Data point	Work $\dot{W}$	Isooctane Eff. η_1	Isooctane Heat $\dot{Q}$	Actual fuel Eff. η_1	Actual fuel Heat $\dot{Q}_{loss}$
1	1.06	16.73%	7.42	14.9%	7.55
2	1.20	16.43%	8.49	14.0%	8.56
3	1.24	16.19%	8.87	13.86%	8.92
4	1.12	12.98%	9.76	11.22%	9.98
5	1.09	11.72%	10.36	10.22%	10.64

Table 1: First law efficiencies. All units in KW unless otherwise noted.

The purpose of this assignment was to analyze the 3W-28i (Figure 1), a two-stroke internal combustion engine (ICE) commonly used in unmanned aerial vehicles (UAV), to determine its first and second law efficiencies. The engine is coupled to a KDE 8218 light weight electric motor to maximize motor control while retaining the high specific energy of gasoline to maximize flight time. The assignment is designed to be similar to that of a real-world application where critical performance characteristics of the UAV would be determined.

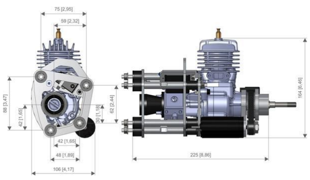

Figure 1: 3W-28i engine overview.

Part 1

A first law balance was conducted with energy flows for five operating data points to determine the first law efficiencies. One balance was conducted assuming that the fuel was 100% isooctane, and a second balance was conducted assuming that actual fuel was being used. The results are included in Table 1, and can be compared to a Carnot cycle efficiency of 87.7% assuming a flame temperature of 2150°C and an inlet temperature of 25°C.

It was assumed that all gases obeyed the ideal gas law to allow the thermophysical properties to be readily accessed. It was assumed that all air consists of 21% O_2 and 79% N_2. For parts 2 through 4 of this assignment, it was assumed that the fuel was isooctane because the exact atomic balance of the fuel was unable to be determined.

An energy balance of the system was completed using Equation 1. The difference between the energy added to the system $\dot{Q}$ and the work done by the engine $\dot{W}$ is equal to $\dot{Q}_{loss}$, the difference in the enthalpies of the reactants $\dot{H}_R$ and the products $\dot{H}_P$. To quantify the reactants and products, an atomic balance was conducted. Equation 1 was simplified by using the assumption that the kinetic and potential energy of the mass entering and leaving the system was neglected. The first law efficiency η_1 is simply the ratio of $\dot{W}$ to $\dot{Q}_{loss}$. For the actual fuel, the first law efficiency was the ratio of $\dot{W}$ to the product of the lower heating value (LHV) and the mass flow rate of the fuel.

$$\dot{Q} - \dot{W} = \dot{H}_R - \dot{H}_P \tag{1}$$

The enthalpies of the products were found using Equation 2, which was obtained by adding the product of the molar flow rate $\dot{n}_x$ and the standardized molar specific enthalpy $\bar{h}_x$ for each of the different products x of the overall reaction (CO_2, H_2O, and N_2). The enthalpies of the reactants were found using Equation 3 using the same method.

$$\dot{H}_P = \dot{n}_{CO_2}\bar{h}_{CO_2} + \dot{n}_{H_2O}\bar{h}_{H_2O} + \dot{n}_{N_2}\bar{h}_{N_2} \tag{2}$$

$$\dot{H}_R = \dot{n}_{C_8H_{18}}\bar{h}_{C_8H_{18}} + \dot{n}_{O_2}\bar{h}_{O_2} + \dot{n}_{N_2}\bar{h}_{N_2} \tag{3}$$

The standardized molar specific enthalpy of each product was found using Equation 4, in which T and P are the temperature and pressure of the fluid in the state of interest, and T_{ref} and P_{ref} are the temperature and pressure of the fluid at a reference state, which is 25°C and 1 atmosphere.

$$\bar{h}(T,P) = \bar{h}_{form} + [\bar{h}(T,P) - \bar{h}(T_{ref}, P_{ref})] \tag{4}$$

Part 2

A second law balance with steady state conditions was used to evaluate the entropy flows and the entropy generated $\dot{\sigma}$ for the hybrid gas-electric system. The entropy flow of the reactants, $\dot{S}_R$, and entropy flow of products,$\dot{S}_R$, are the sum of each reactant or product entropy multiplied by its molar flow rate. The entropy of each fluid was evaluated at its partial pressure, and the crank temperature if its a reactant of exhaust temperature if its a product. The partial pressure was evaluated by multiplying the molar fraction, of the reactant or element, by the atmospheric pressure. $\dot{S}_Q$ was evaluated by dividing $\dot{Q}_{loss}$ by the head temperature at each operating point. All of these terms are in Equation 6 and therefore we can solve for the entropy generated.

$$\dot{S}_R - \dot{S}_P + \dot{S}_Q + \dot{\sigma} = 0 \tag{5}$$

Part 3 and 4

The exergy destroyed for each operating point $X_{destroyed}$ was calculated using Equation 6, and the 2nd law efficiency η_2 was calculated using Equation 7 as shown below:

$$X_{destroyed} = T_{ref}\dot{\sigma} \tag{6}$$

$$\eta_2 = \frac{\dot{W}}{X_{destroyed}} \tag{7}$$

Data point	η_2	Exergy Dest.
1	19.24%	5.53
2	20.99%	5.70
3	21.28%	5.80
4	19.56%	5.73
5	18.42%	5.90

Table 2: Second law efficiencies. Exergy in units of KW.

Part 5

The work per cycle is equal to the area inside the curve of the figure that was provided. This area was calculated using the attached MATLAB code, written by Oregon State students AJ Fillo and Kyle Zada. The code prompts the user to select several points along the curve and the x and y axis, and the shape of the curve is generated by using those points as vertices. After inputting the magnitude of the x and y axis, the code returns a value. The curve from the figure was found to have an area that equated to 15.516 J per stroke. By multiplying this number with the number of power strokes per minute, the power of the engine was estimated. The engine was found to produce approximately 1.681 KW.

Appendix

EES code for solving the problems

```
"Ahmad Bukshaisha and Andrew Alferman"
"ME540 HW4"

"GIVEN INFORMATION"
"Torque/power information"
torque[1] = 13.83*convert(in-lbf,KJ)          "Torque at point 1"
torque[2] = 15.57*convert(in-lbf,KJ)          "Torque at point 2"
torque[3] = 16.07*convert(in-lbf,KJ)          "Torque at point 3"
torque[4] = 14.57*convert(in-lbf,KJ)          "Torque at point 4"
torque[5] = 14.13*convert(in-lbf,KJ)          "Torque at point 5"

speed=6500*convert(rev/min,rad/s)             "Speed in radians/sec"

"Temperature information"
T[0]= 25 [C]                                  "T ref"

T_C[1] = 46.41 [C]                            "crank temp 1"
T_C[2] = 46.79 [C]                            "crank temp 2"
T_C[3] = 44.16 [C]                            "crank temp 3"
T_C[4] = 44.14 [C]                            "crank temp 4"
T_C[5] = 44.58 [C]                            "crank temp 5"

T_H[1] = 228.11 [C]                           "head temp 1"
T_H[2] = 220.16 [C]                           "head temp 2"
T_H[3] = 213.54 [C]                           "head temp 3"
T_H[4] = 220.65 [C]                           "head temp 4"
T_H[5] = 208.56 [C]                           "head temp 5"

T_H_K[1] = converttemp('C','K',T_H[1])
T_H_K[2] = converttemp('C','K',T_H[2])
T_H_K[3] = converttemp('C','K',T_H[3])
T_H_K[4] = converttemp('C','K',T_H[4])
T_H_K[5] = converttemp('C','K',T_H[5])

T_E[1]= 529.94 [C]                            "exhaust temp 1"
T_E[2]= 509.62 [C]                            "exhaust temp 2"
T_E[3]= 497.69 [C]                            "exhaust temp 3"
T_E[4]= 477.46 [C]                            "exhaust temp 4"
T_E[5]= 462.09 [C]                            "exhaust temp 5"

T_ref= converttemp('C','K',T[0])

"Ambient Pressure"
P= 101.3 [kPa]

"Fuel mass flow rates"
m_fuel[1]= 0.1772*convert(g/s,kg/s)           "mass flowrate of fuel 1"
m_fuel[2]= 0.2009*convert(g/s,kg/s)           "mass flowrate of fuel 2"
m_fuel[3]= 0.2093*convert(g/s,kg/s)           "mass flowrate of fuel 3"
m_fuel[4]= 0.2343*convert(g/s,kg/s)           "mass flowrate of fuel 4"
m_fuel[5]= 0.2496*convert(g/s,kg/s)           "mass flowrate of fuel 5"

n_fuel[1]= m_fuel[1]/(C8H18_MW)               "molar flowrate of fuel 1"
n_fuel[2]= m_fuel[2]/(C8H18_MW)               "molar flowrate of fuel 2"
n_fuel[3]= m_fuel[3]/(C8H18_MW)               "molar flowrate of fuel 3"
n_fuel[4]= m_fuel[4]/(C8H18_MW)               "molar flowrate of fuel 4"
n_fuel[5]= m_fuel[5]/(C8H18_MW)               "molar flowrate of fuel 5"

C8H18_MW=molarmass(C8H18)                     "MW of C8H18"

"Calculating all molar flow rates in the chemical reaction"
n_air[1]=(12.5*4.76)*n_fuel[1]                "molar flowrate of air 1"
```

```
n_air[2]=(12.5*4.76)*n_fuel[2]                "molar flowrate of air 2"
n_air[3]=(12.5*4.76)*n_fuel[3]                "molar flowrate of air 3"
n_air[4]=(12.5*4.76)*n_fuel[4]                "molar flowrate of air 4"
n_air[5]=(12.5*4.76)*n_fuel[5]                "molar flowrate of air 5"

n_O2[1]=n_air[1]*0.21                         "molar flow rate of O2 1"
n_O2[2]=n_air[2]*0.21                         "molar flow rate of O2 2"
n_O2[3]=n_air[3]*0.21                         "molar flow rate of O2 3"
n_O2[4]=n_air[4]*0.21                         "molar flow rate of O2 4"
n_O2[5]=n_air[5]*0.21                         "molar flow rate of O2 5"

n_N2_in[1]= n_air[1]*0.79                     "molar flow rate of N2 1"
n_N2_in[2]= n_air[2]*0.79                     "molar flow rate of N2 2"
n_N2_in[3]= n_air[3]*0.79                     "molar flow rate of N2 3"
n_N2_in[4]= n_air[4]*0.79                     "molar flow rate of N2 4"
n_N2_in[5]= n_air[5]*0.79                     "molar flow rate of N2 5"

n_CO2[1]= 8*n_air[1]/(12.5*4.76)              "molar flow rate of CO2 1"
n_CO2[2]= 8*n_air[2]/(12.5*4.76)              "molar flow rate of CO2 2"
n_CO2[3]= 8*n_air[3]/(12.5*4.76)              "molar flow rate of CO2 3"
n_CO2[4]= 8*n_air[4]/(12.5*4.76)              "molar flow rate of CO2 4"
n_CO2[5]= 8*n_air[5]/(12.5*4.76)              "molar flow rate of CO2 5"

n_H2O[1]= 9*n_air[1]/(12.5*4.76)              "molar flow rate of H2O 1"
n_H2O[2]= 9*n_air[2]/(12.5*4.76)              "molar flow rate of H2O 2"
n_H2O[3]= 9*n_air[3]/(12.5*4.76)              "molar flow rate of H2O 3"
n_H2O[4]= 9*n_air[4]/(12.5*4.76)              "molar flow rate of H2O 4"
n_H2O[5]= 9*n_air[5]/(12.5*4.76)              "molar flow rate of H2O 5"

n_N2_out[1]= 47*n_air[1]/(12.5*4.76)          "molar flow rate of N2 out 1"
n_N2_out[2]= 47*n_air[2]/(12.5*4.76)          "molar flow rate of N2 out 2"
n_N2_out[3]= 47*n_air[3]/(12.5*4.76)          "molar flow rate of N2 out 3"
n_N2_out[4]= 47*n_air[4]/(12.5*4.76)          "molar flow rate of N2 out 4"
n_N2_out[5]= 47*n_air[5]/(12.5*4.76)          "molar flow rate of N2 out 5"


"!Rectants enthalpies"
A$='C8H18'
h_std_C8H18[1] = h_form_C8H18 + DELTAh_C8H18[1] "enthalpy STD for C8H18 at 5 opertaing points"
h_std_C8H18[2] = h_form_C8H18 + DELTAh_C8H18[2]
h_std_C8H18[3] = h_form_C8H18 + DELTAh_C8H18[3]
h_std_C8H18[4] = h_form_C8H18 + DELTAh_C8H18[4]
h_std_C8H18[5] = h_form_C8H18 + DELTAh_C8H18[5]

DELTAh_C8H18[1] = (h_C8H18[1] - h_C8H18_ref)
DELTAh_C8H18[2] = (h_C8H18[2] - h_C8H18_ref)
DELTAh_C8H18[3] = (h_C8H18[3] - h_C8H18_ref)
DELTAh_C8H18[4] = (h_C8H18[4] - h_C8H18_ref)
DELTAh_C8H18[5] = (h_C8H18[5] - h_C8H18_ref)

h_C8H18[1] = enthalpy(A$, T=T_C[1])
h_C8H18[2] = enthalpy(A$, T=T_C[2])
h_C8H18[3] = enthalpy(A$, T=T_C[3])
h_C8H18[4] = enthalpy(A$, T=T_C[4])
h_C8H18[5] = enthalpy(A$, T=T_C[5])

h_C8H18_ref = enthalpy(A$, T=T[0])
h_form_C8H18 = enthalpy_formation(A$)

B$='O2'
h_std_O2[1] = h_form_O2 + DELTAh_O2[1]        "enthalpy STD for O2 at 5 opertaing points"
h_std_O2[2] = h_form_O2 + DELTAh_O2[2]
h_std_O2[3] = h_form_O2 + DELTAh_O2[3]
```

```
h_std_O2[4] = h_form_O2 + DELTAh_O2[4]
h_std_O2[5] = h_form_O2 + DELTAh_O2[5]

DELTAh_O2[1] = (h_O2[1] - h_O2_ref)
DELTAh_O2[2] = (h_O2[2] - h_O2_ref)
DELTAh_O2[3] = (h_O2[3] - h_O2_ref)
DELTAh_O2[4] = (h_O2[4] - h_O2_ref)
DELTAh_O2[5] = (h_O2[5] - h_O2_ref)

h_O2[1] = enthalpy(B$, T=T_C[1])
h_O2[2] = enthalpy(B$, T=T_C[2])
h_O2[3] = enthalpy(B$, T=T_C[3])
h_O2[4] = enthalpy(B$, T=T_C[4])
h_O2[5] = enthalpy(B$, T=T_C[5])

h_O2_ref = enthalpy(B$, T=T[0])
h_form_O2 = enthalpy_formation(B$)

C$='N2'
h_std_N2[1] = h_form_N2 + DELTAh_N2[1]          "enthalpy STD for N2 at 5 opertaing points"
h_std_N2[2] = h_form_N2 + DELTAh_N2[2]
h_std_N2[3] = h_form_N2 + DELTAh_N2[3]
h_std_N2[4] = h_form_N2 + DELTAh_N2[4]
h_std_N2[5] = h_form_N2 + DELTAh_N2[5]

DELTAh_N2[1] = (h_N2[1] - h_N2_ref)
DELTAh_N2[2] = (h_N2[2] - h_N2_ref)
DELTAh_N2[3] = (h_N2[3] - h_N2_ref)
DELTAh_N2[4] = (h_N2[4] - h_N2_ref)
DELTAh_N2[5] = (h_N2[5] - h_N2_ref)

h_N2[1] = enthalpy(C$, T=T_C[1])
h_N2[2] = enthalpy(C$, T=T_C[2])
h_N2[3] = enthalpy(C$, T=T_C[3])
h_N2[4] = enthalpy(C$, T=T_C[4])
h_N2[5] = enthalpy(C$, T=T_C[5])

h_N2_ref = enthalpy(C$, T=T[0])
h_form_N2 = enthalpy_formation(C$)

"!product enthalpies"
D$='CO2'
h_std_CO2[1] = h_form_CO2 + DELTAh_CO2[1]          "enthalpy STD for CO2 at 5 opertaing points"
h_std_CO2[2] = h_form_CO2 + DELTAh_CO2[2]
h_std_CO2[3] = h_form_CO2 + DELTAh_CO2[3]
h_std_CO2[4] = h_form_CO2 + DELTAh_CO2[4]
h_std_CO2[5] = h_form_CO2 + DELTAh_CO2[5]

DELTAh_CO2[1] = (h_CO2[1] - h_CO2_ref)
DELTAh_CO2[2] = (h_CO2[2] - h_CO2_ref)
DELTAh_CO2[3] = (h_CO2[3] - h_CO2_ref)
DELTAh_CO2[4] = (h_CO2[4] - h_CO2_ref)
DELTAh_CO2[5] = (h_CO2[5] - h_CO2_ref)

h_CO2[1] = enthalpy(D$, T=T_E[1])
h_CO2[2] = enthalpy(D$, T=T_E[2])
h_CO2[3] = enthalpy(D$, T=T_E[3])
h_CO2[4] = enthalpy(D$, T=T_E[4])
h_CO2[5] = enthalpy(D$, T=T_E[5])

h_CO2_ref = enthalpy(D$, T=T[0])
h_form_CO2=enthalpy_formation(D$)
```

```
E$='H2O'                                     "enthalpy STD for H2O at 5 opertaing points"
h_std_H2O[1] =enthalpy(E$, T=T_E[1])
h_std_H2O[2] =enthalpy(E$, T=T_E[2])
h_std_H2O[3] =enthalpy(E$, T=T_E[3])
h_std_H2O[4] =enthalpy(E$, T=T_E[4])
h_std_H2O[5] =enthalpy(E$, T=T_E[5])

F$='N2'                                      "enthalpy STD for N2 at 5 opertaing points"
h_std_N2_OUT[1] = h_form_N2_OUT + DELTAh_N2_OUT[1]
h_std_N2_OUT[2] = h_form_N2_OUT + DELTAh_N2_OUT[2]
h_std_N2_OUT[3] = h_form_N2_OUT + DELTAh_N2_OUT[3]
h_std_N2_OUT[4] = h_form_N2_OUT + DELTAh_N2_OUT[4]
h_std_N2_OUT[5] = h_form_N2_OUT + DELTAh_N2_OUT[5]

DELTAh_N2_OUT[1] = (h_N2_OUT[1] - h_N2_OUT_ref)
DELTAh_N2_OUT[2] = (h_N2_OUT[2] - h_N2_OUT_ref)
DELTAh_N2_OUT[3] = (h_N2_OUT[3] - h_N2_OUT_ref)
DELTAh_N2_OUT[4] = (h_N2_OUT[4] - h_N2_OUT_ref)
DELTAh_N2_OUT[5] = (h_N2_OUT[5] - h_N2_OUT_ref)

h_N2_OUT[1] = enthalpy(F$, T=T_E[1])
h_N2_OUT[2] = enthalpy(F$, T=T_E[2])
h_N2_OUT[3] = enthalpy(F$, T=T_E[3])
h_N2_OUT[4] = enthalpy(F$, T=T_E[4])
h_N2_OUT[5] = enthalpy(F$, T=T_E[5])

h_N2_OUT_ref = enthalpy(F$, T=T[0])
h_form_N2_OUT = enthalpy_formation(F$)

"hhhh=enthalpy(H2O, T=206.85[c])"


"EQUATIONS"

"1st law"
Q[1] - W[1] = H_R[1] - H_P[1]
Q[2] - W[2] = H_R[2] - H_P[2]
Q[3] - W[3] = H_R[3] - H_P[3]
Q[4] - W[4] = H_R[4] - H_P[4]
Q[5] - W[5] = H_R[5] - H_P[5]

"calculating W from system"
W[1] = torque[1] * speed
W[2] = torque[2] * speed
W[3] = torque[3] * speed
W[4] = torque[4] * speed
W[5] = torque[5] * speed

"adding up the enthalpies of the reactants"
H_R[1] = n_fuel[1]*h_std_C8H18[1] + n_O2[1]*h_std_O2[1] + n_N2_in[1]*h_std_N2[1]
H_R[2] = n_fuel[2]*h_std_C8H18[2] + n_O2[2]*h_std_O2[2] + n_N2_in[2]*h_std_N2[2]
H_R[3] = n_fuel[3]*h_std_C8H18[3] + n_O2[3]*h_std_O2[3] + n_N2_in[3]*h_std_N2[3]
H_R[4] = n_fuel[4]*h_std_C8H18[4] + n_O2[4]*h_std_O2[4] + n_N2_in[4]*h_std_N2[4]
H_R[5] = n_fuel[5]*h_std_C8H18[5] + n_O2[5]*h_std_O2[5] + n_N2_in[5]*h_std_N2[5]

"adding up the enthalpies of the products"
H_P[1]= n_CO2[1]*h_std_CO2[1] + n_H2O[1]*h_std_H2O[1] + n_N2_OUT[1]*h_std_N2_OUT[1]
H_P[2]= n_CO2[2]*h_std_CO2[2] + n_H2O[2]*h_std_H2O[2] + n_N2_OUT[2]*h_std_N2_OUT[2]
H_P[3]= n_CO2[3]*h_std_CO2[3] + n_H2O[3]*h_std_H2O[3] + n_N2_OUT[3]*h_std_N2_OUT[3]
H_P[4]= n_CO2[4]*h_std_CO2[4] + n_H2O[4]*h_std_H2O[4] + n_N2_OUT[4]*h_std_N2_OUT[4]
H_P[5]= n_CO2[5]*h_std_CO2[5] + n_H2O[5]*h_std_H2O[5] + n_N2_OUT[5]*h_std_N2_OUT[5]
```

```
"calculating the Q loss to use for calculating the efficiency"
Q_loss[1] = H_R[1] - H_P[1]
Q_loss[2] = H_R[2] - H_P[2]
Q_loss[3] = H_R[3] - H_P[3]
Q_loss[4] = H_R[4] - H_P[4]
Q_loss[5] = H_R[5] - H_P[5]

 "calculating the efficiency"
eta[1]=W[1] /  ( Q_loss[1]  )
eta[2]=W[2] /  ( Q_loss[2] )
eta[3]=W[3] /  ( Q_loss[3]  )
eta[4]=W[4] /  ( Q_loss[4] )
eta[5]=W[5] /  ( Q_loss[5] )

"calculating carnot"
T_flame = converttemp('c','k',2150 )
eta_carnot = 1 - T_ref/T_flame


"calculating the efficiency of the actual fuel using the LHV from the paper"
LHV_b = 42611 [J/g]
eta_partb[1] = W[1] / (m_fuel[1] * LHV_b)
eta_partb[2] = W[2] / (m_fuel[2] * LHV_b)
eta_partb[3] = W[3] / (m_fuel[3] * LHV_b)
eta_partb[4] = W[4] / (m_fuel[4] * LHV_b)
eta_partb[5] = W[5] / (m_fuel[5] * LHV_b)


"! Calculating rectants entropy "

"the total reactant molar flowrate"
n_R_tot[1] = n_fuel[1] + n_O2[1] + n_N2_in [1]
n_R_tot[2] = n_fuel[2] + n_O2[2] + n_N2_in [2]
n_R_tot[3] = n_fuel[3] + n_O2[3] + n_N2_in [3]
n_R_tot[4] = n_fuel[4] + n_O2[4] + n_N2_in [4]
n_R_tot[5] = n_fuel[5] + n_O2[5] + n_N2_in [5]


s_c8h18[1]=entropy(A$,T=T_C[1],P=n_fuel[1]/n_R_tot[1]*P)
s_c8h18[2]=entropy(A$,T=T_C[2],P=n_fuel[2]/n_R_tot[2]*P)
s_c8h18[3]=entropy(A$,T=T_C[3],P=n_fuel[3]/n_R_tot[3]*P)
s_c8h18[4]=entropy(A$,T=T_C[4],P=n_fuel[4]/n_R_tot[4]*P)
s_c8h18[5]=entropy(A$,T=T_C[5],P=n_fuel[5]/n_R_tot[5]*P)

s_O2[1]=entropy(B$,T=T_C[1],P=n_O2[1]/n_R_tot[1]*P)
s_O2[2]=entropy(B$,T=T_C[2],P=n_O2[2]/n_R_tot[2]*P)
s_O2[3]=entropy(B$,T=T_C[3],P=n_O2[3]/n_R_tot[3]*P)
s_O2[4]=entropy(B$,T=T_C[4],P=n_O2[4]/n_R_tot[4]*P)
s_O2[5]=entropy(B$,T=T_C[5],P=n_O2[5]/n_R_tot[5]*P)

s_N2[1]=entropy(C$,T=T_C[1],P=n_N2_in[1]/n_R_tot[1]*P)
s_N2[2]=entropy(C$,T=T_C[2],P=n_N2_in[2]/n_R_tot[3]*P)
s_N2[3]=entropy(C$,T=T_C[3],P=n_N2_in[3]/n_R_tot[4]*P)
s_N2[4]=entropy(C$,T=T_C[4],P=n_N2_in[4]/n_R_tot[4]*P)
s_N2[5]=entropy(C$,T=T_C[5],P=n_N2_in[5]/n_R_tot[5]*P)

"!Calculating products entropy"

n_P_tot[1] = n_CO2[1] + n_H2O[1] + n_N2_OUT[1]
n_P_tot[2] = n_CO2[2] + n_H2O[2] + n_N2_OUT[2]
n_P_tot[3] = n_CO2[3] + n_H2O[3] + n_N2_OUT[3]
n_P_tot[4] = n_CO2[4] + n_H2O[4] + n_N2_OUT[4]
n_P_tot[5] = n_CO2[5] + n_H2O[5] + n_N2_OUT[5]
```

```
s_CO2[1]=entropy(D$,T=T_E[1],P=n_CO2[1]/n_P_tot[1]*P)
s_CO2[2]=entropy(D$,T=T_E[2],P=n_CO2[2]/n_P_tot[2]*P)
s_CO2[3]=entropy(D$,T=T_E[3],P=n_CO2[3]/n_P_tot[3]*P)
s_CO2[4]=entropy(D$,T=T_E[4],P=n_CO2[4]/n_P_tot[4]*P)
s_CO2[5]=entropy(D$,T=T_E[5],P=n_CO2[5]/n_P_tot[5]*P)

s_H2O[1]=entropy(E$,T=T_E[1],P=n_H2O[1]/n_P_tot[1]*P)
s_H2O[2]=entropy(E$,T=T_E[2],P=n_H2O[2]/n_P_tot[2]*P)
s_H2O[3]=entropy(E$,T=T_E[3],P=n_H2O[3]/n_P_tot[3]*P)
s_H2O[4]=entropy(E$,T=T_E[4],P=n_H2O[4]/n_P_tot[4]*P)
s_H2O[5]=entropy(E$,T=T_E[5],P=n_H2O[5]/n_P_tot[5]*P)

s_N2_OUT[1]=entropy(C$,T=T_E[1],P=n_N2_OUT[1]/n_P_tot[1]*P)
s_N2_OUT[2]=entropy(C$,T=T_E[2],P=n_N2_OUT[2]/n_P_tot[2]*P)
s_N2_OUT[3]=entropy(C$,T=T_E[3],P=n_N2_OUT[3]/n_P_tot[3]*P)
s_N2_OUT[4]=entropy(C$,T=T_E[4],P=n_N2_OUT[4]/n_P_tot[4]*P)
s_N2_OUT[5]=entropy(C$,T=T_E[5],P=n_N2_OUT[5]/n_P_tot[5]*P)


S_Q[1] = -Q[1] / T_H_K[1]
S_Q[2] =-Q[2] / T_H_K[2]
S_Q[3] = -Q[3] / T_H_K[3]
S_Q[4] = -Q[4] / T_H_K[4]
S_Q[5] = -Q[5] / T_H_K[5]


"!entopy balnce (2nd law)"
S_R[1] = n_fuel[1]*s_c8h18[1] + n_O2[1]*s_O2[1] + n_N2_in[1]*s_N2[1]
S_R[2] = n_fuel[2]*s_c8h18[2] + n_O2[2]*s_O2[2] + n_N2_in[2]*s_N2[2]
S_R[3] = n_fuel[3]*s_c8h18[3] + n_O2[3]*s_O2[3] + n_N2_in[3]*s_N2[3]
S_R[4] = n_fuel[4]*s_c8h18[4] + n_O2[4]*s_O2[4] + n_N2_in[4]*s_N2[4]
S_R[5] = n_fuel[5]*s_c8h18[5] + n_O2[5]*s_O2[5] + n_N2_in[5]*s_N2[5]


S_P[1] = n_CO2[1]*s_CO2[1] + n_H2O[1]*s_H2O[1] +  n_N2_OUT[1]*s_N2_OUT[1]
S_P[2] = n_CO2[2]*s_CO2[2] + n_H2O[2]*s_H2O[2] + n_N2_OUT[1]*s_N2_OUT[2]
S_P[3] = n_CO2[3]*s_CO2[3] + n_H2O[3]*s_H2O[3] + n_N2_OUT[1]*s_N2_OUT[3]
S_P[4] = n_CO2[4]*s_CO2[4] + n_H2O[4]*s_H2O[4] + n_N2_OUT[1]*s_N2_OUT[4]
S_P[5] = n_CO2[5]*s_CO2[5] + n_H2O[5]*s_H2O[5] + n_N2_OUT[1]*s_N2_OUT[5]

"entropy produced obtained from this equation"
S_R[1] - S_P[1] + S_Q[1] + sigma_prod[1] = 0
S_R[2] - S_P[2] +S_Q[2]  + sigma_prod[2] = 0
S_R[3] - S_P[3] + S_Q[3] + sigma_prod[3] = 0
S_R[4] - S_P[4] + S_Q[4] + sigma_prod[4] = 0
S_R[5] - S_P[5] + S_Q[5] + sigma_prod[5] = 0


 "! head temperatureexergy destroyed"
X_dest[1] = T_ref* sigma_prod[1]
X_dest[2] = T_ref* sigma_prod[2]
X_dest[3] = T_ref* sigma_prod[3]
X_dest[4] = T_ref* sigma_prod[4]
X_dest[5] = T_ref* sigma_prod[5]

"!second law"
eta_2[1] = W[1] / X_dest[1]
eta_2[2] = W[2] / X_dest[2]
eta_2[3] = W[3] / X_dest[3]
eta_2[4] = W[4] / X_dest[4]
eta_2[5] = W[5] / X_dest[5]
```

```
"!Question 5"
Areaofgraph = 0.015516 [KJ/rev]
speed_2= 6500*convert(rev/min,rev/s)
W_estimated =Areaofgraph*speed_2



Q_partb[1] =(m_fuel[1] * LHV_b)
Q_partb[2] = (m_fuel[2] * LHV_b)
Q_partb[3] =  (m_fuel[3] * LHV_b)
Q_partb[4] =  (m_fuel[4] * LHV_b)
Q_partb[5] =  (m_fuel[5] * LHV_b)
```

Ahmad Bukshaisha and Andrew Alferman

ME540 HW4

GIVEN INFORMATION

Torque/power information

$torque_1 = 13.83 \cdot \left| 0.000112985 \cdot \frac{kJ}{in-lbf} \right|$ *Torque at point 1*

$torque_2 = 15.57 \cdot \left| 0.000112985 \cdot \frac{kJ}{in-lbf} \right|$ *Torque at point 2*

$torque_3 = 16.07 \cdot \left| 0.000112985 \cdot \frac{kJ}{in-lbf} \right|$ *Torque at point 3*

$torque_4 = 14.57 \cdot \left| 0.000112985 \cdot \frac{kJ}{in-lbf} \right|$ *Torque at point 4*

$torque_5 = 14.13 \cdot \left| 0.000112985 \cdot \frac{kJ}{in-lbf} \right|$ *Torque at point 5*

$speed = 6500 \cdot \left| 0.1047 \cdot \frac{rad/s}{rev/min} \right|$ *Speed in radians/sec*

Temperature information

$T_0 = 25$ [C] *T ref*

$T_{C,1} = 46.41$ [C] *crank temp 1*

$T_{C,2} = 46.79$ [C] *crank temp 2*

$T_{C,3} = 44.16$ [C] *crank temp 3*

$T_{C,4} = 44.14$ [C] *crank temp 4*

$T_{C,5} = 44.58$ [C] *crank temp 5*

$T_{H,1} = 228.11$ [C]

head temp 1

$T_{H,2} = 220.16$ [C] *head temp 2*

$T_{H,3} = 213.54$ [C] *head temp 3*

$T_{H,4} = 220.65$ [C] *head temp 4*

$T_{H,5} = 208.56$ [C] *head temp 5*

$T_{H,K,1} = \textbf{ConvertTemp}\left[C, K, T_{H,1}\right]$

$T_{H,K,2} = \textbf{ConvertTemp}\left[C, K, T_{H,2}\right]$

$T_{H,K,3} = \textbf{ConvertTemp}\left[C, K, T_{H,3}\right]$

$T_{H,K,4} = \textbf{ConvertTemp}\left[C, K, T_{H,4}\right]$

$T_{H,K,5} = \textbf{ConvertTemp}\left[C, K, T_{H,5}\right]$

$T_{E,1} = 529.94$ [C] *exhaust temp 1*

$T_{E,2} = 509.62$ [C] *exhaust temp 2*

$T_{E,3} = 497.69$ [C] *exhaust temp 3*

$T_{E,4} = 477.46$ [C] *exhaust temp 4*

$T_{E,5} = 462.09$ [C] *exhaust temp 5*

$T_{ref} = \textbf{ConvertTemp}\left[C, K, T_0\right]$

Ambient Pressure

$P = 101.3$ [kPa]

Fuel mass flow rates

$m_{fuel,1} = 0.1772 \cdot \left| 0.001 \cdot \frac{kg/s}{g/s} \right|$ *mass flowrate of fuel 1*

$m_{fuel,2} = 0.2009 \cdot \left| 0.001 \cdot \frac{kg/s}{g/s} \right|$ *mass flowrate of fuel 2*

$m_{fuel,3} = 0.2093 \cdot \left| 0.001 \cdot \frac{kg/s}{g/s} \right|$ *mass flowrate of fuel 3*

$m_{fuel,4} = 0.2343 \cdot \left| 0.001 \cdot \frac{kg/s}{g/s} \right|$ *mass flowrate of fuel 4*

$m_{fuel,5} = 0.2496 \cdot \left| 0.001 \cdot \frac{kg/s}{g/s} \right|$ *mass flowrate of fuel 5*

$n_{fuel,1} = \frac{m_{fuel,1}}{C8H18_{MW}}$

molar flowrate of fuel 1

$n_{fuel,2} = \dfrac{m_{fuel,2}}{C8H18_{MW}}$ *molar flowrate of fuel 2*

$n_{fuel,3} = \dfrac{m_{fuel,3}}{C8H18_{MW}}$ *molar flowrate of fuel 3*

$n_{fuel,4} = \dfrac{m_{fuel,4}}{C8H18_{MW}}$ *molar flowrate of fuel 4*

$n_{fuel,5} = \dfrac{m_{fuel,5}}{C8H18_{MW}}$ *molar flowrate of fuel 5*

$C8H18_{MW} = \mathbf{MolarMass}\left[C8H18\right]$ *MW of C8H18*

Calculating all molar flow rates in the chemical reaction

$n_{air,1} = 12.5 \cdot 4.76 \cdot n_{fuel,1}$ *molar flowrate of air 1*

$n_{air,2} = 12.5 \cdot 4.76 \cdot n_{fuel,2}$ *molar flowrate of air 2*

$n_{air,3} = 12.5 \cdot 4.76 \cdot n_{fuel,3}$ *molar flowrate of air 3*

$n_{air,4} = 12.5 \cdot 4.76 \cdot n_{fuel,4}$ *molar flowrate of air 4*

$n_{air,5} = 12.5 \cdot 4.76 \cdot n_{fuel,5}$ *molar flowrate of air 5*

$n_{O2,1} = n_{air,1} \cdot 0.21$ *molar flow rate of O2 1*

$n_{O2,2} = n_{air,2} \cdot 0.21$ *molar flow rate of O2 2*

$n_{O2,3} = n_{air,3} \cdot 0.21$ *molar flow rate of O2 3*

$n_{O2,4} = n_{air,4} \cdot 0.21$ *molar flow rate of O2 4*

$n_{O2,5} = n_{air,5} \cdot 0.21$ *molar flow rate of O2 5*

$n_{N2,in,1} = n_{air,1} \cdot 0.79$ *molar flow rate of N2 1*

$n_{N2,in,2} = n_{air,2} \cdot 0.79$ *molar flow rate of N2 2*

$n_{N2,in,3} = n_{air,3} \cdot 0.79$ *molar flow rate of N2 3*

$n_{N2,in,4} = n_{air,4} \cdot 0.79$ *molar flow rate of N2 4*

$n_{N2,in,5} = n_{air,5} \cdot 0.79$ *molar flow rate of N2 5*

$n_{CO2,1} = 8 \cdot \dfrac{n_{air,1}}{12.5 \cdot 4.76}$ *molar flow rate of CO2 1*

$n_{CO2,2} = 8 \cdot \dfrac{n_{air,2}}{12.5 \cdot 4.76}$ *molar flow rate of CO2 2*

$n_{CO2,3} = 8 \cdot \frac{n_{air,3}}{12.5 \cdot 4.76}$ *molar flow rate of CO2 3*

$n_{CO2,4} = 8 \cdot \frac{n_{air,4}}{12.5 \cdot 4.76}$ *molar flow rate of CO2 4*

$n_{CO2,5} = 8 \cdot \frac{n_{air,5}}{12.5 \cdot 4.76}$ *molar flow rate of CO2 5*

$n_{H2O,1} = 9 \cdot \frac{n_{air,1}}{12.5 \cdot 4.76}$ *molar flow rate of H2O 1*

$n_{H2O,2} = 9 \cdot \frac{n_{air,2}}{12.5 \cdot 4.76}$ *molar flow rate of H2O 2*

$n_{H2O,3} = 9 \cdot \frac{n_{air,3}}{12.5 \cdot 4.76}$ *molar flow rate of H2O 3*

$n_{H2O,4} = 9 \cdot \frac{n_{air,4}}{12.5 \cdot 4.76}$ *molar flow rate of H2O 4*

$n_{H2O,5} = 9 \cdot \frac{n_{air,5}}{12.5 \cdot 4.76}$ *molar flow rate of H2O 5*

$n_{N2,out,1} = 47 \cdot \frac{n_{air,1}}{12.5 \cdot 4.76}$ *molar flow rate of N2 out 1*

$n_{N2,out,2} = 47 \cdot \frac{n_{air,2}}{12.5 \cdot 4.76}$ *molar flow rate of N2 out 2*

$n_{N2,out,3} = 47 \cdot \frac{n_{air,3}}{12.5 \cdot 4.76}$ *molar flow rate of N2 out 3*

$n_{N2,out,4} = 47 \cdot \frac{n_{air,4}}{12.5 \cdot 4.76}$ *molar flow rate of N2 out 4*

$n_{N2,out,5} = 47 \cdot \frac{n_{air,5}}{12.5 \cdot 4.76}$ *molar flow rate of N2 out 5*

Rectants enthalpies

A$ = 'C8H18'

$h_{std,C8H18,1} = h_{form,C8H18} + \Delta h_{C8H18,1}$ *enthalpy STD for C8H18 at 5 opertaing points*

$h_{std,C8H18,2} = h_{form,C8H18} + \Delta h_{C8H18,2}$

$h_{std,C8H18,3} = h_{form,C8H18} + \Delta h_{C8H18,3}$

$h_{std,C8H18,4} = h_{form,C8H18} + \Delta h_{C8H18,4}$

$h_{std,C8H18,5} = h_{form,C8H18} + \Delta h_{C8H18,5}$

$\Delta h_{C8H18,1} = h_{C8H18,1} - h_{C8H18,ref}$

$\Delta h_{C8H18,2} = h_{C8H18,2} - h_{C8H18,ref}$

$\Delta h_{C8H18,3} = h_{C8H18,3} - h_{C8H18,ref}$

$\Delta h_{C8H18,4} = h_{C8H18,4} - h_{C8H18,ref}$

$\Delta h_{C8H18,5} = h_{C8H18,5} - h_{C8H18,ref}$

$h_{C8H18,1} = \mathbf{h}\left[A\$, T = T_{C,1}\right]$

$h_{C8H18,2} = \mathbf{h}\left[A\$, T = T_{C,2}\right]$

$h_{C8H18,3} = \mathbf{h}\left[A\$, T = T_{C,3}\right]$

$h_{C8H18,4} = \mathbf{h}\left[A\$, T = T_{C,4}\right]$

$h_{C8H18,5} = \mathbf{h}\left[A\$, T = T_{C,5}\right]$

$h_{C8H18,ref} = \mathbf{h}\left[A\$, T = T_0\right]$

$h_{form,C8H18} = \mathbf{Enthalpy}_{formation}\left[A\$\right]$

B$ = 'O2'

$h_{std,O2,1} = h_{form,O2} + \Delta h_{O2,1}$ *enthalpy STD for O2 at 5 opertaing points*

$h_{std,O2,2} = h_{form,O2} + \Delta h_{O2,2}$

$h_{std,O2,3} = h_{form,O2} + \Delta h_{O2,3}$

$h_{std,O2,4} = h_{form,O2} + \Delta h_{O2,4}$

$h_{std,O2,5} = h_{form,O2} + \Delta h_{O2,5}$

$\Delta h_{O2,1} = h_{O2,1} - h_{O2,ref}$

$\Delta h_{O2,2} = h_{O2,2} - h_{O2,ref}$

$\Delta h_{O2,3} = h_{O2,3} - h_{O2,ref}$

$\Delta h_{O2,4} = h_{O2,4} - h_{O2,ref}$

$\Delta h_{O2,5} = h_{O2,5} - h_{O2,ref}$

$h_{O2,1} = \mathbf{h}\left[B\$, T = T_{C,1}\right]$

$h_{O2,2} = \mathbf{h}\left[B\$, T = T_{C,2}\right]$

$h_{O2,3} = \mathbf{h}\left[B\$, T = T_{C,3}\right]$

$h_{O2,4} = \mathbf{h}\left[B\$, T = T_{C,4}\right]$

$h_{O2,5} = \mathbf{h}\left[B\$, T = T_{C,5}\right]$

$h_{O2,ref} = \mathbf{h}\left[B\$, T = T_0\right]$

$h_{form,O2} = \mathbf{Enthalpy}_{formation}\left[B\$\right]$

$C\$ = \text{'N2'}$

$h_{std,N2,1} = h_{form,N2} + \Delta h_{N2,1}$ *enthalpy STD for N2 at 5 opertaing points*

$h_{std,N2,2} = h_{form,N2} + \Delta h_{N2,2}$

$h_{std,N2,3} = h_{form,N2} + \Delta h_{N2,3}$

$h_{std,N2,4} = h_{form,N2} + \Delta h_{N2,4}$

$h_{std,N2,5} = h_{form,N2} + \Delta h_{N2,5}$

$\Delta h_{N2,1} = h_{N2,1} - h_{N2,ref}$

$\Delta h_{N2,2} = h_{N2,2} - h_{N2,ref}$

$\Delta h_{N2,3} = h_{N2,3} - h_{N2,ref}$

$\Delta h_{N2,4} = h_{N2,4} - h_{N2,ref}$

$\Delta h_{N2,5} = h_{N2,5} - h_{N2,ref}$

$h_{N2,1} = \mathbf{h}\left[C\$, T = T_{C,1}\right]$

$h_{N2,2} = \mathbf{h}\left[C\$, T = T_{C,2}\right]$

$h_{N2,3} = \mathbf{h}\left[C\$, T = T_{C,3}\right]$

$h_{N2,4} = \mathbf{h}\left[C\$, T = T_{C,4}\right]$

$h_{N2,5} = \mathbf{h}\left[C\$, T = T_{C,5}\right]$

$h_{N2,ref} = \mathbf{h}\left[C\$, T = T_0\right]$

$h_{form,N2} = \mathbf{Enthalpy}_{formation}\left[C\$\right]$

product enthalpies

$D\$ = \text{'CO2'}$

$h_{std,CO2,1} = h_{form,CO2} + \Delta h_{CO2,1}$ *enthalpy STD for CO2 at 5 opertaing points*

$h_{std,CO2,2} = h_{form,CO2} + \Delta h_{CO2,2}$

$h_{std,CO2,3} = h_{form,CO2} + \Delta h_{CO2,3}$

$h_{std,CO2,4} = h_{form,CO2} + \Delta h_{CO2,4}$

$h_{std,CO2,5} = h_{form,CO2} + \Delta h_{CO2,5}$

$\Delta h_{CO2,1} = h_{CO2,1} - h_{CO2,ref}$

$\Delta h_{CO2,2} = h_{CO2,2} - h_{CO2,ref}$

$\Delta h_{CO2,3} = h_{CO2,3} - h_{CO2,ref}$

$\Delta h_{CO2,4} = h_{CO2,4} - h_{CO2,ref}$

$\Delta h_{CO2,5} = h_{CO2,5} - h_{CO2,ref}$

$h_{CO2,1} = \mathbf{h}[D\$, T = T_{E,1}]$

$h_{CO2,2} = \mathbf{h}[D\$, T = T_{E,2}]$

$h_{CO2,3} = \mathbf{h}[D\$, T = T_{E,3}]$

$h_{CO2,4} = \mathbf{h}[D\$, T = T_{E,4}]$

$h_{CO2,5} = \mathbf{h}[D\$, T = T_{E,5}]$

$h_{CO2,ref} = \mathbf{h}[D\$, T = T_0]$

$h_{form,CO2} = \mathbf{Enthalpy}_{formation}[D\$]$

E$ = 'h2o' *enthalpy STD for H2O at 5 opertaing points*

$h_{std,H2O,1} = \mathbf{h}[E\$, T = T_{E,1}]$

$h_{std,H2O,2} = \mathbf{h}[E\$, T = T_{E,2}]$

$h_{std,H2O,3} = \mathbf{h}[E\$, T = T_{E,3}]$

$h_{std,H2O,4} = \mathbf{h}[E\$, T = T_{E,4}]$

$h_{std,H2O,5} = \mathbf{h}[E\$, T = T_{E,5}]$

F$ = 'N2' *enthalpy STD for N2 at 5 opertaing points*

$h_{std,N2,OUT,1} = h_{form,N2,OUT} + \Delta h_{N2,OUT,1}$

$h_{std,N2,OUT,2} = h_{form,N2,OUT} + \Delta h_{N2,OUT,2}$

$h_{std,N2,OUT,3} = h_{form,N2,OUT} + \Delta h_{N2,OUT,3}$

$h_{std,N2,OUT,4} = h_{form,N2,OUT} + \Delta h_{N2,OUT,4}$

$h_{std,N2,OUT,5} = h_{form,N2,OUT} + \Delta h_{N2,OUT,5}$

$\Delta h_{N2,OUT,1} = h_{N2,OUT,1} - h_{N2,OUT,ref}$

$\Delta h_{N2,OUT,2} = h_{N2,OUT,2} - h_{N2,OUT,ref}$

$\Delta h_{N2,OUT,3} = h_{N2,OUT,3} - h_{N2,OUT,ref}$

$\Delta h_{N2,OUT,4} = h_{N2,OUT,4} - h_{N2,OUT,ref}$

$\Delta h_{N2,OUT,5} = h_{N2,OUT,5} - h_{N2,OUT,ref}$

$h_{N2,OUT,1} = \mathbf{h}[F\$, T = T_{E,1}]$

$h_{N2,OUT,2} = \mathbf{h}[F\$, T = T_{E,2}]$

$h_{N2,OUT,3} = \mathbf{h}\left[F\$, T = T_{E,3} \right]$

$h_{N2,OUT,4} = \mathbf{h}\left[F\$, T = T_{E,4} \right]$

$h_{N2,OUT,5} = \mathbf{h}\left[F\$, T = T_{E,5} \right]$

$h_{N2,OUT,ref} = \mathbf{h}\left[F\$, T = T_{0} \right]$

$h_{form,N2,OUT} = \mathbf{Enthalpy}_{formation}\left[F\$ \right]$

hhhh=enthalpy(H2O, T=206.85$_C$)

EQUATIONS

1st law

$Q_1 - W_1 = H_{R,1} - H_{P,1}$

$Q_2 - W_2 = H_{R,2} - H_{P,2}$

$Q_3 - W_3 = H_{R,3} - H_{P,3}$

$Q_4 - W_4 = H_{R,4} - H_{P,4}$

$Q_5 - W_5 = H_{R,5} - H_{P,5}$

calculating W from system

$W_1 = torque_1 \cdot speed$

$W_2 = torque_2 \cdot speed$

$W_3 = torque_3 \cdot speed$

$W_4 = torque_4 \cdot speed$

$W_5 = torque_5 \cdot speed$

adding up the enthalpies of the reactants

$H_{R,1} = n_{fuel,1} \cdot h_{std,C8H18,1} + n_{O2,1} \cdot h_{std,O2,1} + n_{N2,in,1} \cdot h_{std,N2,1}$

$H_{R,2} = n_{fuel,2} \cdot h_{std,C8H18,2} + n_{O2,2} \cdot h_{std,O2,2} + n_{N2,in,2} \cdot h_{std,N2,2}$

$H_{R,3} = n_{fuel,3} \cdot h_{std,C8H18,3} + n_{O2,3} \cdot h_{std,O2,3} + n_{N2,in,3} \cdot h_{std,N2,3}$

$H_{R,4} = n_{fuel,4} \cdot h_{std,C8H18,4} + n_{O2,4} \cdot h_{std,O2,4} + n_{N2,in,4} \cdot h_{std,N2,4}$

$H_{R,5} = n_{fuel,5} \cdot h_{std,C8H18,5} + n_{O2,5} \cdot h_{std,O2,5} + n_{N2,in,5} \cdot h_{std,N2,5}$

adding up the enthalpies of the products

$H_{P,1} = n_{CO2,1} \cdot h_{std,CO2,1} + n_{H2O,1} \cdot h_{std,H2O,1} + n_{N2,out,1} \cdot h_{std,N2,OUT,1}$

$H_{P,2} = n_{CO2,2} \cdot h_{std,CO2,2} + n_{H2O,2} \cdot h_{std,H2O,2} + n_{N2,out,2} \cdot h_{std,N2,OUT,2}$

$$H_{P,3} = n_{CO2,3} \cdot h_{std,CO2,3} + n_{H2O,3} \cdot h_{std,H2O,3} + n_{N2,out,3} \cdot h_{std,N2,OUT,3}$$

$$H_{P,4} = n_{CO2,4} \cdot h_{std,CO2,4} + n_{H2O,4} \cdot h_{std,H2O,4} + n_{N2,out,4} \cdot h_{std,N2,OUT,4}$$

$$H_{P,5} = n_{CO2,5} \cdot h_{std,CO2,5} + n_{H2O,5} \cdot h_{std,H2O,5} + n_{N2,out,5} \cdot h_{std,N2,OUT,5}$$

calculating the Q loss to use for calculating the efficiency

$$Q_{loss,1} = H_{R,1} - H_{P,1}$$

$$Q_{loss,2} = H_{R,2} - H_{P,2}$$

$$Q_{loss,3} = H_{R,3} - H_{P,3}$$

$$Q_{loss,4} = H_{R,4} - H_{P,4}$$

$$Q_{loss,5} = H_{R,5} - H_{P,5}$$

calculating the efficiency

$$\eta_1 = \frac{W_1}{Q_{loss,1}}$$

$$\eta_2 = \frac{W_2}{Q_{loss,2}}$$

$$\eta_3 = \frac{W_3}{Q_{loss,3}}$$

$$\eta_4 = \frac{W_4}{Q_{loss,4}}$$

$$\eta_5 = \frac{W_5}{Q_{loss,5}}$$

calculating carnot

$$T_{flame} = \textbf{ConvertTemp}\left[C , K , 2150 \right]$$

$$\eta_{carnot} = 1 - \frac{T_{ref}}{T_{flame}}$$

calculating the efficiency of the actual fuel using the LHV from the paper

$LHV_b = 42611$ [J/g]

$$\eta_{partb,1} = \frac{W_1}{m_{fuel,1} \cdot LHV_b}$$

$$\eta_{partb,2} = \frac{W_2}{m_{fuel,2} \cdot LHV_b}$$

$$\eta_{partb,3} = \frac{W_3}{m_{fuel,3} \cdot LHV_b}$$

$$\eta_{partb,4} = \frac{W_4}{m_{fuel,4} \cdot LHV_b}$$

$$\eta_{partb,5} = \frac{W_5}{m_{fuel,5} \cdot LHV_b}$$

Calculating rectants entropy

the total reactant molar flowrate

$$n_{R,tot,1} = n_{fuel,1} + n_{O2,1} + n_{N2,in,1}$$

$$n_{R,tot,2} = n_{fuel,2} + n_{O2,2} + n_{N2,in,2}$$

$$n_{R,tot,3} = n_{fuel,3} + n_{O2,3} + n_{N2,in,3}$$

$$n_{R,tot,4} = n_{fuel,4} + n_{O2,4} + n_{N2,in,4}$$

$$n_{R,tot,5} = n_{fuel,5} + n_{O2,5} + n_{N2,in,5}$$

$$s_{c8h18,1} = \mathbf{s}\left[A\$, T = T_{C,1}, P = \frac{n_{fuel,1}}{n_{R,tot,1}} \cdot P\right]$$

$$s_{c8h18,2} = \mathbf{s}\left[A\$, T = T_{C,2}, P = \frac{n_{fuel,2}}{n_{R,tot,2}} \cdot P\right]$$

$$s_{c8h18,3} = \mathbf{s}\left[A\$, T = T_{C,3}, P = \frac{n_{fuel,3}}{n_{R,tot,3}} \cdot P\right]$$

$$s_{c8h18,4} = \mathbf{s}\left[A\$, T = T_{C,4}, P = \frac{n_{fuel,4}}{n_{R,tot,4}} \cdot P\right]$$

$$s_{c8h18,5} = \mathbf{s}\left[A\$, T = T_{C,5}, P = \frac{n_{fuel,5}}{n_{R,tot,5}} \cdot P\right]$$

$$s_{O2,1} = \mathbf{s}\left[B\$, T = T_{C,1}, P = \frac{n_{O2,1}}{n_{R,tot,1}} \cdot P\right]$$

$$s_{O2,2} = \mathbf{s}\left[B\$, T = T_{C,2}, P = \frac{n_{O2,2}}{n_{R,tot,2}} \cdot P\right]$$

$$s_{O2,3} = \mathbf{s}\left[B\$, T = T_{C,3}, P = \frac{n_{O2,3}}{n_{R,tot,3}} \cdot P\right]$$

$$s_{O2,4} = \mathbf{s}\left[B\$, T = T_{C,4}, P = \frac{n_{O2,4}}{n_{R,tot,4}} \cdot P\right]$$

$$s_{O2,5} = \mathbf{s}\left[B\$, T = T_{C,5}, P = \frac{n_{O2,5}}{n_{R,tot,5}} \cdot P\right]$$

$$s_{N2,1} = \mathbf{s}\left[C\$, T = T_{C,1}, P = \frac{n_{N2,in,1}}{n_{R,tot,1}} \cdot P\right]$$

$$s_{N2,2} = \mathbf{s}\left[C\$, T = T_{C,2}, P = \frac{n_{N2,in,2}}{n_{R,tot,3}} \cdot P\right]$$

$$s_{N2,3} = \mathbf{s}\left[C\$, T = T_{C,3} , P = \frac{n_{N2,in,3}}{n_{R,tot,4}} \cdot P \right]$$

$$s_{N2,4} = \mathbf{s}\left[C\$, T = T_{C,4} , P = \frac{n_{N2,in,4}}{n_{R,tot,4}} \cdot P \right]$$

$$s_{N2,5} = \mathbf{s}\left[C\$, T = T_{C,5} , P = \frac{n_{N2,in,5}}{n_{R,tot,5}} \cdot P \right]$$

Calculating products entropy

$$n_{P,tot,1} = n_{CO2,1} + n_{H2O,1} + n_{N2,out,1}$$

$$n_{P,tot,2} = n_{CO2,2} + n_{H2O,2} + n_{N2,out,2}$$

$$n_{P,tot,3} = n_{CO2,3} + n_{H2O,3} + n_{N2,out,3}$$

$$n_{P,tot,4} = n_{CO2,4} + n_{H2O,4} + n_{N2,out,4}$$

$$n_{P,tot,5} = n_{CO2,5} + n_{H2O,5} + n_{N2,out,5}$$

$$s_{CO2,1} = \mathbf{s}\left[D\$, T = T_{E,1} , P = \frac{n_{CO2,1}}{n_{P,tot,1}} \cdot P \right]$$

$$s_{CO2,2} = \mathbf{s}\left[D\$, T = T_{E,2} , P = \frac{n_{CO2,2}}{n_{P,tot,2}} \cdot P \right]$$

$$s_{CO2,3} = \mathbf{s}\left[D\$, T = T_{E,3} , P = \frac{n_{CO2,3}}{n_{P,tot,3}} \cdot P \right]$$

$$s_{CO2,4} = \mathbf{s}\left[D\$, T = T_{E,4} , P = \frac{n_{CO2,4}}{n_{P,tot,4}} \cdot P \right]$$

$$s_{CO2,5} = \mathbf{s}\left[D\$, T = T_{E,5} , P = \frac{n_{CO2,5}}{n_{P,tot,5}} \cdot P \right]$$

$$s_{H2O,1} = \mathbf{s}\left[E\$, T = T_{E,1} , P = \frac{n_{H2O,1}}{n_{P,tot,1}} \cdot P \right]$$

$$s_{H2O,2} = \mathbf{s}\left[E\$, T = T_{E,2} , P = \frac{n_{H2O,2}}{n_{P,tot,2}} \cdot P \right]$$

$$s_{H2O,3} = \mathbf{s}\left[E\$, T = T_{E,3} , P = \frac{n_{H2O,3}}{n_{P,tot,3}} \cdot P \right]$$

$$s_{H2O,4} = \mathbf{s}\left[E\$, T = T_{E,4} , P = \frac{n_{H2O,4}}{n_{P,tot,4}} \cdot P \right]$$

$$s_{H2O,5} = \mathbf{s}\left[E\$, T = T_{E,5} , P = \frac{n_{H2O,5}}{n_{P,tot,5}} \cdot P \right]$$

$$s_{N2,OUT,1} = \mathbf{s}\left[C\$, T = T_{E,1} , P = \frac{n_{N2,out,1}}{n_{P,tot,1}} \cdot P \right]$$

$$s_{N2,OUT,2} = \mathbf{s}\left[C\$, T = T_{E,2} , P = \frac{n_{N2,out,2}}{n_{P,tot,2}} \cdot P \right]$$

$$s_{N2,OUT,3} = \mathbf{s}\left[C\$, T = T_{E,3}, P = \frac{n_{N2,out,3}}{n_{P,tot,3}} \cdot P\right]$$

$$s_{N2,OUT,4} = \mathbf{s}\left[C\$, T = T_{E,4}, P = \frac{n_{N2,out,4}}{n_{P,tot,4}} \cdot P\right]$$

$$s_{N2,OUT,5} = \mathbf{s}\left[C\$, T = T_{E,5}, P = \frac{n_{N2,out,5}}{n_{P,tot,5}} \cdot P\right]$$

$$S_{Q,1} = \frac{-Q_1}{T_{H,K,1}}$$

$$S_{Q,2} = \frac{-Q_2}{T_{H,K,2}}$$

$$S_{Q,3} = \frac{-Q_3}{T_{H,K,3}}$$

$$S_{Q,4} = \frac{-Q_4}{T_{H,K,4}}$$

$$S_{Q,5} = \frac{-Q_5}{T_{H,K,5}}$$

entopy balnce (2nd law)

$$S_{R,1} = n_{fuel,1} \cdot s_{c8h18,1} + n_{O2,1} \cdot s_{O2,1} + n_{N2,in,1} \cdot s_{N2,1}$$

$$S_{R,2} = n_{fuel,2} \cdot s_{c8h18,2} + n_{O2,2} \cdot s_{O2,2} + n_{N2,in,2} \cdot s_{N2,2}$$

$$S_{R,3} = n_{fuel,3} \cdot s_{c8h18,3} + n_{O2,3} \cdot s_{O2,3} + n_{N2,in,3} \cdot s_{N2,3}$$

$$S_{R,4} = n_{fuel,4} \cdot s_{c8h18,4} + n_{O2,4} \cdot s_{O2,4} + n_{N2,in,4} \cdot s_{N2,4}$$

$$S_{R,5} = n_{fuel,5} \cdot s_{c8h18,5} + n_{O2,5} \cdot s_{O2,5} + n_{N2,in,5} \cdot s_{N2,5}$$

$$S_{P,1} = n_{CO2,1} \cdot s_{CO2,1} + n_{H2O,1} \cdot s_{H2O,1} + n_{N2,out,1} \cdot s_{N2,OUT,1}$$

$$S_{P,2} = n_{CO2,2} \cdot s_{CO2,2} + n_{H2O,2} \cdot s_{H2O,2} + n_{N2,out,1} \cdot s_{N2,OUT,2}$$

$$S_{P,3} = n_{CO2,3} \cdot s_{CO2,3} + n_{H2O,3} \cdot s_{H2O,3} + n_{N2,out,1} \cdot s_{N2,OUT,3}$$

$$S_{P,4} = n_{CO2,4} \cdot s_{CO2,4} + n_{H2O,4} \cdot s_{H2O,4} + n_{N2,out,1} \cdot s_{N2,OUT,4}$$

$$S_{P,5} = n_{CO2,5} \cdot s_{CO2,5} + n_{H2O,5} \cdot s_{H2O,5} + n_{N2,out,1} \cdot s_{N2,OUT,5}$$

entropy produced obtained from this equation

$$S_{R,1} - S_{P,1} + S_{Q,1} + \sigma_{prod,1} = 0$$

$$S_{R,2} - S_{P,2} + S_{Q,2} + \sigma_{prod,2} = 0$$

$$S_{R,3} - S_{P,3} + S_{Q,3} + \sigma_{prod,3} = 0$$

$$S_{R,4} - S_{P,4} + S_{Q,4} + \sigma_{prod,4} = 0$$

$S_{R,5} - S_{P,5} + S_{Q,5} + \sigma_{prod,5} = 0$

head temperatureexergy destroyed

$X_{dest,1} = T_{ref} \cdot \sigma_{prod,1}$

$X_{dest,2} = T_{ref} \cdot \sigma_{prod,2}$

$X_{dest,3} = T_{ref} \cdot \sigma_{prod,3}$

$X_{dest,4} = T_{ref} \cdot \sigma_{prod,4}$

$X_{dest,5} = T_{ref} \cdot \sigma_{prod,5}$

second law

$$\eta_{2,1} = \frac{W_1}{X_{dest,1}}$$

$$\eta_{2,2} = \frac{W_2}{X_{dest,2}}$$

$$\eta_{2,3} = \frac{W_3}{X_{dest,3}}$$

$$\eta_{2,4} = \frac{W_4}{X_{dest,4}}$$

$$\eta_{2,5} = \frac{W_5}{X_{dest,5}}$$

Question 5

$Areaofgraph = 0.015516$ [KJ/rev]

$$speed_2 = 6500 \cdot \left| 0.016666667 \cdot \frac{rev/s}{rev/min} \right|$$

$W_{estimated} = Areaofgraph \cdot speed_2$

$Q_{partb,1} = m_{fuel,1} \cdot LHV_b$

$Q_{partb,2} = m_{fuel,2} \cdot LHV_b$

$Q_{partb,3} = m_{fuel,3} \cdot LHV_b$

$Q_{partb,4} = m_{fuel,4} \cdot LHV_b$

$Q_{partb,5} = m_{fuel,5} \cdot LHV_b$

SOLUTION

Unit Settings: SI C kPa kJ molar deg

A$ = 'C8H18'
Areaofgraph = 0.01552 [KJ/rev]
B$ = 'O2'
C$ = 'N2'
$C8H18_{MW}$ = 114.2 [kg/kmol]
D$ = 'CO2'
E$ = 'h2o'
η_{carnot} = 0.877
F$ = 'N2'
$h_{C8H18,ref}$ = -208737 [kj/kmol]
$h_{CO2,ref}$ = -393486 [kj/kmol]
$h_{form,C8H18}$ = -208737 [kj/kmol]
$h_{form,CO2}$ = -393486 [kj/kmol]
$h_{form,N2}$ = 0 [kj/kmol]
$h_{form,N2,OUT}$ = 0 [kj/kmol]
$h_{form,O2}$ = 0 [kj/kmol]
$h_{N2,OUT,ref}$ = 0 [kj/kmol]
$h_{N2,ref}$ = 0 [kj/kmol]
$h_{O2,ref}$ = 0 [kj/kmol]
LHV_b = 42611 [J/g]
P = 101.3 [kPa]
speed = 680.7 [rad/s]
$speed_2$ = 108.3 [rev/s]
T_{flame} = 2423 [K]
T_{ref} = 298.2 [k]
$W_{estimated}$ = 1.681 [KW]

No unit problems were detected.

KEY VARIABLES
Q1 a
η_{carnot} = 0.877
W_1 = 1.064 [KW]
W_2 = 1.197 [KW]
W_3 = 1.236 [KW]
W_4 = 1.121 [KW]
W_5 = 1.087 [KW]
η_1 = 0.1673 [-]
η_2 = 0.1643 [-]
η_3 = 0.1619 [-]
η_4 = 0.1298 [-]
η_5 = 0.1172 [-]
Q_1 = 7.42 [KW]
Q_2 = 8.485 [KW]
Q_3 = 8.867 [KW]
Q_4 = 9.755 [KW]
Q_5 = 10.36 [KW]

Q1 b
$\eta_{partb,1}$ = 0.1409 [-]
$\eta_{partb,2}$ = 0.1399 [-]
$\eta_{partb,3}$ = 0.1386 [-]
$\eta_{partb,4}$ = 0.1122 [-]
$\eta_{partb,5}$ = 0.1022 [-]
$Q_{partb,1}$ = 7.551 [kw]

$Q_{partb,2}$ = 8.561 [kw]
$Q_{partb,3}$ = 8.918 [kw]
$Q_{partb,4}$ = 9.984 [kw]
$Q_{partb,5}$ = 10.64 [kw]

Q2

$\sigma_{prod,1}$ = 0.01854 [KW/k]
$\sigma_{prod,2}$ = 0.01913 [KW/k]
$\sigma_{prod,3}$ = 0.01948 [KW/k]
$\sigma_{prod,4}$ = 0.01921 [KW/k]
$\sigma_{prod,5}$ = 0.01979 [KW/k]

Q3

$X_{dest,1}$ = 5.528 [KW]
$X_{dest,2}$ = 5.704 [KW]
$X_{dest,3}$ = 5.807 [KW]
$X_{dest,4}$ = 5.729 [KW]
$X_{dest,5}$ = 5.901 [KW]

Q4

$\eta_{2,1}$ = 0.1924
$\eta_{2,2}$ = 0.2099
$\eta_{2,3}$ = 0.2128
$\eta_{2,4}$ = 0.1956
$\eta_{2,5}$ = 0.1842

Q5

$W_{estimated}$ = 1.681 [KW]

Arrays Table: Main

	$T_{E,i}$	$h_{std,H2O,i}$	$\Delta h_{C8H18,i}$	$\Delta h_{CO2,i}$	$\Delta h_{N2,i}$	$\Delta h_{N2,OUT,i}$
	[C] {[]}	[kj/kmol] {[]}	[kj/kmol] {[]}	[kj/kmol] {[]}	[kj/kmol] {[]}	[kj/kmol] {[]}
0						
1	529.9 {0}	-223705 {0}	4135 {0}	22990 {0}	622.4 {0}	15158 {0}
2	509.6 {0}	-224491 {0}	4211 {0}	21949 {0}	633.5 {0}	14521 {0}
3	497.7 {0}	-224951 {0}	3690 {0}	21340 {0}	557 {0}	14148 {0}
4	477.5 {0}	-225725 {0}	3686 {0}	20315 {0}	556.4 {0}	13517 {0}
5	462.1 {0}	-226310 {0}	3773 {0}	19540 {0}	569.2 {0}	13040 {0}

Arrays Table: Main

	$\Delta h_{O2,i}$	$H_{P,i}$	$H_{R,i}$	Q_i	$Q_{loss,i}$	$S_{P,i}$	$S_{Q,i}$
	[kj/kmol] {[]}	[KW] {[]}	[KW] {[]}	[KW] {[]}	[KW] {[]}	[KW/k] {[]}	[KW/k] {[]}
0							
1	628 {0}	-6.616 {0}	-0.2598 {0}	7.42 {0}	6.356 {0}	0.02307 {0}	-0.0148 {0}
2	639.1 {0}	-7.581 {0}	-0.2933 {0}	8.485 {0}	7.287 {0}	0.02388 {0}	-0.0172 {0}
3	561.8 {0}	-7.946 {0}	-0.3149 {0}	8.867 {0}	7.631 {0}	0.02414 {0}	-0.01822 {0}
4	561.2 {0}	-8.987 {0}	-0.3526 {0}	9.755 {0}	8.635 {0}	0.02499 {0}	-0.01976 {0}
5	574.1 {0}	-9.648 {0}	-0.3737 {0}	10.36 {0}	9.274 {0}	0.02549 {0}	-0.02151 {0}

Arrays Table: Main

	$S_{R,i}$	T_i	$T_{C,i}$	$T_{H,i}$	$T_{H,K,i}$	W_i	$X_{dest,i}$	η_i
	[mixed] {[]}	[C] {[]}	[C] {[]}	[C] {[]}	[K] {[]}	[KW] {[]}	[KW] {[]}	[-] {[]}
0		25 {0}						
1	0.01933 {0}		46.41 {0}	228.1 {0}	501.3 {0}	1.064 {0}	5.528 {0}	0.1673 {0}
2	0.02195 {0}		46.79 {0}	220.2 {0}	493.3 {0}	1.197 {0}	5.704 {0}	0.1643 {0}
3	0.02289 {0}		44.16 {0}	213.5 {0}	486.7 {0}	1.236 {0}	5.807 {0}	0.1619 {0}
4	0.02553 {0}		44.14 {0}	220.7 {0}	493.8 {0}	1.121 {0}	5.729 {0}	0.1298 {0}
5	0.0272 {0}		44.58 {0}	208.6 {0}	481.7 {0}	1.087 {0}	5.901 {0}	0.1172 {0}

Arrays Table: Main

	$\eta_{2,i}$
0	
1	
2	
3	
4	
5	

Arrays Table: Main

	$\eta_{partb,i}$	$h_{C8H18,i}$	$h_{CO2,i}$	$h_{N2,i}$	$h_{N2,OUT,i}$	$h_{O2,i}$	$h_{std,C8H18,i}$
	[-] {[]}	[kj/kmol] {[]}	[kj/kmol] {[]}	[kj/kmol] {[]}	[kj/kmol] {[]}	[kj/kmol] {[]}	[kj/kmol] {[]}
0							
1	0.1409 {0}	-204602 {0}	-370496 {0}	622.4 {0}	15158 {0}	628 {0}	-204602 {0}
2	0.1399 {0}	-204526 {0}	-371537 {0}	633.5 {0}	14521 {0}	639.1 {0}	-204526 {0}
3	0.1386 {0}	-205047 {0}	-372146 {0}	557 {0}	14148 {0}	561.8 {0}	-205047 {0}
4	0.1122 {0}	-205051 {0}	-373171 {0}	556.4 {0}	13517 {0}	561.2 {0}	-205051 {0}
5	0.1022 {0}	-204964 {0}	-373946 {0}	569.2 {0}	13040 {0}	574.1 {0}	-204964 {0}

Arrays Table: Main

	$h_{std,CO2,i}$ [kj/kmol] {[]}	$h_{std,N2,i}$ [kj/kmol] {[]}	$h_{std,N2,OUT,i}$ [kj/kmol] {[]}	$h_{std,O2,i}$ [kj/kmol] {[]}	$m_{fuel,i}$ [kg/s] {[]}	$n_{CO2,i}$ [kmol/s] {[]}	$n_{H2O,i}$ [kmol/s] {[]}
0							
1	-370496 {0}	622.4 {0}	15158 {0}	628 {0}	0.0001772 {0}	0.00001241 {0}	0.00001396 {0}
2	-371537 {0}	633.5 {0}	14521 {0}	639.1 {0}	0.0002009 {0}	0.00001407 {0}	0.00001583 {0}
3	-372146 {0}	557 {0}	14148 {0}	561.8 {0}	0.0002093 {0}	0.00001466 {0}	0.00001649 {0}
4	-373171 {0}	556.4 {0}	13517 {0}	561.2 {0}	0.0002343 {0}	0.00001641 {0}	0.00001846 {0}
5	-373946 {0}	569.2 {0}	13040 {0}	574.1 {0}	0.0002496 {0}	0.00001748 {0}	0.00001967 {0}

Arrays Table: Main

	$n_{N2,in,i}$ [kmol/s] {[]}	$n_{N2,out,i}$ [kmol/s] {[]}	$n_{O2,i}$ [kmol/s] {[]}	$n_{P,tot,i}$ [kmol/s] {[]}	$n_{R,tot,i}$ [kmol/s] {[]}	$n_{air,i}$ [kmol/s] {[]}
0						
1	0.00007292 {0}	0.00007291 {0}	0.00001938 {0}	0.00009928 {0}	0.00009385 {0}	0.0000923 {0}
2	0.00008267 {0}	0.00008266 {0}	0.00002198 {0}	0.0001126 {0}	0.0001064 {0}	0.0001046 {0}
3	0.00008613 {0}	0.00008612 {0}	0.00002289 {0}	0.0001173 {0}	0.0001109 {0}	0.000109 {0}
4	0.00009641 {0}	0.0000964 {0}	0.00002563 {0}	0.0001313 {0}	0.0001241 {0}	0.000122 {0}
5	0.0001027 {0}	0.0001027 {0}	0.0000273 {0}	0.0001398 {0}	0.0001322 {0}	0.00013 {0}

Arrays Table: Main

	$n_{fuel,i}$ [kmol/s] {[]}	$s_{CO2,i}$ [kj/kmol-k] {[]}	$s_{H2O,i}$ [kj/kmol-k] {[]}	$s_{N2,i}$ [kj/kmol-k] {[]}	$s_{N2,OUT,i}$ [kj/kmol-k] {[]}	$s_{O2,i}$ [kj/kmol-k] {[]}	$s_{c8h18,i}$ [kj/kmol-k] {[]}
0							
1	0.000001551 {0}	274.9 {0}	240.1 {0}	195.6 {0}	223.6 {0}	220.2 {0}	514.7 {0}
2	0.000001759 {0}	273.6 {0}	239.1 {0}	196 {0}	222.8 {0}	220.2 {0}	515 {0}
3	0.000001832 {0}	272.8 {0}	238.5 {0}	196.3 {0}	222.3 {0}	220 {0}	513.3 {0}
4	0.000002051 {0}	271.5 {0}	237.5 {0}	195.4 {0}	221.5 {0}	220 {0}	513.3 {0}
5	0.000002185 {0}	270.4 {0}	236.7 {0}	195.4 {0}	220.9 {0}	220 {0}	513.6 {0}

Arrays Table: Main

	$\sigma_{prod,i}$ [KW/k] {[]}	$torque_i$ [kJ] {[]}
0		
1	0.01854 {0}	0.001563 {0}
2	0.01913 {0}	0.001759 {0}
3	0.01948 {0}	0.001816 {0}
4	0.01921 {0}	0.001646 {0}
5	0.01979 {0}	0.001596 {0}

Plot area calculating MATLAB code

```
%PLOT_GRAB_VER_2
%AUTHORS: AJ Fillo (filloa@oregonstate.edu) and Kyle
 Zada(zadak@oregonstate.edu)

%DESCRIPTION: The following code has been developed to pull data
 points off
%of an image of a plot. To start, save an image of a plot that is
%compatible with the Matlab software. Next, press the run button. This
 will
%open up a prompt window to search for the plot image. Once loaded
 into
%Matlab, click at the x/y-origin, x_extreme, and y_extreme in that
 order to
%calibrate the plot image. Follow the on-screen inquires and enter the
%assocated values/answers. Once complete, you can click on specific
 data
%points you wish to pull off the image (and error bars if specified).
 Once you are done, click anywhere
%outside of the plot (same number of times you click per point). For
 example,
%if you have x-error bars only, you will click three times per point
 total and therefore
%click three times to exit the program. Your data will be saved under
 the 'DATA' matrix.


%UPDATES
%Ver 2
    %Changed calculation of error bars from x,y coordinates to
 absolute error from point position
    %Changed output title of the data point plot

clear
clc
close all

[filename, pathname, filterindex] = uigetfile('*.*'); %gets File name
 and path

plot_img = imread([pathname,filename]); %reads in image file
figure
imshow(plot_img)                        %Plots image
axis image
title('In Order, Select Origin, X-Axis Extreme, Y-Axis
 Extreme','fontsize',16)
[x_pix_val,y_pix_val] = ginput(3);  %calls user mouse input from plot

x_axis_form = input('X-axis linear or log? Enter lin or log\n','s');
  %user input for axis type (linear or log)
y_axis_form = input('Y-axis linear or log? Enter lin or log\n','s');
  %user input for axis type (linear or log)
```

```
err_x = input('Are error bars present on the plot for the x-axis?
 Enter Y or N\n','s'); %user input for if error bars are present in
 the x-axis
err_y = input('Are error bars present on the plot for the y-axis?
 Enter Y or N\n','s'); %user input for if error bars are present in
 the y-axis

x_or_val = input('What is X-origin value?\n');
  %user input from x_axis value of the origin
y_or_val = input('What is Y-origin value?\n');
  %user input from y_axis value of the origin
x_axis_val = input('What is X-Extreme value?\n');
  %user input from x_axis value of the extreme
y_axis_val = input('What is Y-Extreme value?\n');
  %user input from y_axis value of the extreme

cal_x = (x_pix_val(2)-x_pix_val(1))/(x_axis_val-x_or_val);
  %calibration of the x_axis with respect to pixels per value
cal_y = (y_pix_val(1)-y_pix_val(3))/(y_axis_val-y_or_val);
  %calibration of the y_axis with repsect to pixels per value

b = 1;  %Initial condition for stopping the data picking process (=1
 means continue)
i = 1;  %Initial condition for the index for data points
title({'Select All Points of Interest.','Select error bars from
 positive to negative starting with x THEN Click outside axes to
 end'},'fontsize',12)

%The following while loop is used to pick points (pixels) from the
 plot
%until the user hits the cursor outside of the axes of the plot (data
 point
%collection will stop)
while b == 1
    if err_x == 'Y'  & err_y == 'Y'
        [x_points(i),y_points(i)] = ginput(1);
  %Graphical input of data points from the cursor, saved as x and y
 pixel coordinates
        [x_points_err_x_pos(i),x_points_err_y_pos(i)] = ginput(1);
  %Graphical input of positive error bar from the cursor, saved as x
 and y pixel coordinates
        [x_points_err_x_neg(i),x_points_err_y_neg(i)] = ginput(1);
  %Graphical input of negative error bar from the cursor, saved as x
 and y pixel coordinates
        [y_points_err_x_pos(i),y_points_err_y_pos(i)] = ginput(1);
  %Graphical input of positive error bar from the cursor, saved as x
 and y pixel coordinates
        [y_points_err_x_neg(i),y_points_err_y_neg(i)] = ginput(1);
  %Graphical input of negative error bar from the cursor, saved as x
 and y pixel coordinates
        type = 1;
    elseif err_x == 'Y'  & err_y == 'N'
```

```
        [x_points(i),y_points(i)] = ginput(1);
 %Graphical input of data points from the cursor, saved as x and y
pixel coordinates
        [x_points_err_x_pos(i),x_points_err_y_pos(i)] = ginput(1);
 %Graphical input of positive error bar from the cursor, saved as x
and y pixel coordinates
        [x_points_err_x_neg(i),x_points_err_y_neg(i)] = ginput(1);
 %Graphical input of negative error bar from the cursor, saved as x
and y pixel coordinates
        type = 2;
    elseif err_x == 'N'  & err_y == 'Y'
        [x_points(i),y_points(i)] = ginput(1);
 %Graphical input of data points from the cursor, saved as x and y
pixel coordinates
        [y_points_err_x_pos(i),y_points_err_y_pos(i)] = ginput(1);
 %Graphical input of positive error bar from the cursor, saved as x
and y pixel coordinates
        [y_points_err_x_neg(i),y_points_err_y_neg(i)] = ginput(1);
 %Graphical input of negative error bar from the cursor, saved as x
and y pixel coordinates
        type = 3;
    else
        [x_points(i),y_points(i)] = ginput(1);
 %Graphical input of data points from the cursor, saved as x and y
pixel coordinates
        type = 4;
    end

        if x_points(i) > x_pix_val(2) || y_points(i) < y_pix_val(3)
 %If cursor clicks outside the maximum values of x or y, data
collection stops
        x_points = x_points(1:i-1); %x data points pixels are saved,
not including the stopping click
        y_points = y_points(1:i-1); %y data points pixels are saved,
not including the stopping click
            if type == 1
              x_points_err_x_pos = x_points_err_x_pos(1:i-1);
              x_points_err_y_pos = x_points_err_y_pos(1:i-1);
              x_points_err_x_neg = x_points_err_x_neg(1:i-1);
              x_points_err_y_neg = x_points_err_y_neg(1:i-1);

              y_points_err_x_pos = y_points_err_x_pos(1:i-1);
              y_points_err_y_pos = y_points_err_y_pos(1:i-1);
              y_points_err_x_neg = y_points_err_x_neg(1:i-1);
              y_points_err_y_neg = y_points_err_y_neg(1:i-1);
            elseif type == 2
              x_points_err_x_pos = x_points_err_x_pos(1:i-1);
              x_points_err_y_pos = x_points_err_y_pos(1:i-1);
              x_points_err_x_neg = x_points_err_x_neg(1:i-1);
              x_points_err_y_neg = x_points_err_y_neg(1:i-1);
            elseif type == 3
              y_points_err_x_pos = y_points_err_x_pos(1:i-1);
              y_points_err_y_pos = y_points_err_y_pos(1:i-1);
              y_points_err_x_neg = y_points_err_x_neg(1:i-1);
```

```
          y_points_err_y_neg = y_points_err_y_neg(1:i-1);
        else
            break
        end
        b = 0;
    elseif x_points(i) < x_pix_val(1) || y_points(i) >
 y_pix_val(1)  %If cursor clicks outside the minimum values of x or y,
 data collection stops
        x_points = x_points(1:i-1); %x data points pixels are saved,
 not including the stopping click
        y_points = y_points(1:i-1); %y data points pixels are saved,
 not including the stopping click

          if type == 1
          x_points_err_x_pos = x_points_err_x_pos(1:i-1);
          x_points_err_y_pos = x_points_err_y_pos(1:i-1);
          x_points_err_x_neg = x_points_err_x_neg(1:i-1);
          x_points_err_y_neg = x_points_err_y_neg(1:i-1);

          y_points_err_x_pos = y_points_err_x_pos(1:i-1);
          y_points_err_y_pos = y_points_err_y_pos(1:i-1);
          y_points_err_x_neg = y_points_err_x_neg(1:i-1);
          y_points_err_y_neg = y_points_err_y_neg(1:i-1);
        elseif type == 2
          x_points_err_x_pos = x_points_err_x_pos(1:i-1);
          x_points_err_y_pos = x_points_err_y_pos(1:i-1);
          x_points_err_x_neg = x_points_err_x_neg(1:i-1);
          x_points_err_y_neg = x_points_err_y_neg(1:i-1);
        elseif type == 3
          y_points_err_x_pos = y_points_err_x_pos(1:i-1);
          y_points_err_y_pos = y_points_err_y_pos(1:i-1);
          y_points_err_x_neg = y_points_err_x_neg(1:i-1);
          y_points_err_y_neg = y_points_err_y_neg(1:i-1);
        else
            break
          end
        b = 0;
    else
        i = i+1;    %Index point increases if cursor does not click
 outside of x or y axis
    end
end

%The following for loop organizes the pixel clicks and transforms them
 to
%actual data points (as seen on the plots).
%The data points are calculated by subtracting the pixel data point
 from the
%origin data point and adding the origin numerical value from the plot
for p = 1:length(x_points)

    if type == 1
    x_values(p) = ((x_points(p)-x_pix_val(1))/cal_x)+ x_or_val;
    y_values(p) = ((y_pix_val(1)- y_points(p))/cal_y)+ y_or_val;
```

```
    x_error_pos(p) = abs((((x_points_err_x_pos(p)-x_pix_val(1))/
cal_x)+ x_or_val)-x_values(p));
    x_error_neg(p) = abs((((x_points_err_x_neg(p)-x_pix_val(1))/
cal_x)+ x_or_val)-x_values(p));

    y_error_pos(p) = abs((((y_pix_val(1)- y_points_err_y_pos(p))/
cal_y)+ y_or_val)-y_values(p));
    y_error_neg(p) = abs((((y_pix_val(1)- y_points_err_y_neg(p))/
cal_y)+ y_or_val)-y_values(p));

    elseif type == 2
    x_values(p) = ((x_points(p)-x_pix_val(1))/cal_x)+ x_or_val;
    y_values(p) = ((y_pix_val(1)- y_points(p))/cal_y)+ y_or_val;

    x_error_pos(p) = abs((((x_points_err_x_pos(p)-x_pix_val(1))/
cal_x)+ x_or_val)-x_values(p));
    x_error_neg(p) = abs((((x_points_err_x_neg(p)-x_pix_val(1))/
cal_x)+ x_or_val)-x_values(p));

    elseif type ==3
    x_values(p) = ((x_points(p)-x_pix_val(1))/cal_x)+ x_or_val;
    y_values(p) = ((y_pix_val(1)- y_points(p))/cal_y)+ y_or_val;

    y_error_pos(p) = abs((((y_pix_val(1)- y_points_err_y_pos(p))/
cal_y)+ y_or_val)-y_values(p));
    y_error_neg(p) = abs((((y_pix_val(1)- y_points_err_y_neg(p))/
cal_y)+ y_or_val)-y_values(p));

    else
    x_values(p) = ((x_points(p)-x_pix_val(1))/cal_x)+ x_or_val;
    y_values(p) = ((y_pix_val(1)- y_points(p))/cal_y)+ y_or_val;
    end

end

%The data points are stored in this matrix depending on the type of
 error
%bars used here (if at all)
    if type == 1
    DATA = [transpose(x_values), transpose(y_values),
 transpose(x_error_pos), transpose(x_error_neg),
 transpose(y_error_pos), transpose(y_error_neg)];
    elseif type == 2
    DATA = [transpose(x_values), transpose(y_values),
 transpose(x_error_pos), transpose(x_error_neg)];
    elseif type ==3
    DATA = [transpose(x_values), transpose(y_values),
 transpose(y_error_pos), transpose(y_error_neg)];
    else
    DATA = [transpose(x_values), transpose(y_values)];
    end
```

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