APPENDICES

APPENDIX A

PROGRAM CODE

```
clc
clearall
Ru=8.3145; % Universal gas constant (kJ/kmol.K)
%-------------------------------------------------------------------
%----------------- Assumption for Brayton cycle ---------------------
%-------------------------------------------------------------------
T1=288; %Inlet air temperature (K)
rp=2:30; %Pressure ratio
ma=1; %Air mass flow rate (kg/s)
mf=0.01612; %Fuel mass flow rate (kg/s)
Eta=[0.7 0.8 0.9]; %Isentropic efficiency for both compressor and
turbine
%-------------------------------------------------------------------
%-------------------------- Fuel properties ------------------------
%-------------------------------------------------------------------
% Fuel type: LPG (60% Propane (C3H8) & 40% Butane (C4H10) by volume)
CV=46300; %Calorific value for LPG (kJ/kg)
% 1- Propane (C3H8) ======> Abbreviation (P)
M_P=44; %Molecular weight for propane (kg/kmol)
Cp_P=2.77; %Specific heat at constant pressure for propane (kJ/kg.K)
y_P=0.6; %Mole fraction of propane in fuel
x_P=0.5322; %Mass fraction of propane in fuel
% 2- Butane (C4H10) ======> Abbreviation (B)
M_B=58; %Molecular weight for Butane (kg/kmol)
Cp_B=2.42; %Specific heat at constant pressure for Butane (kJ/kg.K)
y_B=0.4; %Mole fraction of Butane in fuel
x_B=0.4718; %Mass fraction of Butane in fuel
%-------------------------------------------------------------------
%-------------------------- Air properties -------------------------
%-------------------------------------------------------------------
% Composition of air
% 23.3% O2 & 76.7% N2 (By mass)
% 21% O2 & 79% N2 (By volume)
M_O2=32; %Molecular weight for O2 (kg/kmol)
M_N2=28; %Molecular weight for N2 (kg/kmol)
M_CO2=44; %Molecular weight for CO2 (kg/kmol)
M_H2O=18; %Molecular weight for H2O (kg/kmol)
Ma=28.84; %Molecular weight for air (kg/kmol)
R_O2=Ru/M_O2; %Gas constant for O2 (kJ/kg.K)
R_N2=Ru/M_N2; %Gas constant for N2 (kJ/kg.K)
R_CO2=Ru/M_CO2; %Gas constant for CO2 (kJ/kg.K)
R_H2O=Ru/M_H2O; %Gas constant for H2O (kJ/kg.K)
Ra=Ru/Ma; %Gas constant for air (kJ/kg.K)

a1_N2=xlsread('data',1,'B2:F2');      %Coefficients for N2 temperature-
dependent specific heats (T<=1000)
a1_O2=xlsread('data',1,'B3:F3');      %Coefficients for O2 temperature-
dependent specific heats (T<=1000)
a1_CO2=xlsread('data',1,'B4:F4');     %Coefficients for CO2 temperature-
dependent specific heats (T<=1000)
```

```
a1_H2O=xlsread('data',1,'B5:F5');    %Coefficients for H2O temperature-dependent specific heats (T<=1000)
a2_N2=xlsread('data',1,'B7:F7');     %Coefficients for N2 temperature-dependent specific heats (1000<T<3200)
a2_O2=xlsread('data',1,'B8:F8');     %Coefficients for O2 temperature-dependent specific heats (1000<T<3200)
a2_CO2=xlsread('data',1,'B9:F9');    %Coefficients for CO2 temperature-dependent specific heats (1000<T<3200)
a2_H2O=xlsread('data',1,'B10:F10');  %Coefficients for H2O temperature-dependent specific heats (1000<T<3200)
y_O2=0.21; %Mole fraction of O2 in air
x_O2=0.233; %Mass fraction of O2 in air
y_N2=0.79; %Mole fraction of N2 in air
x_N2=0.767; %Mass fraction of N2 in air
%---------------------------------------------------------------------
%------------------------ Combustion Chamber ------------------------
%---------------------------------------------------------------------
xCO2=0.048; %mass fraction of CO2 in products
xH2O=0.025; %mass fraction of H2O in products
xO2=0.172; %mass fraction of O2 in products
xN2=0.755; %mass fraction of N2 in products
yCO2=0.03124; %mole fraction of CO2 in products
yH2O=0.04043; %mole fraction of H2O in products
yO2=0.15438; %mole fraction of O2 in products
yN2=0.77395; %mole fraction of N2 in products
Mmix=M_CO2*yCO2+M_H2O*yH2O+M_O2*yO2+M_N2*yN2; %Molecular weight for products (kg/kmol)
Rmix=Ru/Mmix; %Gas constant for products (kJ/kg.K)
%---------------------------------------------------------------------
%------------------------- Process 1 ---> 2 ------------------------
%---------------------------------------------------------------------
for i=1:length(Eta)
for j=1:length(rp)
T2si(i,j)=T1*rp(j)^(0.4/1.4);     % initial value for T2s
T2s(i,j)=T2si(i,j);
for it=1:1000
            LMT12=(T2s(i,j)-T1)/log(T2s(i,j)/T1);
if LMT12<=1000

Cp_O2(i,j)=R_O2*(a1_O2(1)+a1_O2(2)*LMT12+a1_O2(3)*LMT12^2+a1_O2(4)*LMT12^3+a1_O2(5)*LMT12^4);
Cp_N2(i,j)=R_N2*(a1_N2(1)+a1_N2(2)*LMT12+a1_N2(3)*LMT12^2+a1_N2(4)*LMT12^3+a1_N2(5)*LMT12^4);
Cpa(i,j)=Cp_O2(i,j)*x_O2+Cp_N2(i,j)*x_N2;
elseif LMT12>1000 & LMT12<3200
Cp_O2(i,j)=R_O2*(a2_O2(1)+a2_O2(2)*LMT12+a2_O2(3)*LMT12^2+a2_O2(4)*LMT12^3+a2_O2(5)*LMT12^4);
Cp_N2(i,j)=R_N2*(a2_N2(1)+a2_N2(2)*LMT12+a2_N2(3)*LMT12^2+a2_N2(4)*LMT12^3+a2_N2(5)*LMT12^4);
Cpa(i,j)=Cp_O2(i,j)*x_O2+Cp_N2(i,j)*x_N2;
else
end
T2s(i,j)=T1*exp((Ra/Cpa(i,j))*log(rp(j)));
end
T2(i,j)=((T2s(i,j)-T1)/Eta(i))+T1;
Wc(i,j)=ma*Cpa(i,j)*(T2(i,j)-T1);    % compressor power (kW)
end
```

```
end
%-------------------------------------------------------------------
%------------------------- Process 2 ---> 3 ------------------------
%-------------------------------------------------------------------
for i=1:length(Eta)
for j=1:length(rp)
        T3i=1300;  %Initial value for T3 (K)
T3(i,j)=T3i;
for it=1:1000
            LMT23=(T3(i,j)-T2(i,j))/log(T3(i,j)/T2(i,j));
if LMT23<=1000
CpO2(i,j)=R_O2*(a1_O2(1)+a1_O2(2)*LMT23+a1_O2(3)*LMT23^2+a1_O2(4)*LMT23^
3+a1_O2(5)*LMT23^4);
CpN2(i,j)=R_N2*(a1_N2(1)+a1_N2(2)*LMT23+a1_N2(3)*LMT23^2+a1_N2(4)*LMT23^
3+a1_N2(5)*LMT23^4);
CpH2O(i,j)=R_H2O*(a1_H2O(1)+a1_H2O(2)*LMT23+a1_H2O(3)*LMT23^2+a1_H2O(4)*
LMT23^3+a1_H2O(5)*LMT23^4);
CpCO2(i,j)=R_CO2*(a1_CO2(1)+a1_CO2(2)*LMT23+a1_CO2(3)*LMT23^2+a1_CO2(4)*
LMT23^3+a1_CO2(5)*LMT23^4);
Cpmix(i,j)=CpO2(i,j)*xO2+CpN2(i,j)*xN2+CpCO2(i,j)*xCO2+CpH2O(i,j)*xH2O;
elseif LMT23>1000 & LMT23<3200
CpO2(i,j)=R_O2*(a2_O2(1)+a2_O2(2)*LMT23+a2_O2(3)*LMT23^2+a2_O2(4)*LMT23^
3+a2_O2(5)*LMT23^4);
CpN2(i,j)=R_N2*(a2_N2(1)+a2_N2(2)*LMT23+a2_N2(3)*LMT23^2+a2_N2(4)*LMT23^
3+a2_N2(5)*LMT23^4);
CpH2O(i,j)=R_H2O*(a2_H2O(1)+a2_H2O(2)*LMT23+a2_H2O(3)*LMT23^2+a2_H2O(4)*
LMT23^3+a2_H2O(5)*LMT23^4);
CpCO2(i,j)=R_CO2*(a2_CO2(1)+a2_CO2(2)*LMT23+a2_CO2(3)*LMT23^2+a2_CO2(4)*
LMT23^3+a2_CO2(5)*LMT23^4);
Cpmix(i,j)=CpO2(i,j)*xO2+CpN2(i,j)*xN2+CpCO2(i,j)*xCO2+CpH2O(i,j)*xH2O;
else
end
            T3(i,j)=T2(i,j)+((mf*CV)/((mf+ma)*Cpmix(i,j)));
end
Qadd(i,j)=(ma+mf)*Cpmix(i,j)*(T3(i,j)-T2(i,j));    % Heat added (kW)
end
end
%-------------------------------------------------------------------
%------------------------- Process 3 ---> 4 ------------------------
%-------------------------------------------------------------------
for i=1:length(Eta)
for j=1:length(rp)
T4si(i,j)=T3(i,j)*(1/rp(j))^(0.4/1.4);     % initial value for T2s
T4s(i,j)=T4si(i,j);
for it=1:1000
            LMT34=(T3(i,j)-T4s(i,j))/log(T3(i,j)/T4s(i,j));
if LMT34<=1000
CpO2(i,j)=R_O2*(a1_O2(1)+a1_O2(2)*LMT34+a1_O2(3)*LMT34^2+a1_O2(4)*LMT34^
3+a1_O2(5)*LMT34^4);
CpN2(i,j)=R_N2*(a1_N2(1)+a1_N2(2)*LMT34+a1_N2(3)*LMT34^2+a1_N2(4)*LMT34^
3+a1_N2(5)*LMT34^4);
CpH2O(i,j)=R_H2O*(a1_H2O(1)+a1_H2O(2)*LMT34+a1_H2O(3)*LMT34^2+a1_H2O(4)*
LMT34^3+a1_H2O(5)*LMT34^4);
CpCO2(i,j)=R_CO2*(a1_CO2(1)+a1_CO2(2)*LMT34+a1_CO2(3)*LMT34^2+a1_CO2(4)*
LMT34^3+a1_CO2(5)*LMT34^4);

Cpmix(i,j)=CpO2(i,j)*xO2+CpN2(i,j)*xN2+CpCO2(i,j)*xCO2+CpH2O(i,j)*xH2O;
```

```
elseif LMT34>1000 & LMT34<3200
CpO2(i,j)=R_O2*(a2_O2(1)+a2_O2(2)*LMT34+a2_O2(3)*LMT34^2+a2_O2(4)*LMT34^
3+a2_O2(5)*LMT34^4);
CpN2(i,j)=R_N2*(a2_N2(1)+a2_N2(2)*LMT34+a2_N2(3)*LMT34^2+a2_N2(4)*LMT34^
3+a2_N2(5)*LMT34^4);
CpH2O(i,j)=R_H2O*(a2_H2O(1)+a2_H2O(2)*LMT34+a2_H2O(3)*LMT34^2+a2_H2O(4)*
LMT34^3+a2_H2O(5)*LMT34^4);
CpCO2(i,j)=R_CO2*(a2_CO2(1)+a2_CO2(2)*LMT34+a2_CO2(3)*LMT34^2+a2_CO2(4)*
LMT34^3+a2_CO2(5)*LMT34^4);
Cpmix(i,j)=CpO2(i,j)*xO2+CpN2(i,j)*xN2+CpCO2(i,j)*xCO2+CpH2O(i,j)*xH2O;
else
end
            T4s(i,j)=T3(i,j)*exp((Rmix/Cpmix(i,j))*log(1/rp(j)));
end
        T4(i,j)=T3(i,j)-((T3(i,j)-T4s(i,j))*Eta(i));
Wt(i,j)=(ma+mf)*Cpmix(i,j)*(T3(i,j)-T4(i,j));    % turbine power (kW)
end
end
figure(1)
holdon
gridon
plot(rp,Wc(1,:),'bx-')
plot(rp,Wc(2,:),'go-')
plot(rp,Wc(3,:),'rd-')
legend('Eta_C = 0.7','Eta_C = 0.8','Eta_C = 0.9')
xlabel('Pressure ratio (rp)')
ylabel('Compressor power (W.c) [kW]')
figure(2)
holdon
gridon
plot(rp,Wt(1,:),'bx-')
plot(rp,Wt(2,:),'go-')
plot(rp,Wt(3,:),'rd-')
legend('Eta_T = 0.7','Eta_T = 0.8','Eta_T = 0.9')
xlabel('Pressure ratio (rp)')
ylabel('Turbine power (W.t) [kW]')
Wnet=Wt-Wc;
figure(3)
holdon
gridon
plot(rp,Wnet(1,:),'bx-')
plot(rp,Wnet(2,:),'go-')
plot(rp,Wnet(3,:),'rd-')
legend('Eta_C = Eta_T = 0.7','Eta_C = Eta_T = 0.8','Eta_C = Eta_T =
0.9')
xlabel('Pressure ratio (rp)')
ylabel('Net power (W.net) [kW]')
Eff=Wnet./Qadd;
SFC=(mf*3600)./Wnet;
E_nov=1-sqrt(T1./T3);
E_th=1-(T1./T3);
figure(4)
holdon
gridon
plot(rp,SFC(1,:),'bx-')
plot(rp,SFC(2,:),'go-')
plot(rp,SFC(3,:),'rd-')
```

```
legend('Eta_C = Eta_T = 0.7','Eta_C = Eta_T = 0.8','Eta_C = Eta_T =
0.9')
xlabel('Pressure ratio (rp)')
ylabel('Specific fuel consumption [kg/kW.h]')
figure(5)
holdon
gridon
plot(rp,Eff(1,:),'bx-')
plot(rp,E_nov(1,:),'k+-')
plot(rp,E_th(1,:),'ms-')
legend('Actual Efficiency','NovicovEfficiency','Carnot Efficiency')
xlabel('Pressure ratio (rp)')
ylabel('Efficiency')
figure(6)
holdon
gridon
plot(rp,Eff(2,:),'go-')
plot(rp,E_nov(2,:),'k+-')
plot(rp,E_th(2,:),'ms-')
legend('Actual Efficiency','NovicovEfficiency','Carnot Efficiency')
xlabel('Pressure ratio (rp)')
ylabel('Efficiency')
figure(7)
holdon
gridon
plot(rp,Eff(3,:),'rd-')
plot(rp,E_nov(3,:),'k+-')
plot(rp,E_th(3,:),'ms-')
legend('Actual Efficiency','NovicovEfficiency','Carnot Efficiency')
xlabel('Pressure ratio (rp)')
ylabel('Efficiency')
figure(8)
holdon
gridon
plot(rp,Eff(1,:),'bx-')
plot(rp,Eff(2,:),'go-')
plot(rp,Eff(3,:),'rd-')
legend('Eta_C = Eta_T = 0.7','Eta_C = Eta_T = 0.8','Eta_C = Eta_T =0.9')
xlabel('Pressure ratio (rp)')
ylabel('Actual Efficiency')
```

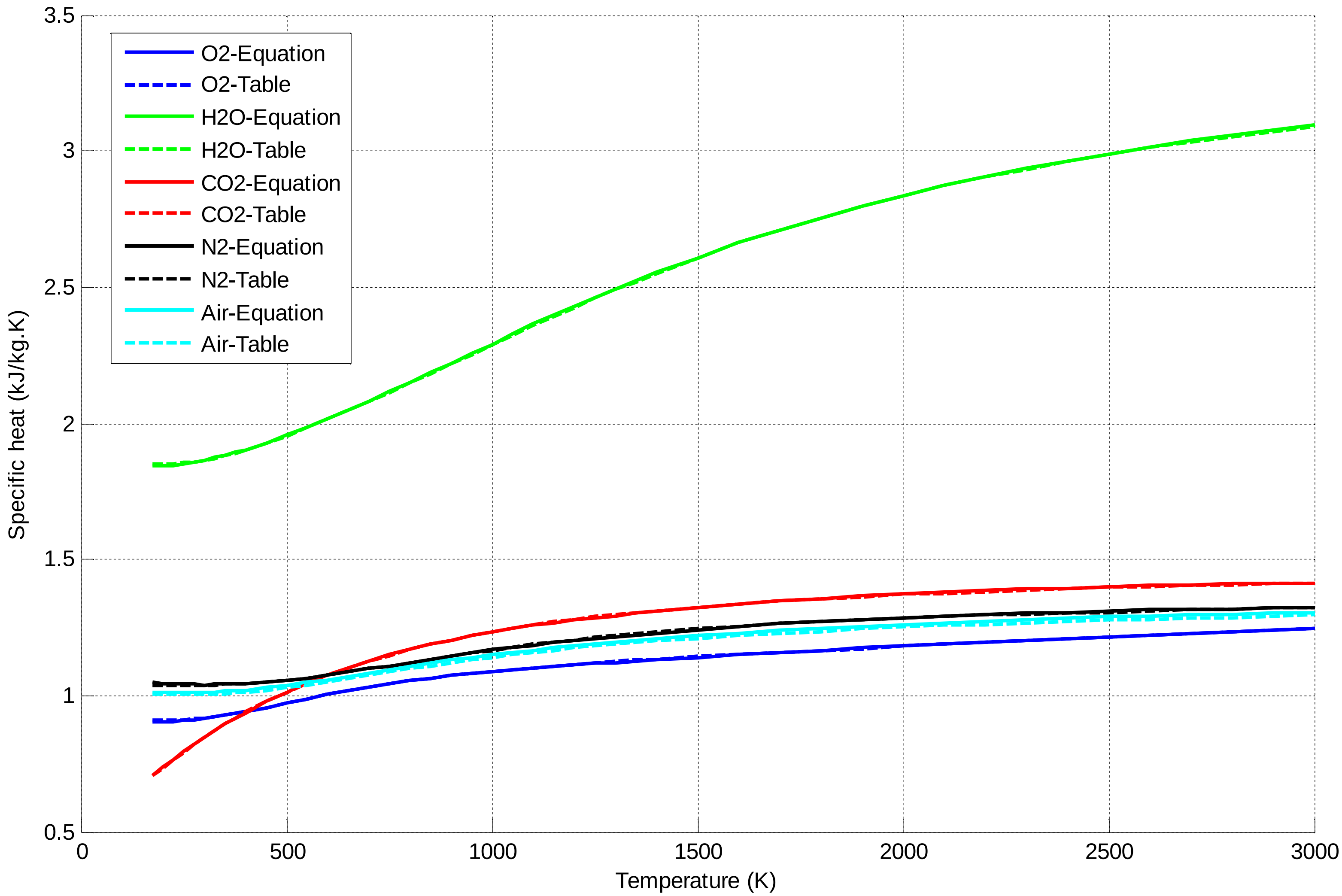
APPENDIX B

MATLAB CODE FOR SPECIFIC HEATS

```
clc
clearall
%------------------------------------------------------------------
%-------------------------- Air properties -------------------------
%------------------------------------------------------------------
% Composition of air
% 23.3% O2 & 76.7% N2 (By mass)
% 21% O2 & 79% N2 (By volume)
M_O2=32; %Molecular weight for O2 (kg/kmol)
M_N2=28; %Molecular weight for N2 (kg/kmol)
M_CO2=44; %Molecular weight for CO2 (kg/kmol)
M_H2O=18; %Molecular weight for H2O (kg/kmol)
R_O2=Ru/M_O2; %Gas constant for O2 (kJ/kg.K)
R_N2=Ru/M_N2; %Gas constant for N2 (kJ/kg.K)
R_CO2=Ru/M_CO2; %Gas constant for CO2 (kJ/kg.K)
R_H2O=Ru/M_H2O; %Gas constant for H2O (kJ/kg.K)

a1_N2=xlsread('data',1,'B2:F2');     %Coefficients for N2 temperature-
dependent specific heats (T<=1000)
a1_O2=xlsread('data',1,'B3:F3');     %Coefficients for O2 temperature-
dependent specific heats (T<=1000)
a1_CO2=xlsread('data',1,'B4:F4');    %Coefficients for CO2
temperature-dependent specific heats (T<=1000)
a1_H2O=xlsread('data',1,'B5:F5');    %Coefficients for H2O
temperature-dependent specific heats (T<=1000)

a2_N2=xlsread('data',1,'B7:F7');     %Coefficients for N2 temperature-
dependent specific heats (1000<T<3200)
a2_O2=xlsread('data',1,'B8:F8');     %Coefficients for O2 temperature-
dependent specific heats (1000<T<3200)
a2_CO2=xlsread('data',1,'B9:F9');    %Coefficients for CO2
temperature-dependent specific heats (1000<T<3200)
a2_H2O=xlsread('data',1,'B10:F10');  %Coefficients for H2O
temperature-dependent specific heats (1000<T<3200)

T_table=xlsread('data2',1,'A1:A46');     %Temperaturen range from
table
CpN2=xlsread('data2',1,'C1:C46');      %Cp for N2 from table
CpO2=xlsread('data2',1,'D1:D46');      %Cp for O2 from table
CpCO2=xlsread('data2',1,'B1:B46');     %Cp for CO2 from table
CpH2O=xlsread('data2',1,'E1:E46');     %Cp for H2O from table
Cpa=xlsread('data2',1,'F1:F46');       %Cp for air from table

y_O2=0.21; %Mole fraction of O2 in air
x_O2=0.233; %Mass fraction of O2 in air
y_N2=0.79; %Mole fraction of N2 in air
x_N2=0.767; %Mass fraction of N2 in air
%------------------------------------------------------------------
%-------------------------- Specific heat (Cp) ----------------------
%------------------------------------------------------------------
```

```
TT=T_table';
T1=TT(1:22);
fori=1:length(T1)

Cp1_O2(i)=R_O2*(a1_O2(1)+a1_O2(2)*T1(i)+a1_O2(3)*T1(i)^2+a1_O2(4)*T1(i
)^3+a1_O2(5)*T1(i)^4);

Cp1_N2(i)=R_N2*(a1_N2(1)+a1_N2(2)*T1(i)+a1_N2(3)*T1(i)^2+a1_N2(4)*T1(i
)^3+a1_N2(5)*T1(i)^4);

Cp1_CO2(i)=R_CO2*(a1_CO2(1)+a1_CO2(2)*T1(i)+a1_CO2(3)*T1(i)^2+a1_CO2(4
)*T1(i)^3+a1_CO2(5)*T1(i)^4);

Cp1_H2O(i)=R_H2O*(a1_H2O(1)+a1_H2O(2)*T1(i)+a1_H2O(3)*T1(i)^2+a1_H2O(4
)*T1(i)^3+a1_H2O(5)*T1(i)^4);
Cpa1(i)=Cp1_O2(i)*x_O2+Cp1_N2(i)*x_N2;
end
T2=TT(23:end);
fori=1:length(T2)

Cp2_O2(i)=R_O2*(a2_O2(1)+a2_O2(2)*T2(i)+a2_O2(3)*T2(i)^2+a2_O2(4)*T2(i
)^3+a2_O2(5)*T2(i)^4);

Cp2_N2(i)=R_N2*(a2_N2(1)+a2_N2(2)*T2(i)+a2_N2(3)*T2(i)^2+a2_N2(4)*T2(i
)^3+a2_N2(5)*T2(i)^4);

Cp2_CO2(i)=R_CO2*(a2_CO2(1)+a2_CO2(2)*T2(i)+a2_CO2(3)*T2(i)^2+a2_CO2(4
)*T2(i)^3+a2_CO2(5)*T2(i)^4);

Cp2_H2O(i)=R_H2O*(a2_H2O(1)+a2_H2O(2)*T2(i)+a2_H2O(3)*T2(i)^2+a2_H2O(4
)*T2(i)^3+a2_H2O(5)*T2(i)^4);
Cpa2(i)=Cp2_O2(i)*x_O2+Cp2_N2(i)*x_N2;
end
Cp_O2=[Cp1_O2 Cp2_O2];
Cp_N2=[Cp1_N2 Cp2_N2];
Cp_CO2=[Cp1_CO2 Cp2_CO2];
Cp_H2O=[Cp1_H2O Cp2_H2O];
Cp_a=[Cpa1 Cpa2];
figure(1)
holdon
gridon
plot(TT,Cp_O2,'b-')
plot(TT,CpO2,'b--')
plot(TT,Cp_H2O,'g-')
plot(TT,CpH2O,'g--')
plot(TT,Cp_CO2,'r-')
plot(TT,CpCO2,'r--')
plot(TT,Cp_N2,'k-')
plot(TT,CpN2,'k--')
plot(TT,Cp_a,'c-')
plot(TT,Cpa,'c--')
legend('O2-Equation','O2-Table','H2O-Equation','H2O-Table','CO2-
Equation','CO2-Table','N2-Equation','N2-Table','Air-Equation','Air-
Table')
xlabel('Temperature (K)')
ylabel('Specific heat (kJ/kg.K)')
```

APPENDIX C



Ideal-gas constant-pressure specificheats for some gases