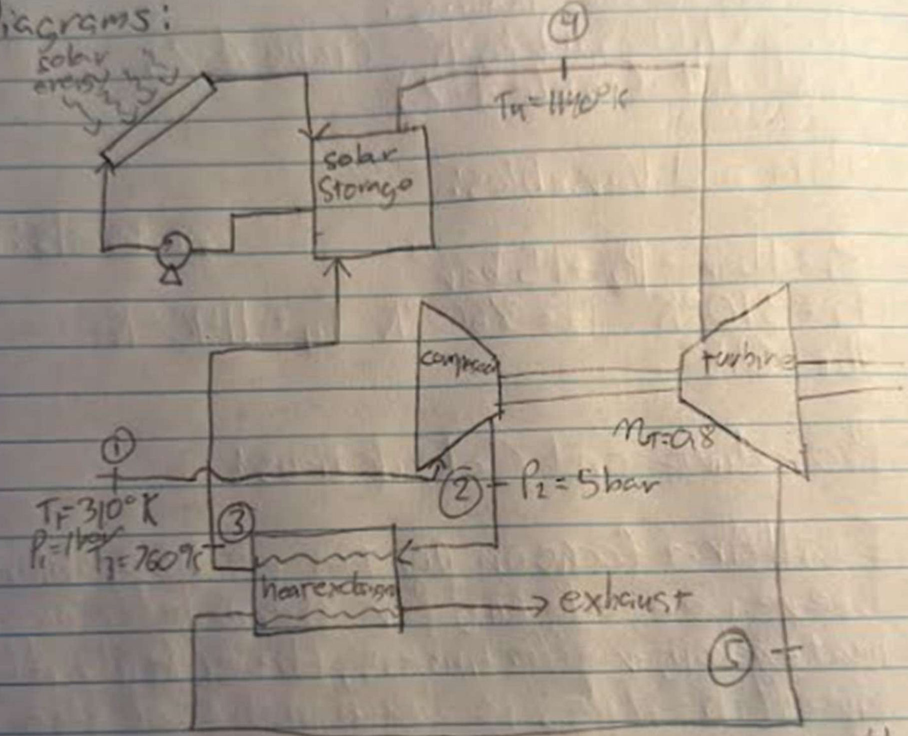
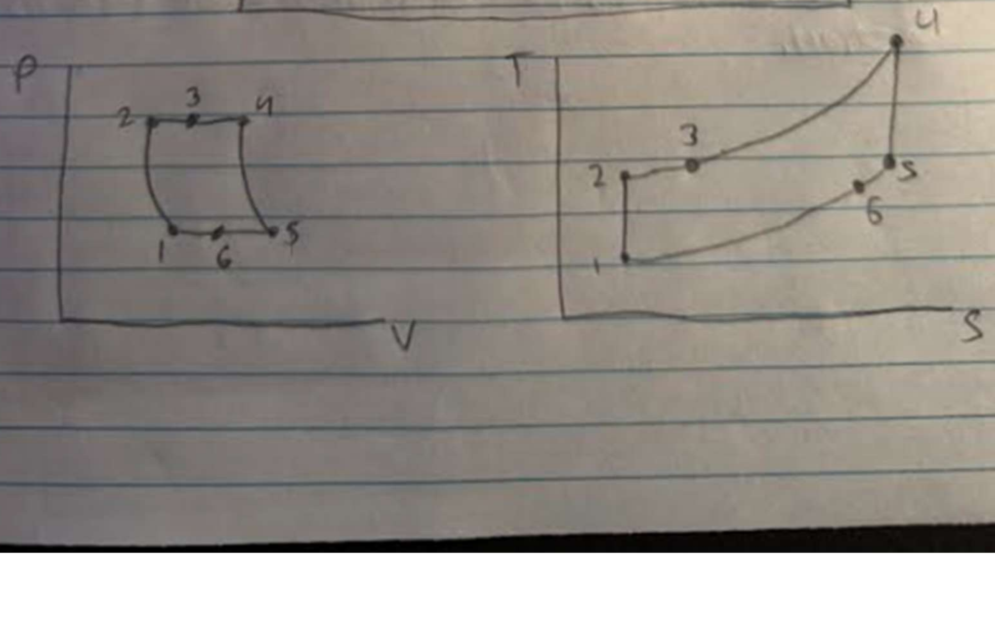
1 Purpose:

Calculate the thermal efficiency, heat exchanger effectiveness, the air mass flow rate for 500 kW, and thermal efficiency if the heat exchanger is at 100% efficiency.

Diagrams:





Sources:

Cengel, Boles, and Kanoglu Thermodynamics an Engineering Approach 9th Edition

Design Considerations:

I assume the following:
1. $c_p = 1.005\ kJ/kg \cdot K$ (table A-2)
2. $k = 1.4$ (table A-2)

Data and Varibles:

materials: air

$P_1 = 1\ bar$ $P_2 = 5\ bar$
$T_1 = 310°K$ $T_2 = 760°K$ $T_4 = 1140°K$
$\eta_T = 0.8$

Procedure and Calculations:

I will first focus on part a of the problem where we are looking for thermal efficiency and heat exchanger effectiveness, the calculations for all the states is shown in the calculations section.

① $T_1 = 310°K$ $P_1 = 1\,bar$ ② $T_2 = 491°K$ $P_2 = 5\,bar$ ③ $T_3 = 760°K$ ④ $T_4 = 1140°K$ $P_4 = 5\,bar$ ⑤ $T_5 = 804°K$ $P_5 = 1\,bar$ ⑥ $T_6 = 535°K$

$P_1 = 1\,bar = 100\,kPa$ $\eta_T = 0.8$
$P_2 = 5\,bar = 500\,kPa$
$T_1 = 310°K$
$T_3 = 760°K$
$T_4 = 1140°K$

part a $T_2 = T_1 \cdot \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = 310 \cdot \left(\frac{5}{1}\right)^{\frac{1.4-1}{1.4}} = 491°K$

$T_5' = T_4 \cdot \left(\frac{P_5}{P_4}\right)^{\frac{k-1}{k}} = 1140 \cdot \left(\frac{1}{5}\right)^{\frac{1.4-1}{1.4}} = 720°K$

$T_5 = \eta_T = \frac{T_4 - T_5}{T_4 - T_5'} \rightarrow 0.8 = \frac{1140 - T_5}{1140 - 720} \rightarrow T_5 = 804°K$

$\dot{m} c_p (T_3 - T_2) = \dot{m} c_p (T_5 - T_6) \rightarrow 760 - 491 = 804 - T_6$
$T_6 = 535°K$

$Q_{in} = c_p(T_4 - T_3) = 1.005(1140 - 760) = 382\,kJ/kg$
$W_{net} = c_p(T_4 - T_5) - c_p(T_2 - T_1) = 1.005(1140 - 804) - 1.005(491 - 310)$
$W_{net} = 156\,kJ/kg$

← a

$\eta = \frac{W_{net}}{Q_{in}} \cdot 100 = \frac{156}{382} \cdot 100 = 40.8\%$

$\epsilon = \frac{T_3 - T_2}{T_5 - T_2} \cdot 100 = \frac{760 - 491}{804 - 491} \cdot 100 = 85.9\%$

part b $\dot{m}\, c_p((T_4 - T_5) - (T_2 - T_1)) = 500 \rightarrow \dot{m} \cdot 1.005((1140 - 804) - (491 - 310)) = 50$

$\dot{m} = 3.21\ kg/s$ ← b

part c $\epsilon = 100\%$

$1 = \frac{T_3 - T_2}{T_6 - T_2} \rightarrow 1 = \frac{760 - 491}{T_5 - 491} \rightarrow T_5 = 760\ °K$

$W_{net} = c_p(T_4 - T_5) - c_p(T_2 - T_1) = 1.005(1140 - 760) - 1.005(491 - 31$

$W_{net} = 200\ kJ/kg$

$Q_{in} = c_p(T_4 - T_3) = 1.005(1140 - 760) = 382\ kJ/kg$

$\eta = \frac{W_{net}}{Q_{in}} \cdot 100 = \frac{200}{382} \cdot 100 = 52.4\%$ ← c

Summary:

The thermal efficiency was 40.8% while the heat exchanger effectiveness is 85.9%. The air mass flow rate is 3.21 kg/s. The thermal efficiency at 100% heat exchanger effectiveness is 52.4%

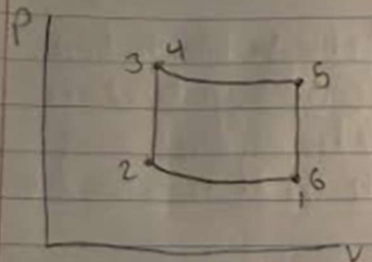
Analysis:

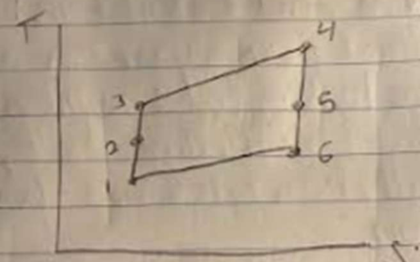
In this problem a lot of the answers rely heavily on pressure and temperature. Maybe if it gets colder out the answers found could differ by varying margins.

2 Purpose:

Calculate the pressure of combustion gases at the turbine exit. Find the velocity of the gases at the nozzle exit. Find the thrust for the engine if the diffuser inlet is a diameter of 1.6 m

Diagrams:





Sources:

Cengal, Boles, and Kanoglu Thermodynamics an Engineering Approach 9th Edition

Design Considerations:

I assume the following:

1. $c_p = 1.005$ kJ/kg·K (table A-2)
2. $k = 1.4$ (table A-2)
3. $R = 0.287$ kJ/kg·K

Data and Variables:

$V = 900\ km/hr \to 250\ m/s$

air temp. $= -35°C$

$P_1 = 40\ kPa$

$T_4 = 1223°K \quad T_1 = 238°K$

$W_T = 500\ kJ/kg$

$\eta_c = 80\% \quad \eta_T = 90\%$

Procedure and Calculations:

I will first focus on part a of the problem where we are looking for the pressure of combustion gases at the turbine exit, the calculations for all the states are shown in the calculations section.

①	②	③	④	⑤	⑥
$T_1 = 238°K$	$T_2 = 269°K$	$T_3 = 767°K$	$T_4 = 1223°K$	$T_5 = 725°K$	$T_6 = 653°K$
$P_1 = 40\ kPa$	$P_2 = 61.4\ kPa$	$P_3 = 82.8\ kPa$	$P_4 = 82.8\ kPa$	$P_5 = 72.7\ kPa$	$P_6 = 40\ kPa$
$V_1 = 250\ m/s$					$V_6 = 12.03\ m/s$

$$T_2 = \frac{V_1^2}{2c_p} + T_1 = \frac{250^2}{2(1.005\times10^3)} + 238 = 269°K$$

$$T_2 = T_1 \cdot \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \to 269 = 238 \cdot \left(\frac{P_2}{40}\right)^{\frac{1.4-1}{1.4}} \to P_2 = 61.4\ kPa$$

$$W_T = c_p(T_4 - T_5) \to 500 = 1.005(1223 - T_5) \to T_5 = 725°K$$

$$T_3 - T_2 = T_4 - T_5 \to T_3 - 269 = 1223 - 725 \to T_3 = 767°K$$

$$\eta_c = \frac{T_3 - T_2}{T_3' - T_2} \to 0.8 = \frac{767 - 269}{T_3' - 269} \to T_3' = 892°K$$

$$\eta_T = \frac{T_4 - T_5'}{T_4 - T_5} \to 0.9 = \frac{1223 - T_5'}{1223 - 725} \to T_5' = 772°K$$

$$P_3 = P_2 \cdot \left(\frac{T_3}{T_2}\right)^{\frac{k-1}{k}} \to P_3 = 61.4 \cdot \left(\frac{767}{269}\right)^{\frac{1.4-1}{1.4}} = 82.8\ kPa$$

a

$$P_5 = P_4 \cdot \left(\frac{T_5'}{T_4}\right)^{\frac{k-1}{k}} = 82.8 \cdot \left(\frac{775}{1223}\right)^{\frac{1.4-1}{1.4}} = 72.7\ kPa$$

$P_4 = 82.8\ kPa$

$$T_6 = T_5' \cdot \left(\frac{P_6}{P_5}\right)^{\frac{1.4-1}{1.4}} = 725 \cdot \left(\frac{40}{72.7}\right)^{\frac{1.4-1}{1.4}} = 653°K$$

b

$$V_6 = \sqrt{2c_p(T_5 - T_6)} = \sqrt{2 \cdot 1.005(725 - 653)} = 12.03 m/s$$

$$F = \dot{m}(V_6 - V_1)$$

$$\dot{m} = \frac{V_1 A_1}{v_1}$$

$$A_1 = \frac{\pi}{4} d^2 = \frac{\pi}{4} \cdot 1.6^2 = 2.01 m^2$$

$$v_1 = \frac{R_1 T_1}{P_1} = \frac{0.287 \cdot 238}{40} = 1.71 m^3/kg$$

$$F = \frac{250 \cdot 2.01}{1.71}(12.03 - 250) = -69929.78 N$$

$$F = -69.9 kN$$

C

Summary:
The pressure of the combustion gasses at the turbine exit is 72.7kPa. The velocity of the gasses at the exit is 1203m/s. The thrust for the engine is -69.9kN.

Analysis:
In real life the answer to C would be positive, but due to the senario and assumptions made the number ended up as negative. I also feel that the gas at the exit would be faster than stated here.