

{Consider a natural gas furnace with the following assumptions

- SSSF with negligible changes in kinetic and potential energy
- Natural gas can be approximated as methane (CH₄)
- Room temperature for fuel and air of 70 F
- Constant total pressure of 14.7 psia

With this information, determine:

- a) Maximum combustion temperature in the absence of heat transfer (adiabatic flame temperature)
- b) Water vapor dewpoint in exhaust products for part a
- c) Plot of adiabatic flame temperature and dewpoint versus percent excess air from 0 to 50%
- d) Plot of furnace efficiency versus exhaust temperature from 100 F to 200 F with 20% excess air}

PROCEDURE ExMoist(n_p, n_H2O, T_ex, P_ex, h_H2O_g: T_dp_ex, h_H2O)

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P_v = n_H2O/N_p*P_ex           "partial pressure of water vapor assuming no liquid water"
T_dp_ex = Temperature(Water, P=P_v, x=1.0) "dewpoint of exhaust products"
IF(T_ex < T_dp_ex) THEN
  P_v = Pressure(Water, T=T_ex, x=1.0) "saturation water vapor pressure"
  n_H2O_g = (n_p - n_H2O)*P_v/P_ex/(1 - P_v/P_ex) "moles of H2O vapor in products per unit mole of fuel"
  h_H2O_l = h_H2O_g - Enthalpy_Vaporization(Water, T=T_ex) "specific molar enthalpy of H2O liquid at T_ex"
  h_H2O = (n_H2O_g*h_H2O_g + (n_H2O - n_H2O_g)*h_H2O_l)/n_H2O "specific molar enthalpy of H2O vapor/liquid mixture at T_ex"
  T_dp_ex = T_ex
ELSE
  h_H2O = h_H2O_g "no condensation, so all of H2O products are in the vapor phase"
ENDIF

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END

"Parameters for complete combustion of methane with excess air according the following reaction"

CH4 + 2(1+E)(O2+3.76N2) --> CO2 + 2H2O + 2EO2 + 2(1+E)*3.76N2

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E = 0.0 "excess air as a fraction of stoichiometric air"
n_CH4 = 1 "reactant and product moles are given per unit mole of methane as the fuel"
n_O2_R = 2*(1 + E) "moles of oxygen reactants per mole of fuel"
n_N2 = 2*(1 + E)*3.76 "moles of nitrogen reactants and products per unit mole of fuel"
n_CO2 = 1 "moles of carbon dioxide products per unit mole of fuel"
n_H2O = 2 "moles of H2O products per unit mole of fuel"
n_O2_P = 2*E "moles of O2 in products per unit mole of fuel (due to excess oxygen)"

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$n_p = n_{CO_2} + n_{H_2O} + n_{O_2_P} + n_{N_2}$ "total moles of products per mole of fuel"

"Reactant Conditions and Properties "

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T_r = 70 [F] "room conditions assumed for combustion air, fuel, and heat exchanger inlet"
P_r = 14.7 [psia] "atmospheric pressure"
h_CH4 = Enthalpy(CH4, T=T_r) "specific molar enthalpy of fuel at T_r"
h_O2_R = Enthalpy(O2, T=T_r) "specific molar enthalpy of O2 at T_r"
h_N2_R = Enthalpy(N2, T=T_r) "specific molar enthalpy of N2 at T_r"

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$h_R = n_{CH_4}h_{CH_4} + n_{O_2_R}h_{O_2_R} + n_{N_2}h_{N_2_R}$ "specific molar enthalpy of reactants per unit mole of fuel at T_r"

"Exhaust Conditions and Properties "

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T_ex = T_r "exhaust temperature: can be specified or calculated based on specification of q_h"
P_ex = P_r "constant pressure combustion"

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h_CO2_ex = Enthalpy(CO2, T=T_ex) "specific molar enthalpy of CO2 at T_ex"
h_H2O_g_ex = Enthalpy(H2O, T=T_ex) "specific molar enthalpy of H2O vapor at T_ex"
h_O2_ex = Enthalpy(O2, T=T_ex) "specific molar enthalpy of O2 products at T_ex"
h_N2_ex = Enthalpy(N2, T=T_ex) "specific molar enthalpy of N2 products at T_ex"

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{Call ExMoist(n_p, n_H2O, T_ex, P_ex, h_H2O_g_ex: T_dp_ex, h_H2O_ex)}

"evaluate condensation and determine moles of H2O vapor, if needed"

$$h_{H_2O_ex} = h_{H_2O_g_ex}$$

$$h_{ex} = n_{CO_2}h_{CO_2_ex} + n_{H_2O}h_{H_2O_ex} + n_{O_2}P h_{O_2_ex} + n_{N_2}h_{N_2_ex} \quad \text{"specific molar enthalpy of products per unit mole of fuel at } T_{ex}\text{"}$$

"Energy Balance"

$$\{q_{molar} = 0.0 \text{ [Btu/lbmol]}\}$$

$$q_{molar} = h_{ex} - h_R$$

$$MW_{CH_4} = \text{MolarMass}(\text{Methane})$$

$$q_h = -q_{molar}/MW_{CH_4}$$

"set to zero to solve for maximum possible T_{ex} based on energy balance"

"heat transfer per unit mole of fuel"

"molecular weight of fuel"

"heat transfer from furnace per unit mass of fuel"

"Furnace Efficiency"

$$HHV = 23900 \text{ [Btu/lbm]}$$

$$eff_{furn} = q_h/HHV$$

"higher heating value for methane"

"furnace efficiency"

SOLUTION

Unit Settings: Eng F psia molar deg

$$E = 0.00$$

$$HHV = 23900 \text{ [Btu/lbm]}$$

$$h_{CO_2,ex} = -169230 \text{ [Btu/lbmol]}$$

$$h_{H_2O,ex} = -104016 \text{ [Btu/lbmol]}$$

$$h_{N_2,ex} = -48.69 \text{ [Btu/lbmol]}$$

$$h_{O_2,ex} = -49.1 \text{ [Btu/lbmol]}$$

$$h_R = -32594 \text{ [Btu/lbmol]}$$

$$n_{CH_4} = 1$$

$$n_{H_2O} = 2$$

$$n_{O_2,P} = 0.00$$

$$n_p = 10.52$$

$$P_r = 14.7 \text{ [psia]}$$

$$q_{molar} = -345034.95 \text{ [Btu/lbmol]}$$

$$T_r = 70 \text{ [F]}$$

$$eff_{furn} = 0.90$$

$$h_{CH_4} = -32130 \text{ [Btu/lbmol]}$$

$$h_{ex} = -377629 \text{ [Btu/lbmol]}$$

$$h_{H_2O,g,ex} = -104016 \text{ [Btu/lbmol]}$$

$$h_{N_2,R} = -48.69 \text{ [Btu/lbmol]}$$

$$h_{O_2,R} = -49.1 \text{ [Btu/lbmol]}$$

$$MW_{CH_4} = 16.04 \text{ [lbm/lbmol]}$$

$$n_{CO_2} = 1$$

$$n_{N_2} = 7.52$$

$$n_{O_2,R} = 2$$

$$P_{ex} = 14.7 \text{ [psia]}$$

$$q_h = 21506.9 \text{ [Btu/lbm]}$$

$$T_{ex} = 70 \text{ [F]}$$

No unit problems were detected.

EES suggested units (shown in purple) for $h_{CO_2_ex}$ h_{ex} $h_{H_2O_ex}$ $h_{H_2O_g_ex}$ $h_{N_2_ex}$ $h_{O_2_ex}$.

Parametric Table: Table 2

	T_{ex} [F]	eff_{furn}
Run 1	100	0.96
Run 2	105	0.95
Run 3	110	0.94
Run 4	115	0.93
Run 5	120	0.92
Run 6	125	0.91
Run 7	130	0.89
Run 8	135	0.88
Run 9	140	0.88
Run 10	145	0.88
Run 11	150	0.88
Run 12	155	0.88
Run 13	160	0.88
Run 14	165	0.88
Run 15	170	0.88

Parametric Table: Table 2

	T_{ex} [F]	eff_{furn}
Run 16	175	0.87
Run 17	180	0.87
Run 18	185	0.87
Run 19	190	0.87
Run 20	195	0.87
Run 21	200	0.87



