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Materials:

* Air as an Ideal gas

Sources:

Çengel & Boles Thermodynamics: An engineering approach 8th Ed. McGraw Hill. 2015

Purpose:

Evaluate the effectiveness of the regeneration heat exchanger. Compare the calculated effectiveness of the regeneration heat exchanger against typical effectiveness values from the provided figure. Find the produced power if the reheater is turned off. Find the change in thermal efficiency.

Drawings:

Design Considerations:
1.) Air behaves as an Ideal gas
2.) Cp and Cv are constant
3.) No losses due to heat or friction
4.) Cp = 1.005 kJ/kg K

Figure 1:

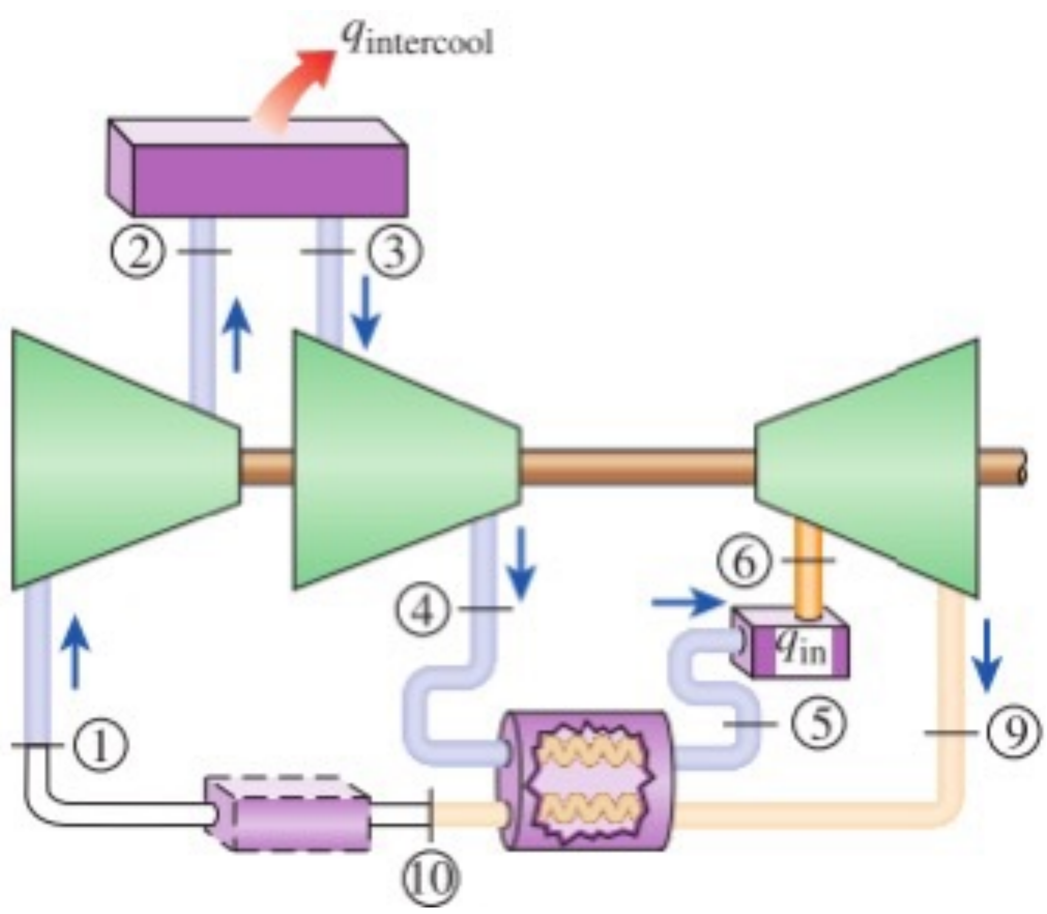
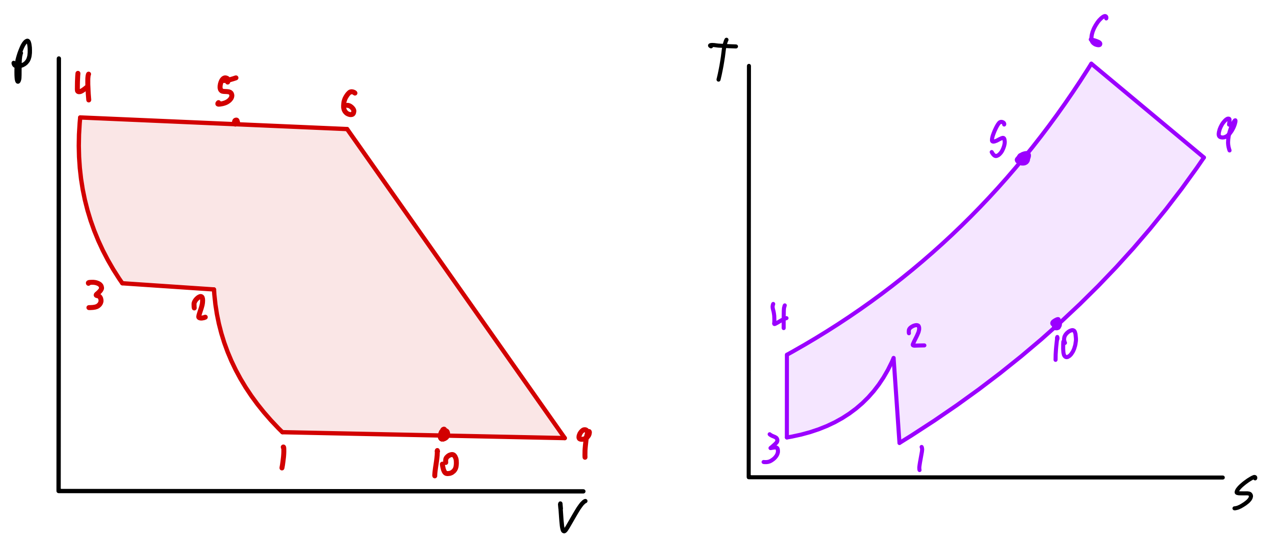


Figure 2:



Procedure:

Initially I copied all the pressures and temperatures from the original problem. Then I found all the equations I could that related the changed states (5, 6, 9 and 10). Then I chose two equations: the regenerator effectiveness formula and the isentropic pressure temperature for constant specific heats formula. after solving for the effectiveness of the regenerator using the values from the original problem I substituted T5 for T6 in the second equation then Substituted T9 in the first equation for the second equation. After solving for T5 I then used all the previously found equations to calculate all the missing Temperatures. With all the temperatures calculated I then found the Net Work and used it to calculate the Thermal Efficiency.

9-133 Air enters a gas turbine with two stages of compression and two stages of expansion at 100 kPa and 17°C. This system uses a regenerator as well as reheating and intercooling. The pressure ratio across each compressor is 4. And 300 kJ/kg of heat is added to the air in each combustion chamber. Determine this system's thermal efficiency

Given values are in light blue

Constant cp, cv

Regen add $q_{in} = 300$ Regen

Isentropic → P const → Isentropic → P const → P const → Isentropic → P const → Isentropic → P const → P const →

1	2	3	4	5	6	7	8	9	10
$P_1 = 100$ kPa	$P_2 = 400$ kPa	$P_3 = 400$ kPa	$P_4 = 1600$ kPa	$P_5 = 1600$ kPa	$P_6 = 1600$ kPa			$P_9 = 100$ kPa	$P_{10} = 100$ kPa
$T_1 = 290$ °K	$T_2 = 431$ °K	$T_3 = 290$ °K	$T_4 = 431$ °K	$T_5 = 411$ °K	$T_6 = 709.5$ °K			$T_9 = 321.3$ °K	$T_{10} = 341.3$

$T_4 = T_5 + x$

$x = T_4 - T_5$

$T_9 = T_{10} + x$

$x = T_9 - T_{10}$

$$\boxed{T_4 - T_5 = T_9 - T_{10}}$$

$T_6 = T_5 + \frac{q_{in}}{c_p}$

$T_6 = T_5 + 298.5$

$$\boxed{T_9 = T_6 \left(\frac{P_9}{P_6}\right)^{\frac{k-1}{k}}}$$

$q_{regen} = \varepsilon \cdot c_p (T_9 - T_4)$

$\varepsilon = \frac{q_{regen}}{c_p (T_9 - T_4)}$

$$\boxed{\varepsilon = \frac{T_5 - T_4}{T_9 - T_4}}$$

$W_{out} = c_p (T_6 - T_9)$

$W_{in} = c_p (T_2 - T_1)$

$W_{in} = c_p (T_4 - T_3)$

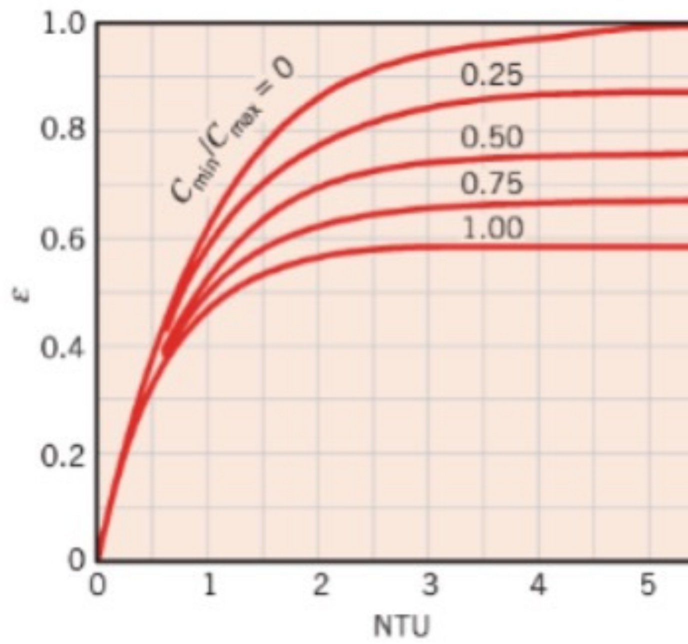
If 800 kW of power is produced by the original config. then $m = 800 / W_{net}$

Problem 9-133

$$\varepsilon = \frac{T_5 - T_4}{T_9 - T_4}$$

$$\varepsilon = \frac{451 - 431}{640.5 - 431}$$

$$\varepsilon = 0.1826$$



Given that the tabulated values for the effectiveness of the heat exchanger tend to be above 0.2, our heat exchanger is performing terribly.

$$T_9 = T_6 \left(\frac{P_9}{P_6}\right)^{\frac{k-1}{k}} \qquad \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

$$T_9 = (T_5 + 298.5)\cdot(16)^{\frac{0.4}{1.4}}$$

$$T_9 = (T_5 + 298.5)\cdot 0.453$$

$$T_9 = 0.453T_5 + 135$$

Substitute T_9 with $2.2T_5 + 659$

$$\varepsilon = \frac{T_5 - T_4}{T_9 - T_4}$$

$$0.1826 = \left(\frac{T_5 - 431\,°K}{T_9 - 431\,°K}\right)$$

$$0.1826 = \left(\frac{T_5 - 431\,°K}{(0.453T_5 + 135) - 431}\right)$$

$$0.1826 = \left(\frac{T_5 - 431\,°K}{0.453T_5 - 295.8}\right)$$

$$0.1826(0.453 \cdot T_5 - 295.8) = (T_5 - 431)$$

$$0.0826 \cdot T_5 - 54 = T_5 - 431$$

$$0.0826 \cdot T_5 = T_5 - 377$$

$$0.0826 \cdot T_5 - T_5 = -377$$

$$0.9173\; T_5 = 377$$

$$T_5 = \frac{377}{0.9173} = 411\,°K$$

$$T_5 = 411\,°K$$

$$T_6 = 411 + \left(\frac{300}{1.005}\right)$$

$$T_6 = 709.5\,°K$$

$$T_9 = 709.5 \cdot \left(\frac{1}{16}\right)^{\frac{0.4}{1.4}}$$

$$T_9 = 321.3\,°K$$

$$T_{10} = 321.3 - (411 - 431)$$

$$T_{10} = 341.3\,°K$$

$$W_{out} = 1.005(709.5 - 321.3) = 390 \frac{kJ}{kg}$$

$$W_{in} = 1.005(431 - 290) = -141.7 \frac{kJ}{kg}$$

$$W_{in} = 1.005(431 - 290) = -141.6\; kJ/kg$$

$$W_{net} = 390 - 141.7 - 141.6 = 106.7\; kJ/kg$$

$$\eta_{th} = \frac{W_{net}}{Q_{in}}$$

$$\boxed{\eta_{th} = \frac{106.7}{300} = 35.57\,\%}$$

$$Power = \left(\frac{800}{226.8}\right)\cdot 106.7$$

$$\boxed{Power = 376\; kW}$$

After reviewing the data it appears that the efficiency has gone down and the regenerator is causing a loss instead of a gain. Thus I recalculated states 6 and 9 after removing 5 and 10. Then I recalculated the Thermal Efficiency.

$$T_6 = 431 + \left(\frac{300}{1.005}\right)$$

$$T_6 = 729.5\ °K$$

$$T_9 = 729.5 \cdot \left(\frac{1}{16}\right)^{\frac{0.4}{1.4}}$$

$$T_9 = 330.4\ °K$$

$$W_{out} = 1.005\,(729.5 - 330.4) = 401.1\ \frac{KJ}{Kg}$$

$$W_{in} = 1.005\,(431 - 290) = -141.7\ \frac{KJ}{Kg}$$

$$W_{in} = 1.005\,(431 - 290) = -141.6\ KJ/Kg$$

$$W_{net} = 401.1 - 141.7 - 141.6 = 117.8\ KJ/Kg$$

$$\eta_{th} = \frac{W_{net}}{Q_{in}}$$

$$\boxed{\eta_{th} = \frac{117.8}{300} = 39\ \%}$$

$$Power = \left(\frac{800}{226.8}\right) \cdot 117.8$$

$$\boxed{Power = 415.5\ KW}$$

Summary:

In the original problem the Thermal efficiency was 37.8% and the power produced was 800 kW. While under a lower load with only 300 kj/kg of Qin from the combustion chamber, the Thermal efficiency dropped to 35.6% and the power produced was 376 kW. After removing the regenerator Thermal efficiency was 39.3% and the power produced was 416 kW.

Analysis:

When the engine operates at a lower load with reduced combustion chamber heat input, thermal efficiency drops from 37.8% to 35.6%, indicating decreased energy conversion efficiency. Removing the regenerator from the system leads to a notable improvement in thermal efficiency, rising to 39.3%, suggesting its presence can introduce inefficiencies under certain conditions. Corresponding changes in power output accompany these variations, emphasizing the interconnectedness of thermal efficiency, heat input, and power generation.

Problem 2

Materials:

* Air as an Ideal gas

Sources:

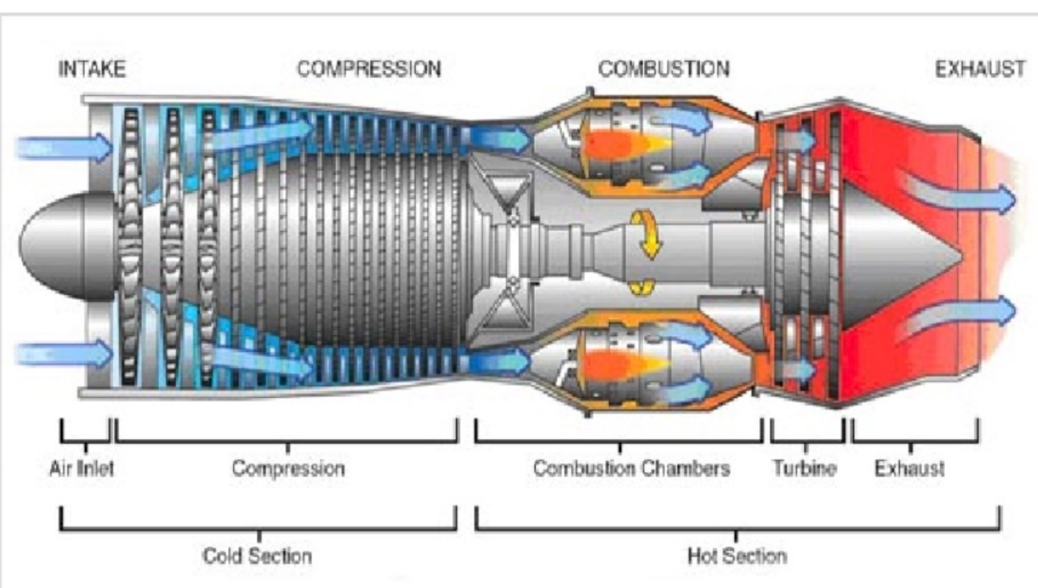
Çengel & Boles Thermodynamics: An engineering approach 8th Ed. McGraw Hill. 2015

Purpose:

The primary objective is to replicate the problem solution while introducing modifications to the compressor and turbine efficiencies, set respectively to 80% and 85%. Utilizing variable specific heats Cp and Cv, the problem instructs to determine the pressure and temperature of all states within the cycle, including actual states exiting the compressor and turbine. Subsequently, the propulsive efficiency of the jet propulsion cycle is recalculated and compared to the initial solution. The problem prompts an examination of any observed changes in propulsion efficiency, focusing on the underlying reasons for such variations.

Drawings:

Figure 1:

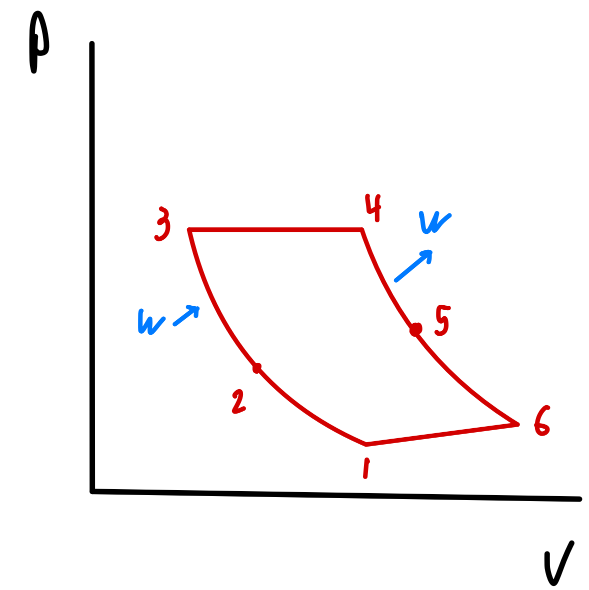


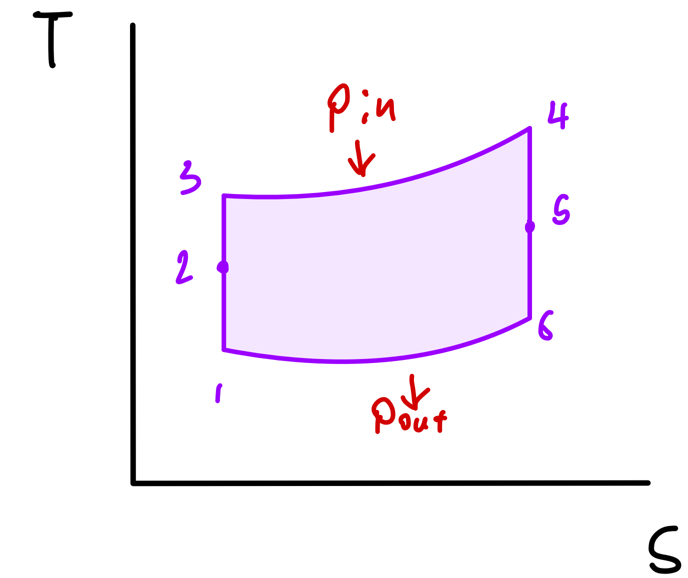
Design Considerations:

1.) Air behaves as an Ideal gas
2.) Cp and Cv are variable
3.) No losses due to heat or friction

Procedure:

First I got the initial values for velocity, temperature and pressure at the inlet and the pressure ratio. Then I calculated the enthalpy for the second state using the first law. After getting enthalpy I found the rest of the values for state 2 using Table A-17. Then I calculated the pressure using the pressure ratio between state 1 and 2 and again for state 3 and state 3s. For the intermediate states I use the efficiency formulas for the turbine and the compressor. Using pressure ratios or the first law I calculated all the Pr or h values for the states. Then I interpolated the missing values for all the states from Table A-17. Next I calculated the exit velocity using the first law. Finally I calculated the propulsive efficiency for both the original problem and the test problem.





$V_1 = 240\ m/s$ $\qquad P_r = 13$

const P → 1 → Isentropic → 2 → Isentropic → 3 → 3s → P const. → 4 → Isentropic → 5 → 5s → Isentropic → 6 → P const

1: $T_1 = 260°K$, $P_1 = 45\ kPa$, $h_1 = 260.1\ kJ/kg$, $P_{r_1} = 0.8405$

2: $T_2 = 288.7°K$, $P_2 = 62\ kPa$, $h_2 = 288.9\ kJ/kg$, $P_{r_2} = 1.158$

3: $T_3 = 587°K$, $P_3 = 806\ kPa$, $h_3 = 593.6\ kJ/kg$, $P_{r_3} = 15.054$

3s: $T_{3s} = 528.7°K$, $P_{3s} = 550.5\ kPa$, $h_{3s} = 532.66\ kJ/kg$, $P_{r_{3s}} = 10.283$

4: $T_4 = 830°K$, $P_4 = 806\ kPa$, $h_4 = 855.03\ kJ/kg$, $P_{r_4} = 55.095$

5: $T_5 = 545.25°K$, $P_5 = 168\ kPa$, $h_5 = 550.33\ kJ/kg$, $P_{r_5} = 11.5$

5s: $T_{5s} = 493.75°K$, $P_{5s} = 117.5\ kPa$, $h_{5s} = 496.6\ kJ/kg$, $P_{r_{5s}} = 8.044$

6: $T_6 = 376.6°K$, $P_6 = 45\ kPa$, $h_6 = 377.4\ kJ/kg$, $P_{r_6} = 3.08$, $V_6 = 488.26\ m/s$

$$\frac{V_1^2}{2} + h_1 = h_2$$

$$h_2 = \frac{(240\ m/s)^2}{2 \cdot 1000} + 260.1\ \frac{kJ}{kg}$$

$$h_2 = 288.9\ kJ/kg$$

$$\left(\frac{P_{r_2}}{P_{r_1}}\right) = \left(\frac{P_2}{P_1}\right)$$

$$P_2 = 45\left(\frac{0.8405}{1.158}\right)$$

$$P_2 = 62\ kPa$$

$$P_3 = 13 \cdot P_2$$

$$P_3 = 13 \cdot 62$$

$$P_3 = 806\ kPa$$

$$\left(\frac{P_{r_3}}{P_{r_2}}\right) = \left(\frac{P_3}{P_2}\right)$$

$$P_{r_3} = 1.158\left(\frac{806}{62}\right)$$

$$P_{r_3} = 15.054$$

Interp. = T_3, h_3

$$(h_4 - h_5) = (h_3 - h_2)$$

$$h_5 = -593.6 + 288.9 + 855.03$$

$$h_5 = 550.33\ kJ/kg$$

Interp. = T_5, P_{r_5}

$$\left(\frac{P_{r_5}}{P_{r_4}}\right) = \left(\frac{P_5}{P_4}\right)$$

$$P_5 = 806\left(\frac{11.5}{55.095}\right)$$

$$P_5 = 168\ kPa$$

$$\left(\frac{P_{r_6}}{P_{r_5}}\right) = \left(\frac{P_6}{P_5}\right)$$

$$P_{r_6} = 11.5\left(\frac{45}{168}\right)$$

$$P_{r_6} = 3.08$$

Interp. T_6, h_6

$$V_6^2 = 2(h_{5s} - h_6)$$

$$V_6 = \sqrt{2(496.6 - 377.4) \cdot 1000}$$

$$V_6 = 488.26\ m/s$$

State 3s

$$\eta_c = \frac{h_{3s} - h_2}{h_3 - h_2}$$

$$0.8 = \frac{h_{3s} - 288.9}{593.6 - 288.9}$$

$$h_{3s} = 532.66$$

Interp. = T_{3s}, P_{r3s}

$$\left(\frac{P_{r3s}}{P_{r3}}\right) = \left(\frac{P_{3s}}{P_3}\right)$$

$$P_{3s} = 806\left(\frac{10.2825}{15.054}\right)$$

$$P_{3s} = 550.5 \text{ kPa}$$

State 5s

$$\eta_T = \frac{h_4 - h_5}{h_4 - h_{5s}}$$

$$0.85 = \frac{855.03 - 550.33}{855.03 - h_{5s}}$$

$$h_{5s} = 496.6$$

Interp. T_{5s}, P_{5s}

$$\left(\frac{P_{r5s}}{P_{r4}}\right) = \left(\frac{P_{5s}}{P_4}\right)$$

$$P_{5s} = 806\left(\frac{8.844}{55.095}\right)$$

$$P_{5s} = 117.5 \text{ kPa}$$

Problem 9-142

$$\eta_p = \frac{\cancel{\dot{m}}(V_{exit} - V_{inlet})V_{plane}}{\cancel{\dot{m}}\, c_p (T_4 - T_3)}$$

$$\eta_p = \frac{(564.52 - 240)\cdot 240}{1.005(830.15 - 601)\cdot 1000}$$

$$\eta_p = 0.338$$

$$\eta_p = 33.8\%$$

Test Problem.

$$\eta_p = \frac{\cancel{\dot{m}}(V_{exit} - V_{inlet})V_{plane}}{\cancel{\dot{m}}(h_4 - h_3)}$$

$$\eta_p = \frac{(488.26 - 240)\cdot 240}{(855.03 - 532.66)\cdot 1000}$$

$$\eta_p = 0.185$$

$$\eta_p = 18.5\%$$

Summary:

The velocity at the exit of the original problem was 564.5 m/s and the Propulsive Efficiency was 33.8%. For the test problem with inefficiencies in the compressor and the turbine, the velocity at the exit was 488 m/s and the Propulsive Efficiency was 18.5%

Analysis:

The exit velocity decreases notably from 564.5 m/s to 488 m/s, reflecting reduced thrust generation. This reduction correlates with a significant drop in propulsive efficiency from 33.8% to 18.5%, highlighting the system's diminished ability to convert thrust into useful work. These inefficiencies lead to decreased pressure ratios across components, resulting in lower overall thrust and propulsive efficiency. Addressing and minimizing inefficiencies in the compressor and turbine are crucial for optimizing jet propulsion system performance and fuel efficiency in practical applications.