AAE339: Aerospace Propulsion

HW4: Propulsion Thermochemistry

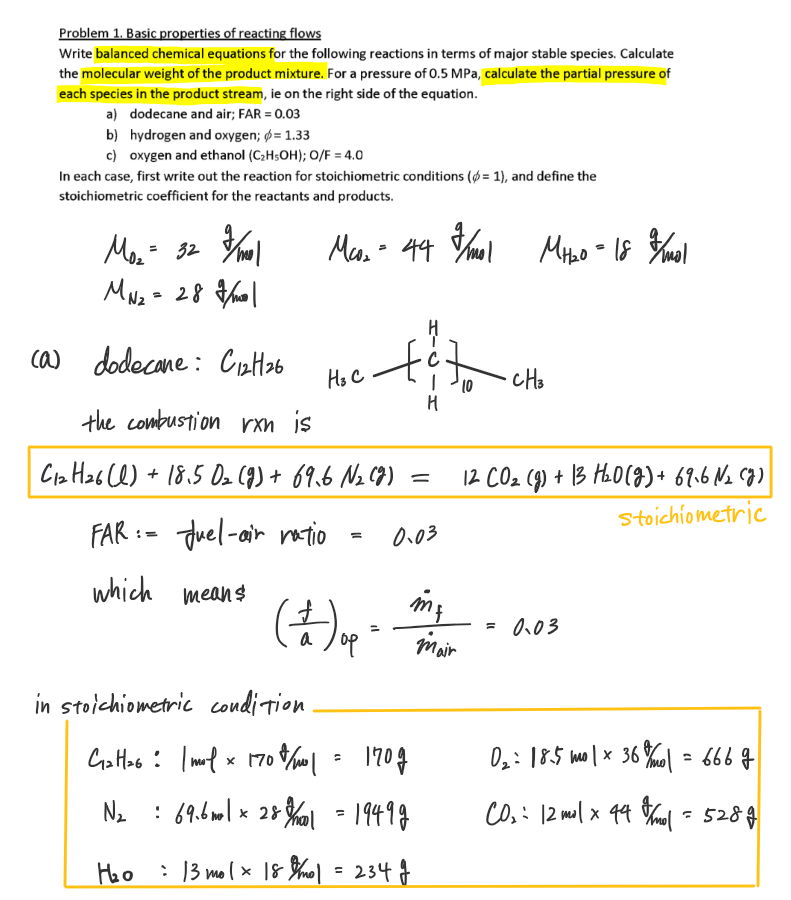
Dr. Anderson

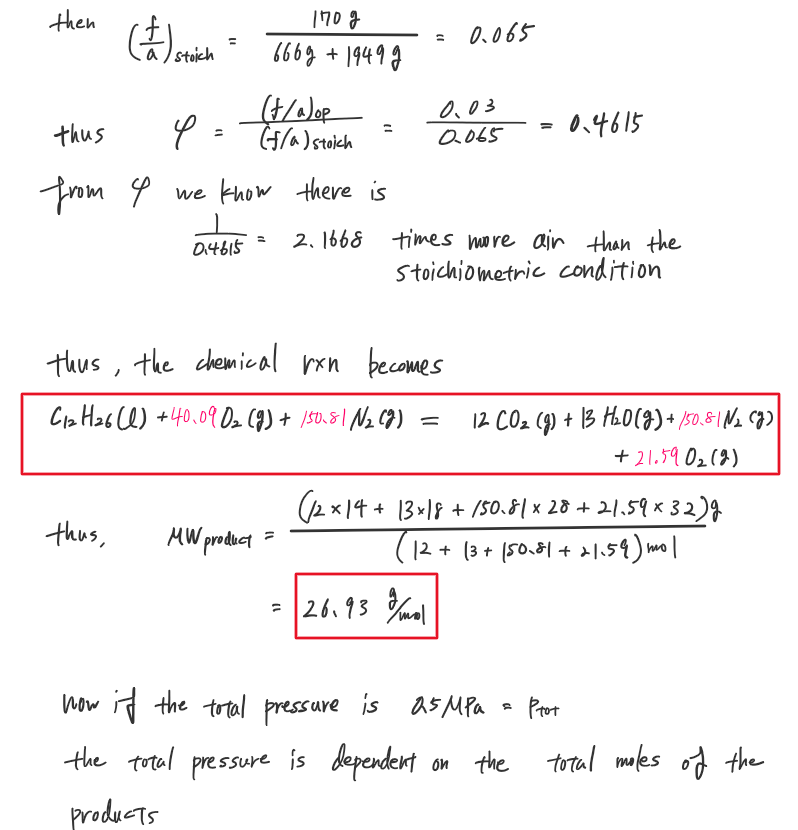
Tomoki Koike

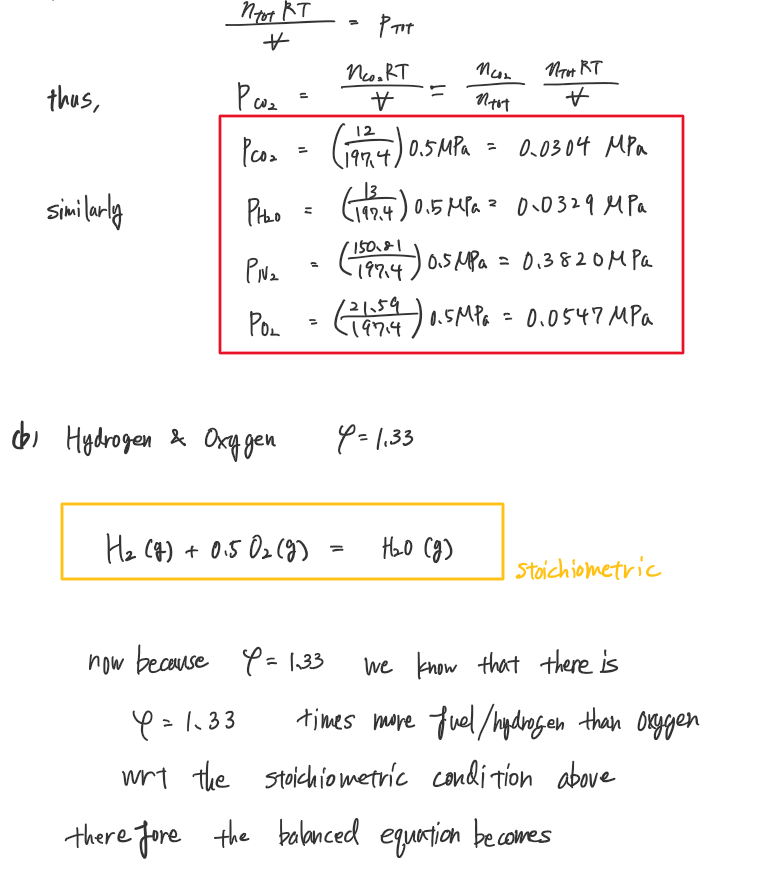
February 12, 2020

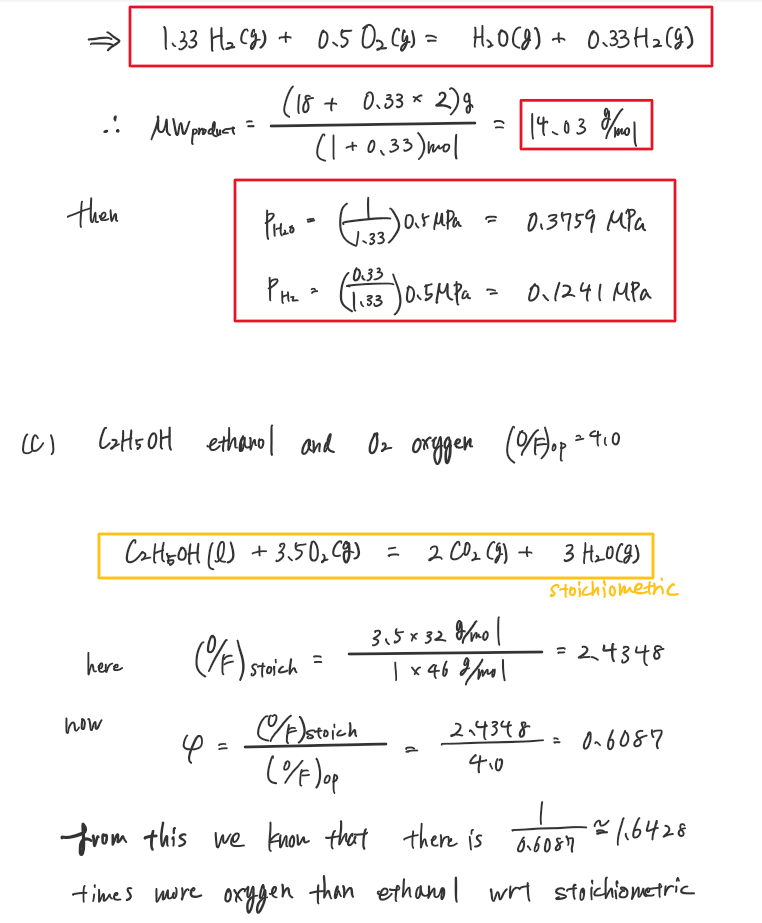
A close up of a tower

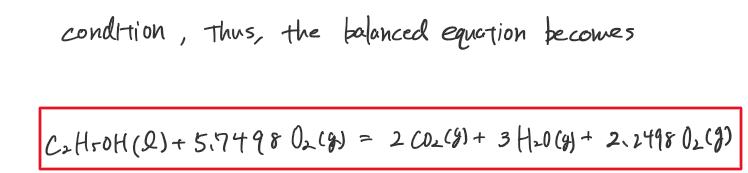
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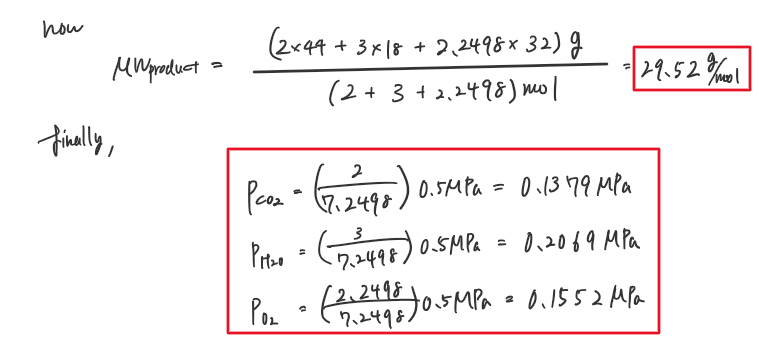


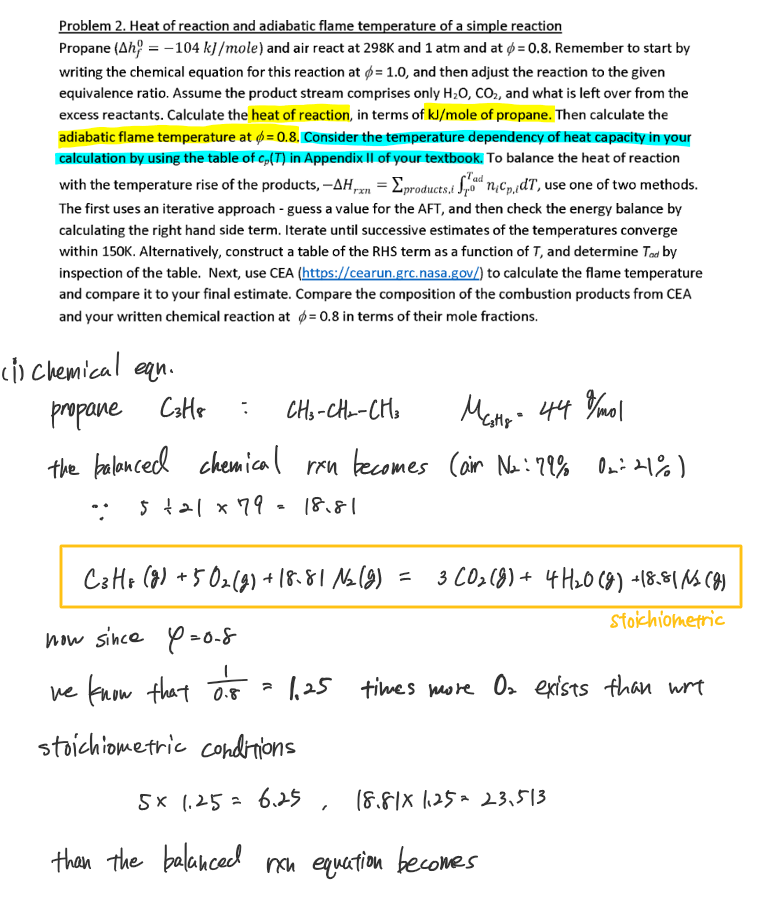


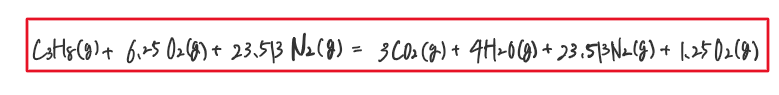


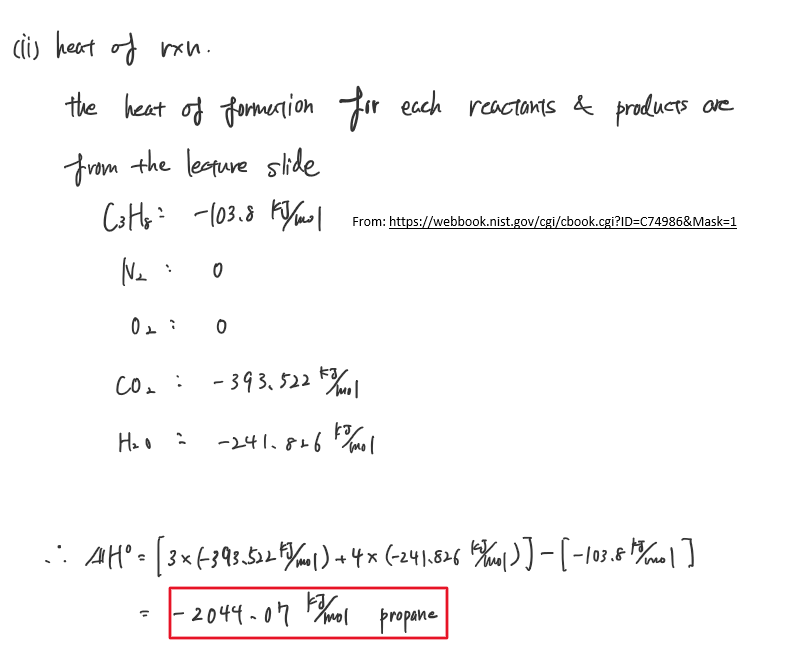


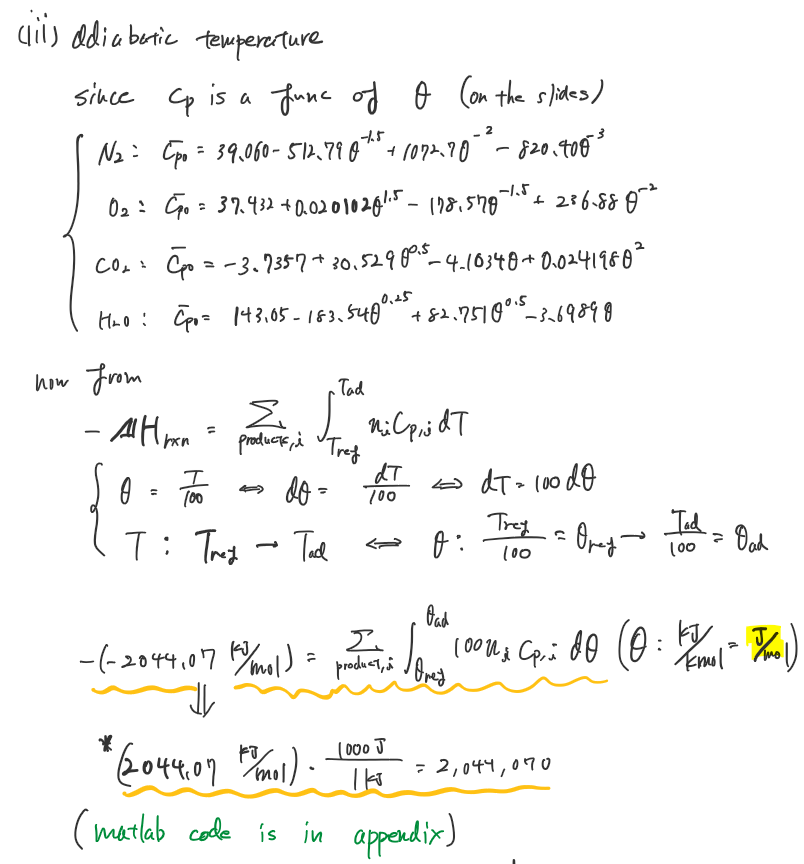


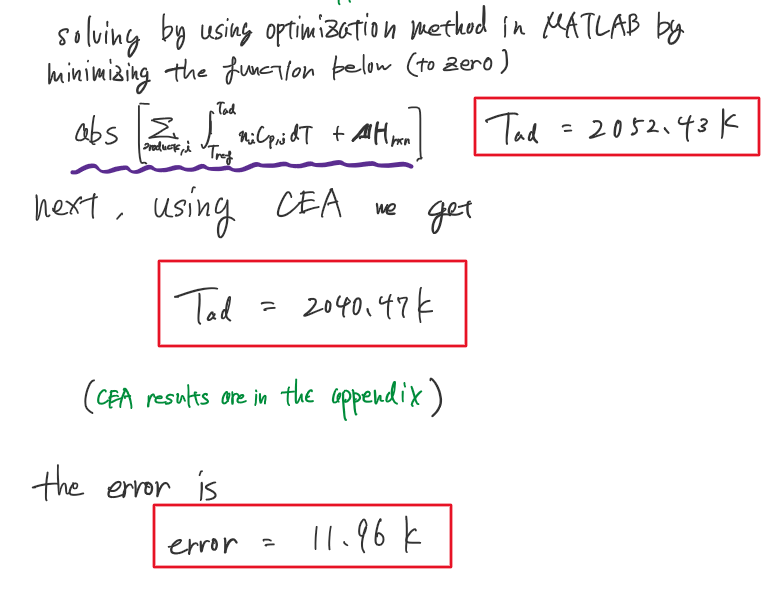


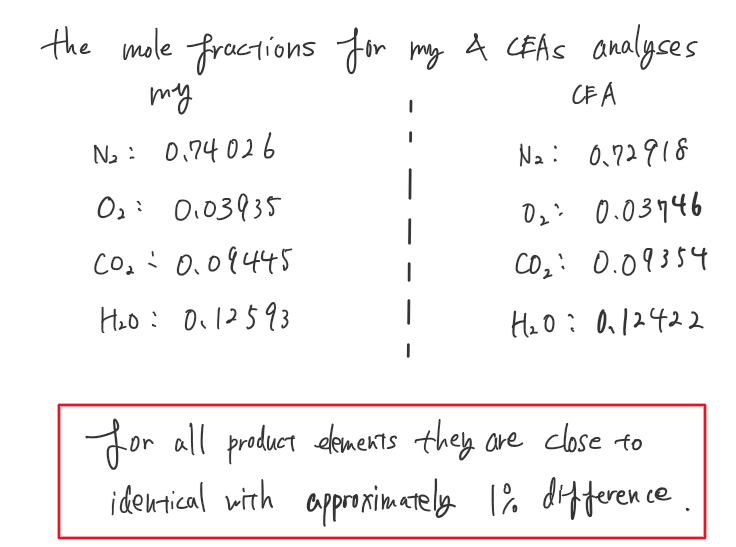


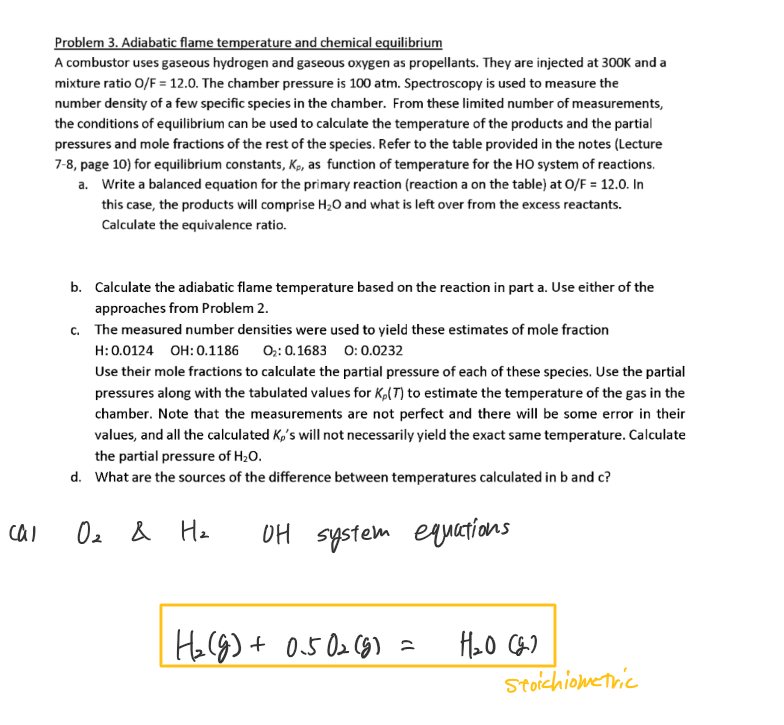


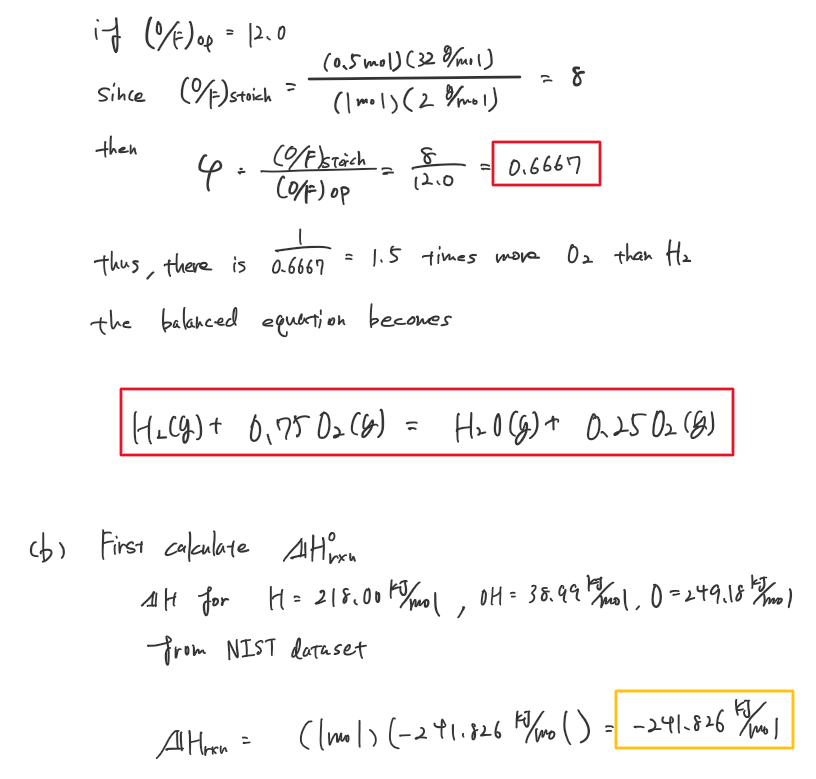


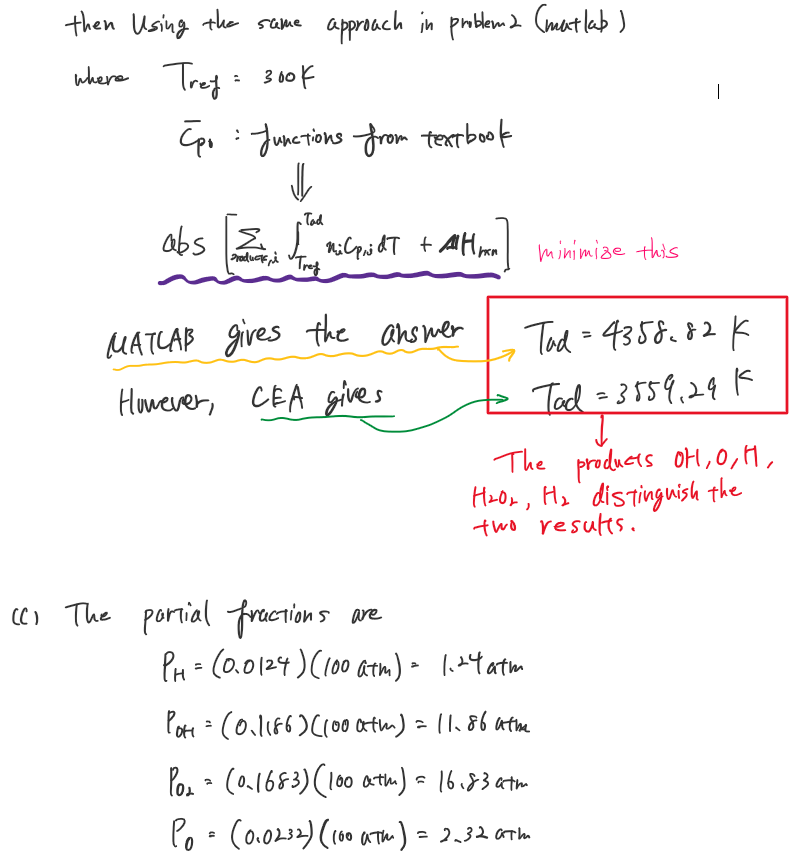


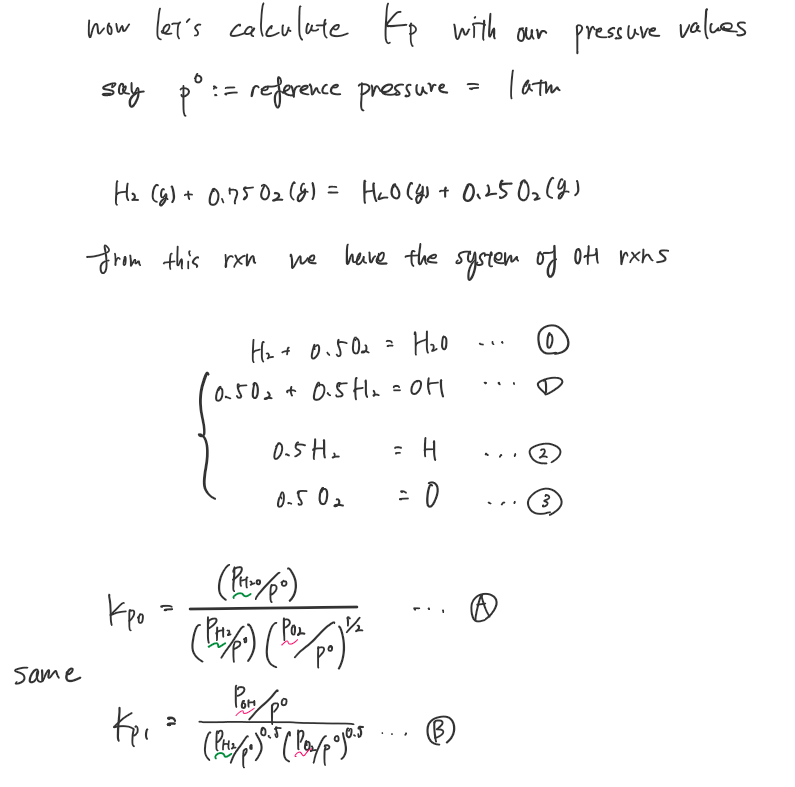
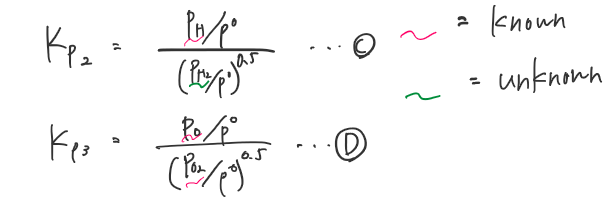


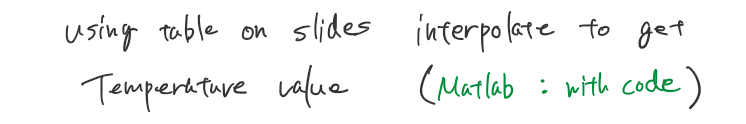
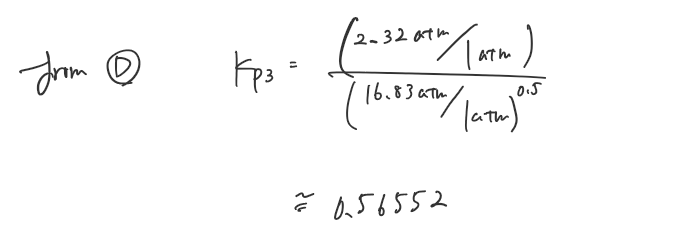


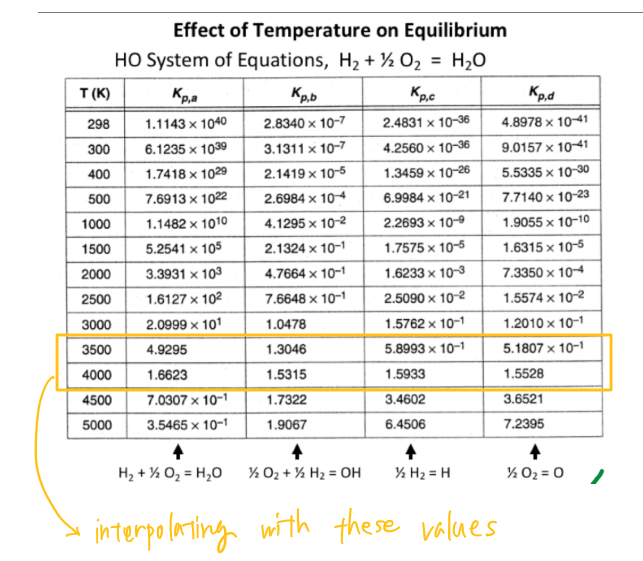


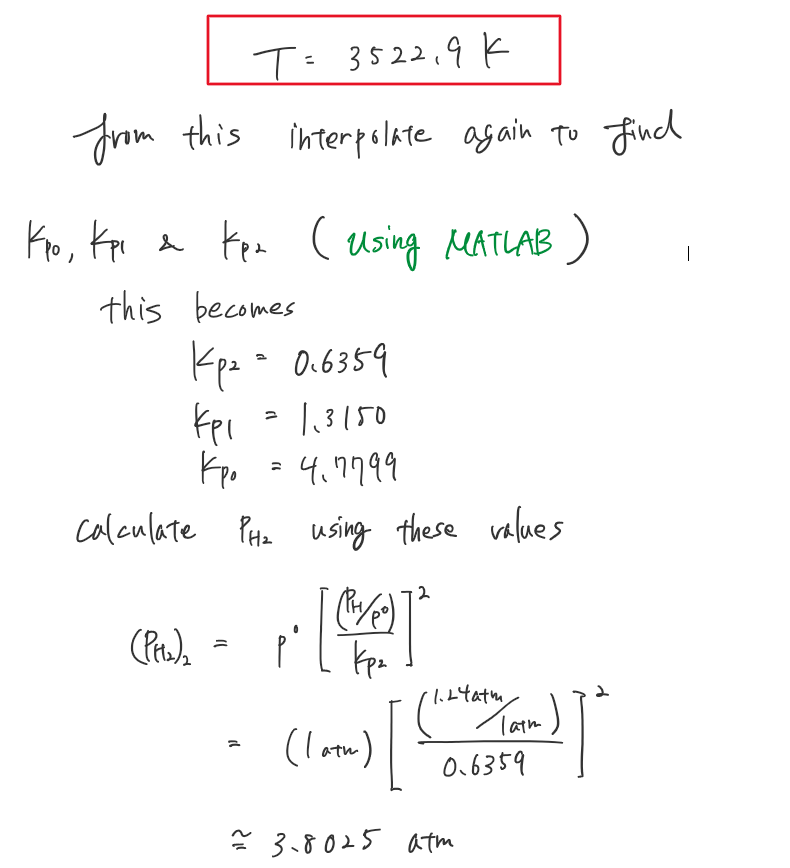


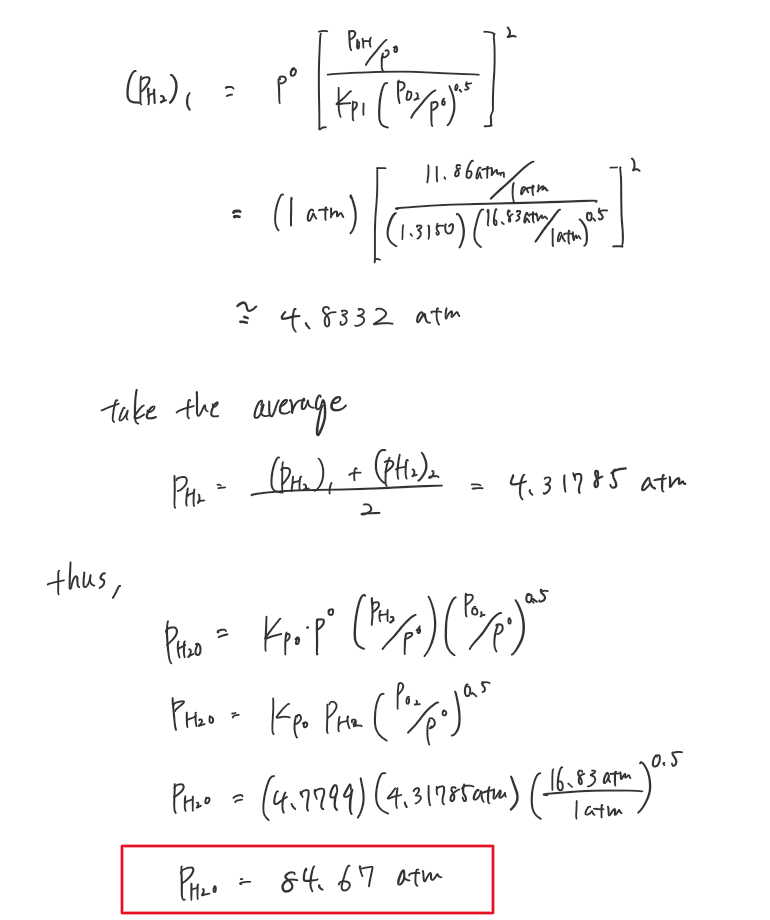


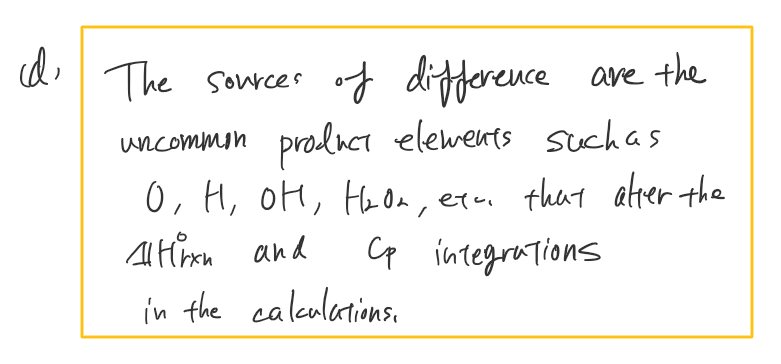












Appendix

>>Matlab Code

## **AAE339 matlab code**

clear all; close all; clc;

### problem 2

% Optimazation for the sum of integrals to equal the heat of reaction

[x,fval,exitflag,output,lambda,grad,hessian] = HW4\_opt\_T\_ad\_p2([301], [300], [3500]);

vpa(x, 10)

### problem 3

#### <b>

% Optimazation for the sum of integrals to equal the heat of reaction

[x2,fval2,exitflag2,output2,lambda2,grad2,hessian2] = HW4\_opt\_T\_ad\_p3([301], [300], [5000]);

vpa(x2, 10)

#### <c>

% interpolating

T\_chamber = two\_point\_interpolate(0.56552,0.51807,1.5528,3500,4000);

Kp2 = two\_point\_interpolate(3522.9,3500,4000,0.58993,1.5933);

Kp1 = two\_point\_interpolate(3522.9,3500,4000,1.3046,1.5315);

Kp0 = two\_point\_interpolate(3522.9,3500,4000,4.9295,1.6623);

function obj = HW4\_p2\_objective(T\_ad)

% Functions for the Cp for each element in the product

nitrogen\_Cp = @(theta) 39.060-512.79\*theta.^(-1.5)+1072.7\*theta.^(-2)-820.40\*theta.^(-3);

oxygen\_Cp = @(theta) 37.432+0.020102\*theta.^(1.5)-178.57\*theta.^(-1.5)+236.88\*theta.^(-2);

carbon\_dioxide\_Cp = @(theta) -3.7357+30.529\*theta.^(0.5)-4.1034\*theta+0.024198\*theta.^2;

water\_vapor\_Cp = @(theta) 143.05-183.54\*theta.^(0.25)+82.751\*theta.^(0.5)-3.6989\*theta;

% Moles

n\_n2 = 23.513; %[moles]

n\_o2 = 1.25;

n\_co2 = 3;

n\_h2o = 4;

T\_ref = 278; %[K]

theta\_ref = T\_ref/100;

theta\_ad = T\_ad/100;

% Summations of integrations

H\_rxn = (n\_n2\*integral(nitrogen\_Cp,theta\_ref,theta\_ad) + n\_o2\*integral(oxygen\_Cp,theta\_ref,theta\_ad) + ...

n\_co2\*integral(carbon\_dioxide\_Cp,theta\_ref,theta\_ad) + n\_h2o\*integral(water\_vapor\_Cp,theta\_ref,theta\_ad))\*100;

obj = abs(H\_rxn - 2.0447\*10^6);

end

function [x,fval,exitflag,output,lambda,grad,hessian] = HW4\_opt\_T\_ad\_p2(x0,lb,ub)

%% Start with the default options

options = optimoptions('fmincon');

%% Modify options setting

options = optimoptions(options,'Display', 'off');

options = optimoptions(options,'PlotFcn', { @optimplotfunccount @optimplotfval });

options = optimoptions(options,'HessianApproximation', 'bfgs');

[x,fval,exitflag,output,lambda,grad,hessian] = ...

fmincon(@HW4\_p2\_objective,x0,[],[],[],[],lb,ub,[],options);

function obj = HW4\_p3\_objective(T\_ad)

% Functions for the Cp for each element in the product

oxygen\_Cp = @(theta) 37.432+0.020102\*theta.^(1.5)-178.57\*theta.^(-1.5)+236.88\*theta.^(-2);

water\_vapor\_Cp = @(theta) 143.05-183.54\*theta.^(0.25)+82.751\*theta.^(0.5)-3.6989\*theta;

%hydro\_monoxide\_Cp = @(theta) 81.546-59.350\*theta.^(0.25)+17.329\*theta.^(0.75)-4.266\*theta;

%hydro\_molecule\_Cp = @(theta) 20.78603+4.850638\*10.^(-10)\*(theta/10)...

% -1.582916\*10.^(-10)\*(theta/10).^2+1.525102\*10.^(-11)\*(theta/10).^3+3.196347\*10.^(-11)\*(theta/10).^2;

% Moles

n\_o2 = 0.25;

n\_h2o = 1;

T\_ref = 300; %[K]

theta\_ref = T\_ref/100;

theta\_ad = T\_ad/100;

% Summations of integrations

H\_rxn = (n\_o2\*integral(oxygen\_Cp,theta\_ref,theta\_ad) + n\_h2o\*integral(water\_vapor\_Cp,theta\_ref,theta\_ad))\*100;

obj = abs(H\_rxn - 241.826\*10^3);

end

function [x,fval,exitflag,output,lambda,grad,hessian] = HW4\_opt\_T\_ad\_p3(x0,lb,ub)

%% Start with the default options

options = optimoptions('fmincon');

%% Modify options setting

options = optimoptions(options,'Display', 'off');

options = optimoptions(options,'PlotFcn', { @optimplotfunccount @optimplotfval });

options = optimoptions(options,'HessianApproximation', 'bfgs');

[x,fval,exitflag,output,lambda,grad,hessian] = ...

fmincon(@HW4\_p3\_objective,x0,[],[],[],[],lb,ub,[],options);

function y = two\_point\_interpolate(x,x\_low,x\_high,y\_low,y\_high)

slope = (y\_high - y\_low) / (x\_high - x\_low);

y = slope \* (x - x\_low) + y\_low;

end

>>CEA results

For problem 2

\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

NASA-GLENN CHEMICAL EQUILIBRIUM PROGRAM CEA2, FEBRUARY 5, 2004

BY BONNIE MCBRIDE AND SANFORD GORDON

REFS: NASA RP-1311, PART I, 1994 AND NASA RP-1311, PART II, 1996

\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

### CEA analysis performed on Sun 09-Feb-2020 17:49:04

# Problem Type: "Rocket" (Infinite Area Combustor)

prob case=1111\_\_\_\_\_\_\_\_\_\_\_7282 ro equilibrium

# Pressure (1 value):

p,atm= 1

# Equivalence based on Fuel/Oxid. wt ratio (Eq 9.19\*) (1 value):

phi= 0.8

# You selected the following fuels and oxidizers:

reac

fuel C3H8 mole=100.0000 t,k= 298.000

oxid Air mole=100.0000 t,k= 298.000

# You selected these options for output:

# short version of output

output short

# Proportions of any products will be expressed as Mole Fractions.

# Heat will be expressed as siunits

output siunits

# Input prepared by this script:prepareInputFile.cgi

### IMPORTANT: The following line is the end of your CEA input file!

end

THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM

COMPOSITION DURING EXPANSION FROM INFINITE AREA COMBUSTOR

Pin = 14.7 PSIA

CASE = 1111\_\_\_\_\_\_\_\_\_\_\_

REACTANT MOLES ENERGY TEMP

KJ/KG-MOL K

FUEL C3H8 100.0000000 -104691.036 298.000

OXIDANT Air 100.0000000 -129.895 298.000

O/F= 19.59862 %FUEL= 4.854693 R,EQ.RATIO= 0.800304 PHI,EQ.RATIO= 0.800000

CHAMBER THROAT

Pinf/P 1.0000 1.8045

P, BAR 1.0132 0.56152

T, K 2040.47 1819.87

RHO, KG/CU M 1.7019-1 1.0584-1

H, KJ/KG -119.53 -451.65

U, KJ/KG -714.87 -982.18

G, KJ/KG -19273.5 -17534.9

S, KJ/(KG)(K) 9.3871 9.3871

M, (1/n) 28.497 28.521

(dLV/dLP)t -1.00047 -1.00011

(dLV/dLT)p 1.0156 1.0043

Cp, KJ/(KG)(K) 1.5938 1.4598

GAMMAs 1.2321 1.2521

SON VEL,M/SEC 856.4 815.0

MACH NUMBER 0.000 1.000

PERFORMANCE PARAMETERS

Ae/At 1.0000

CSTAR, M/SEC 1174.6

CF 0.6939

Ivac, M/SEC 1466.0

Isp, M/SEC 815.0

MOLE FRACTIONS

\*Ar 0.00877 0.00877

\*CO 0.00088 0.00016

\*CO2 0.09354 0.09434

\*H 0.00003 0.00000

\*H2 0.00025 0.00006

H2O 0.12422 0.12517

\*NO 0.00347 0.00183

\*N2 0.72918 0.73064

\*O 0.00017 0.00004

\*OH 0.00203 0.00075

\*O2 0.03746 0.03824

\* THERMODYNAMIC PROPERTIES FITTED TO 20000.K

For problem 3

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NASA-GLENN CHEMICAL EQUILIBRIUM PROGRAM CEA2, FEBRUARY 5, 2004

BY BONNIE MCBRIDE AND SANFORD GORDON

REFS: NASA RP-1311, PART I, 1994 AND NASA RP-1311, PART II, 1996

\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

### CEA analysis performed on Tue 11-Feb-2020 13:09:56

# Problem Type: "Rocket" (Infinite Area Combustor)

prob case=1111\_\_\_\_\_\_\_\_\_\_\_1362 ro equilibrium

# Pressure (1 value):

p,atm= 100

# Oxidizer/Fuel Wt. ratio (1 value):

o/f= 12

# You selected the following fuels and oxidizers:

reac

fuel H2 mole=100.0000 t,k= 300.000

oxid O2 mole=100.0000 t,k= 300.000

# You selected these options for output:

# short version of output

output short

# Proportions of any products will be expressed as Mole Fractions.

# Heat will be expressed as siunits

output siunits

# Input prepared by this script:prepareInputFile.cgi

### IMPORTANT: The following line is the end of your CEA input file!

end

THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM

COMPOSITION DURING EXPANSION FROM INFINITE AREA COMBUSTOR

Pin = 1469.6 PSIA

CASE = 1111\_\_\_\_\_\_\_\_\_\_\_

REACTANT MOLES ENERGY TEMP

KJ/KG-MOL K

FUEL H2 100.0000000 53.359 300.000

OXIDANT O2 100.0000000 54.358 300.000

O/F= 12.00000 %FUEL= 7.692308 R,EQ.RATIO= 0.661390 PHI,EQ.RATIO= 0.661390

CHAMBER THROAT

Pinf/P 1.0000 1.7311

P, BAR 101.33 58.531

T, K 3559.29 3372.16

RHO, KG/CU M 6.6625 0 4.1082 0

H, KJ/KG 3.6042 -804.29

U, KJ/KG -1517.22 -2229.03

G, KJ/KG -46860.1 -45204.2

S, KJ/(KG)(K) 13.1666 13.1666

M, (1/n) 19.459 19.679

(dLV/dLP)t -1.02763 -1.02307

(dLV/dLT)p 1.4934 1.4373

Cp, KJ/(KG)(K) 6.4682 6.1769

GAMMAs 1.1360 1.1341

SON VEL,M/SEC 1314.4 1271.1

MACH NUMBER 0.000 1.000

PERFORMANCE PARAMETERS

Ae/At 1.0000

CSTAR, M/SEC 1940.3

CF 0.6551

Ivac, M/SEC 2392.0

Isp, M/SEC 1271.1

MOLE FRACTIONS

\*H 0.01237 0.00967

HO2 0.00070 0.00049

\*H2 0.03406 0.02853

H2O 0.64249 0.66548

H2O2 0.00009 0.00006

\*O 0.02327 0.01917

\*OH 0.11870 0.10357

\*O2 0.16832 0.17304

\* THERMODYNAMIC PROPERTIES FITTED TO 20000.K