AEEM4063 - Assignment 2A

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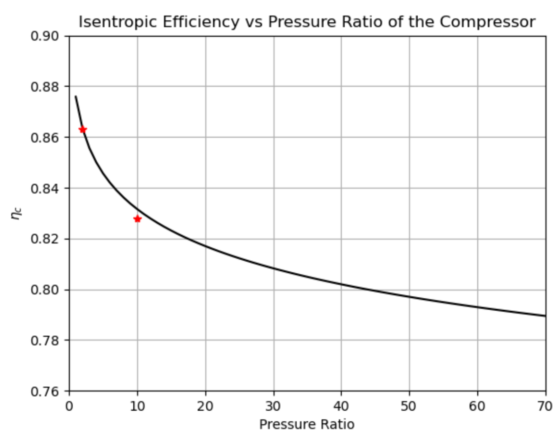
Problem 2.1

$\eta_c = 0.85$, $r = 4.0$, $\gamma = 1.4$

$\eta_c = \frac{(r)^{(\gamma-1)/\gamma}-1}{(r)^{(\gamma-1)/\gamma\eta_{\infty c}}-1}$
$\eta_c * ((r)^{(\gamma-1)/\gamma\eta_{\infty c}} - 1) = (r)^{(\gamma-1)/\gamma} - 1$
$(r)^{(\gamma-1)/\gamma\eta_{\infty c}} - 1 = ((r)^{(\gamma-1)/\gamma} - 1)/\eta_c$
$(r)^{(\gamma-1)/\gamma\eta_{\infty c}} = ((r)^{(\gamma-1)/\gamma} - 1)/\eta_c + 1$
$(\gamma-1)/\gamma\eta_{\infty c}\log(r) = \log(((r)^{(\gamma-1)/\gamma} - 1)/\eta_c + 1)$
$\eta_{\infty c} = \frac{(\gamma-1)/\gamma\log(r)}{\log(((r)^{(\gamma-1)/\gamma}-1)/\eta_c+1)}$

plug in η_c, r, and γ and solve: $\boxed{\eta_{\infty c} = 0.876}$



Problem 2.2

$r = 11$, $\eta_c = 0.82$, combustion pressure loss = 0.4 bar, $\eta_{comb} = 0.99$, TIT= $T_{03} = 1150$ K, $\eta_{tg} = 0.87$, $\eta_{tp} = 0.89$, $\eta_m = 0.98$, $P_a = 1$ bar, $T_a = 288$ K, $\dot{W}_{pt} = 20$ MW, $c_{pc} = 1.005$, $c_{pg} = 1.148$, $\gamma_c = 1.4$, $\gamma_t = 1.333$

$T_{02} - T_{01} = \frac{T_{01}}{\eta_c}(r^{(\frac{\gamma-1}{\gamma})} - 1)$
$T_{01} = T_a = 288$ K (stationary inlet)
$T_{02} - T_{01} = \frac{288}{0.82}(11^{0.4/1.4} - 1) = 345.6$ K

$W_{tg} = \frac{c_{pc}}{\eta_m}(T_{02} - T_{01}) = \frac{1.005}{0.99}(345.6) = 354.42$ kJ/kg

$T_{03} - T_{04} = \frac{W_{tg}}{c_{pg}} = \frac{354.43}{1.148} = 308.74$ K
$P_{03} = P_{02} - P_{loss}$, $P_{02} = r * P_{01} = 11 * 1 = 11$ bar, $P_{03} = 10.6$ bar

$T_{03} - T_{04} = \eta_{tg}T_{03}(1 - (\frac{1}{P_{03}/P_{04}})^{\frac{\gamma-1}{\gamma}})$
$308.75 = (0.87)(1150)(1 - \frac{1}{P_{03}/P_{04}}^{\frac{0.4}{1.4}})$, $P_{03}/P_{04} = 4.375$, $P_{04} = 2.43$ bar

$T_{04} - T_{05} = \eta_{tp}T_{04}(1 - (\frac{1}{P_{04}/P_{05}})^{\frac{\gamma-1}{\gamma}})$
turbine perfectly expands: $P_{05} = 1$ bar
$T_{04} = T_{03} - 1150 = 841.26$ K
$T_{04} - T_{05} = (0.89)(841.26)(1 - (\frac{1}{2.43/1})^{0.333/1.333}) = 148.94$ K

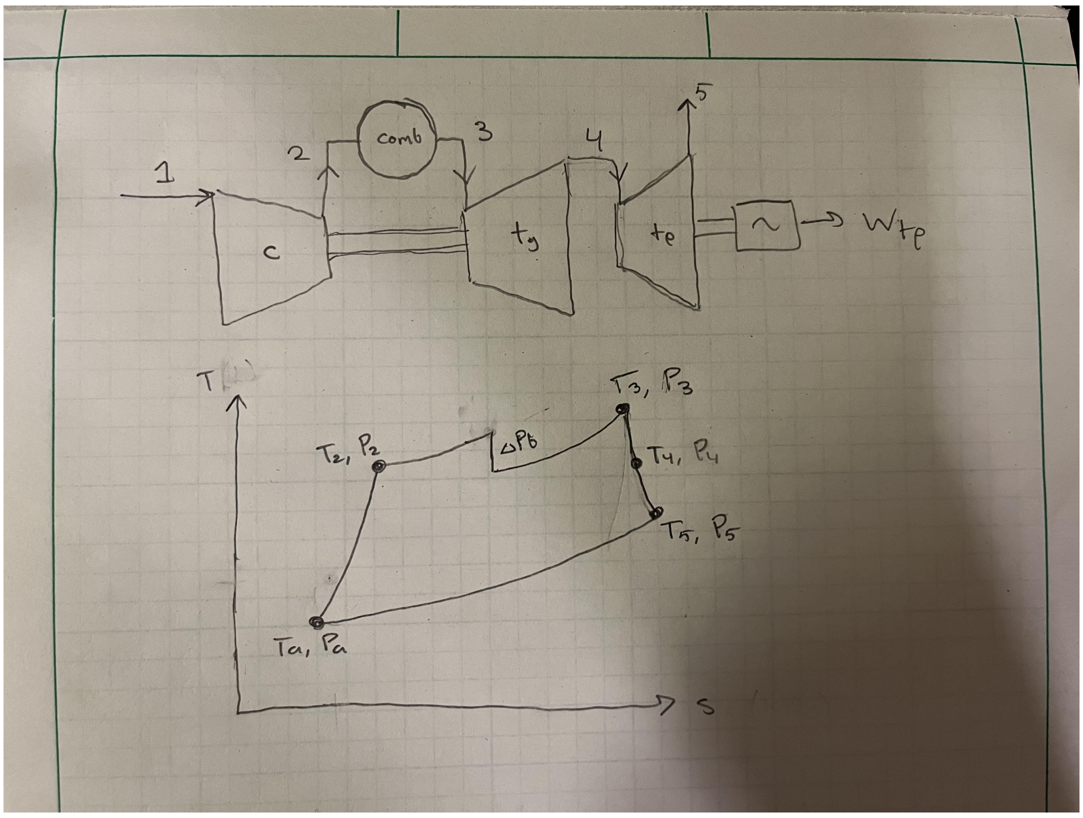
$W_{tp} = c_{pg}(T_{04} - T_{05})(\eta_m) = (1.148)(148.94)(0.98) = 167.56$ kWs/kg

$\dot{m} = \frac{W_{pt}}{W_{tp}} = \frac{20(1000)}{167.56} = 119.4$ kg/s
$\boxed{\dot{m} = 119.4 \text{ kg/s}}$

$T_{02} = 633.6$ K, $T_{03} - T_{02} = 1150 - 633.6 = 516.4$ K
from fig 2.17: $f = 0.0142$
$f_a = f/\eta_{comb} = 0.0142/0.99 = 0.01434$

$SFC = \frac{f_a(3600)}{W_{tp}} = \frac{(0.01434)(3600)}{167.56} = 0.3081$ kg/kWh

$\boxed{SFC = 0.308 \text{ kg/kWh}}$



Problem 2.4

	A	B	C
$\eta_{\infty c}$	0.87	0.88	0.89
$\eta_{\infty t}$	0.89	0.88	0.88
r	9	12	16
$\Delta P_b/P_{02}$ (%)	5	5	5
T_{03} (K)	1150	1400	1600
cooling bleed (%)	–	2.5	5
$\dot{m}$ (kg/s)	75	80	85

$c_{pc} = 1.005$, $c_{pg} = 1.148$, $\gamma_c = 1.4$, $\gamma_t = 1.333$, $\eta_m = 0.99$, $\eta_b = 0.99$

Part A

Version A

$\frac{n-1}{n} = \frac{\gamma_c - 1}{\gamma_c \eta_{\infty c}} = \frac{0.4}{1.4(0.87)} = 0.3284$

$\frac{m-1}{m} = \frac{\eta_{\infty t}(\gamma_t - 1)}{\gamma_t} = \frac{0.89 * 0.333}{1.333} = 0.2223$

$T_{02}/T_{01} = (r)^{\frac{n-1}{n}} = (9)^{0.3284} = 2.058$

assume standard day conditions: $T_{01} = 288.15$ K $\rightarrow T_{02} = 593.01$ K

because of losses: $P_{03} = P_{02}(1 - \frac{\Delta P_b}{P_{02}}) = 9(0.95) = 8.55$ bar

assuming turbine fully expands to ambient: $P_{04} = 1$ bar, $P_{03}/P_{04} = \frac{8.55}{1} = 8.55$

$T_{03}/T_{04} = (P_{03}/P_{04})^{\frac{m-1}{m}} = (8.55)^{0.2223} = 1.611$

$T_{04} = 713.84$ K

$W_c = \frac{c_{pc}}{\eta_m}(T_{02} - T_{01}) = \frac{1.005}{0.99}(593.01 - 288.15) = 309.48$ kJ/kg

$W_t = c_{pg}(T_{03} - T_{04}) = 1.148(1150 - 713.84) = 500.7$ kJ/kg

$W_{net} = W_t - W_c = 500.7 - 309.48 = 191.22$ kJ/kg

$P = W_{net} * \dot{m} = 191.22 * 75 = 14341.5$

$\boxed{P = 14341.5 \text{ kW}}$

$\Delta T_b = 1150 - 593.01 = 556.99$ K, from fig 2.17: $f = 0.015$

$f_a = f/\eta_b = 0.015/0.99 = 0.0152$

$SFC = f/W_{net} = 0.0152/191.22 * 3600 = 0.2862$ kg/kWh

$\boxed{SFC = 0.2862 \text{ kg/kWh}}$

Version B

same process as Version A:
$\frac{n-1}{n} = \frac{0.4}{1.4(0.88)} = 0.3247$
$\frac{m-1}{m} = \frac{0.88(0.333)}{1.333} = 0.22$

$T_{02}/T_{01} = 12^{0.3247} = 2.241$
$T_{01} = 288.15$ K, $T_{02} = 645.74$ K

$P_{03} = 12(0.95) = 11.4$ bar
$P_{04} = 1$ bar, $P_{03}/P_{04} = 11.4$
$T_{03}/T_{04} = 11.4^{0.22} = 1.708$
$T_{04} = 819.67$ K

$W_c = \frac{1.005}{0.99}(645.74 - 288.15) = 363$ kJ/kg
$W_t = c_{pg}(T_{03} - T_{04})(1 - \text{bleed }\%) = (1.148)(1400 - 819.67)(1 - 0.025) = 649.56$ kJ/kg
$W_{net} = 649.56 - 363 = 286.56$ kJ/kg

$P = 286.56 * 80 = 22924.8$ kW
$\boxed{P = 22924.8 \text{ kW}}$

$\Delta T_b = 1400 - 645.74 = 754.26$ K, $f = 0.021$
$f_a = 0.021/0.99 = 0.0212$
$SFC = 0.0212/286.56 * 3600 = 0.2663$ kg/kWh
$\boxed{SFC = 0.2663 \text{ kg/kWh}}$

Version C

same process again:
$\frac{n-1}{n} = \frac{0.4}{1.4(0.89)} = 0.321$
$\frac{m-1}{m} = \frac{0.88(0.333)}{1.333} = 0.22$

$T_{02}/T_{01} = 16^{0.321} = 2.435$
$T_{01} = 288.15$ K, $T_{02} = 701.65$ K

$P_{03} = 16(0.95) = 15.2$ bar
$P_{04} = 1$ bar, $P_{03}/P_{04} = 15.2$
$T_{03}/T_{04} = 15.2^{0.22} = 1.82$
$T_{04} = 879.12$ K

$W_c = \frac{1.005}{0.99}(701.65 - 288.15) = 419.765$ kJ/kg
$W_t = (1.148)(1600 - 879.12)(1 - 0.05) = 786.19$ kJ/kg
$W_{net} = 786.19 - 419.765 = 366.425$ kJ/kg

$P = 366.425 * 85 = 31146.125$ kW
$\boxed{P = 31146.125 \text{ kW}}$

$\Delta T_b = 1600 - 701.65 = 898.35$ K, $f = 0.0265$
$f_a = 0.0265/0.99 = 0.0268$
$SFC = 0.0268/366.425 * 3600 = 0.2633$ kg/kWh
$\boxed{SFC = 0.2633 \text{ kg/kWh}}$

Part B

	A → B	A → C
P	$\frac{22924.8}{14341.5}(100) = \boxed{159.85\ \%}$	$\frac{31146.125}{14341.5}(100) = \boxed{217.175\ \%}$
SFC	$(1 - \frac{0.2663}{0.2862})(100) = \boxed{6.95\ \%}$	$(1 - \frac{0.2633}{0.2862})(100) = \boxed{8.0\ \%}$