 1

a. Nitrogen gas initially at 8.5 bar expands isentropically to 1 bar and 423.15 K. Assuming nitrogen to be an ideal gas, calculate the initial temperature and the work produced per mole of nitrogen. [5]

$$\Delta S = R\left[A\ln(\tau) + \left[B\,\frac{T}{\tau} + \frac{D}{T^2}\left(\frac{\tau+1}{2}\right)\right](\tau - 1) - ln\left(\frac{P}{P_o}\right)\right]$$

b. A steam power plant operating on a regenerative cycle, as illustrated in Fig. 8.5, includes just one feedwater heater. Steam enters the turbine at 4500 kPa and 773.15 K (500°C) and exhausts at 20 kPa. Steam for the feedwater heater is extracted from the turbine at 350 kPa, and in condensing raises the temperature of the feedwater to within 6 K (6°C) of its condensation temperature at 350 kPa. If the turbine and pump efficiencies are both 0.78, what is the thermal efficiency of the cycle and what fraction of the steam entering the turbine is extracted for the feedwater heater? [15]

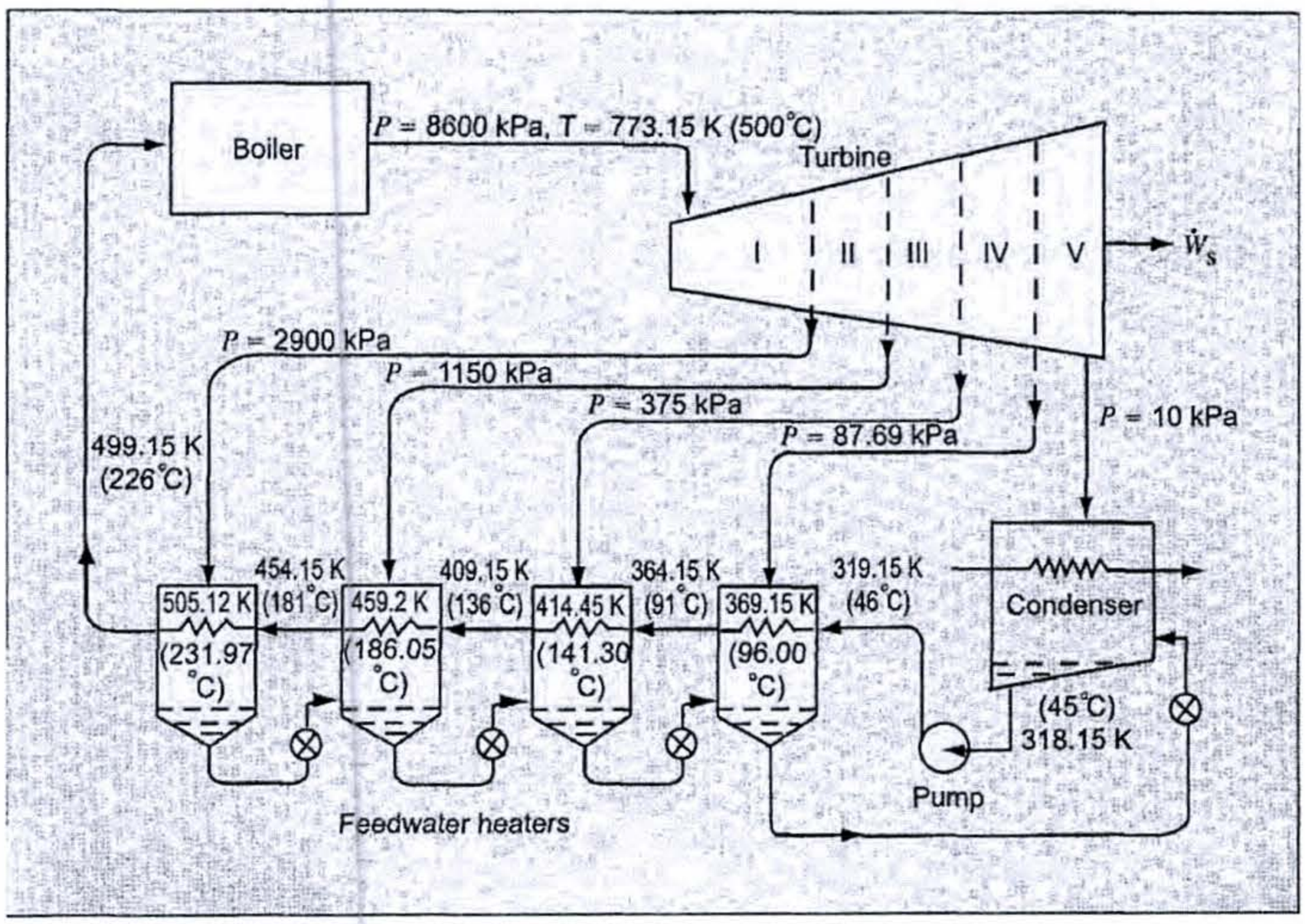

Figure A1: Steam power plant with feedwater heating

c. What are the important factors which govern the choice of a refrigerant? [5]

QUESTION 2

a. Air at 1 atm and 308.15 K (35°C) is compressed in a staged reciprocating compressor (with intercooling) to a final pressure of 50 atm. For each stage, the inlet gas temperature is 308.15 K (35°C) and the maximum allowable outlet temperature is 473.15 K (200°C). Mechanical power is the same for all stages, and isentropic efficiency is 65% for each stage. The volumetric flowrate of air is 0.5 m^3s^{-1} at the inlet to the first stage.

i. How many stages are required? [6]

ii. What is the mechanical-power requirement per stage? [3]

$$W_S(isentropic) = C_P T_1 \left[\left(\frac{P_2}{P_1}\right)^{R/C_P} - 1\right]$$

iii. What is the heat duty for each intercooler? [2]

iv. Water is the coolant for the intercoolers. It enters at 298.15 K (25°C) and leaves at 318.15 K (45°C). What is the cooling-water rate per intercooler? [4]

Assume air is an ideal gas with C_p= (7/2)R.

b. From the fundamental Property Relations and Maxwell's equations derive the general equations which relate the properties of homogenous fluids of constant composition to temperature and pressure: [10]

$$dH = C_P dT + \left[V - T\left(\frac{\partial V}{\partial T}\right)_P\right] dP$$

$$dS = C_P \frac{dT}{T} - \left(\frac{\partial V}{\partial T}\right)_P dP$$

QUESTION 3

a. Cool water at 15°C is throttled from 5 atm to 1 atm, as in a kitchen faucet. What is the temperature change of the water? What is the lost work per kilogram of water for this everyday household happening? At 288.15 K and 1 atm, the volume expansivity, β for liquid water is about 1.5 x 10^{-4} K^{-1}. The surroundings temperature T is 293.15 K. State carefully any assumptions you make. The steam tables are a source of data. [10]

b. A refrigeration system requires 1.5 kW of power for a refrigeration rate of 4 kW.

i. What is the coefficient of performance? [4]

ii. How much heat is rejected in the condenser? [2]

iii. If heat rejection is at 313.15 K, what is the lowest temperature the system can possibly maintain? [3]

c. A stream of water at 85°C, flowing at the rate of 5 kg s^{-1} is formed by mixing water at 24°C with saturated steam at 400 kPa. Assuming adiabatic operation, at what rates are the steam and water fed to the mixer? [6]

QUESTION 4

a. The combustion gases in a petrol engine cylinder are at 30 bar and 800degC before expansion. The gases expand through a volume ratio (V_2/V_1) of (8.5/1) and occupy 510 cm^3 after expansion. When the engine is air cooled the polytropic expansion index n = 1.15. What is the temperature and pressure of the gas after expansion, and what is the work output? [10]

b. 1 kg of air is taken through a Diesel cycle. Initially the air is at 15 °C and 1 atm. The compression ratio is 15 and the heat added is 1850 kJ. Calculate the mean effective pressure of the cycle. [5]

c. SI engines need liquid fuels with high volatility for carburetion whilst CI engine fuels are less volatile, more viscous and heavier than petrol.

i. What is a SI engine? [2]

ii. What is a CI engine? [2]

iii. What is carburetion? [2]

iv. What is antiknocking? [2]

v. Discuss why sulphur in petroleum fuels is regulated. [2]

(END OF QUESTION PAPER)