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**OLLSCOIL NA hEIREANN**
*The National University of Ireland*

**National University of Ireland, Galway.**

***Summer Examinations, 2000/01***

**Third Year Mechanical & Biomedical Engineering Examination**

**APPLIED THERMODYNAMICS**

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**Attempt *FOUR* Questions**
**Time allowed: 3 Hours**

The following are available:
*Tables A-1, A-2(a), A-2(b), A-4 to A-8, A-11 to A-13, A-26, A-27 and figures A-9, A-10, A-14 and A-33 from Cengel and Boles, "Thermodynamics: an engineering approach" (3rd ed.) Enthalpy-Entropy Diagram for steam by Hickson and Taylor.*

**1(a)** Starting with the equation $Tds = du + pdv$, prove that the entropy change of an ideal gas in any process is given by:

$$s_2 - s_1 = c_v \ln(T_2 / T_1) + R \ln(v_2 / v_1)$$ ***(10)***

**(b)** A completely insulated, rigid vessel of total volume 20 litres contains 5 litres of helium at 6 MPa and 293K, separated by a partition from an evacuated chamber of volume 15 litres. Initially, the gas is at rest. The partition is suddenly removed, and after some time, the gas returns to equilibrium, filling the whole vessel.

Find the final pressure and temperature of the helium. ***(7)***

Calculate the total entropy change of the helium. ***(5)***

What is the entropy change of the surroundings? ***(3)***

2. In a simple power plant, steam circulates at 2.2 kg/s and enters the pump as saturated liquid at 50°C. Steam enters the boiler at 12.5 MPa and leaves it at 11 MPa and 600°C. The turbine isentropic efficiency is 85%.

(a) Calculate the power output and the thermal efficiency of the plant. *(18)*

(b) What turbine efficiency would be required to raise the cycle thermal efficiency to 37%? (Assume that only the turbine exit condition is allowed to change – all other states remain the same). *(3)*

(c) It is suggested that a single reheat stage be added to the plant to boost efficiency. Sketch a T-s diagram showing both the original cycle and the *most efficient possible* single-stage reheat cycle which would not exceed the maximum pressure and temperature of the basic cycle. Include the 12.5 MPa constant pressure line in the diagram. *(4)*

3. A heat pump used for domestic heating operates on the ideal vapour-compression cycle with refrigerant R134a. Ambient temperature is 5°C, and the house interior is to be maintained at 20°C. Under these conditions the house loses heat to the environment at a rate of 15 kW. The evaporator pressure is 0.2 MPa and the condenser pressure is 1 MPa.

(a) Sketch the cycle on a *T-s* diagram and calculate the required mass flow rate of refrigerant, the power input, and the coefficient of performance. *(15)*

(b) The compressor in the heat pump is powered by mains electricity, which is supplied by a remote generating station which operates at a thermal efficiency of 39%. Calculate the coefficient of performance in an alternative form which reflects the true cost of the energy input. *(5)*

(c) Calculate the coefficient of performance for a Carnot heat pump operating at the same interior and ambient temperatures. *(5)*

4. **Figure 4** shows a power plant cooling tower where 2.5 kg/s of water at 40°C (from the power plant condenser) enters the top of the cooling tower, and the cooled water leaves the bottom at 20°C. The air-water vapour mixture enters the bottom of the cooling tower at 100 kPa, and has a dry-bulb temperature of 22°C and a wet-bulb temperature of 15°C. The air-water vapour mixture leaves the tower at 95 kPa, 30°C, with a relative humidity of 80%.

   Determine the mass flow rate of air that must be used and the fraction of the incoming water that evaporates.

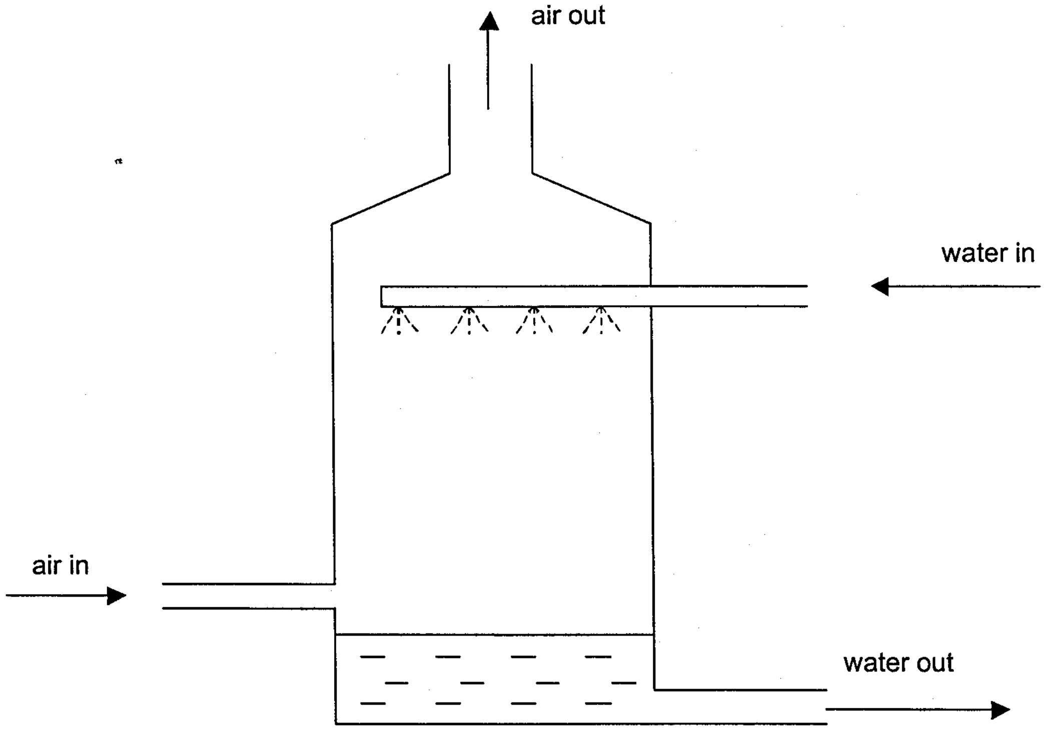


**Figure 4** Schematic diagram of cooling tower.

**5** Consider a theoretical engine operating on the ideal air-standard Diesel cycle with a compression ratio of 20 and a cut-off ratio of 2.5. The air at the engine's inlet is at 101 kPa and 20°C.

**(a)** Calculate the pressure and temperature at the end of the compression process, the end of the constant pressure heat addition process, and the end of the expansion process. *(15)*

**(b)** Sketch the air-standard Diesel cycle on $p$-$v$ and $T$-$s$ diagrams. *(4)*

**(c)** On the same $p$-$v$ and $T$-$s$ diagrams, show a Diesel cycle with a higher cut-off ratio. Is this cycle with higher cut-off ratio more or less efficient? Explain your answer (in 100 words or less) with reference to the diagrams. *(6)*

**6.** A 1.6 litre four-cylinder four-stroke spark ignition engine is tested at a speed of 5000 rpm. The brake power is measured as 60.8 kW and the fuel consumption is 4.04 g/s. Cylinder pressure and piston position are recorded during the test, giving the indicator (*p*-*V*) diagram shown in **Figure 6**. The fuel is petrol with a calorific value of 48.34 MJ/kg.

**(a)** Calculate the overall efficiency and the brake mean effective pressure of the engine. *(12)*

**(b)** Estimate the indicated work per cylinder per cycle, mentioning your method (an accuracy of ±50J is adequate)

Calculate the indicated mean effective pressure and the mechanical efficiency. *(4)*

What is the engine's compression ratio? *(3)*

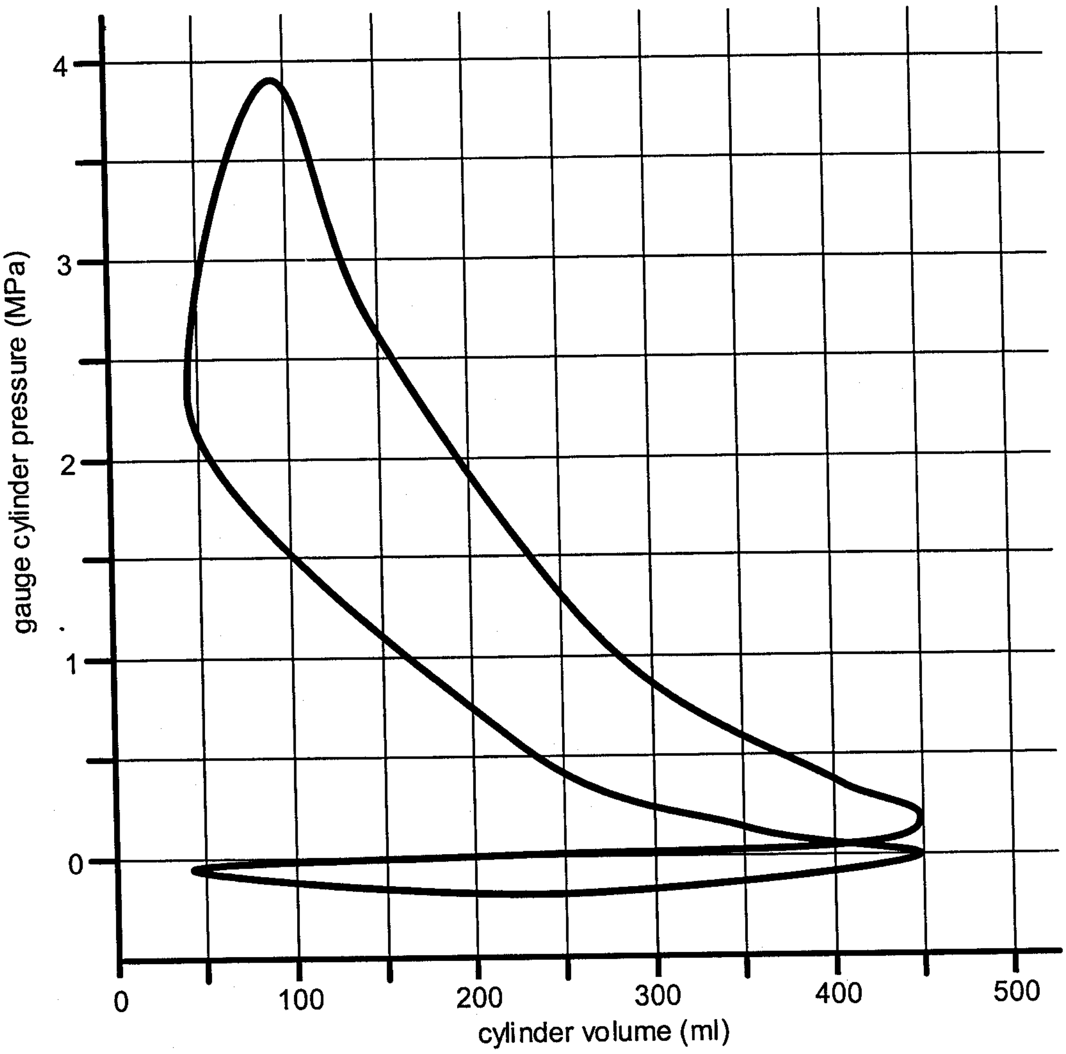


**Figure 6** Indicator diagram recorded for engine of Question 6.