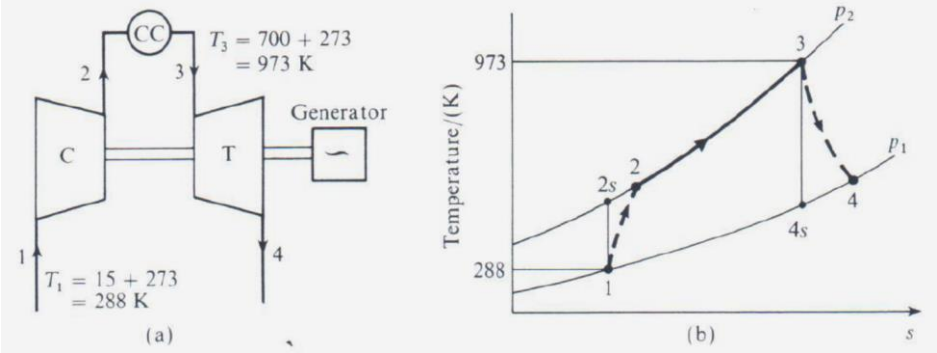
Example 6

A gas-turbine unit has a pressure ratio of 10/1 and a maximum cycle temperature of 700°C. The isentropic efficiencies of the compressor and turbine are 0.82 and 0.85 respectively. Calculate the power output of an electric generator geared to the turbine when the air enters the compressor at 15°C at the rate of 15 kg/s. Take C_p=1.005 kJ/kgK and γ=1.4 for compression process, and take C_p=1.11 kJ/kgK and γ=1.333 for the expansion process.



From the equation for an isentropic process

$$\frac{T_{2s}}{T_1} = \left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma}$$

Therefore,

$$T_{2s} = 288 \times (10)^{(0.4)/1.4} = 288 \times 1.931 = 566.128\text{K}$$

Then,

$$\eta_{comp} = \frac{T_{2s} - T_1}{T_2 - T_1} = \frac{566.128 - 288}{T_2 - 288} = 0.82$$

$$T_2 = 614.99\text{K}$$

Similarly for turbine

$$\frac{T_3}{T_{4s}} = \left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma}$$

$$T_{4s} = \left(\frac{973}{10^{0.333/1.333}}\right) = \frac{973}{1.778} = 547.244\text{K}$$

Then,

$$\eta_{turb} = \frac{T_3 - T_4}{T_3 - T_{4s}} = \frac{973 - T_4}{973 - 547.244} = 0.85$$

$$T_4 = 611.11\text{K}$$

$$W_{compressor,in} = C_p(T_2 - T_1) = 1.005(614.99 - 288) = 1.005 \times 326.8 = 328.434\ {}^{kJ}/_{kg}$$

$$W_{turbine,out} = C_p(T_3 - T_4) = 1.11(973 - 611.11) = 1.11 \times 361.89 = 401.698\ {}^{kJ}/_{kg}$$

Therefore,

$$W_{net} = \text{Turbine work output - Compressor work input}$$

$$= 401.698 - 328.434 = 73.26\ {}^{kJ}/_{kg}$$

$$P_{output} = 73.26 \times 15 = 1098.96 kW$$

Calculate the cycle efficiency and the work ratio of the plant by assuming that C_P for the combustion process is 1.11kJ/kgK.

$$q_{in} = C_p(T_3 - T_2) = 1.11(973 - 614.99) = 397.39\ {}^{kJ}/_{kg}$$

Therefore,

$$\eta_{cycle} = \frac{W_{net}}{q_{in}} = \frac{73.26}{397.39} = 0.1844$$

$$\text{Work ratio} = \frac{W_{net}}{W_{gross,out}} = \frac{73.26}{401.698} = 0.1824$$