Scilab Textbook Companion for Internal Combustion Engines by R. K. Rajput[1]

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Book Description

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Scilab numbering policy used in this document and the relation to the above book.

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

AP Appendix to Example(Scilab Code that is an Appednix to a particular Example of the above book)

For example, Exa 3.51 means solved example 3.51 of this book. Sec 2.3 means a scilab code whose theory is explained in Section 2.3 of the book.

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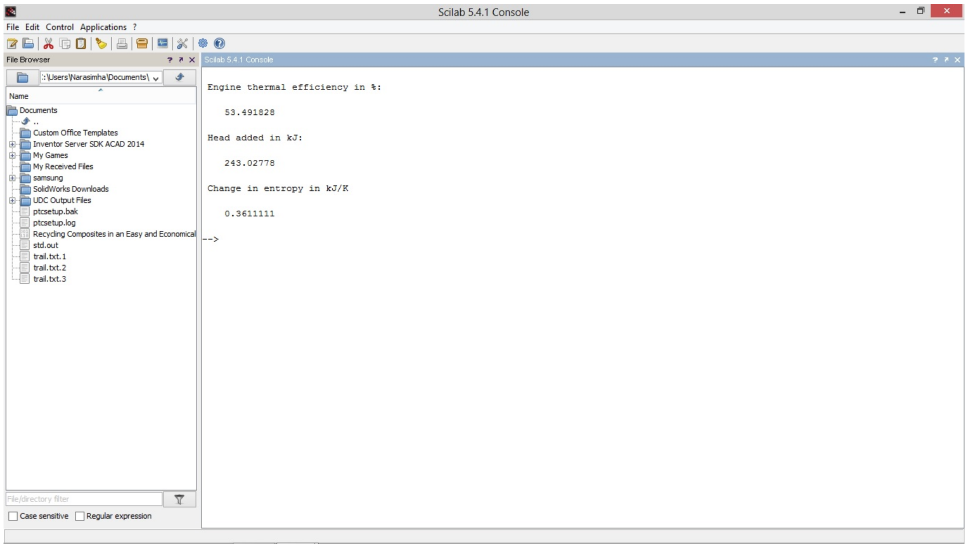
Chapter 3

Air Standard cycles

Scilab code Exa 3.1 `Carnot engine`

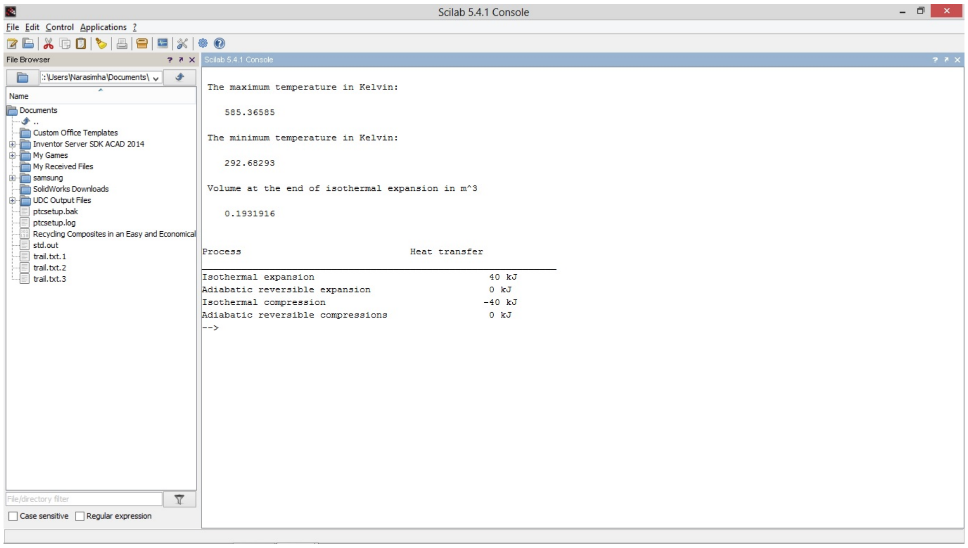
```
clc;funcprot(0);//EXAMPLE 3.1
// Initialisation of Variables
t1=673;.......................//Max temp in Kelvin
t3=313;;....................//Min temp in Kelvin
W=130;..................//Work produced in kJ
//calculations
etath=(t1-t3)/t1;.................//Engine thermal
   efficiency
disp(etath*100,"Engine thermal efficiency in %:")
ha=W/etath;...................//Heat added in kJ
disp(ha,"Head added in kJ:")
dels=(ha-W)/t3;...........//Change in entropy
disp(dels,"Change in entropy in kJ/K")
```

Scilab code Exa 3.2 `Carnot power cycle`



```
 Engine thermal efficiency in %:

    53.491828

 Head added in kJ:

    243.02778

 Change in entropy in kJ/K

    0.3611111

-->
```

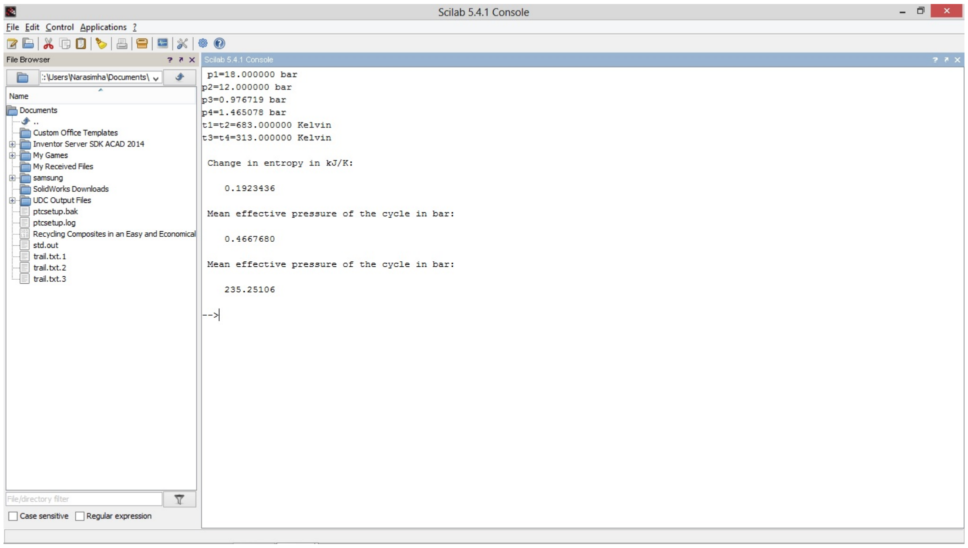
Figure 3.1: Carnot engine



```
 The maximum temperature in Kelvin:

    585.36585

 The minimum temperature in Kelvin:

    292.68293

 Volume at the end of isothermal expansion in m^3

    0.1931916


Process                              Heat transfer
____________________________________________________________
Isothermal expansion                              40 kJ
Adiabatic reversible expansion                    0 kJ
Isothermal compression                           -40 kJ
Adiabatic reversible compressions                 0 kJ
-->
```

Figure 3.2: Carnot power cycle

```
clc;funcprot(0);//EXAMPLE 3.2
// Initialisation of Variables
m=0.5;.....................//Mass of air in kg
etath=0.5;.................//Thermal efficiency of engine
hie=40;...................//Heat transferred during isothermal expansion in kJ
p1=7;...................//Pressure in bar at the beginning of expansion
v1=0.12;..................//Volume in m^3 at the beginning of expansion
cv=0.721;..................//Specific heat at constant volume in kJ/kgK
cp=1.008;..................//Specific heat at constant pressure in kJ/kgK
R=287;.....................//Gas constant in J/kgK
//Calculations
t1=(p1*10^5*v1)/(R*m);...................//Max temp in K
t2=t1*(1-etath);.......................//Min temp in K
disp(t1,"The maximum temperature in Kelvin:")
disp(t2,"The minimum temperature in Kelvin:")
v2=(%e^((hie*1000)/(m*R*t1)))*v1;.................//Volume at the end of isothermal expansion in m^3
disp(v2,"Volume at the end of isothermal expansion in m^3")
printf("\n\n")
printf("Process                              Heat transfer\n")
printf("-----------------------------------------------------\n")
printf("Isothermal expansion                          %d kJ\n",hie)
printf("Adiabatic reversible expansion                %d kJ\n",0)
```



```
 p1=18.000000 bar
p2=12.000000 bar
p3=0.976719 bar
p4=1.465078 bar
t1=t2=683.000000 Kelvin
t3=t4=313.000000 Kelvin

 Change in entropy in kJ/K:

    0.1923436

 Mean effective pressure of the cycle in bar:

    0.4667680

 Mean effective pressure of the cycle in bar:

    235.25106

-->
```

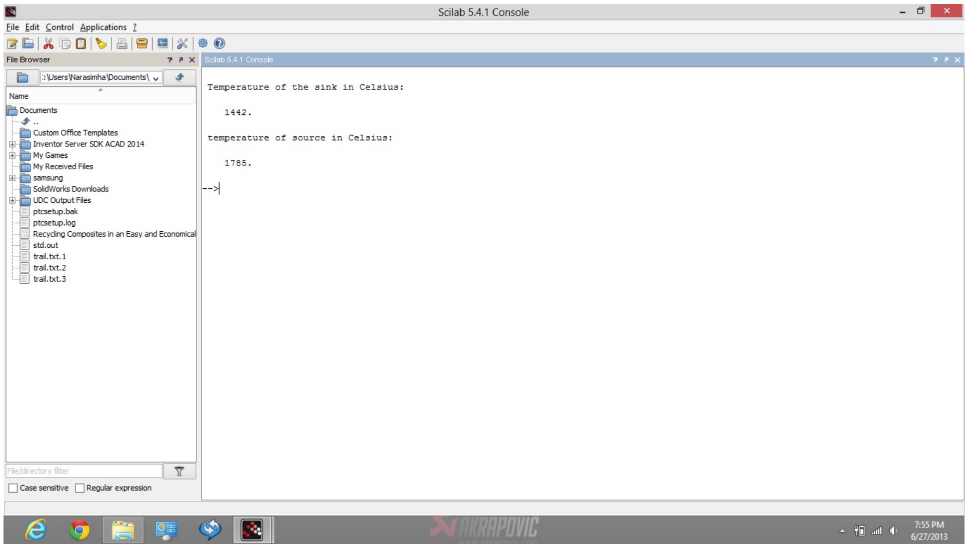
Figure 3.3: Efficiencies of carnot cycle

```
printf(”Isothermal compression                    %d kJ\n”,-hie)
printf(”Adiabatic reversible compressions             %d kJ”,0)
```

Scilab code Exa 3.3 `Efficiencies of carnot cycle`

```
clc;funcprot(0);//EXAMPLE 3.3
// Initialisation of Variables
p1=18;...................//Maximum pressure in bar
t1=410+273;.............//Maximum temperature in Kelvin
ric=6;......................//Ratio of isentropic compression
rie=1.5;..................//Ratio of isothermal expansion
```

```
v1=0.18;...................//Volume of air at the beginning of expansion
ga=1.4;....................//Degree of freedom of gas
R=287;......................//Gas constant in J/kgK
nc=210;...................//no of working cycles
//Calculations

t4=t1/(ric^(ga-1));..............//Min temp in K
t3=t4;
p4=p1/(ric^ga);...................//Min pressure in bar
p2=p1/rie;........................//pressure of gas before isentropic expansion in bar
p3=p2*((1/6)^ga);..................//Pressure of gas after isentropic expansion in bar
printf("p1=%f bar \np2=%f bar \np3=%f bar \np4=%f bar \nt1=t2=%f Kelvin \nt3=t4=%f Kelvin \n",p1,p2,p3,p4,t1,t3)
dels=(p1*10^5*v1*log(rie))/(1000*t1);.....................//Change in entropy
disp(dels,"Change in entropy in kJ/K:")
qs=t1*dels;........................//Heat supplied in kJ
Qr=t4*dels;........................//Heat rejected in kJ
eta=(qs-Qr)/qs;.............//Efficiency of the cycle
v3byv1=ric*rie;Vs=(v3byv1-1)*v1;..................//Stroke volume
pm=((qs-Qr)*10^3)/(Vs*10^5);.........//Mean effective pressure of the cycle in bar
disp(pm,"Mean effective pressure of the cycle in bar:")
P=(qs-Qr)*(nc/60);..........................//Power of engine
disp(P,"Mean effective pressure of the cycle in bar:")
```

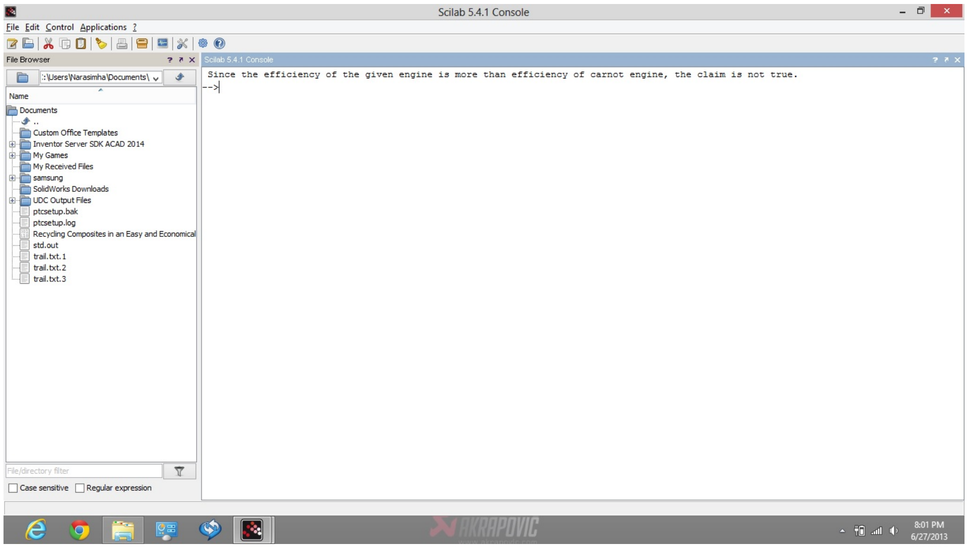


```
Temperature of the sink in Celsius:

   1442.

temperature of source in Celsius:

   1785.

-->
```

Figure 3.4: Carnot Engine

Scilab code Exa 3.4 `Carnot Engine`

```
clc;funcprot(0);//EXAMPLE 3.4
// Initialisation of Variables
eta=1/6;....................//Efficiency of the engine
rts=70;..................//The amount of temp which is reduced in the sink in C
//Calculation
t1byt2=1/(1-eta);
t2=(rts+273)/((2*eta*t1byt2)-t1byt2+1);............//Temperature of the sink in K
disp(t2-273,"Temperature of the sink in Celsius:")
t1=t1byt2*t2;...............//Temperature of source in K
```



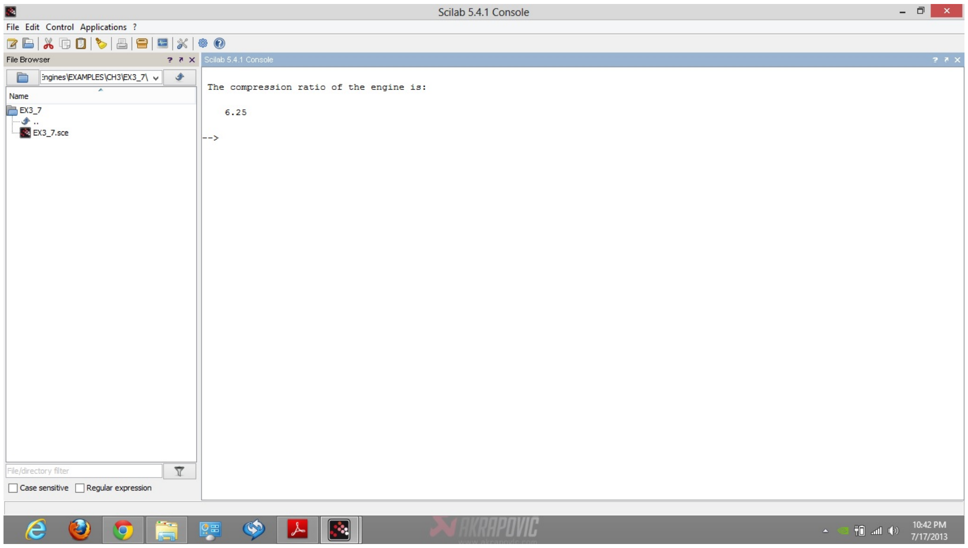
```
Since the efficiency of the given engine is more than efficiency of carnot engine, the claim is not true.
-->
```

Figure 3.5: Carnot Engine

```
disp(t1-273,"temperature of source in Celsius:")
```

Scilab code Exa 3.5 Carnot Engine

```
clc;funcprot(0);//EXAMPLE 3.5
// Initialisation of Variables
t1=1990;......................//Temperature of the
   heat source in K
t2=850;...................//Temperature of the sink
   in K
Q=32.5;...................//Heat supplied in kJ/min
P=0.4;....................//Power developed by the
   engine in kW
//Calculations
eta=1-(t2/t1);...........//Efficiency of carnot
   engine
```



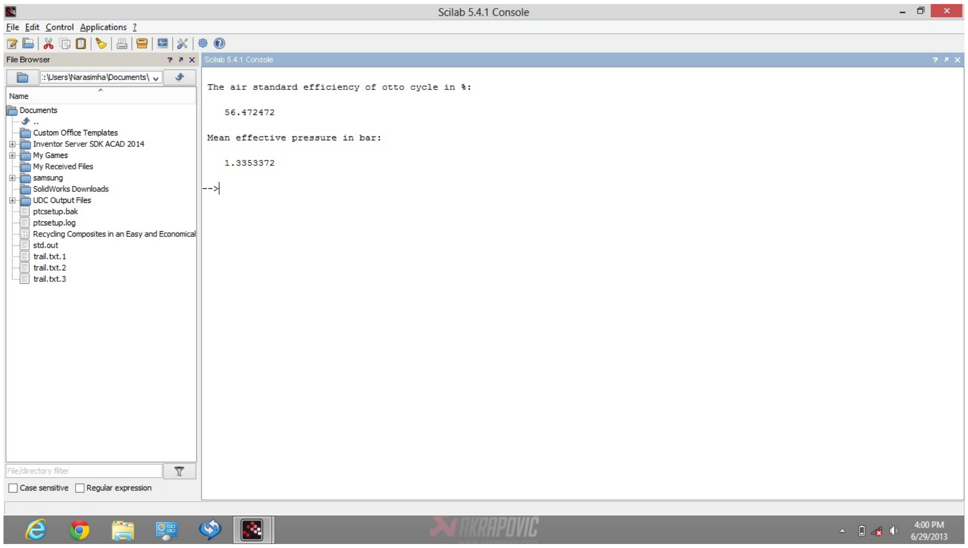
```
The compression ratio of the engine is:

    6.25

-->
```

Figure 3.6: Otto cycle

```
etath=P/(Q/60);...................//Efficiency of the given engine
if (etath>eta) then printf("Since the efficiency of the given engine is more than efficiency of carnot engine, the claim is not true.")
end
```

Scilab code Exa 3.7 `Otto cycle`

```
clc;funcprot(0);//EXAMPLE 3.7
// Initialisation of Variables
etaotto=0.6;.............//Efficiency of otto engine
ga=1.5;.................//Ratio of specific heats
//Calculations
r=(1/(1-etaotto))^(1/(ga-1));................//Compression ratio
```



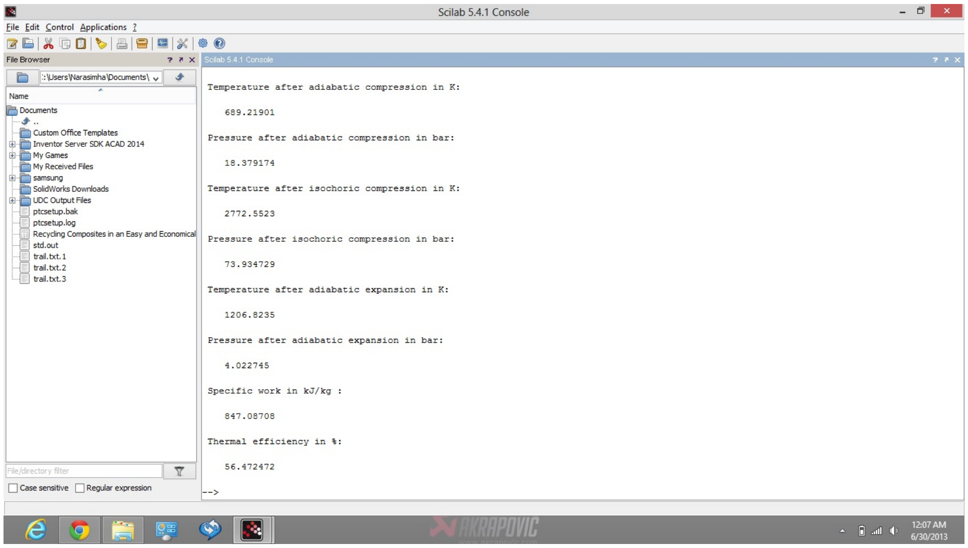
```
The air standard efficiency of otto cycle in %:

   56.472472

Mean effective pressure in bar:

   1.3353372

-->
```

Figure 3.7: Otto cycle

```
disp(r,"The compression ratio of the engine is:")
```

Scilab code Exa 3.8 `Otto cycle`

```
clc;funcprot(0);//EXAMPLE 3.8
// Initialisation of Variables
D=0.25;........................//Engine bore in m
L=0.375;.....................//Engine stroke in m
Vc=0.00263;..................//Clearence volume in m^3
p1=1;....................//Initial pressure in bar
t1=323;.....................//Initial temperature in K
p3=25;......................//Max pressure in bar
ga=1.4;......................//Ratio of specific heats
//Calculations
Vs=(%pi/4)*D*D*L;.................//Swept volume in m^3
```



```
Temperature after adiabatic compression in K:

   689.21901

Pressure after adiabatic compression in bar:

   18.379174

Temperature after isochoric compression in K:

   2772.5523

Pressure after isochoric compression in bar:

   73.934729

Temperature after adiabatic expansion in K:

   1206.8235

Pressure after adiabatic expansion in bar:

   4.022745

Specific work in kJ/kg :

   847.08708

Thermal efficiency in %:

   56.472472

-->
```

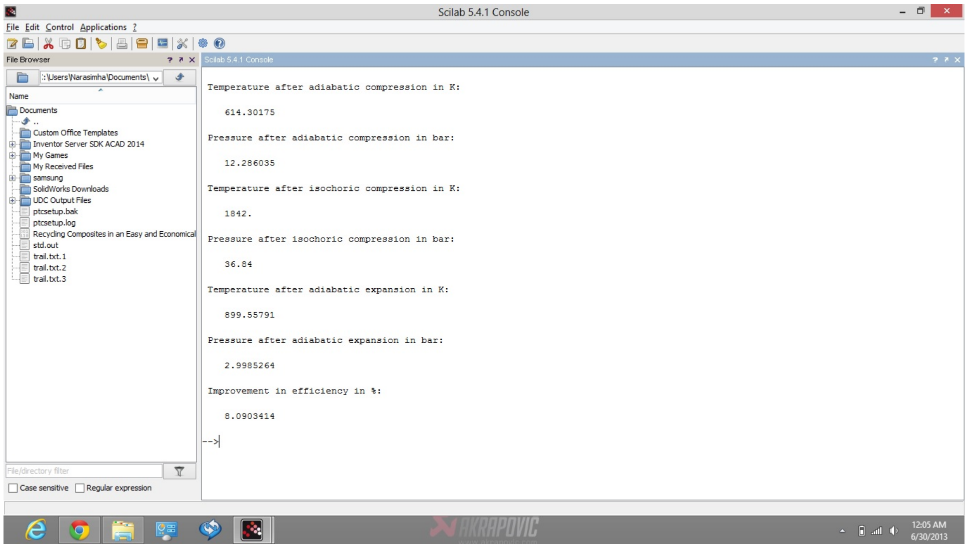
Figure 3.8: Otto Cycle

```
r=round((Vs+Vc)/Vc);..........................//Compression ratio
etaotto=1-(1/(r^(ga-1)));..................//Air standard efficiency of otto cycle
disp(etaotto*100,"The air standard efficiency of otto cycle in %:")
p2=p1*((r)^ga);
rp=p3/p2;..........................//Pressure ratio
pm=(p1*r*((r^(ga-1))-1)*(rp-1))/((ga-1)*(r-1));................//Mean effective pressure in bar
disp(pm,"Mean effective pressure in bar:")
```

Scilab code Exa 3.9 `Otto Cycle`

```
clc;funcprot(0);//EXAMPLE 3.9
// Initialisation of Variables
```

```
p1=1;......................//Pressure in bar
t1=300;......................//Temperature in K
Q=1500;......................//Heat added in kJ/kg
r=8;......................//Compression ratio
Cv=0.72;...................//Specific heat at constant volume
ga=1.4;......................//Ratio of specific heats
//Calculations
t2=t1*(r)^(ga-1);..........//Temperature after adiabatic compression in K
p2=p1*(r^ga);..............//Pressure after adiabatic compression in bar
t3=(Q/Cv)+t2;.................//Temperature after isochoric compression in K
p3=(p2*t3)/t2;................//Pressure after isochoric compression in bar
t4=t3/(r^(ga-1));......................//Temperature after adiabatic expansion in K
p4=p3*(1/(r^(ga)));................//Pressure after adiabatic expansion in bar
Ws=Cv*(t3-t2-t4+t1);.........//Specific work in kJ/kg
etath=1-(1/(r^(ga-1)));............//Thermal efficiency
disp(t2,”Temperature after adiabatic compression in K:”)
disp(p2,”Pressure after adiabatic compression in bar:”)
disp(t3,”Temperature after isochoric compression in K:”)
disp(p3,”Pressure after isochoric compression in bar:”)
disp(t4,”Temperature after adiabatic expansion in K:”)
disp(p4,”Pressure after adiabatic expansion in bar:”)
disp(Ws,”Specific work in kJ/kg :”)
```



```
Temperature after adiabatic compression in K:

   614.30175

Pressure after adiabatic compression in bar:

   12.286035

Temperature after isochoric compression in K:

   1842.

Pressure after isochoric compression in bar:

   36.84

Temperature after adiabatic expansion in K:

   899.55791

Pressure after adiabatic expansion in bar:

   2.9985264

Improvement in efficiency in %:

   8.0903414

-->
```

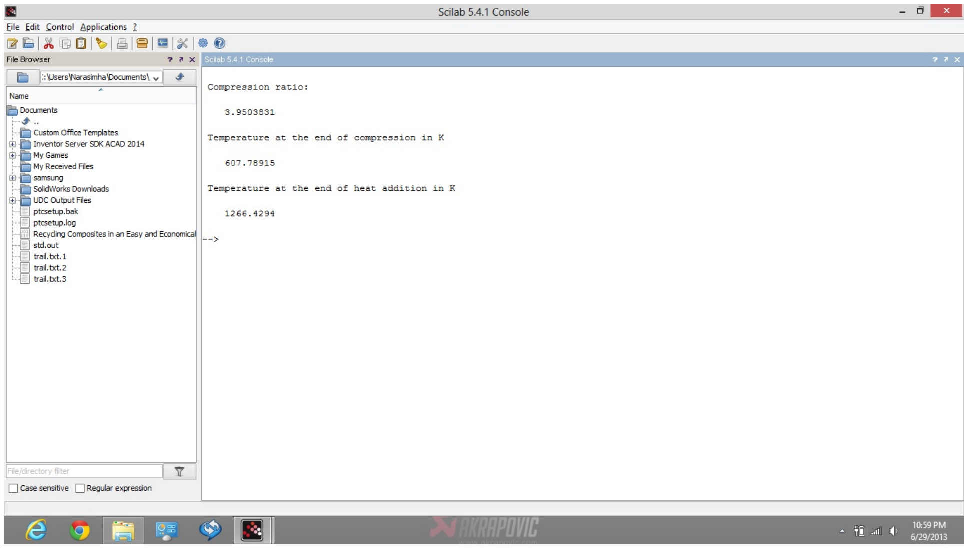
Figure 3.9: Otto cycle and Atkinson cycle

```
disp(etath*100,"Thermal efficiency in %:")
```

Scilab code Exa 3.10 `Otto cycle and Atkinson cycle`

```
clc;funcprot(0);//EXAMPLE 3.10
// Initialisation of Variables
r=6;..............//Compression ratio
p1=1;.................//Pressure after isochoric expansion in bar
t1=300;................//Temperature after isochoric expansion in K
t3=1842;...............//Temperature after isochoric compression in K
ga=1.4;...............//Ratio of specific heats
//Calculations
```

```
p2=p1*(r^ga);...............//Pressure after adiabatic compression in bar
t2=t1*(r^(ga-1));.............//Temperature after adiabatic compression in K
p3=p2*(t3/t2);.................//pressure after isochoric compression in bar
t4=t3/(r^(ga-1));..............//Temperature after adiabatic expansion in K
p4=p3*(1/(r^(ga)));...........//Pressure after adiabatic expansion in bar
etaotto=1-(1/(r^(ga-1)));...........//Efficiency of otto cycle
p5=p1;
t5=((p5/p3)^((ga-1)/ga))*t3;................//Atkinson cycle temp after further adiabatic expansion in K
etatk=1-((ga*(t5-t1))/(t3-t2));...........//Efficiency of atkinson cycle
disp(t2,"Temperature after adiabatic compression in K:")
disp(p2,"Pressure after adiabatic compression in bar:")
disp(t3,"Temperature after isochoric compression in K:")
disp(p3,"Pressure after isochoric compression in bar:")
disp(t4,"Temperature after adiabatic expansion in K:")
disp(p4,"Pressure after adiabatic expansion in bar:")
disp((etatk-etaotto)*100,"Improvement in efficiency in %:")
```

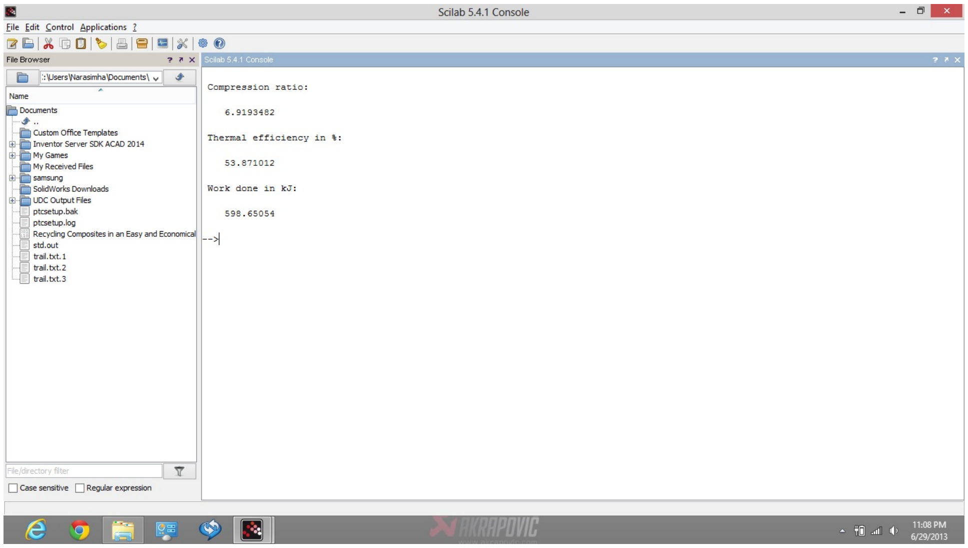


```
Compression ratio:

   3.9503831

Temperature at the end of compression in K

   607.78915

Temperature at the end of heat addition in K

   1266.4294

-->
```

Figure 3.10: Otto cycle

Scilab code Exa 3.11 `Otto cycle`

```
clc;funcprot(0);//EXAMPLE 3.11
// Initialisation of Variables
p1=1;.....................//Initial pressure in bar
t1=343;...................//Initial temperature in K
p2=7;.....................//Pressure after adiabatic compression
Qs=465;.................//Heat addition at constant volume in kJ/kg
cp=1;.....................//Specific heat at constant pressure in kJ/kg
cv=0.706;.................//Specific heat at constant volume in kJ/kg
ga=cp/cv;.................//Ratio of specific heats
//Calculations
r=(p2/p1)^(1/ga);...............//Compression ratio
t2=t1*(r^(ga-1));......................//Temperature at the end of compression in K
t3=t2+(Qs/cv);.............//Temperature at the end
```



```
Compression ratio:

   6.9193482

Thermal efficiency in %:

   53.871012

Work done in kJ:

   598.65054

-->
```

Figure 3.11: Otto cycle

```
of heat addition in K
disp(r,"Compression ratio:")
disp(t2,"Temperature at the end of compression in K")
disp(t3,"Temperature at the end of heat addition in K")
```

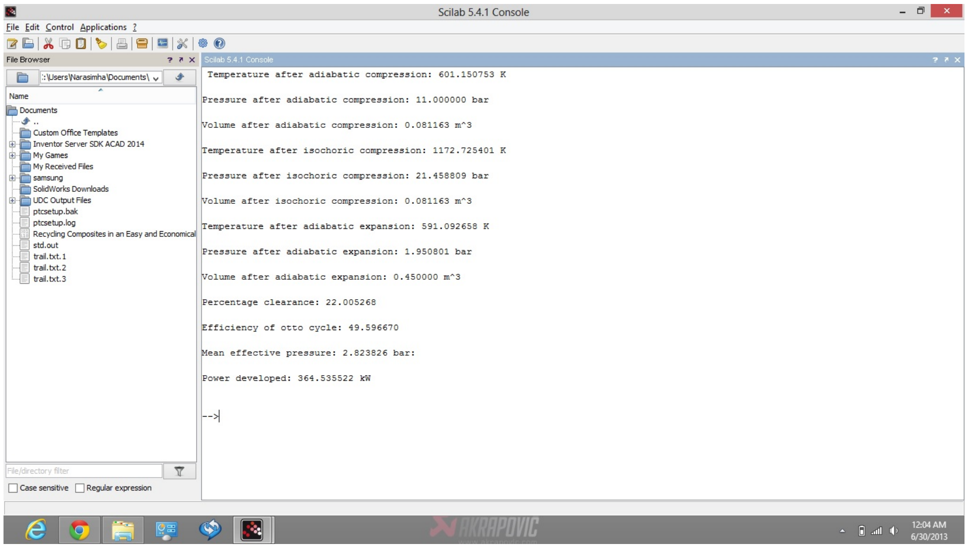
Scilab code Exa 3.12 `Otto cycle`

```
clc;funcprot(0);//EXAMPLE 3.12
// Initialisation of Variables
ga=1.4;..............//Ratio of specific heats
p2byp1=15;...............//Ratio pressure at the end of compression to that of pressure at the start
t1=311;................//Initial temperature in K
t3=2223;...............//Maximum temperature in K
```

```
R=0.287;................//Gas constant in kJ/kg K
//Calculations
r=p2byp1^(1/ga);................//Compression ratio
etath=1-(1/(r^(ga-1)));.............//Thermal efficiency
t2=t1*(r^(ga-1));...........//Temperature at the end of compression in K
t4=t3/(r^(ga-1));...........//Temperature at the end of isothermal expansion in K
cv=R/(ga-1);................//Specific heat at constant volume in kJ/kg
Q=cv*(t3-t2);..............//Heat supplied in kJ/kg of air
Qr=cv*(t4-t1);.................//Heat rejected in kJ/kg of air
W=Q-Qr;.................//Work done
disp(r,"Compression ratio:")
disp(etath*100,"Thermal efficiency in %:")
disp(W,"Work done in kJ:")
```

Scilab code Exa 3.13 `Otto cycle`

```
clc;funcprot(0);//EXAMPLE 3.13
// Initialisation of Variables
v1=0.45;.............//Initial volume in m^3
p1=1;...............//Initial pressure in bar
t1=303;.............//Initial temperature in K
p2=11;...................//Pressure at the end of compression stroke in bar
Q=210;...................//heat added at constant volume in kJ
N=210;.................//No of working cycles per min
```

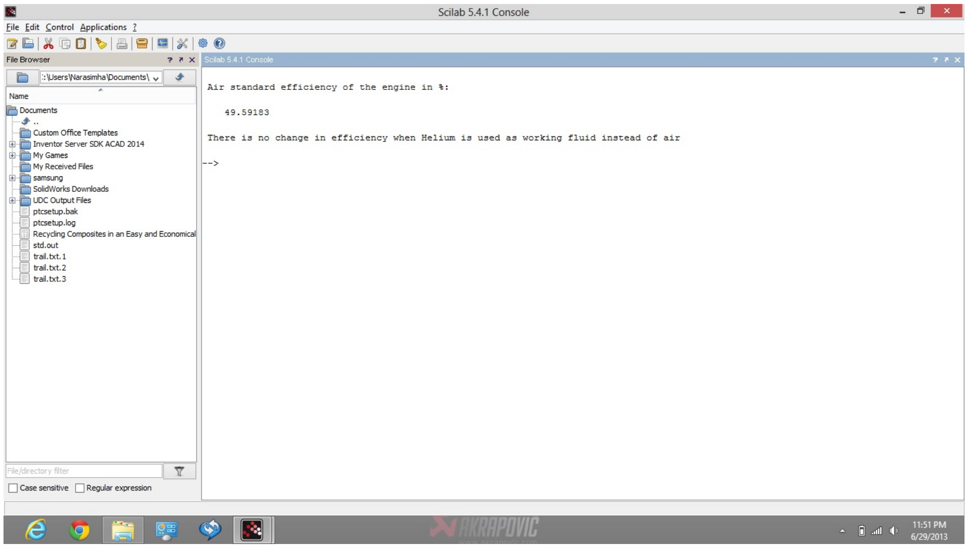


```
 Temperature after adiabatic compression: 601.150753 K

Pressure after adiabatic compression: 11.000000 bar

Volume after adiabatic compression: 0.081163 m^3

Temperature after isochoric compression: 1172.725401 K

Pressure after isochoric compression: 21.458809 bar

Volume after isochoric compression: 0.081163 m^3

Temperature after adiabatic expansion: 591.092658 K

Pressure after adiabatic expansion: 1.950801 bar

Volume after adiabatic expansion: 0.450000 m^3

Percentage clearance: 22.005268

Efficiency of otto cycle: 49.596670

Mean effective pressure: 2.823826 bar:

Power developed: 364.535522 kW


-->
```

Figure 3.12: Otto cycle

```
ga=1.4;..............//Ratio of specific heats
R=287;..................//Gas constant in kJ/kgK
cv=0.71;..................//Specific heat at constant volume in kJ/kg
//Calculations
r=(p2/p1)^(1/ga);....................//Compression ratio
t2=t1*(r^(ga-1));....................//Temperature at the end of adiabatic compression
v2=(t2*p1*v1)/(t1*p2);..................//Volume at the end of adiabatic compression in m^3
m=(p1*v1*10^5)/(R*t1);.................//Mass of engine fluid in kg
t3=(Q/(m*cv))+t2;....................//Temperature at the end of isochoric compression in K
p3=(t3/t2)*p2;.................//Pressure at the end of isochoric compression in bar
v3=v2;
t4=t3*(1/r)^(ga-1);....................//Temperature at the end of adiabatic expansion in K
```

```
p4=p3*(1/r)^ga;......................//Pressure at the end of adiabatic expansion in bar
v4=v1;
pc=(v2*100)/(v1-v2);..................//Percentage clearence
etaotto=1-(1/(r^(ga-1)));........................//Efficiency of otto cycle
Qr=m*cv*(t4-t1);...............................//Heat rejected in kJ/kg
pm=((Q-Qr)*1000)/((v1-v2)*100000);......//Mean effective pressure in bar
P=(Q-Qr)*(N/60);.........................//Power developed in kW
printf("Temperature after adiabatic compression: %f K\n\n",t2)
printf("Pressure after adiabatic compression: %f bar\n\n",p2)
printf("Volume after adiabatic compression: %f m^3\n\n",v2)
printf("Temperature after isochoric compression: %f K\n\n",t3)
printf("Pressure after isochoric compression: %f bar\n\n",p3)
printf("Volume after isochoric compression: %f m^3\n\n",v3)
printf("Temperature after adiabatic expansion: %f K\n\n",t4)
printf("Pressure after adiabatic expansion: %f bar\n\n",p4)
printf("Volume after adiabatic expansion: %f m^3\n\n",v4)
printf("Percentage clearance: %f\n\n",pc)
printf("Efficiency of otto cycle: %f\n\n",etaotto*100)
printf("Mean effective pressure: %f bar:\n\n",pm)
printf("Power developed: %f kW\n\n",P)
```

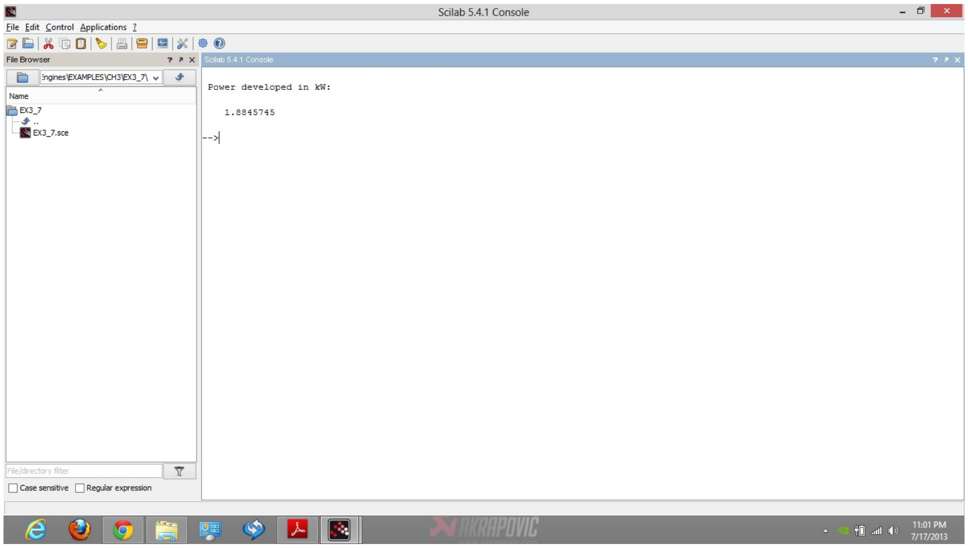


```
Air standard efficiency of the engine in %:

   49.59183

There is no change in efficiency when Helium is used as working fluid instead of air

-->
```

Figure 3.13: Otto cycle

Scilab code Exa 3.14 `Otto cycle`

```
clc;funcprot(0);//EXAMPLE 3.14
// Initialisation of Variables
t1=310;.................//Min temperature in K
t3=1220;................//Max temperature in K
ga=1.4;.................//Ratio of specific heats for air
cph=5.22;............//Specific heat at constant volume for helium in kJ/kg
cvh=3.13;...............//Specific heat at constant pressure for helium in kJ/kg
//Calculations
r=(t3/t1)^(1/((ga-1)*2));..............//Compression ratio
```

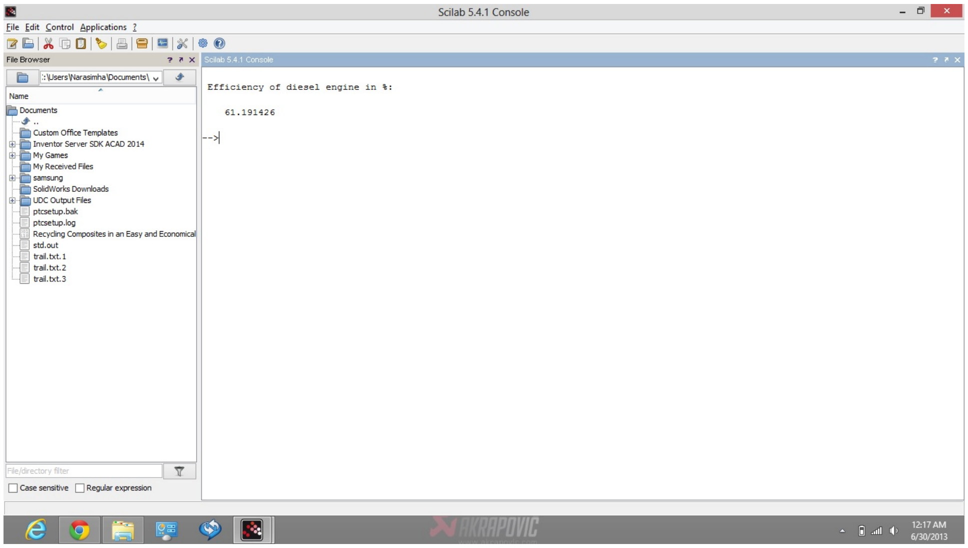


```
Power developed in kW:

   1.8845745

-->
```

Figure 3.14: Otto cycle

```
etaotto=1-(1/(r^(ga-1)));.................//Air standard efficiency
gah=cph/cvh;.................//Ratio of specific heats for Helium
rh=(t3/t1)^(1/((gah-1)*2));...............//Compression ratio when Helium is used
etaottoh=1-(1/(rh^(gah-1)));.................//Air standard efficiency when Helium is used
disp(etaotto*100,”Air standard efficiency of the engine in %:”)
if ((round (etaotto)- round (etaottoh)) == 0) then disp(”There is no change in efficiency when Helium is used as working fluid instead of air”)
end
```

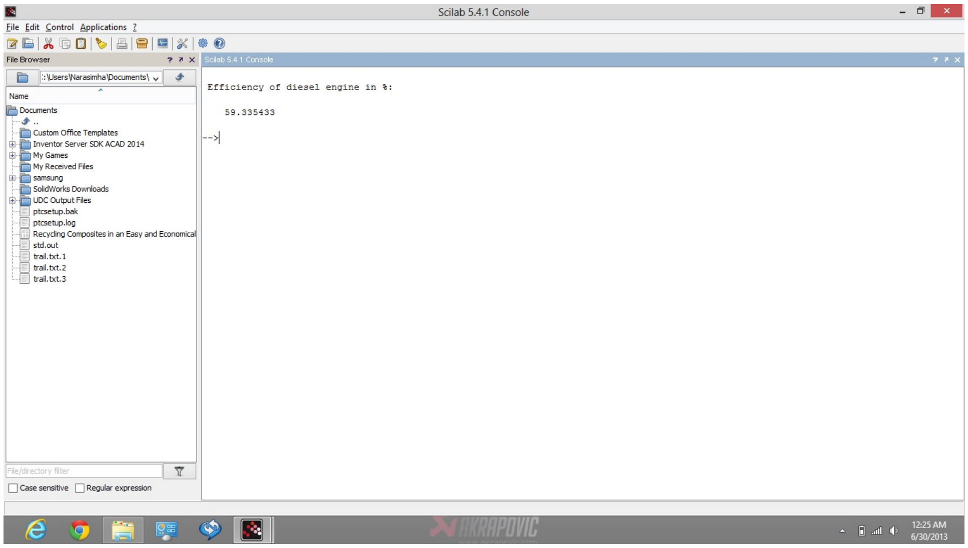
Scilab code Exa 3.15 `Otto cycle`



```
Efficiency of diesel engine in %:

   61.191426

-->
```

Figure 3.15: Diesel Cycle

```
clc;funcprot(0);//EXAMPLE 3.15
// Initialisation of Variables
t1=310;.........//Minimum temperature in K
t3=1450;............//maximum temperature in K
m=0.38;...........//Mass of working fluid in kg
cv=0.71;...........//Specific heat at constant volume in kJ/kg
//Calculations
t4=sqrt(t1*t3);............//Temperature at the end of adiabatic expansion in K
t2=t4;
W=cv*(t3-t2-t4+t1);..................//Work done in kJ/kg
P=W*(m/60);.................//Power developed in kW
disp (P,"Power developed in kW:")
```



```
Efficiency of diesel engine in %:

   59.335433

-->
```

Figure 3.16: Diesel Cycle

Scilab code Exa 3.17 `Diesel Cycle`

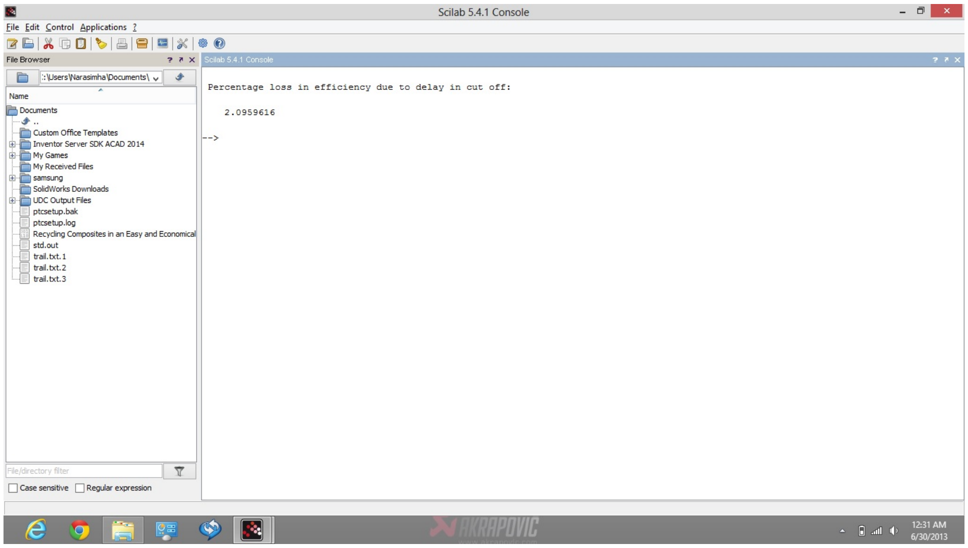
```
clc;funcprot(0);//EXAMPLE 3.17
// Initialisation of Variables
r=15;...................//Compression ratio
ga=1.4;..............//Ratio os fpecific heats for air
perQ=6;................//Heat addition at constant pressure takes place at 6% of stroke
//Calculations
rho=1+((perQ/100)*(r-1));............//Cut off ratio
etad=1-((((rho^ga)-1)/(rho-1))*(1/(ga*(r^(ga-1)))));..................//Efficiency of diesel engine
disp(etad*100,"Efficiency of diesel engine in %:")
```

Scilab code Exa 3.18 `Diesel Cycle`

```
clc;funcprot(0);//EXAMPLE 3.18
// Initialisation of Variables
L=0.25;..............//Engine stroke in m
D=0.15;.................//Engine bore in m
v2=0.0004;...............//Clearance volume in m^3
pers=5;...............//Percentage of stroke when
   fuel injection occurs
ga=1.4;..............//Ratio of specific heats
//Calculations
Vs=(%pi/4)*D*D*L;.............//Swept volume in m^3
Vt=Vs+v2;....................//Total cylinder volume
    in m^3
v3=v2+((pers/100)*Vs);.............//Volume at
   point of cut off
rho=v3/v2;............//Cut off ratio
r=1+(Vs/v2);............//Compression ratio
etad=1-((((rho^ga)-1)/(rho-1))*(1/(ga*(r^(ga-1)))))
   ;.................//Efficiency of diesel engine
disp(etad*100,"Efficiency of diesel engine in %:")
```

Scilab code Exa 3.19 `Diesel Cycle`

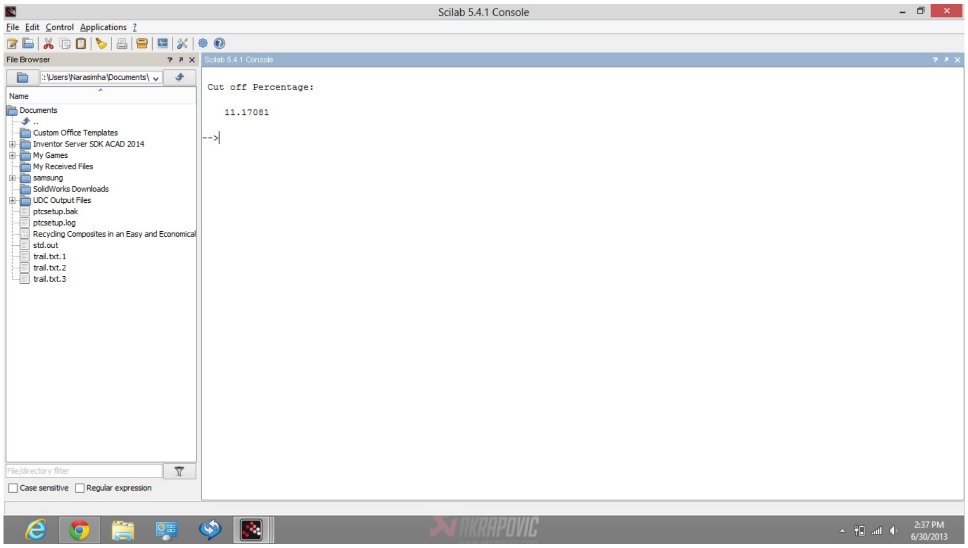
```
clc;funcprot(0);//EXAMPLE 3.19
// Initialisation of Variables
r=14;...................//Compression ratio
pers1=5;...............//Percentage of stroke when
   fuel cut off occurs
pers2=8;...............//Percentage of stroke when
   delayed fuel cut off occurs
v2=1;.....................//Clearance volume in m^3
ga=1.4;..................//Ratio of specific heats
```



```
Percentage loss in efficiency due to delay in cut off:

   2.0959616

-->
```

Figure 3.17: Diesel Cycle

```
//Calculations
//When the fuel is cut off at 5 %
rho1=((pers1/100)*(r-1))+1;.............//Cut off ratio
etad1=1-((((rho1^ga)-1)/(rho1-1))*(1/(ga*(r^(ga-1)))));..................//Efficiency of diesel engine
//When the fuel is cut off at 8 %
rho2=((pers2/100)*(r-1))+1;.............// Delayed Cut off ratio
etad2=1-((((rho2^ga)-1)/(rho2-1))*(1/(ga*(r^(ga-1)))));..................//Efficiency of diesel engine when cut off ratio is deyaled
disp((etad1-etad2)*100,”Percentage loss in efficiency due to delay in cut off:”)
```

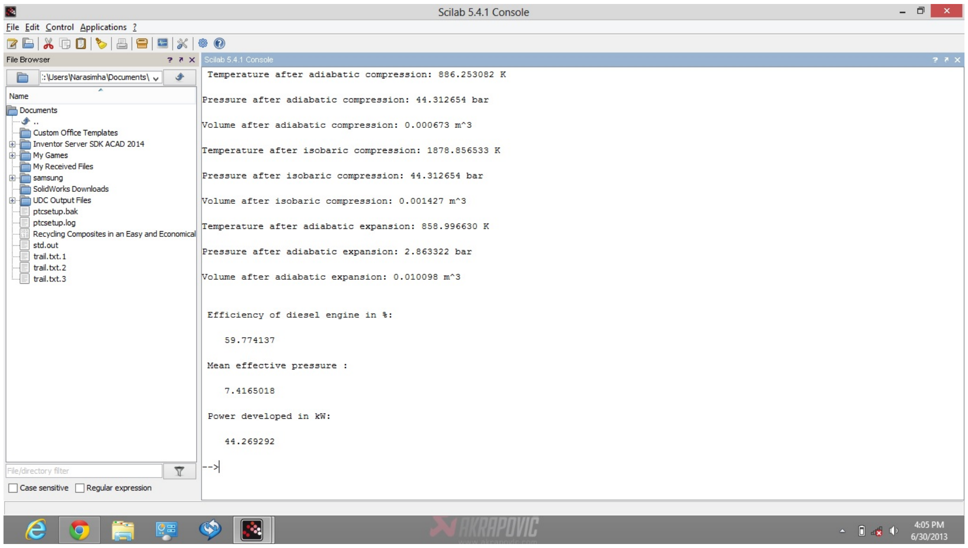


```
Cut off Percentage:

   11.17081

-->
```

Figure 3.18: Diesel Cycle

Scilab code Exa 3.20 `Diesel Cycle`

```
clc;funcprot(0);//EXAMPLE 3.20
// Initialisation of Variables
pm=7.5;.................//Mean effective pressure in bar
r=12.5;..................//Compression ratio
p1=1;....................//Initial pressure in bar
ga=1.4;.................//Ratio of specific heats
//Calculations
k=(pm*(ga-1)*(r-1))/(p1*(r^ga));
c1=(r^(1-ga))/k;c2=(-ga)/k;c=1+(ga/k)-((r^(1-ga))/k);
function[f]=F(rho)
    f=c1*(rho^ga)+c2*rho+c;
endfunction
//Initial guess
rho=2;
//Derivative
function[z]=D(rho)
```



```
 Temperature after adiabatic compression: 886.253082 K

Pressure after adiabatic compression: 44.312654 bar

Volume after adiabatic compression: 0.000673 m^3

Temperature after isobaric compression: 1878.856533 K

Pressure after isobaric compression: 44.312654 bar

Volume after isobaric compression: 0.001427 m^3

Temperature after adiabatic expansion: 858.996630 K

Pressure after adiabatic expansion: 2.863322 bar

Volume after adiabatic expansion: 0.010098 m^3


 Efficiency of diesel engine in %:

    59.774137

 Mean effective pressure :

    7.4165018

 Power developed in kW:

    44.269292

-->
```

Figure 3.19: Diesel cycle

```
    z=c1*ga*(rho^(ga-1))+c2;
endfunction
y=fsolve(rho,F,D)
perc=((y-1)/(r-1))*100;..................//Percentage of cutoff
disp(perc,"Cut off Percentage:")
```

Scilab code Exa 3.21 `Diesel cycle`

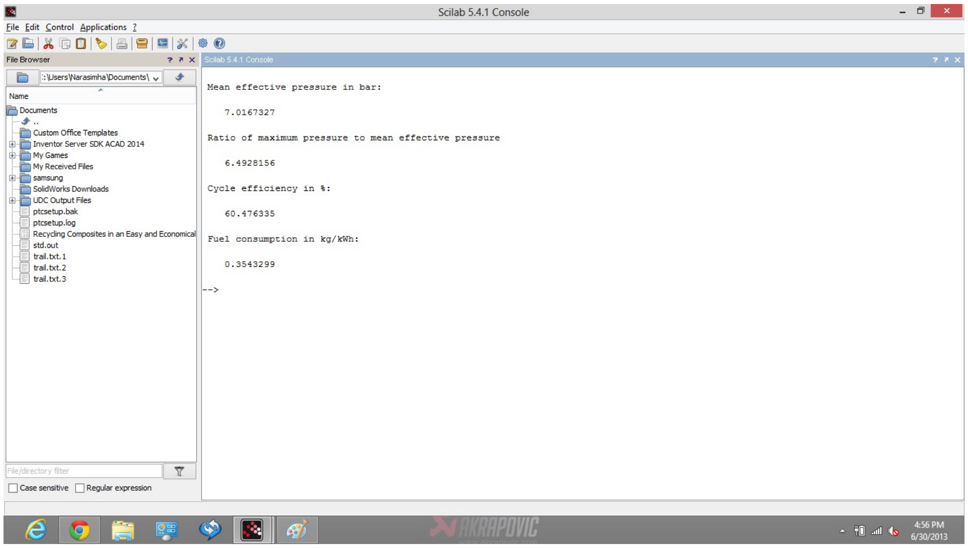
```
clc;funcprot(0);//EXAMPLE 3.21
// Initialisation of Variables
D=0.2;................//Engine bore in m
L=0.3;..............//Engine stroke in m
p1=1;................//Initial pressure in bar
N=380;................//No of working cycles per min
```

```
t1=300;..............//Initial temperature in K
co=8;................//Cut off percentage
r=15;..................//Compression ratio
R=287;.................//gas constant in J/kg
ga=1.4;................//Ratio of specific heats
//Calculations
Vs=(%pi/4)*D*D*L;.............//Stroke volume in m
v1=(r/(r-1))*Vs;................//Volume at the end of isochoric compression in m^3
m=(p1*v1*10^5)/(R*t1);................//Mass of air in cylinder in kg/cycle
p2=p1*(r^ga);.......................//Pressure at the end of isentropic compression in bar
t2=t1*(r^(ga-1));....................//Temperature at the end of isentropic compression in K
v2=Vs/(r-1);..................//Volume at the end of isentropic compressionin m^3
p3=p2;
rho=((r-1)*(co/100))+1;................//Cut off ratio
v3=rho*v2;.......................//Volume at the end of isobaric expansion in m^3
t3=t2*(v3/v2);..................//Temperature at the end of isobaric expansion in K
p4=((rho/r)^ga)*p3;..............//Pressure at the end of adiabatic expansion in bar
t4=((rho/r)^(ga-1))*t3;..............//Temperature at the end of adiabatic expansion in K
v4=v1;
printf(”Temperature after adiabatic compression: %f K\n\n”,t2)
printf(”Pressure after adiabatic compression: %f bar\n\n”,p2)
printf(”Volume after adiabatic compression: %f m^3\n\n”,v2)
printf(”Temperature after isobaric compression: %f K\n\n”,t3)
printf(”Pressure after isobaric compression: %f bar\
```

```
n\n",p3)
printf("Volume after isobaric compression: %f m^3\n\n",v3)
printf("Temperature after adiabatic expansion: %f K\n\n",t4)
printf("Pressure after adiabatic expansion: %f bar\n\n",p4)
printf("Volume after adiabatic expansion: %f m^3\n\n",v4)
etad=1-((((rho^ga)-1)/(rho-1))*(1/(ga*(r^(ga-1)))));..................//Efficiency of diesel engine
disp(etad*100,"Efficiency of diesel engine in %:")
pm=p1*(r^ga)*[ga*(rho-1)-((r^(1-ga))*((rho^ga)-1))]*(1/(ga-1))*1/(r-1);.......//Mean effective pressure
disp(pm,"Mean effective pressure :")
Wdc=(pm*Vs*10^5)/1000;...................//Work done per cycle in kJ/cycle
P=(Wdc*N)/60;...........................//Power developed in kW
disp(P,"Power developed in kW:")
```

Scilab code Exa 3.22 Diesel Cycle

```
clc;funcprot(0);//EXAMPLE 3.22
// Initialisation of Variables
rc=15.3;....................//Compression ratio
re=7.5;...................//Expansion ratio
cp=1.005;.................//Specific heat at constant pressure in kJ/kg K
cv=0.718;..................//Specific heat at constant volume in kJ/kgK
ga=1.4;....................//Ratio of specific heats
```



```
Mean effective pressure in bar:

   7.0167327

Ratio of maximum pressure to mean effective pressure

   6.4928156

Cycle efficiency in %:

   60.476335

Fuel consumption in kg/kWh:

   0.3543299

-->
```

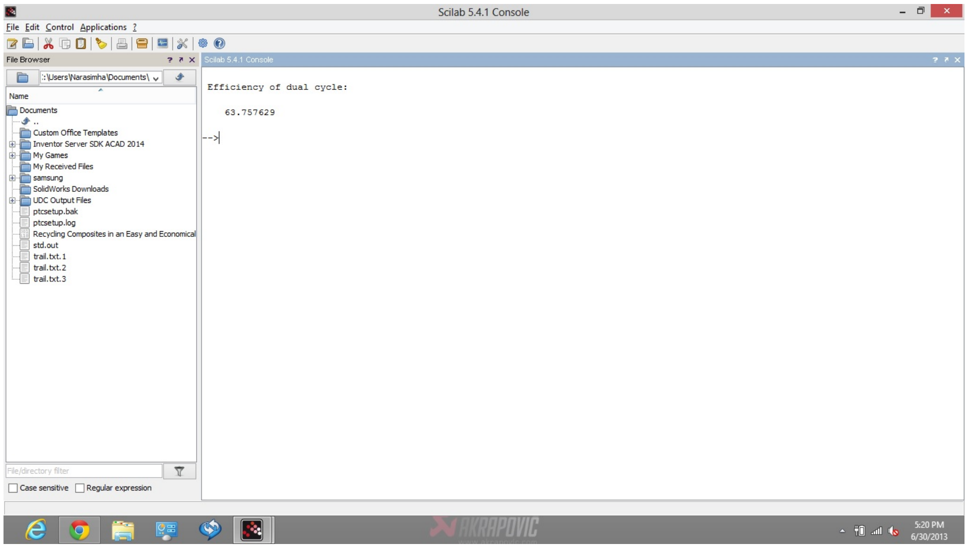
Figure 3.20: Diesel Cycle

```
p1=1;....................//Initial pressure in bar
t1=300;..................//Initial temperature in K
etamech=0.8;..................//Mechanical efficiency
C=42000;...........................//Calorific value of fuel in kJ/kg
rita=0.5;.........................//Ratio of indicated thermal efficiency to air standard efficiency
R=287;..........................//Gas constant in kJ/kgK
//Calculations
t2=t1*(rc^(ga-1));.................//Temperature at the end of adiabatic compression in K
p2=p1*(rc^ga);...................//Pressure at the end of adiabatic compression in bar
t3=(rc*t2)/re;....................//Temperature at the end of constant pressure process in K
v2=1;..................//Volume at the end of adiabatic process in m^3
```

```
m=(p2*v2*10^5)/(R*t2);..................//Mass of
    working fluid in kg
t4=t3*((1/re)^(ga-1));..................//
    Temperature at the end of adiabatic expansion in
    K
W=[m*(cp*(t3-t2))]-[m*(cv*(t4-t1))];........//Work
    done in kJ
pm=W/(rc-1);...............................//Mean
    effective pressure in kN/m^2
disp(pm/100,"Mean effective pressure in bar:")
disp((p2*100)/(pm),"Ratio of maximum pressure to
    mean effective pressure ")
etacy=W/(m*cp*(t3-t2));...............//Cycle
    efficiency
disp(etacy*100,"Cycle efficiency in %:")
etaith=rita*etacy;..................//Indicated
    thermal efficiency
etabth=etaith*etamech;...............//Brake thermal
     efficiency
mf=3600/(etabth*C);................//Fuel
    consumption per kWh
disp(mf,"Fuel consumption in kg/kWh:")
```

Scilab code Exa 3.23 Dual Combustion Cycle

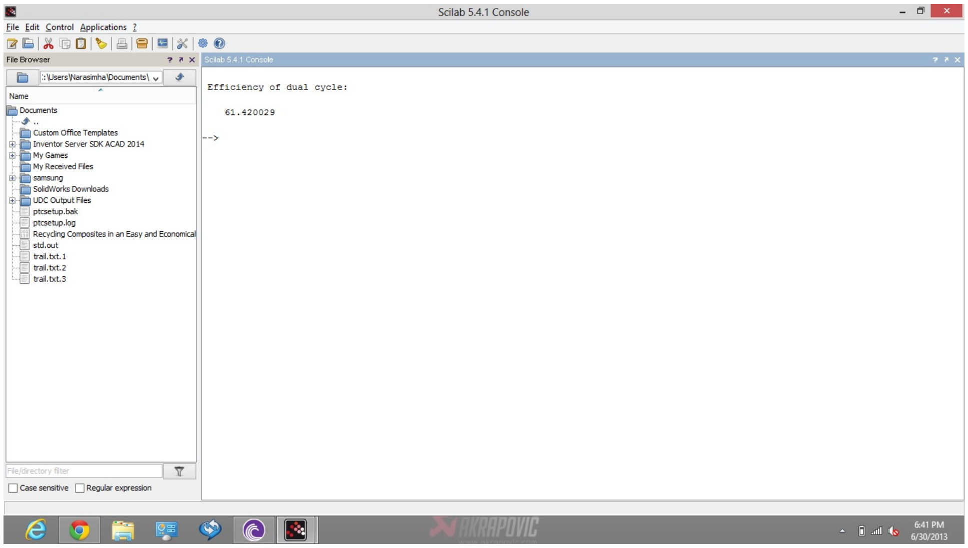
```
clc;funcprot(0);//EXAMPLE 3.23
// Initialisation of Variables
Vs=0.0053;................//Swept volume in m^3
Vc=0.00035;...............//Clearance volume in m^3
v3=Vc;
v2=Vc;
p3=65;..................//Max pressure in bar
co=5;...................//Cut off percentage
```



```
Efficiency of dual cycle:

   63.757629

-->
```

Figure 3.21: Dual Combustion Cycle

```
p4=p3;ga=1.4;................//Ratio of specific heats
t1=353;.....................//Temperature at the start of compression in K
p1=0.9;....................//Pressure at the start of compression in bar
//Calculations
r=1+(Vs/Vc);....................//Compression ratio
rho=(((co/100)*Vs)/Vc)+1;.....................//Cut off ratio
p2=p1*(r^ga);
Beta=p3/p2;...............................//Explosion ratio
etadual=1-[(1/(r^(ga-1)))*((Beta*(rho^ga))-1)*(1/((Beta-1)+(Beta*ga*(rho-1))))];.............//Efficiency of dual cycle
disp(etadual*100,”Efficiency of dual cycle:”)
```

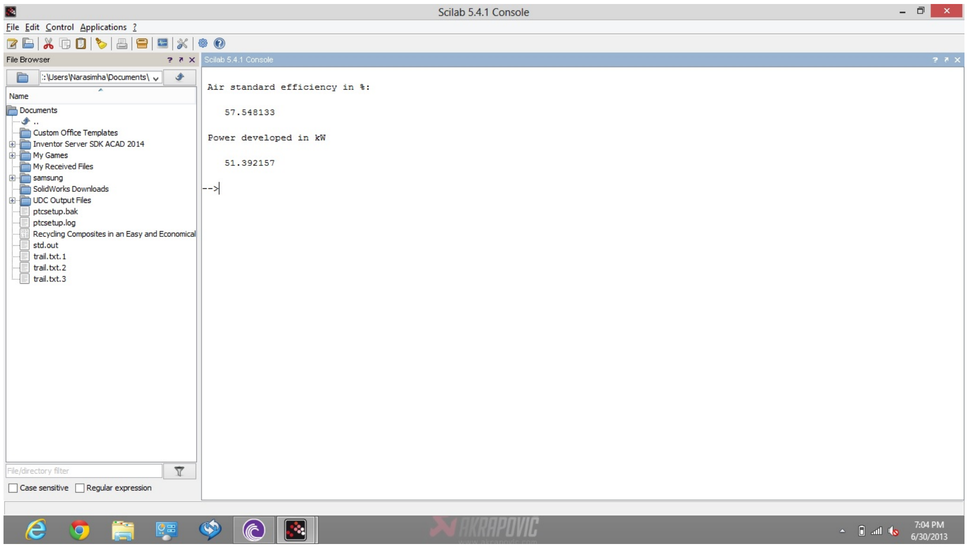


```
Efficiency of dual cycle:

   61.420029

-->
```

Figure 3.22: Dual Combustion Cycle

Scilab code Exa 3.24 `Dual Combustion Cycle`

```
clc;funcprot(0);//EXAMPLE 3.24
// Initialisation of Variables
r=14;.......................//Compression ratio
Beta=1.4;.................//Explosion ratio
co=6;...................//Cut off percentage
ga=1.4;..................//Ratio of specific heats
//Calculation
rho=((co/100)*(r-1))+1;...............//Cut off
   ratio
etadual=1-[(1/(r^(ga-1)))*((Beta*(rho^ga))-1)*(1/((
   Beta-1)+(Beta*ga*(rho-1))))];............//
   Efficiency of dual cycle
disp(etadual*100,"Efficiency of dual cycle:")
```



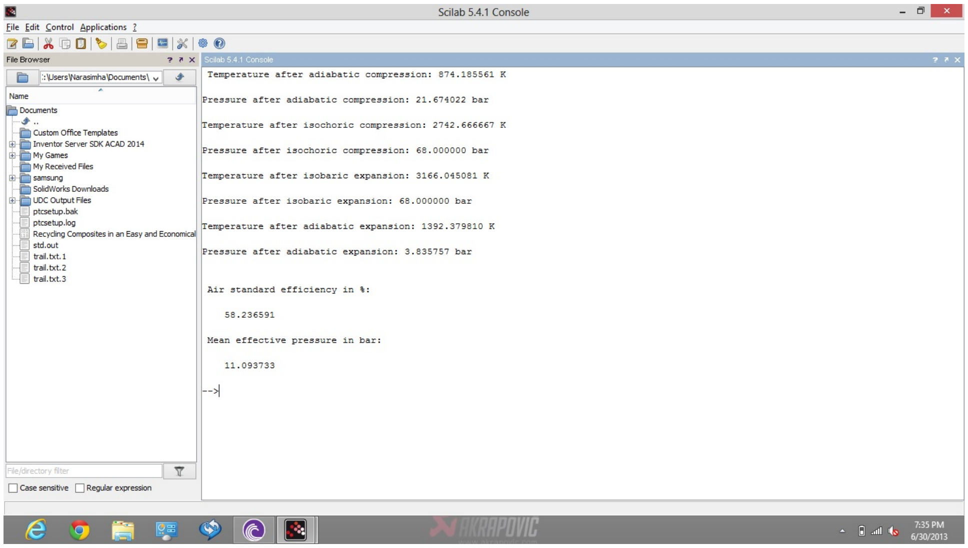
```
Air standard efficiency in %:

   57.548133

Power developed in kW

   51.392157

-->
```

Figure 3.23: Dual Combustion Cycle

Scilab code Exa 3.25 `Dual Combustion Cycle`

```
clc;funcprot(0);//EXAMPLE 3.25
// Initialisation of Variables
D=0.25;.................//Engine bore in m
L=0.3;.............//Engine stroke in m
p1=1;................//Initial pressure in bar
N=3;...............//No of cycles per second
p3=60;................//Maximum pressure in bar
t1=303;..............//Initial temperature in K
co=4;................//Cut off percentage
r=9;..................//Compression ratio
R=287;.................//gas constant in J/kg
cv=0.71;...............//Specific heat at constant volume in kJ/kgK
```

```
cp=1.0;..................//Specific heat at constant pressure in kJ/kgK
ga=1.4;................//Ratio of specific heats
//Calculations
p4=p3;
Vs=(%pi/4)*D*D*L;.............//Stroke volume in m^3
Vc=Vs/(r-1);....................//Clearance volume in m^3
rho=((r-1)*(co/100))+1;................//Cut off ratio
v1=Vc+Vs;.................//Volume after isochoric compression in m^3
p2=p1*(r^ga);................//Pressure after adiabatic compression in bar
t2=t1*(r^(ga-1));..............//Temperature after adiabatic expansion in K
t3=(p3*t2)/p2;..............//Temperature after isochoric compression in K
t4=t3*rho;....................//Temperature after isobaric expansion in K
t5=t4*((rho/r)^(ga-1));.........//Temperature after adiabatic expansion in K
p5=p4*(rho/r)^ga;..............//Pressure after adiabatic expansion in bar
Qs=(cv*(t3-t2)+cp*(t4-t3));.....//Heat supplied in kJ/kg
Qr=cv*(t5-t1);...................//Heat rejected in kJ/kg
etast=1-(Qr/Qs);.................//Air standard efficiency
disp(etast*100,"Air standard efficiency in %:")
m=(p1*v1*10^5)/(R*t1);..............//Mass of air in cycle
W=m*(Qs-Qr);....................//Work done per cycle in kJ
P=W*N;...........................//Power developed in kW
disp(P,"Power developed in kW")
```



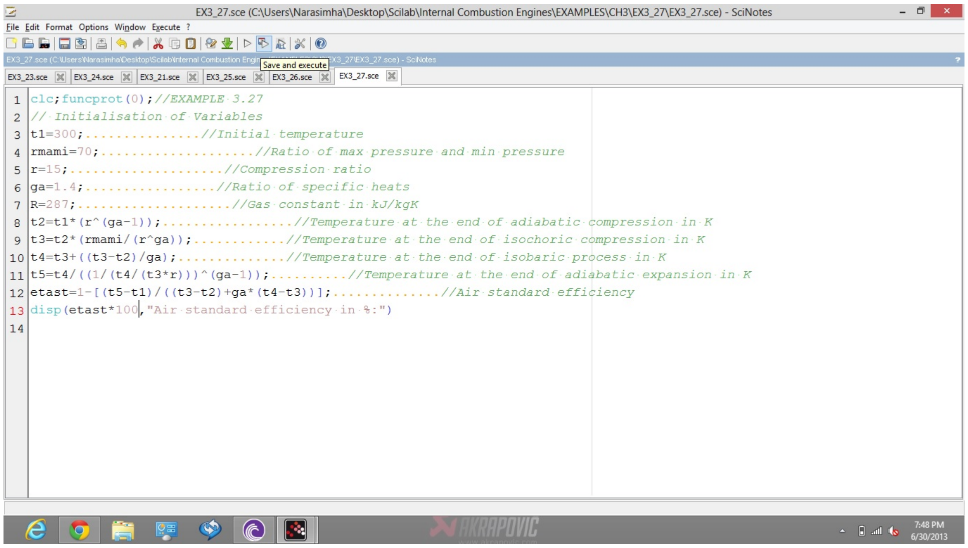
```
 Temperature after adiabatic compression: 874.185561 K

Pressure after adiabatic compression: 21.674022 bar

Temperature after isochoric compression: 2742.666667 K

Pressure after isochoric compression: 68.000000 bar

Temperature after isobaric expansion: 3166.045081 K

Pressure after isobaric expansion: 68.000000 bar

Temperature after adiabatic expansion: 1392.379810 K

Pressure after adiabatic expansion: 3.835757 bar


 Air standard efficiency in %:

    58.236591

 Mean effective pressure in bar:

    11.093733

-->
```

Figure 3.24: Dual Combustion Cycle

Scilab code Exa 3.26 `Dual Combustion Cycle`

```
clc;funcprot(0);//EXAMPLE 3.26
// Initialisation of Variables
p1=1;.................//Initial pressure in bar
t1=363;..............//Initial temperature in K
r=9;.................//Compression ratio
p3=68;...............//Max pressure
p4=p3;
Qs=1750;.............//Total heat supplied
ga=1.4;..............//Ratio of specific heats
R=287;...............//Gas constant in kJ/kgK
cv=0.71;.............//Specific heat at constant
   volume in kJ/kgK
```

```
cp=1;................//Specific heat at constant pressure in kJ/kgK
//Calculations
p2=p1*((r)^ga);............//Pressure at the end of adiabatic compression in bar
t2=t1*((r)^(ga-1));..........//Temperature at the end of adiabatic compression in K
t3=t2*(p3/p2);............//Temperature at the end of isochoric compression in K
Qv=cv*(t3-t2);.............//Heat added at constant volume in kJ/kg
Qp=Qs-Qv;......................//Heat added at constant pressure in kJ/kg
t4=(Qp/cp)+t3;................//Temperature at the end of isobaric expansion in kJ/kg
rho=t4/t3;......................//Cut off ratio
p5=p4*((rho/r)^ga);................//Pressure at the end of adiabatic expansion in kJ/kg
t5=t4*((rho/r)^(ga-1));...........//Temperature at the end of adiabatic expansion in kJ/kg
printf("Temperature after adiabatic compression: %f K\n\n",t2)
printf("Pressure after adiabatic compression: %f bar\n\n",p2)
printf("Temperature after isochoric compression: %f K\n\n",t3)
printf("Pressure after isochoric compression: %f bar\n\n",p3)
printf("Temperature after isobaric expansion: %f K\n\n",t4)
printf("Pressure after isobaric expansion: %f bar\n\n",p4)
printf("Temperature after adiabatic expansion: %f K\n\n",t5)
printf("Pressure after adiabatic expansion: %f bar\n\n",p5)
Qr=cv*(t5-t1);....................//Heat rejected in kJ
```



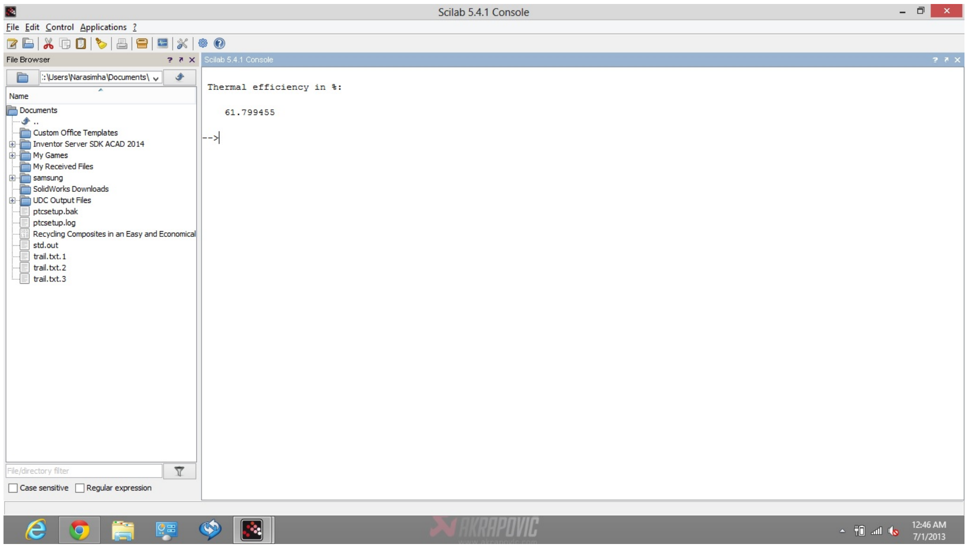
```
clc;funcprot(0);//EXAMPLE 3.27
// Initialisation of Variables
t1=300;...............//Initial temperature
rmami=70;....................//Ratio of max pressure and min pressure
r=15;....................//Compression ratio
ga=1.4;.................//Ratio of specific heats
R=287;....................//Gas constant in kJ/kgK
t2=t1*(r^(ga-1));.................//Temperature at the end of adiabatic compression in K
t3=t2*(rmami/(r^ga));............//Temperature at the end of isochoric compression in K
t4=t3+((t3-t2)/ga);..............//Temperature at the end of isobaric process in K
t5=t4/((1/(t4/(t3*r)))^(ga-1));..........//Temperature at the end of adiabatic expansion in K
etast=1-[(t5-t1)/((t3-t2)+ga*(t4-t3))];..............//Air standard efficiency
disp(etast*100,"Air standard efficiency in %:")
```

Figure 3.25: Dual Combustion Cycle

```
etast=1-(Qr/Qs);..................//Air standard efficiency
disp(etast*100,"Air standard efficiency in %:")
pm=(1/(r-1))*[(68*(rho-1))+(((p4*rho)-(p5*r))/(ga-1))-((p2-r)/(ga-1))];.................//Mean effective pressure in bar
disp(pm,"Mean effective pressure in bar:")
```

Scilab code Exa 3.27 `Dual Combustion Cycle`

```
clc;funcprot(0);//EXAMPLE 3.27
// Initialisation of Variables
t1=300;................//Initial temperature
rmami=70;......................//Ratio of max pressure and min pressure
r=15;......................//Compression ratio
```



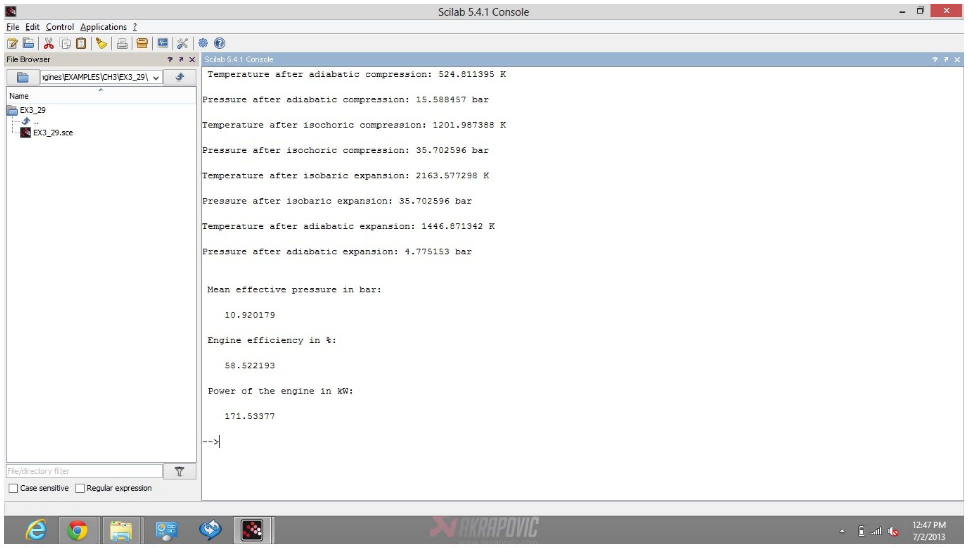
```
Thermal efficiency in %:

   61.799455

-->
```

Figure 3.26: Dual Combustion Cycle

```
ga=1.4;..................//Ratio of specific heats
R=287;.....................//Gas constant in kJ/kgK
t2=t1*(r^(ga-1));..................//Temperature at the end of adiabatic compression in K
t3=t2*(rmami/(r^ga));.............//Temperature at the end of isochoric compression in K
t4=t3+((t3-t2)/ga);...............//Temperature at the end of isobaric process in K
t5=t4/((1/(t4/(t3*r)))^(ga-1));...........//Temperature at the end of adiabatic expansion in K
etast=1-[(t5-t1)/((t3-t2)+ga*(t4-t3))];..............//Air standard efficiency
disp(etast*100,”Air standard efficiency in %:”)
```

Scilab code Exa 3.28 `Dual Combustion Cycle`

```
clc;funcprot(0);//EXAMPLE 3.28
// Initialisation of Variables
t1=373;.............//Initial temperature in K
p1=1;...............//Initial pressure in bar
p3=65;..............//Maximum pressure in bar
R=287;.................//Gas constant in kJ/kg
p4=p3;
ga=1.41;.................//Ratio of specific heats
Vs=0.0085;............//Swept volume in m^3
afr=21;...............//Air fuel ratio
r=15;.................//Compression ratio
C=43890;..............//Calorific value of fuel in kJ/kg
cp=1;................//Specific heat at constant pressure in kJ/kgK
cv=0.71;..............//Specific heat at constant volume in kJ/kgK
//Calculations
Vc=Vs/(r-1);...............//Clearance volume in m^3
v2=Vc;v1=Vs+v2;
v3=Vc;v5=v1;
p2=p1*(r^ga);.....................//Pressure at the end of adiabatic compression in bar
t2=t1*(r^(ga-1));................//Temperature at the end of adiabatic compression in K
t3=(t2*p3)/p2;...................//Temperature at the end of isochoric compression in K
m=(p1*v1*10^5)/(R*t1);............//Mass of air in the cycle in kg
Qv=m*cv*(t3-t2);.....................//Heat added during constant volume process in kJ
fv=Qv/C;.............................//Fuel added during constant volume process in kg
mf=m/afr;..................//Total amount of fuel added in kg
mfib=mf-fv;....................//Total amount of fuel added in isobaric process in kg
Qib=mfib*C;....................//Total amount of
```



```
 Temperature after adiabatic compression: 524.811395 K

Pressure after adiabatic compression: 15.588457 bar

Temperature after isochoric compression: 1201.987388 K

Pressure after isochoric compression: 35.702596 bar

Temperature after isobaric expansion: 2163.577298 K

Pressure after isobaric expansion: 35.702596 bar

Temperature after adiabatic expansion: 1446.871342 K

Pressure after adiabatic expansion: 4.775153 bar


 Mean effective pressure in bar:

    10.920179

 Engine efficiency in %:

    58.522193

 Power of the engine in kW:

    171.53377

-->
```

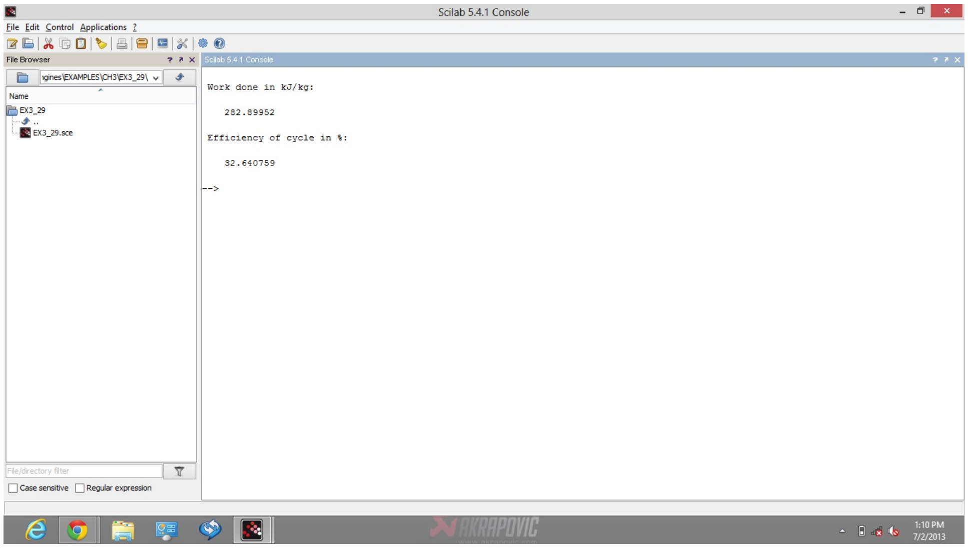
Figure 3.27: Dual Combustion Cycle

```
heat added in isobaric process in kJ
t4=(Qib/((m+mf)*cp))+t3;........//Temperature at the end of isobaric process in K
v4=(v3*t4)/t3;...................//Volume at the end of isobaric process in m^3
t5=t4/((v5/v4)^(ga-1));.........//Temperature at the end of isochoric expansion in K
Qrv=(m+mf)*cv*(t5-t1);...............//Heat rejected during constant volume process in kJ
W=(Qib+Qv)-Qrv;.................//Work done in kJ
etath=W/(Qib+Qv);...................//Thermal efficiency
disp(etath*100,"Thermal efficiency in %:")
```

Scilab code Exa 3.29 `Dual Combustion Cycle`

```
clc;funcprot(0);//EXAMPLE 3.29
// Initialisation of Variables
D=0.25;.............//Engine bore in m
L=0.4;..............//Engine stroke in m
t1=303;.............//Initial temperature in K
R=287;...............//Gas constant in kJ/kgK
p1=1;...............//Initial pressure in bar
N=8;................//No of working cycles per sec
cv=0.71;.............//Specific heat at constant volume in kJ/kgK
cp=1;.................//Specific heat at constant pressure in kJ/kgK
n=1.25;.............//Adiabatic index
rc=9;...............//Compression ratio
re=5;...............//Expansion ratio
rqptqe=2;...........//Ratio of heat liberated at constant pressure to heat liberated at constant volume
//Calculations
p2=p1*(rc^n);.......................//Pressure at the end of adiabatic compression in bar
t2=t1*(rc^(n-1));...................//Temperature at the end of adiabatic compression in K
rho=rc/re;..........................//Cut off ratio
t3=(2*cv*t2)/((2*cv)-(cp*(rho-1)));...............//Temperature at the end of isochoric compression in K
p3=p2*(t3/t2);....................................//Pressure at the end of isochoric compression in bar
p4=p3;t4=rho*t3;.................................//Temperature and pressure at the end of isobaric process
p5=p4*(1/(re^n));.................................//Pressure at the end of adiabatic expansion in bar
t5=t4*(1/(re^(n-1)));.............................//Temperature at the end of adiabatic expansion in K
```

```
pm=(1/(rc-1))*[(p3*(rho-1))+(((p4*rho)-(p5*rc))/(n-1))-((p2-(p1*rc))/(n-1))];................//Mean effective pressure
printf("Temperature after adiabatic compression: %f K\n\n",t2)
printf("Pressure after adiabatic compression: %f bar\n\n",p2)
printf("Temperature after isochoric compression: %f K\n\n",t3)
printf("Pressure after isochoric compression: %f bar\n\n",p3)
printf("Temperature after isobaric expansion: %f K\n\n",t4)
printf("Pressure after isobaric expansion: %f bar\n\n",p4)
printf("Temperature after adiabatic expansion: %f K\n\n",t5)
printf("Pressure after adiabatic expansion: %f bar\n\n",p5)
disp(pm,"Mean effective pressure in bar:")
Vs=(%pi/4)*D*D*L;.....................//Swept volume in m^3
W=(pm*(10^5)*Vs)/1000;.................//Work done per cycle in kJ
m=(p1*(10^5)*(rc/(rc-1))*Vs)/(R*t1);......................//Mass of air per cycle in kg
Qs=m*[cv*(t3-t2)+cp*(t4-t3)];......................//Heat supplied per cycle in kJ
eta=W/Qs;.....................//Engine efficiency
disp(eta*100,"Engine efficiency in %:")
P=W*N;.................//Power of the engine in kW
disp(P,"Power of the engine in kW:")
```

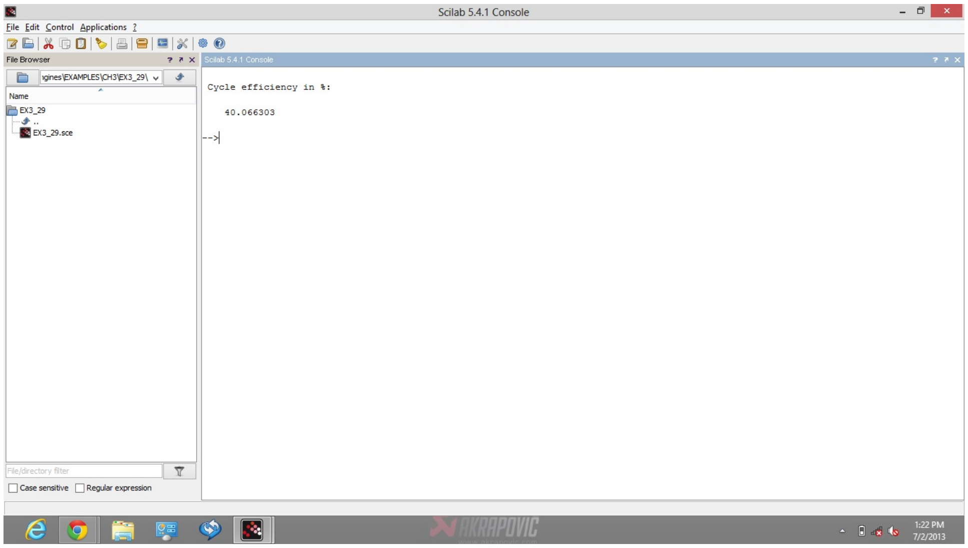


```
Work done in kJ/kg:

   282.89952

Efficiency of cycle in %:

   32.640759

-->
```

Figure 3.28: Atkinson Cycle

Scilab code Exa 3.31 `Atkinson Cycle`

```
clc;funcprot(0);//EXAMPLE 3.31
// Initialisation of Variables
cp=0.92;...................//Specific heat at constant pressure in kJ/kgK
cv=0.75;...................//Specific heat at constant volume in kJ/kgK
p1=1;......................//Pressure at the end of adiabatic expansion in bar
p2=p1;.....................//Pressure at the end of isobaric compression in bar
p3=4;......................//Pressure at the end of isobaric compression in bar
p4=16;.....................//Final pressure after heat addition in bar
t2=300;....................//Temperature at the end of isobaric compression in K
ga=1.22;...................//Ratio of specific heats
//Calculations
```



```
Cycle efficiency in %:

   40.066303

-->
```

Figure 3.29: Brayton Cycle

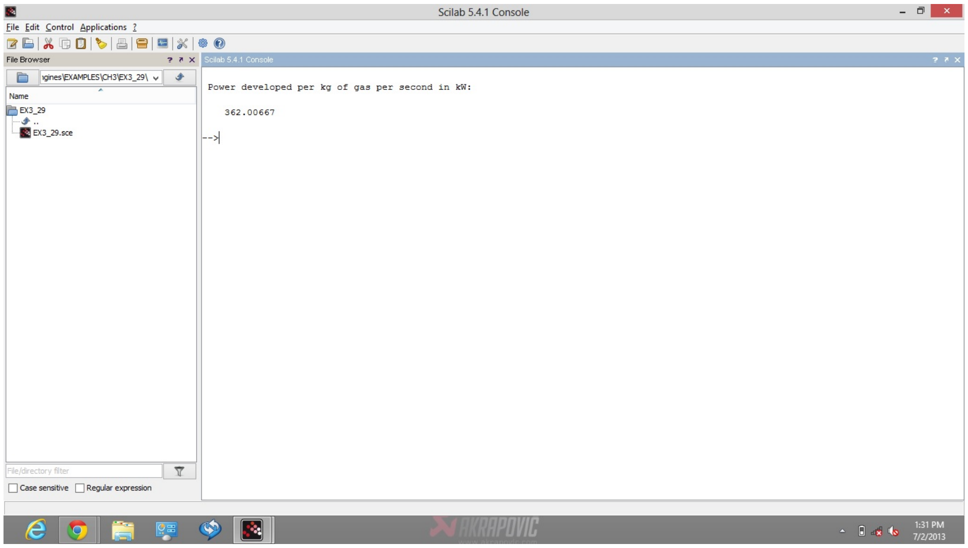
```
t3=t2*((p3/p2)^((ga-1)/ga));.............//Temperature at the end of isobaric compression in K
t4=(p4*t3)/p3;.........................//Final temperature after heat addition in K
t1=t4/((p4/p1)^((ga-1)/ga));....................//Temperature at the end of adiabatic compression in K
Qs=cv*(t4-t3);..........................//Heat supplied in kJ/kg
Qr=cp*(t1-t2);..........................//Heat rejected in kJ/kg
W=Qs-Qr;........................//Work done per kg of gas in kJ
disp(W,”Work done in kJ/kg:”)
eta=W/Qs;.......................//Efficiency of cycle
disp(eta*100,”Efficiency of cycle in %:”)
```

Scilab code Exa 3.32 `Brayton Cycle`

```
clc;funcprot(0);//EXAMPLE 3.32
// Initialisation of Variables
p1=101.325;....................//Pressure of intake air in kPa
t1=300;.......................//Temperature of intake air in kPa
rp=6;.........................//Pressure ratio in the cycle
ga=1.4;.........................//Ratio of specific heats
rtc=2.5;..........................//Ratio of turbine work and compressor work
//Calculations
t2=t1*(rp^((ga-1)/ga));.................//Temperature at the end of isentropic expansion in K
t3=(rtc*(t2-t1))/(1-(1/(rp^((ga-1)/ga))));........//Temperature at the end of isobaric expansion in K
t4=t3/(rp^((ga-1)/ga));......................//Temperature at the end of isentropic compression in K
eta=(t3-t4-t2+t1)/(t3-t2);..................//Cycle efficiency
disp(eta*100,"Cycle efficiency in %:")
```

Scilab code Exa 3.33 `Brayton Cycle`

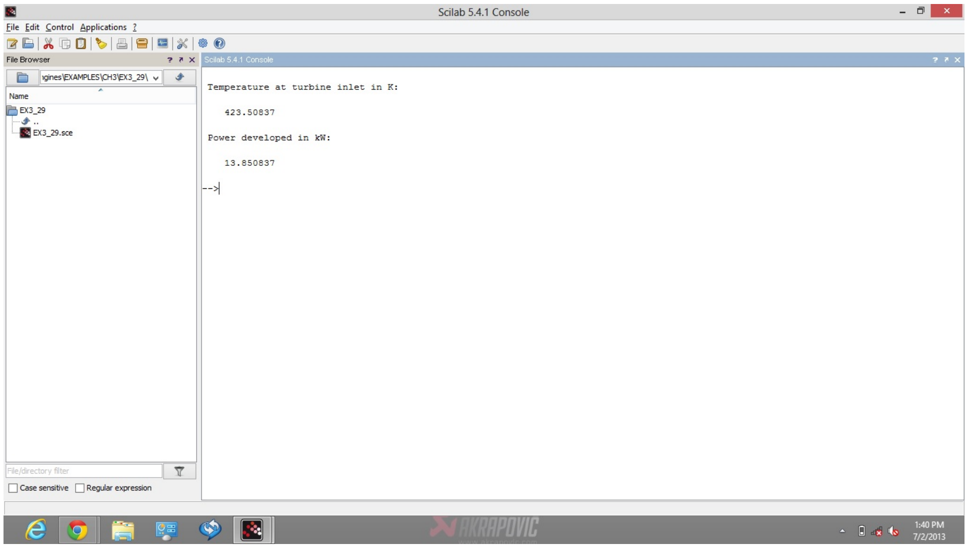
```
clc;funcprot(0);//EXAMPLE 3.33
```



```
Power developed per kg of gas per second in kW:

   362.00667

-->
```

Figure 3.30: Brayton Cycle

```
// Initialisation of Variables
p1=1;......................//Intake pressure in bar
p2=5;......................//Supply pressure in bar
t3=1000;...................//Supply temperature in Kelvin
cp=1.0425;.................//Specific heat at constant pressure in kJ/kgK
cv=0.7662;.................//Specific heat at constant volume in kJ/kgK
ga=cp/cv;..................//Ratio of specific heats
//Calculations
t4=t3*((p1/p2)^((ga-1)/ga));
P=cp*(t3-t4);......................//Power developed per kg of gas per second in kW
disp(P,"Power developed per kg of gas per second in kW:")
```

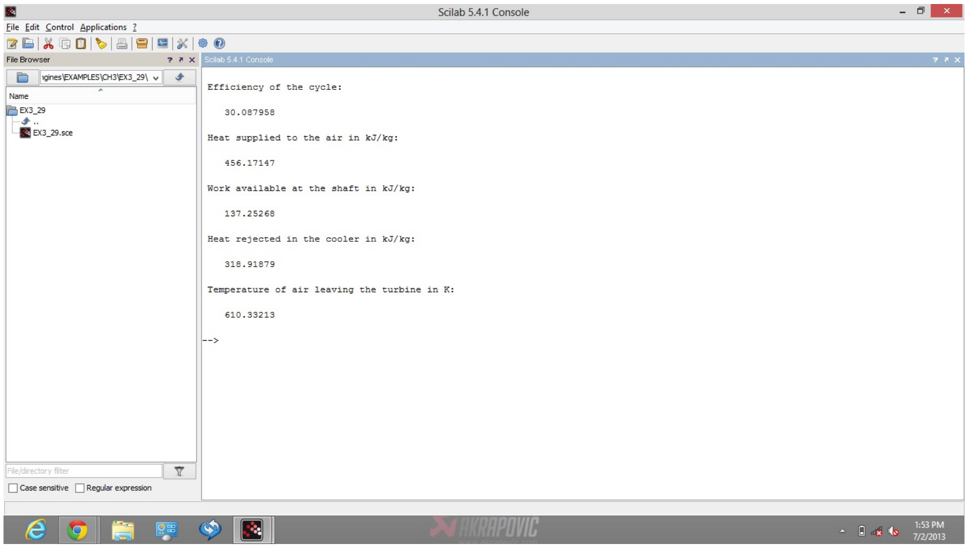


```
Temperature at turbine inlet in K:

   423.50837

Power developed in kW:

   13.850837

-->
```

Figure 3.31: Brayton Cycle

Scilab code Exa 3.34 `Brayton Cycle`

```
clc;funcprot(0);//EXAMPLE 3.34
// Initialisation of Variables
ma=0.1;..................//Air supplied in kg/s
p1=1;....................//Supply pressure in bar
t4=285;................//Temperature of air when supplied to cabin in K
p2=4;..................//Pressure at inlet to turbine in bar
cp=1.0;.................//Specific heat at constant pressure in kJ/kgK
ga=1.4;.................//Ratio of specific heats
//Calculations
t3=t4*((p2/p1)^((ga-1)/ga));...............//Temperature at turbine inlet in K
disp(t3,"Temperature at turbine inlet in K:")
```



```
Efficiency of the cycle:

   30.087958

Heat supplied to the air in kJ/kg:

   456.17147

Work available at the shaft in kJ/kg:

   137.25268

Heat rejected in the cooler in kJ/kg:

   318.91879

Temperature of air leaving the turbine in K:

   610.33213

-->
```

Figure 3.32: Brayton Cycle

```
P=ma*cp*(t3-t4);............................//Power developed in kW
disp(P,"Power developed in kW:")
```

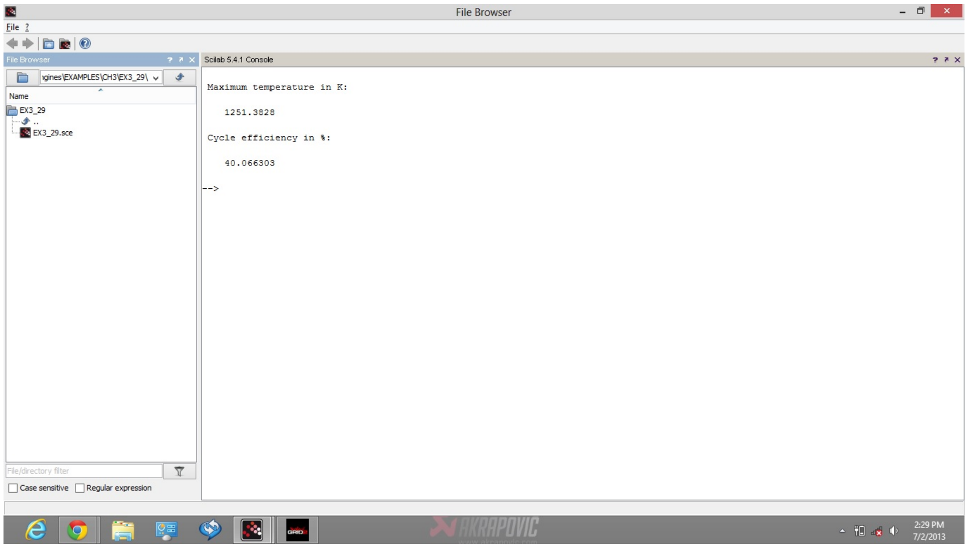
Scilab code Exa 3.35 `Brayton Cycle`

```
clc;funcprot(0);//EXAMPLE 3.35
// Initialisation of Variables
p1=1;.......................//Pressure of air entering the compressor in bar
p2=3.5;.................//Pressure of air while leaving the compressor in bar
t1=293;.................//Temperature of air at the onlet of the compressor in K
t3=873;.................//Temperature of air at the turbine inlet in K
```

```
cp=1.005;...............//Specific heat at constant pressure in kJ/kgK
ga=1.4;...................//Ratio of specific heats
//Calculations
rp=p2/p1;....................//Pressure ratio of the cycle
eta=1-(1/(rp^((ga-1)/ga)));..............//Efficiency of the cycle
disp(eta*100,"Efficiency of the cycle:")
t2=t1*((rp^((ga-1)/ga)));................//Temperature of air while leaving the compressor in K
q1=cp*(t3-t2);................//Heat supplied to the air in kJ/kg
disp(q1,"Heat supplied to the air in kJ/kg:")
W=eta*q1;........................//Work available at the shaft in kJ/kg
disp(W,"Work available at the shaft in kJ/kg:")
q2=q1-W;...............//Heat rejected in the cooler in kJ/kg
disp(q2,"Heat rejected in the cooler in kJ/kg:")
t4=t3/(rp^((ga-1)/ga));.......................//Temperature of air leaving the turbine in K
disp(t4,"Temperature of air leaving the turbine in K:")
```

Scilab code Exa 3.36 `Brayton Cycle`

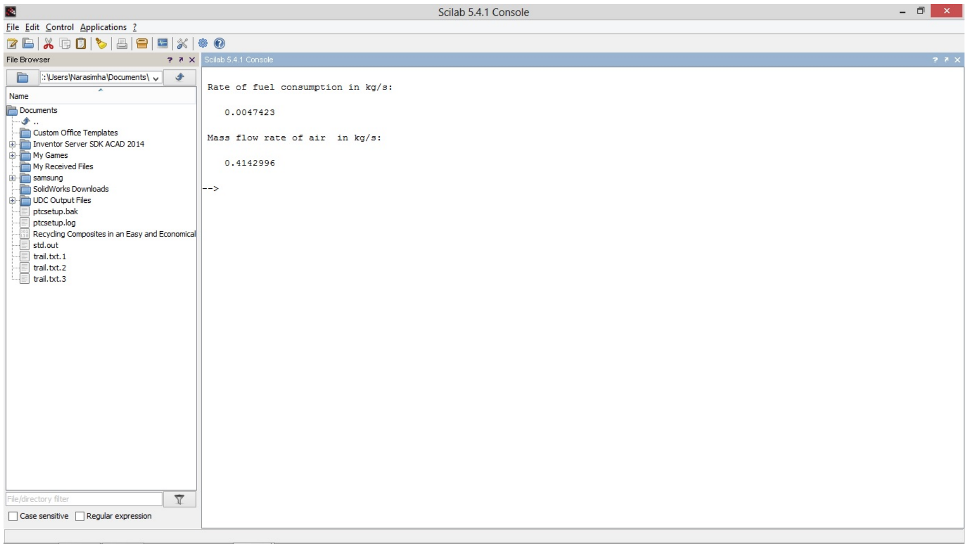
```
clc;funcprot(0);//EXAMPLE 3.36
// Initialisation of Variables
p1=1;...................//Pressure of air entering the compressor in bar
t1=300;.................//Temperature of air
```



```
Maximum temperature in K:

   1251.3828

Cycle efficiency in %:

   40.066303

-->
```

Figure 3.33: Brayton Cycle

```
    entering the compressor in bar
rp=6;.....................//Pressure ratio
rtc=2.5;..................//Ratio of turbine work to
    compressor work
ga=1.4;.............//Ratio of specific heats
//calculations
t2=t1*(rp^((ga-1)/ga));..................//
    Temperature at the end of isentropic expansion in
     K
t3=(rtc*(t2-t1))/(1-(1/(rp^((ga-1)/ga))));........//
    Temperature at the end of isobaric expansion in K
t4=t3/(rp^((ga-1)/ga));......................//
    Temperature at the end of isentropic compression
    in K
eta=(t3-t4-t2+t1)/(t3-t2);...................//Cycle
     efficiency
disp(t3,"Maximum temperature in K:")
disp(eta*100,"Cycle efficiency in %:")
```

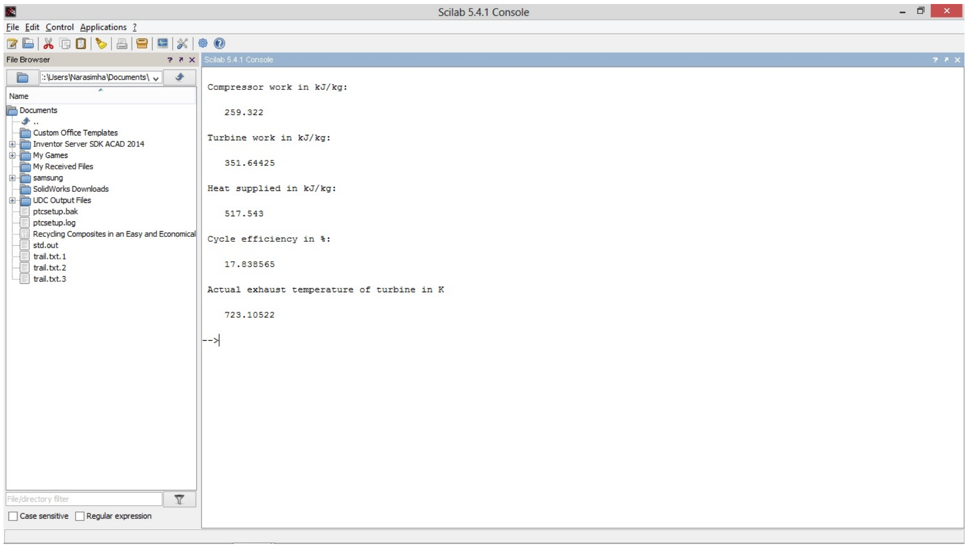


```
Rate of fuel consumption in kg/s:

   0.0047423

Mass flow rate of air  in kg/s:

   0.4142996

-->
```

Figure 3.34: Brayton Cycle

Scilab code Exa 3.37 `Brayton Cycle`

```
clc;funcprot(0);//EXAMPLE 3.37
// Initialisation of Variables
t1=303;.........................//Min temperature in K
t3=1073;.........................//Max temperature in K
C=45000;......................//Calorific value of fuel in kJ/kg
cp=1;.....................//Specific heat at constant pressure in kJ/kgK
ga=1.4;.........................//Ratio os specific heats
diftc=100;...................//Difference between
```



```
Compressor work in kJ/kg:

   259.322

Turbine work in kJ/kg:

   351.64425

Heat supplied in kJ/kg:

   517.543

Cycle efficiency in %:

   17.838565

Actual exhaust temperature of turbine in K

   723.10522

-->
```

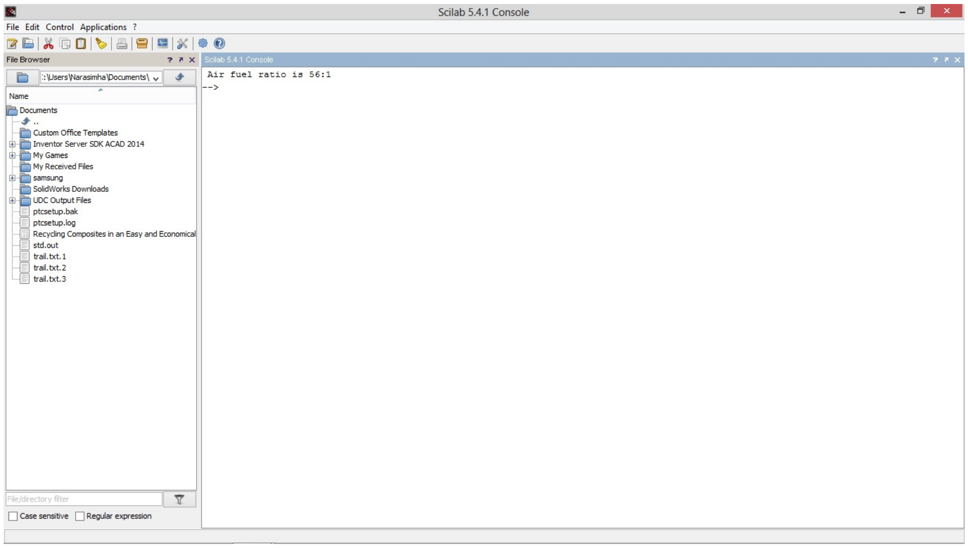
Figure 3.35: Brayton Cycle

```
   work done by turbine and compressor in kW
//Calculations
t2=sqrt(t1*t3); t4 = t2;.....//Assumed
mf=diftc/[C*(1-((t4-t1)/(t3-t2)))];................
   //Fuel used in kg per second
disp(mf,"Rate of fuel consumption in kg/s:")
ma=[diftc-[mf*(t3-t4)]]/[(t3-t4-cp*(t2-t1))
   ];............//Rate of air consumption in kg/s
disp(ma,"Mass flow rate of air  in kg/s:")
```

Scilab code Exa 3.38 Brayton Cycle

```
clc;funcprot(0);//EXAMPLE 3.38
// Initialisation of Variables
t1=300;..................//Inlet temperature in K
p1=1;.....................//Inlet pressure in bar
```

```
ma=1;......................//Mass of air in kg
rp=6.25;.............//Pressure ratio
t3=1073;...........//Maximum temperature in K
etac=0.8;...........//Efficiency of compressor
etat=0.8;............//Efficiency of turbine
ga=1.4;..................//Ratio of specific heats
cp=1.005;.............//Specific heat at constant pressure in kJ/kgK
//Calculations
t2=t1*(rp^((ga-1)/ga));...........//Ideal Temperature of air while leaviing the compressor in K
t21=((t2-t1)/etac)+t1;............//Actual Temperature of air while leaviing the compressor in K
Wcomp=ma*cp*(t21-t1);.............//Compressor work in kJ/kg
t4=t3/(rp^((ga-1)/ga));........//Ideal temperature of air while leaving the turbine in K
t41=t3-(etat*(t3-t4));..........//Actual temperature of air while leaving the turbine in K
Wtur=ma*cp*(t3-t41);...............//Turbine work in kJ/kg
Wnet=Wtur-Wcomp;..................//Net work produced in kJ/kg
Qs=ma*cp*(t3-t21);.................//Heat supplied in kJ/kg
disp(Wcomp,"Compressor work in kJ/kg:")
disp(Wtur,"Turbine work in kJ/kg:")
disp(Qs,"Heat supplied in kJ/kg:")
disp((Wnet/Qs)*100,"Cycle efficiency in %:")
disp(t41,"Actual exhaust temperature of turbine in K")
```

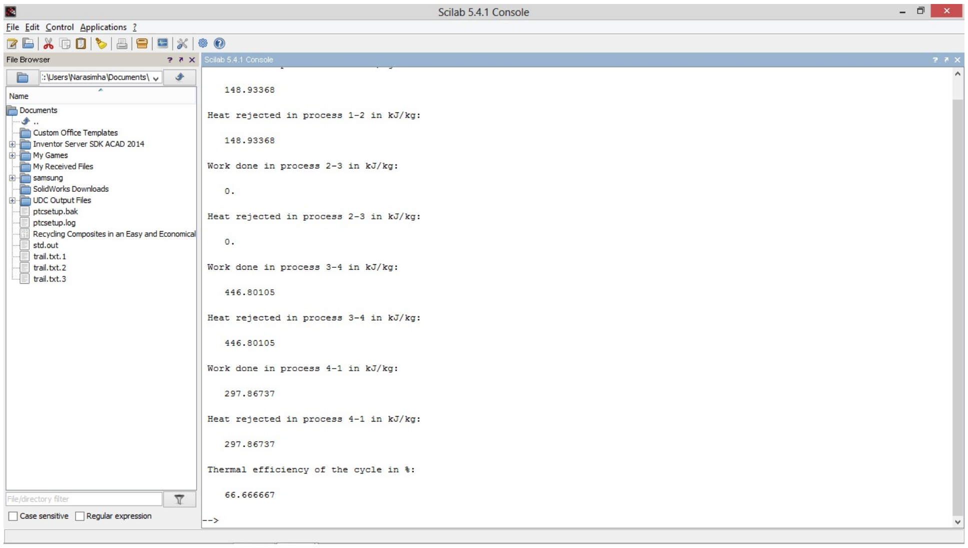


```
 Air fuel ratio is 56:1
-->
```

Figure 3.36: Brayton Cycle

Scilab code Exa 3.39 `Brayton Cycle`

```
clc;funcprot(0);//EXAMPLE 3.39
// Initialisation of Variables
etat=0.85;..............//Turbine efficiency
etac=0.8;...............//Compressor efficiency
t3=1148;................//Max temperature in K
t1=300;.................//Temperature of working fluid when entering the compressor in Kelvin
cp=1;...................//specific heat at constant pressure in kJ/kgK
ga=1.4;.................//ratio of specific heats
p1=1;...................//Pressure of working fluid while entering the compressor in bar
rp=4;...................//Pressure ratio
C=42000;................//Calorific value of fuel used in kJ/kgK
perlcc=10;..............//Percentage loss of calorific value in combustion chamber
//calculations
```



```
   148.93368

Heat rejected in process 1-2 in kJ/kg:

   148.93368

Work done in process 2-3 in kJ/kg:

   0.

Heat rejected in process 2-3 in kJ/kg:

   0.

Work done in process 3-4 in kJ/kg:

   446.80105

Heat rejected in process 3-4 in kJ/kg:

   446.80105

Work done in process 4-1 in kJ/kg:

   297.86737

Heat rejected in process 4-1 in kJ/kg:

   297.86737

Thermal efficiency of the cycle in %:

   66.666667

-->
```

Figure 3.37: Stirling Cycle

```
p2=p1*rp;..................//pressure of air while leaving the compressor in bar
etacc=1-(perlcc/100);............//efficiency of combustion chamber
t2=t1*(rp^((ga-1)/ga));...........//Ideal Temperature of air while leaviing the compressor in K
t21=((t2-t1)/etac)+t1;............//Actual Temperature of air while leaviing the compressor in K
afr=((C*etacc)/(cp*(t3-t21)))-1;...........//Air fuel ratio
printf("Air fuel ratio is %d:1",round(afr))
```

Scilab code Exa 3.40 `Stirling Cycle`

```
clc;funcprot(0);//EXAMPLE 3.40
// Initialisation of Variables
p1=1;...........//pressure before isothermal compression in bar
t1=310;.........//temperature before isothermal compression in K
p3=16;.........//pressure before isothermal expansion in bar
t3=930;.........//temperature before isothermal expansion in K
R=287;.............//Gas constant in kJ/kgK
//Calculations
v1=(R*t1)/(p1*10^5);...............//Volume before isothermal compression in m^3
v3=(R*t3)/(p3*10^5);...............//Volume before isothermal expansion in m^3
v2=v3;v4=v1;..................//2-3 and 1-4 are isochoric processes
r=v1/v2;...................//Compression ratio
q12=R*t1*log(r);...............//Work done and heat rejected in process 1-2
w12=q12;
disp(q12/1000,"Work done in process 1-2 in kJ/kg:")
disp(w12/1000,"Heat rejected in process 1-2 in kJ/kg:")
q23=0;w23=q23;..................//COnstant volume process and hence work done is zero
disp(q23/1000,"Work done in process 2-3 in kJ/kg:")
disp(q23/1000,"Heat rejected in process 2-3 in kJ/kg:")
q34=R*t3*log(r);...............//Work done and heat rejected in process 1-2
w34=q34;
disp(q34/1000,"Work done in process 3-4 in kJ/kg:")
disp(w34/1000,"Heat rejected in process 3-4 in kJ/kg:")
q41=q34-q12;w41=q41;
disp(q41/1000,"Work done in process 4-1 in kJ/kg:")
```

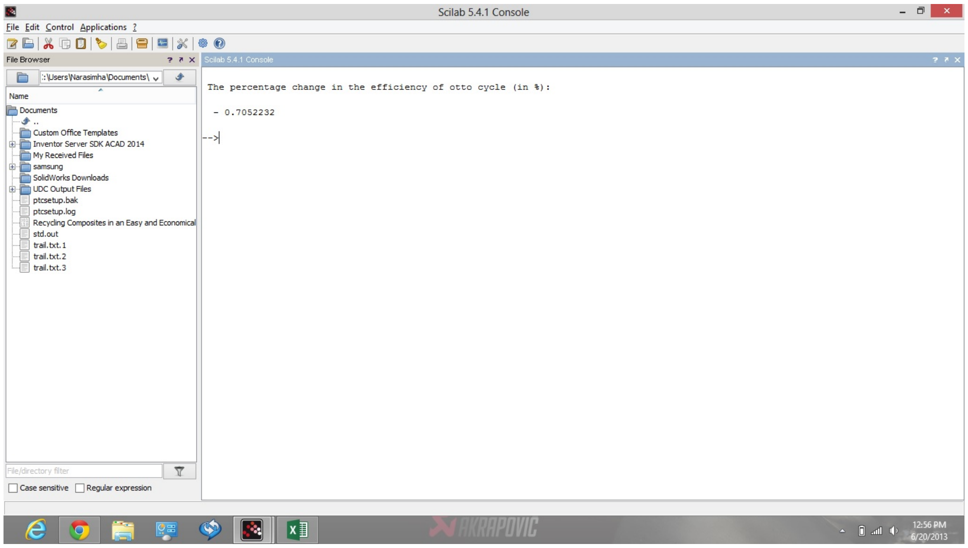
```
disp(w41/1000,"Heat rejected in process 4-1 in kJ/kg
   :")
etath=w41/q34;.....................//Thermal
   efficiency
disp(etath*100,"Thermal efficiency of the cycle in %
   :")
```

Chapter 4

Fuel Air and Actual Cycles

Scilab code Exa 4.2 `Percentage change in otto cycle efficiency`

```
clc;funcprot(0);//EXAMPLE 4.2
// Initialisation of Variables
r=8;..........................//Compression Ratio
ga=1.4;.......................//Degree of freedom
   for the gas
Cvinc=1.1;....................//Increase of specific
    heat at constant volume in percentage
//Calculations
eta=1-1/(r^(ga-1));...........//efficiency of otto
   cycle
deta=(1-eta)*(ga-1)*log(r)*(Cvinc/100);...........
   //Change in efficiency
etach=-deta/eta;...........................//
   Percentage change in efficiency of change in
   efficiency
disp(etach*100,"The percentage change in the
   efficiency of otto cycle (in %):")
```

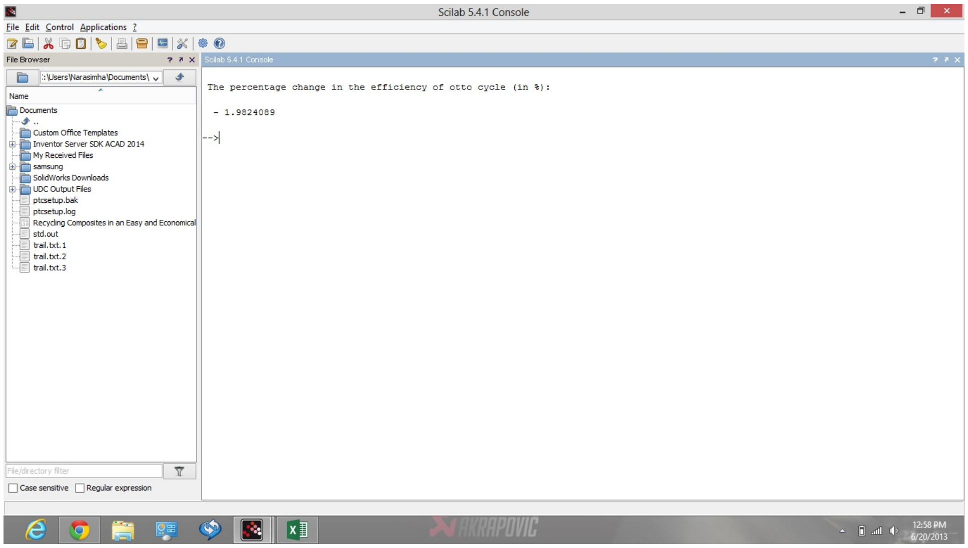


```
The percentage change in the efficiency of otto cycle (in %):

 - 0.7052232

-->
```

Figure 4.1: Percentage change in otto cycle efficiency

Scilab code Exa 4.3 `Percentage change in otto cycle efficiency`

```
clc;funcprot(0);//EXAMPLE 4.3
// Initialisation of Variables
r=7;...........................//Compression Ratio
ga=1.4;........................//Degree of freedom for the gas
Cvinc=3;.....................//Increase of specific heat at constant volume in percentage
//Calculations
eta=1-1/(r^(ga-1));...........//efficiency of otto cycle
deta=(1-eta)*(ga-1)*log(r)*(Cvinc/100);............//Change in efficiency
etach=-deta/eta;.............................//
```



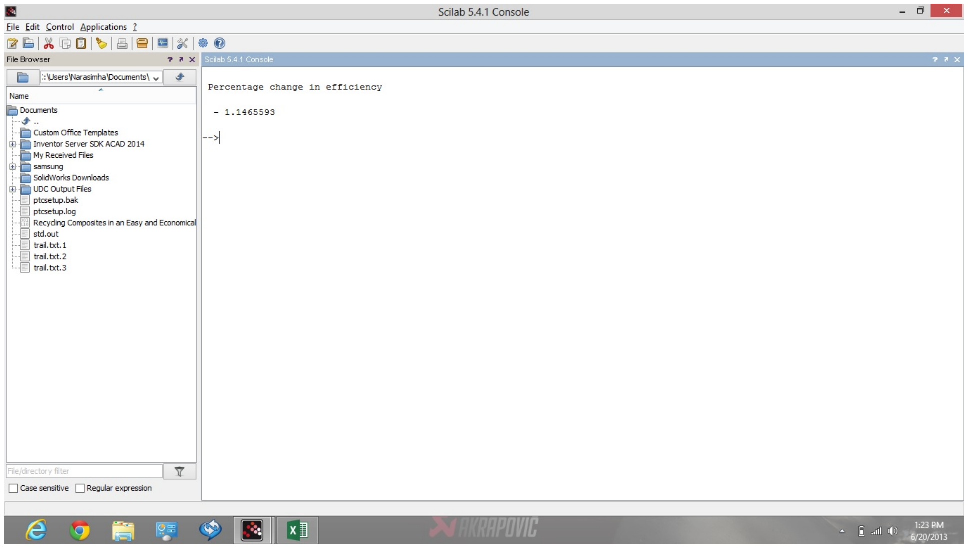
```
The percentage change in the efficiency of otto cycle (in %):

 - 1.9824089

-->
```

Figure 4.2: Percentage change in otto cycle efficiency

```
Percentage change in efficiency of change in efficiency
disp(etach*100,"The percentage change in the efficiency of otto cycle (in %):")
```

Scilab code Exa 4.4 `Change in air standard efficiency`

```
clc;funcprot(0);//EXAMPLE 4.4
// Initialisation of Variables
r=18;...........................//Compression Ratio
co=5;...........................//Cut off percent of stroke
cv=0.71;........................//Mean specific heat for cycle in kJ/kg K
R=0.285;........................//Charecteristic gas constant in kJ/kh K
```



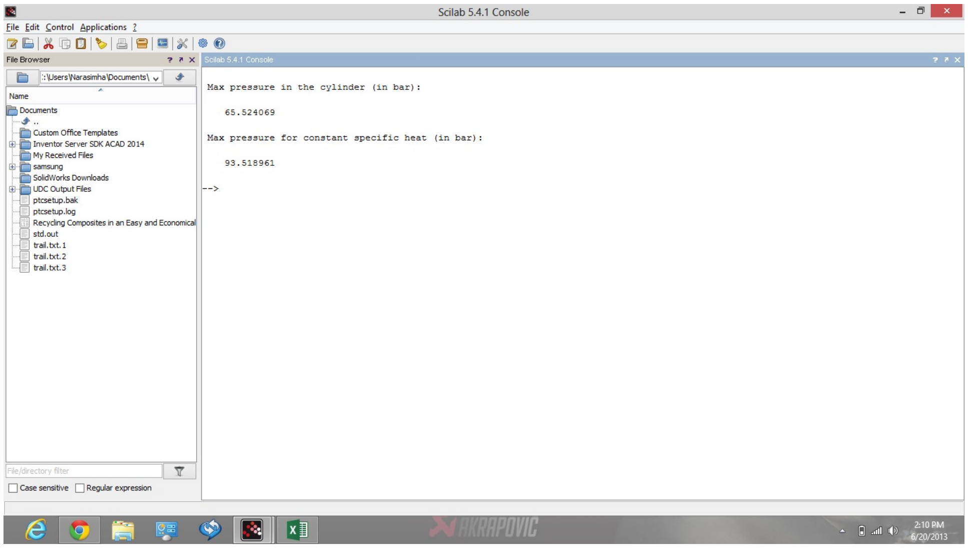
```
Percentage change in efficiency

 - 1.1465593

-->
```

Figure 4.3: Change in air standard efficiency

```
cvinc=2;........................//Percentage increase in mean specific heat of the cycle
//Calculation
rho=(co/100)*(r-1)+1;
ga=1+(R/cv);
eta=1-(1/(ga*(r^(ga-1))))*((rho^ga)-1)/(rho-1);......................//Efficiency of diesel cycle
etach=-((1-eta)/eta)*(ga-1)*(log(r)-(((rho^ga)*log(rho))/((rho^ga)-1))+(1/ga))*(cvinc/100);...//Variation in the air standard efficiency
disp(etach*100,"Percentage change in efficiency ")
```

Scilab code Exa 4.5 `Maximum pressure in cylinder`

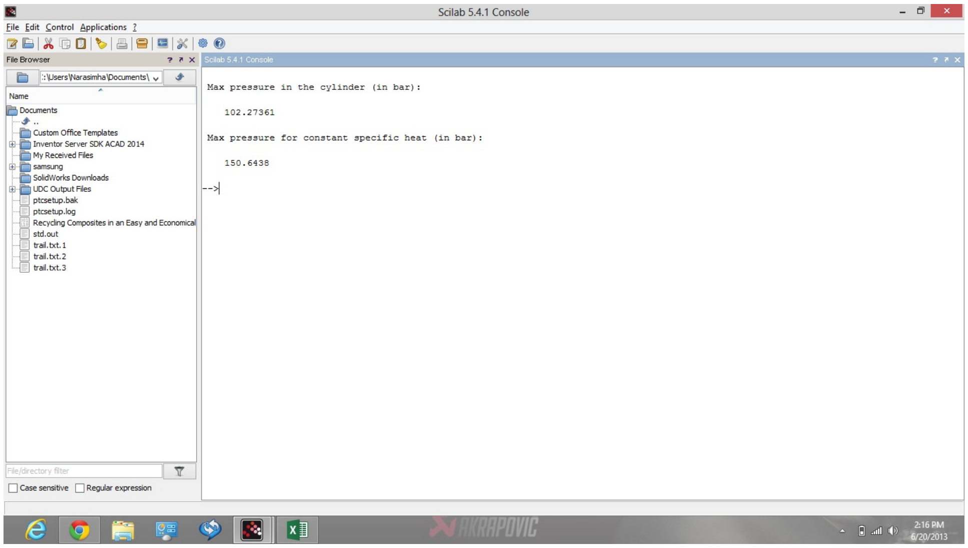
```
clc;funcprot(0);//EXAMPLE 4.5
```



```
Max pressure in the cylinder (in bar):

   65.524069

Max pressure for constant specific heat (in bar):

   93.518961

-->
```

Figure 4.4: Maximum pressure in cylinder

```
// Initialisation of Variables
r=7;......................//Compression ratio
C=44000;..................//Calorific value of fuel used in kJ/kg
afr=15;...................//Air fuel ratio
t1=338;....................//Temperature of the charge at the end of the stroke in Kelvin
p1=1;......................//Pressure of the charge at the end of the stroke in bar
n=1.33;....................//Index of compression
cv=0.71;......//Specific heat constant at constant volume in kJ/kgK
k=20*10^(-5);
//Calculations
p2=p1*(r)^n;
t2=(t1*p2)/(p1*r);
ha=C/(afr+1);......................//Heat added per kg of charge in kJ
t3=((-2*cv)+sqrt((4*cv*cv)+(4*k*((2*cv*t2)+(k*t2*t2)+(2*ha)))))/(2*k);
```



```
Max pressure in the cylinder (in bar):

   102.27361

Max pressure for constant specific heat (in bar):

   150.6438

-->
```

Figure 4.5: Maximum pressure in cylinder

```
p3=(p2*t3)/t2;..............................//Max pressure for constant volume process in bar
P3=p2*((ha/cv)+t2)/t2;.....................//Max pressure for constant specific heat in bar
disp(p3,”Max pressure in the cylinder (in bar):”)
disp(P3,”Max pressure for constant specific heat (in bar):”)
```

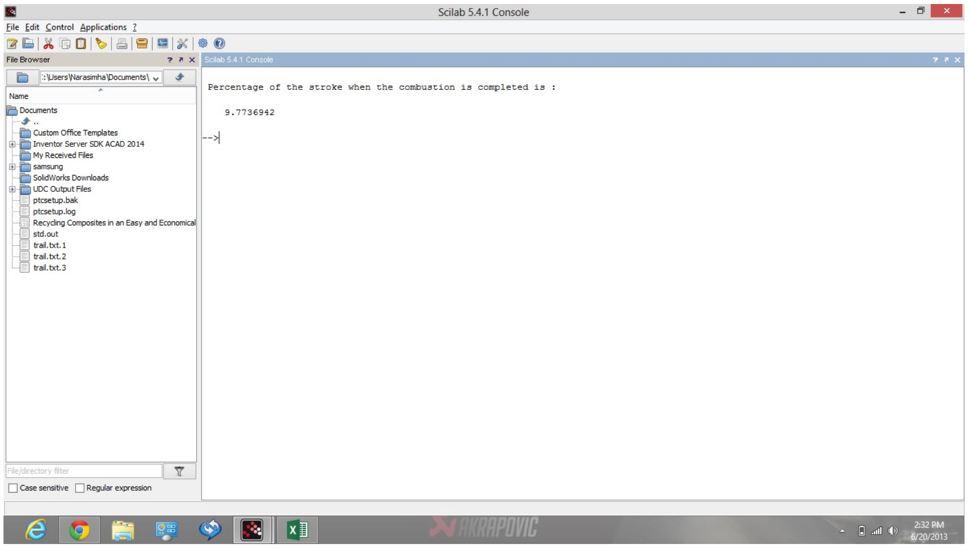
Scilab code Exa 4.6 `Maximum pressure in cylinder`

```
clc;funcprot(0);//EXAMPLE 4.6
// Initialisation of Variables
r=10;......................//Compression ratio
C=48000;...................//Calorific value of fuel used in kJ/kg
afr=15;....................//Air fuel ratio
```

```
t1=330;....................//Temperature of the charge at the end of the stroke in Kelvin
p1=1;......................//Pressure of the charge at the end of the stroke in bar
n=1.36;....................//Index of compression
cv=0.7117;......//Specific heat constant at constant volume in kJ/kgK
k=2.1*10^(-4);
//Calculations
p2=p1*(r)^n;
t2=t1*((p2/p1)^((n-1)/n));
ha=C/(afr+1);......................//Heat added per kg of charge in kJ
t3=((-2*cv)+sqrt((4*cv*cv)+(4*k*((2*cv*t2)+(k*t2*t2)+(2*ha)))))/(2*k);
p3=(p2*t3)/t2;.............................//Max pressure for constant volume process in bar
P3=p2*((ha/cv)+t2)/t2;.....................//Max pressure for constant specific heat in bar
disp(p3,"Max pressure in the cylinder (in bar):")
disp(P3,"Max pressure for constant specific heat (in bar):")
```

Scilab code Exa 4.7 `Percentage of the stroke when the combustion is completed`

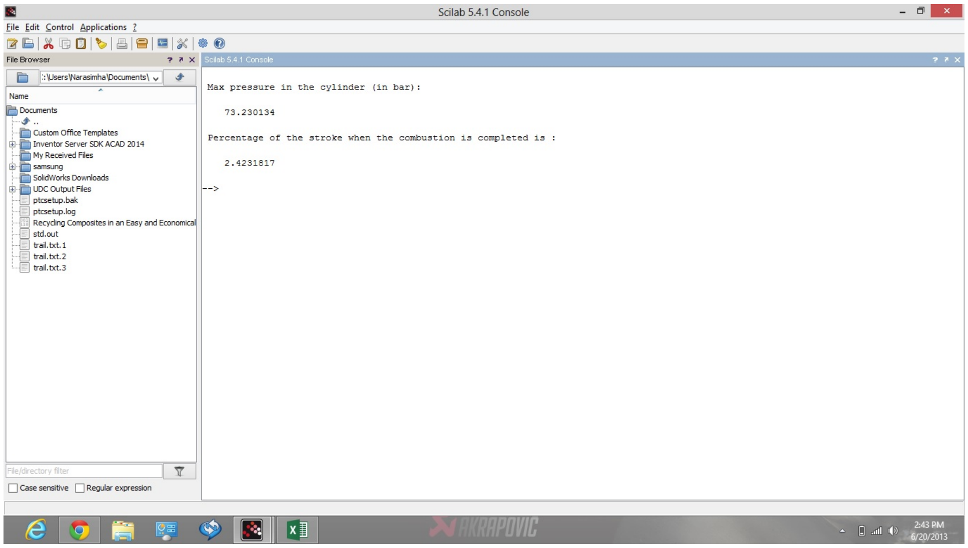
```
clc;funcprot(0);//EXAMPLE 4.7
// Initialisation of Variables
r=15;......................//Compression ratio
C=43000;..................//Calorific value of fuel used in kJ/kg
afr=27;...................//Air fuel ratio
t2=870;....................//Temperature of the charge at the end of the stroke in Kelvin
```



```
Percentage of the stroke when the combustion is completed is :

   9.7736942

-->
```

Figure 4.6: Percentage of the stroke when the combustion is completed

```
cv=0.71;......//Specific heat constant at constant volume in kJ/kgK
R=0.287;.........................//Gas constant in kJ/kgK
k=20*10^(-5);
//Calculations
cp=cv+R;............................//Specific heat at constant pressure
ha=C/(afr+1);......................//Heat added per kg of charge in kJ
t3=((-2*cp)+sqrt((4*cp*cp)+(4*k*((2*cp*t2)+(k*t2*t2)+(2*ha)))))/(2*k);
co=((t3/t2)-1)/(r-1);.............//combustion occupies this amt of stroke
disp(co*100,"Percentage of the stroke when the combustion is completed is :")
```



```
Max pressure in the cylinder (in bar):

   73.230134

Percentage of the stroke when the combustion is completed is :

   2.4231817

-->
```

Figure 4.7: Percentage of the stroke when the combustion is completed

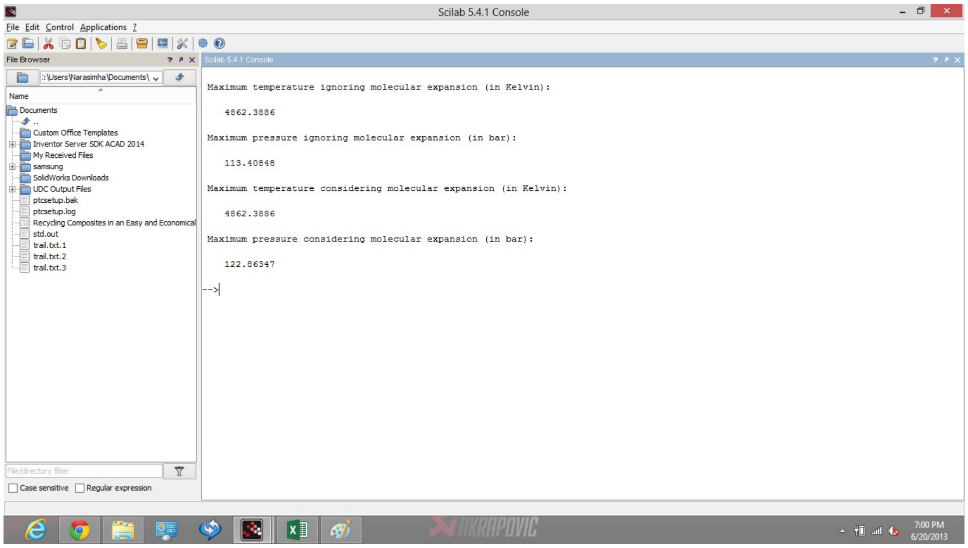
Scilab code Exa 4.8 `Percentage of the stroke when the combustion is completed`

```
clc;funcprot(0);//EXAMPLE 4.8
// Initialisation of Variables
r=14;.......................//Compression ratio
t1=87+273;.....................//Temperature of the charge at the end of the stroke in Kelvin
p1=1;.......................//Pressure of the charge at the end of the stroke in bar
hsupa=1700;.............................//heat supplied per kg of air in kJ
cv=0.71;......//Specific heat constant at constant volume in kJ/kgK
k=20*10^(-5);
ga=1.4;.....................//Degree of freedom
R=0.287;.......................//Gas constant in kJ/kgK
```

```
//Calculations
p2=p1*(r)^ga;
t2=t1*(r^(ga-1));
ha=hsupa/2;.....................//Heat added per kg of charge in kJ
t3=((-2*cv)+sqrt((4*cv*cv)+(4*k*((2*cv*t2)+(k*t2*t2)+(2*ha)))))/(2*k);
p3=(p2*t3)/t2;.............................//Max pressure for constant volume process in bar
P3=p2*((ha/cv)+t2)/t2;.....................//Max pressure for constant specific heat in bar
disp(p3,"Max pressure in the cylinder (in bar):")
cp=cv+R;...............................//Heat capacity at constant pressure in kJ/kgK
t4=((-2*cp)+sqrt((4*cp*cp)+(4*k*((2*cp*t3)+(k*t3*t3)+(2*ha)))))/(2*k);
co=((t4/t3)-1)/(r-1);.............//combustion occupies this amt of stroke
disp(co*100,"Percentage of the stroke when the combustion is completed is :")
```

Scilab code Exa 4.9 Maximum pressure and temperature ignoring and considering fuel

```
clc;funcprot(0);//EXAMPLE 4.9
// Initialisation of Variables
r=8;..........................//Compression ratio
C=44000;...........//Calorific value of fuel in kJ/kg
afr=13.8;....................//Air fuel ratio
t1=343;............................//Temperature of the mixture at the beginning of the compression in Kelvin
p1=1;........................//Pressure of the
```



```
Maximum temperature ignoring molecular expansion (in Kelvin):

   4862.3886

Maximum pressure ignoring molecular expansion (in bar):

   113.40848

Maximum temperature considering molecular expansion (in Kelvin):

   4862.3886

Maximum pressure considering molecular expansion (in bar):

   122.86347

-->
```

Figure 4.8: Maximum pressure and temperature ignoring and considering fuel expansion

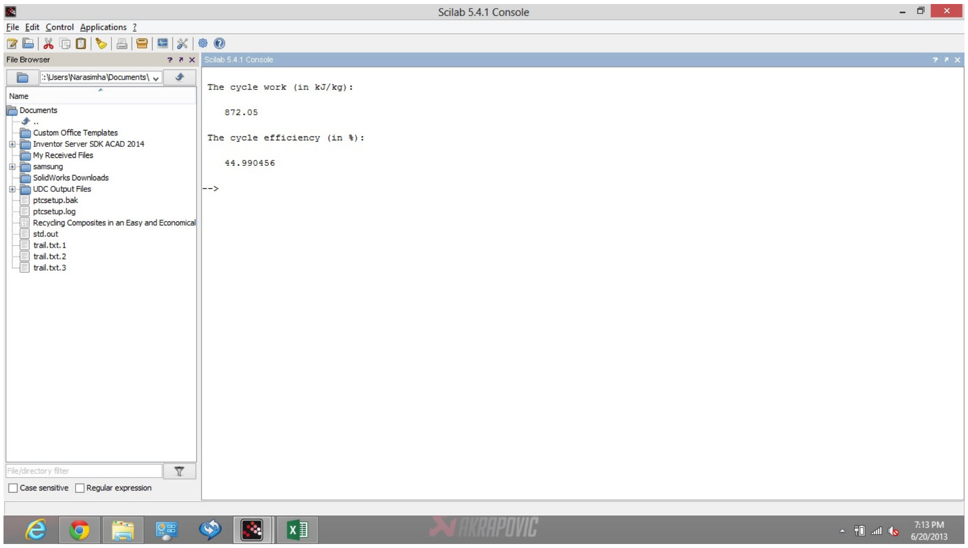
```
    mixture at the beginning of the compression in
    bar
cv=0.716;.......................//Specific heat at
    constant volume in kJ/kgK
in=1.35;........................//Index of
    compression
nc=6;...........................//No of carbon
    elements in the given fuel
nh=14;..........................//No of hydrogen
    elements in the given fuel
mc=12;............................//Atomic mass of
    carbon in amu
mh=2;...............................//atomic mass of
    hydrogen molecule in amu
mo=32;............................//Atomic mass of
    oxygen molecule in amu
//Calculations
//The chemical equation is C6H14 + xO2 ==> yCO2 +
    zH2O
```

```
//x is the no of oxygen molecules required for complete combustion
//y is the no of carbon dioxide molecules produced in complete combustion
//z is the no of Water molecules produced in complete combustion
y=nc;.............................//As no of CO2 molecules is equal to no of C atoms in the fuel
z=nh/2;...........................//No of H2O molecules is equal to half the no of H atoms in the fuel
x=(z/2)+y;..........................//No of oxygen molecules required for combustionis half the no of water molecules plus the no of oxygen molecules
gafr=((x*32)*(100/23))/((mc*y)+(mh*z));.................//Gravimetric air fuel ratio
ms=(gafr/afr)*100;......................//Actual mixture strength
//Since the mixture strength is greater than 100 %
//The mixture is rich in fuel. The combustion is therefore incompplete and hence CO will be formed
d=ms/100;......................//No of fuel molecules required for combustion
//The chemical equation is d(C6H14) + 9.5(O2) ==> a(CO2) + b(CO) + c(H2O)
c=(d*nh)/2;...............................//No of H2O molecules is equal to half the no of H atoms in the fuel
a=(x*2)-(d*nc)-c;........................//Equating atoms of the same element on both sides of equation
b=(d*nc)-a;
//By adding nitrogen on both sides, we are adding the same molecular weight on both sides.
//Air is 79 % nitrogen and 21 % oxygen
//Both N2 and O2 are diatomic molecules
n=x*(79/21);.............................//No of
```

```
   nitrogen molecules
mbc=d+x+n;.............................//Moles
   before combustion
mac=a+b+c+n;.............................//Moles
   after expansion
me=(mac-mbc)/mbc;........................//Molecular
    expansion
t2=(t1*(r^(in-1)));
t3=(t2+(C/((afr+1)*cv)));..................//Maximum
    temperature ignoring molecular expansion in
   Kelvin
p3=p1*r*(t3/t1);...........................//Maximum
    pressure ignoring molecular expansion in bar
t3me=t3;...............................//Maximum
   temperature considering molecular expansion in
   Kelvin
p3me=p3*(mac/mbc);....................//Maximum
   pressure considering molecular expansion in bar
disp(t3,”Maximum temperature ignoring molecular
   expansion (in Kelvin):”)
disp(p3,”Maximum pressure ignoring molecular
   expansion (in bar):”)
disp(t3me,”Maximum temperature considering molecular
    expansion (in Kelvin):”)
disp(p3me,”Maximum pressure considering molecular
   expansion (in bar):”)
```

Scilab code Exa 4.10 `Otto cycle work done and efficiency`

```
clc;funcprot(0);//EXAMPLE 4.10
// Initialisation of Variables
r=7;....................//Compression Ratio
t2=715;.................//Temperature at the end of
```



```
The cycle work (in kJ/kg):

   872.05

The cycle efficiency (in %):

   44.990456

-->
```

Figure 4.9: Otto cycle work done and efficiency

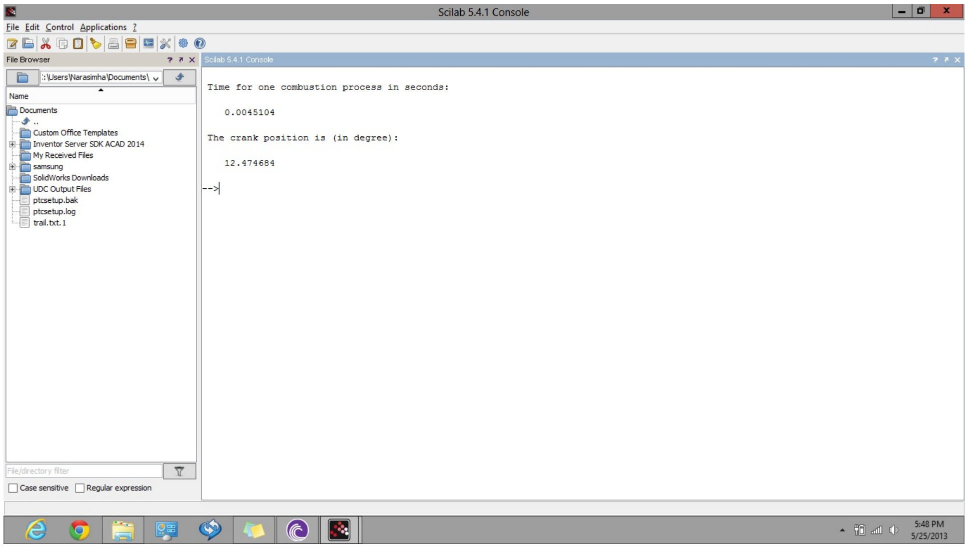
```
   isentropic compression in Kelvin
t4=1610;................//Temperature at the end of
   expansion in Kelvin
//Calculations
vr2=65.8;..................//From steam table
u2=524.2;..................//From steam table
vr4=5.69;..................//From steam table
u4=1307.63;..................//From steam table
vr1=r*vr2;
t1=338;..................//From steam table
u1=241.38;..................//From steam table
vr3=vr4/r;
t3=2800;..................//From steam table
u3=2462.5;..................//From steam table
W=(u3-u2)-(u4-u1);..................//Work done
Qa=(u3-u2);..........................//Heat added
eta=W/Qa;...........................//Cycle
   efficiency
disp(W,"The cycle work (in kJ/kg):")
disp(eta*100,"The cycle efficiency (in %):")
```

Chapter 5

Combustion in SI engines

Scilab code Exa 5.1 `Time for combustion process and total crank rotation`

```
clc;funcprot(0);//EXAMPLE 5.1
// Initialisation of Variables
d=10.2;............//Engine bore in cm
spo=0.6;............//Spark plug offset in cm
vf=15.8;............//Average flame speed in m/s
thetas=20;.............//The angle of the crank when
     spark plug is fired
theta=6.5;..........//Angle by which the Engine
    rotates for combustion to develop (degree)
N=1200;................//Engine rpm
//calculations
dmax=(0.5*d)+spo;.........//Max distance of flame
    travel in cm
tf=(dmax)/(vf*100);................//Time of flame
    travel in seconds
degs=(N/60)*360;...................//Conversion of
    engine rpm into degree/second
ctheta=tf*degs;...............//Crank angle for
    flame travel in degree
```



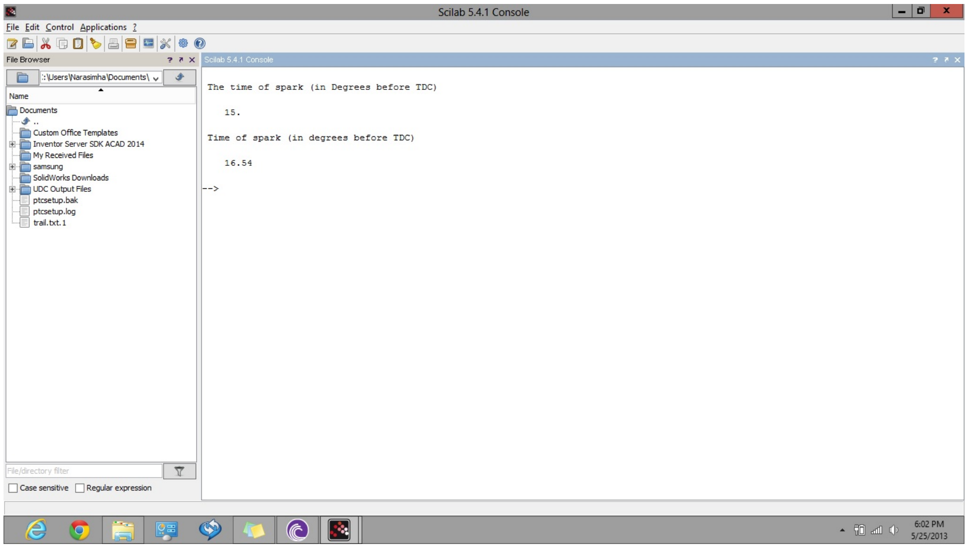
```
Time for one combustion process in seconds:

   0.0045104

The crank position is (in degree):

   12.474684

-->
```

Figure 5.1: Time for combustion process and total crank rotation

```
tc=theta/degs;...................//time for combustion to develop in seconds
top=tf+tc;......................//Time for one combustion process in seconds
thetatot=theta+ctheta;...............//Total crank rotation in degree
thetacp = thetatot-thetas;..........//Crank position
disp(top,”Time for one combustion process in seconds:”)
disp(thetacp,”The crank position is (in degree):”)
```

Scilab code Exa 5.2 `Time of spark`

```
clc;funcprot(0);//EXAMPLE 5.2
// Initialisation of Variables
dp=22;............//Delay period in degree
```



```
The time of spark (in Degrees before TDC)

   15.

Time of spark (in degrees before TDC)

   16.54

-->
```

Figure 5.2: Time of spark

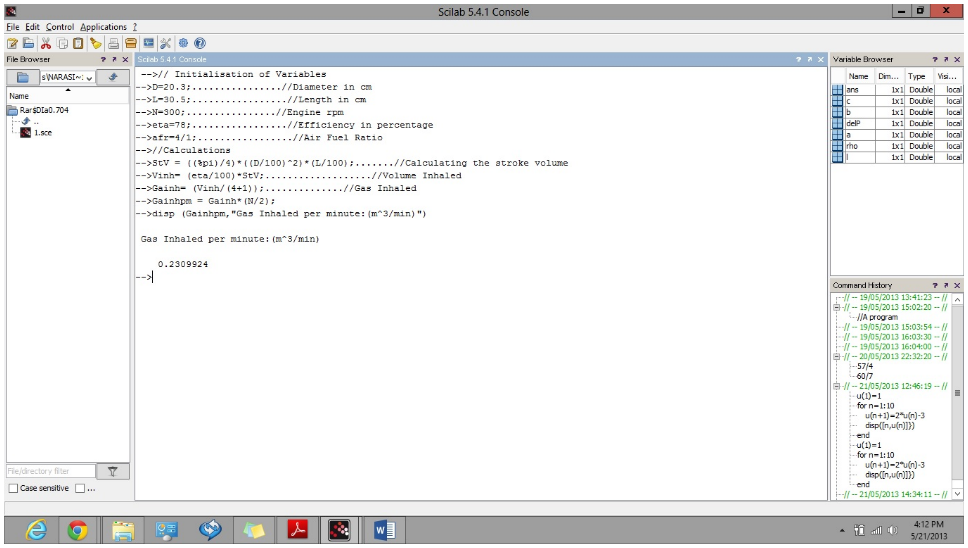
```
cp=17;................//Combustion period in degree
dper=14;................//Delay Percentage
//Calculations
thetad=dp/2;.........//Full throttle half speed will result in delay angle being reduced for the same time
//Thus ignition timing should be arranged so that the total of thetad+cp ends 13 degree after TDC
tsp=(thetad+cp)-13;............//Time of spark in degree
disp(tsp,”The time of spark (in Degrees before TDC)”)
//Half throttle half speed will result in an increase of 14% in delay time over that at full throttle half speed
theta=(dper*thetad)/100;
dtheta=thetad+theta;............//Delay angle
tp=dtheta+cp;................//Total period
tsp=tp-13;..............//
disp(tsp,”Time of spark (in degrees before TDC)”)
```

Chapter 7

Air Capacity of Four Stroke Engines

Scilab code Exa 7.1 `Volume of Gas`

```
clc;funcprot(0);//EXAMPLE 7.1
// Initialisation of Variables
D=20.3;................//Diameter in cm
L=30.5;.................//Length in cm
N=300;................//Engine rpm
eta=78;.................//Efficiency in percentage
afr=4/1;.................//Air Fuel Ratio

//Calculations
StV = ((%pi)/4)*((D/100)^2)*(L/100);.......//Calculating the stroke volume
Vinh= (eta/100)*StV;...................//Volume Inhaled
Gainh= (Vinh/(4+1));..............//Gas Inhaled
Gainhpm = Gainh*(N/2);
disp (Gainhpm,”Gas Inhaled per minute:(m^3/min)”)
```

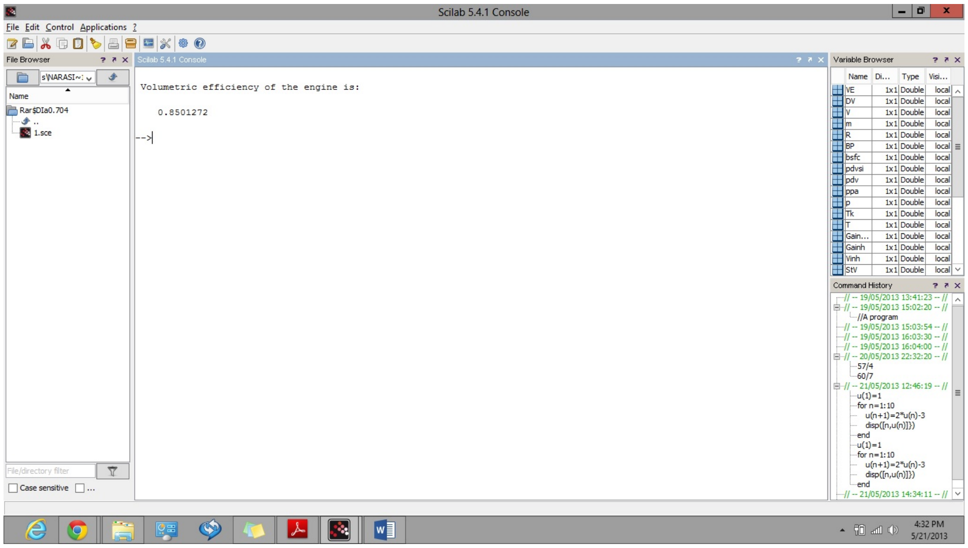


```
-->// Initialisation of Variables
-->D=20.3;................//Diameter in cm
-->L=30.5;.................//Length in cm
-->N=300;................//Engine rpm
-->eta=78;.................//Efficiency in percentage
-->afr=4/1;.................//Air Fuel Ratio
-->//Calculations
-->StV = ((%pi)/4)*((D/100)^2)*(L/100);.......//Calculating the stroke volume
-->Vinh= (eta/100)*StV;...................//Volume Inhaled
-->Gainh= (Vinh/(4+1));..............//Gas Inhaled
-->Gainhpm = Gainh*(N/2);
-->disp (Gainhpm,"Gas Inhaled per minute:(m^3/min)")

 Gas Inhaled per minute:(m^3/min)

    0.2309924
-->
```

Figure 7.1: Volume of Gas

Scilab code Exa 7.2 `Volumetric Efficiency`

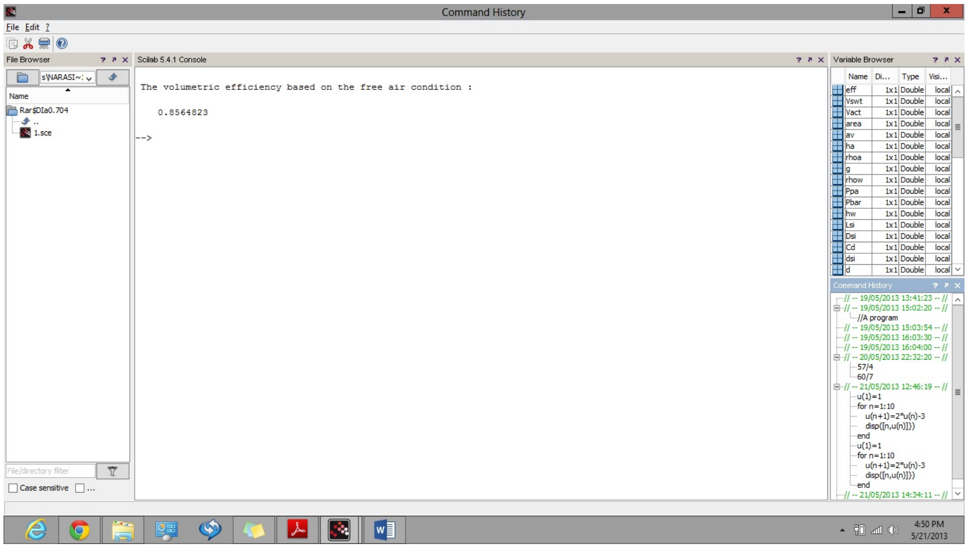
```
clc;funcprot(0)//EXAMPLE 7.2
//Initializing the variables

N=3600;................//engine rpm
T=15;.................//Inlet temperature in degree Celsius
Tk = T+273;..............//Inlet temperature in Kelvin
p=760;................//Inlet pressure in mm of Hg i.e. 1.013 x 10^5 Pa
ppa=1.013*(10^5);.........// Inlet pressure in Pascals
pdv=4066;..............//Total piston displacement
```



```
Volumetric efficiency of the engine is:

   0.8501272

-->
```

Figure 7.2: Volumetric Efficiency

```
    volume in cm^3
pdvsi=pdv*(10^(-6));..............//Total piston displacement volume in m^3
afr=14/1;....................//Air fuel ratio is 14:1
bsfc=0.38;...................// b.s.f.c in kg/kWh
BP=86;..............//power output in kW
R=287;.................//Gas constant for air in J/kg.K
//Calculations
m = (BP*bsfc*afr)/60;...............//Air consumption
V = (m*R*Tk)/ppa;
DV= pdvsi*(N/2);.........//Displacement Volume
VE=V/DV;................//Volumetric Efficiency
disp (VE,"Volumetric efficiency of the engine is:")
```

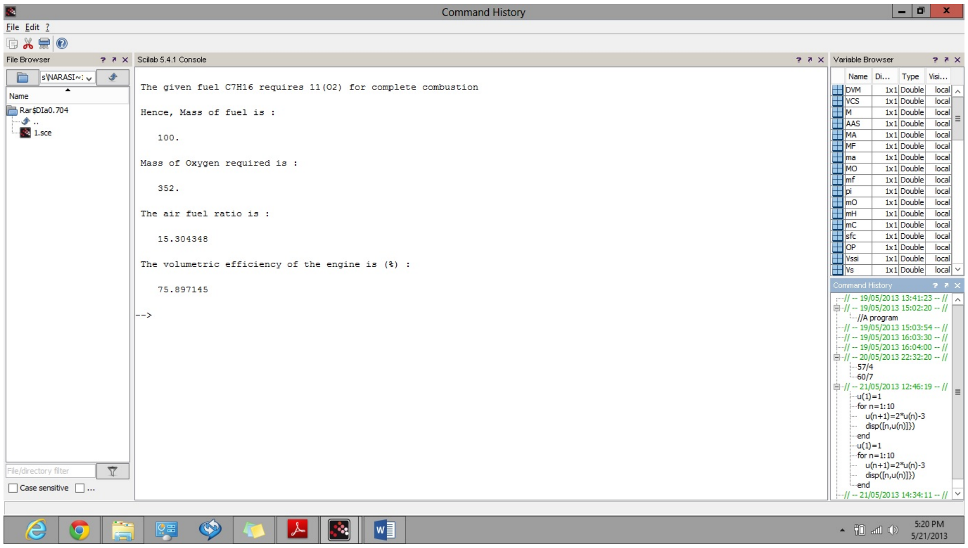


```
The volumetric efficiency based on the free air condition :

   0.8564823

-->
```

Figure 7.3: Volumetric Efficiency

Scilab code Exa 7.3 `Volumetric Efficiency`

```
clc;funcprot(0)//EXAMPLE 7.3

//Initializing the variables
n=4;..............//No of cylinders
d=5;.............//diameter of orifice in cm
dsi=d/100;..........// diameter in m
Cd=0.6;.............//Co-efficient of discharge
D=10;..............//Engine bore in cm
Dsi=d/100;............//Engine bore in m
L=12;................//Engine stroke in cm
Lsi=L/100;............//Engine stroke in m
N=1200;...............//Engine rpm
hw=0.046;............//Pressure drop across orifice in m of water
T = 17;..........//Ambient Temparature in Degree Celsius
Tk = T+273;..........// Ambient Temperature in Kelvin
```



```
The given fuel C7H16 requires 11(O2) for complete combustion

Hence, Mass of fuel is :

   100.

Mass of Oxygen required is :

   352.

The air fuel ratio is :

   15.304348

The volumetric efficiency of the engine is (%) :

   75.897145

-->
```

Figure 7.4: Volumetric Efficiency

```
Pbar = 1;.............// Ambient pressure in bar
Ppa = 1 * (10^5);.......//Ambient pressure in Pascal
R = 287;.............// Gas constant in J/kg.K
rhow = 1000;............//Density of water in kg/m^3
g=9.81;...............//Acceleration due to gravity
//Calculations

rhoa= Ppa/(R*Tk);.........//Density of air
ha= (hw*rhow)/rhoa;
av= sqrt(2*g*ha);.............//Air velocity
area = (%pi/4)*(dsi^2);
Vact = Cd*area*av;.............// V actual
Vswt = n*(%pi/4)*(Dsi^2)*Lsi*(N/60*2);
eff = Vact/Vswt;...............//Volumetric efficiency
disp (eff,"The volumetric efficiency based on the free air condition : ")
```

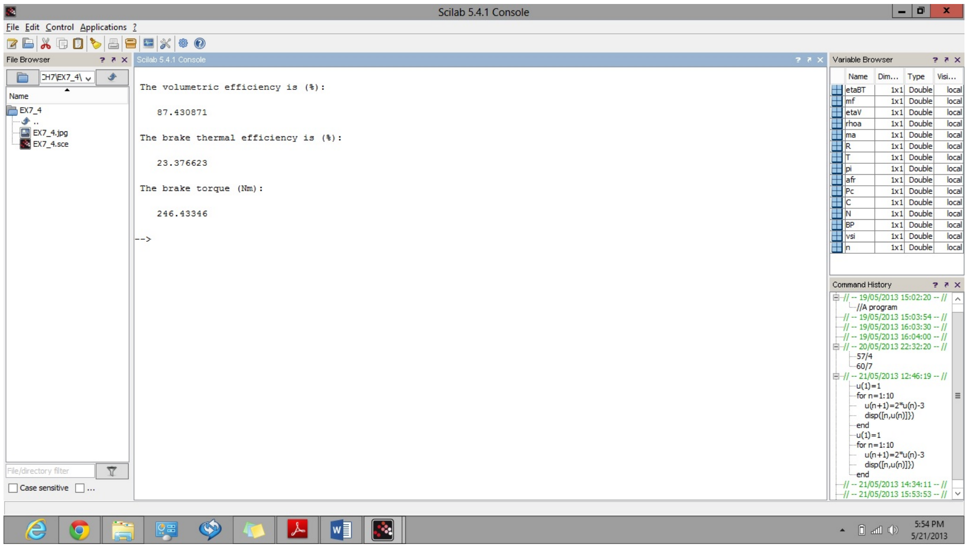
Scilab code Exa 7.4 `Volumetric Efficiency`

```
clc;funcprot(0)//EXAMPLE 7.4

//Initializing the variables
n=1;...................//No of cylinders
k=0.5;
Vs=7000;............//displacement volume in cm^3
Vssi= Vs*(10^(-6));........//displacement volume in m^3
OP=14.7;...................//Power developed in kW
N=450;..................//Engine rpm
sfc=0.272;................//Specific fuel consumption in kg/kWh
//Fuel used is C7H16
mC=12;.............//mass of carbon in amu
mH=1;.................//mass of hydrogen in amu
mO=16;.................//mass of oxygen in amu
pi=1.013 * (10^5);................//initial pressure in pascal
T=30;...................//initial temperature in degree celsius
Tk=30+273;................//initial temperature in degree kelvin
R=287;..................//Gas constant for air in J/kg.K
//calculations
disp("The given fuel C7H16 requires 11(O2) for complete combustion")
mf=(7*mC)+(16*mH);
disp (mf,"Hence, Mass of fuel is :")
MO=11* 2 * mO;
disp (MO,"Mass of Oxygen required is :")
ma = MO/0.23;.......//mass of air
```

```
//Air contains 23% of oxygen by weight
afr = ma/mf;...............//air fuel ratio is the ratio of mass of air to mass of fuel
disp(afr,"The air fuel ratio is :")
MF = sfc * OP;...........//actual fuel consumed in kg/h
MA = afr*MF;
AAS = MA * (1+0.3);.....................//actual air supplied in kg/h
M = AAS + MF;................//mass of charge in kg/h
VCS = ((M/60)*R*Tk)/pi;.............//Volume of charge sucked in m^3/min
DVM = Vssi * (N/2);..............//Displacement volume/min
eta = VCS/DVM;
disp (eta*100,"The volumetric efficiency of the engine is (%) :")
```

Scilab code Exa 7.5 Brake Torque

```
clc;funcprot(0)//EXAMPLE 7.5

//Initializing the variables
n=6;................//No of cylinders
vsi=730*(10^(-6));..........//Piston displacement per cylinder in m^3
BP=80;.............//Power produced per cylinder in kW
N=3100;...........//Engine rpm
C=44*(10^6);...........//Calorific value of petrol in J/kg
Pc=28;........//Petrol consumed per hour in kg
```



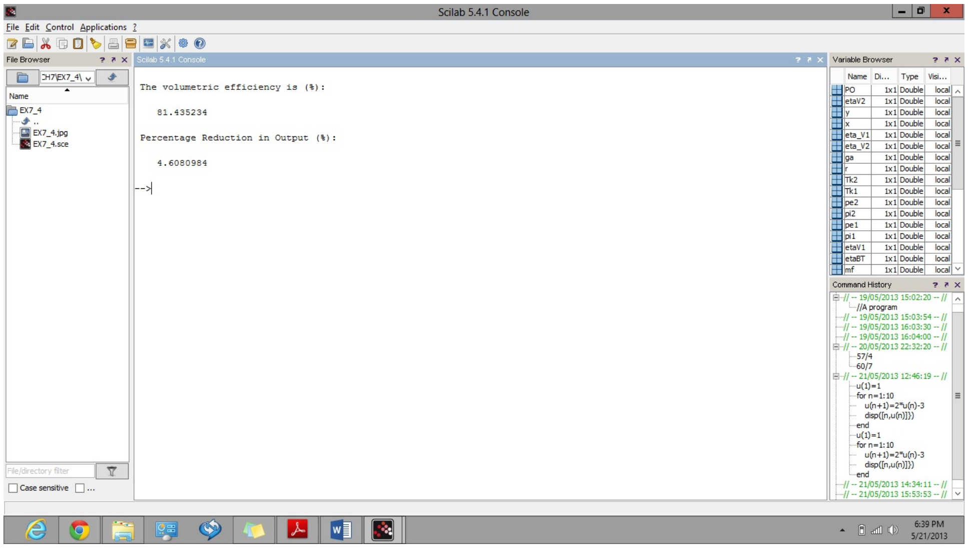
```
The volumetric efficiency is (%):

   87.430871

The brake thermal efficiency is (%):

   23.376623

The brake torque (Nm):

   246.43346

-->
```

Name	Dim...	Type	Visi...
etaBT	1x1	Double	local
mf	1x1	Double	local
etaV	1x1	Double	local
rhoa	1x1	Double	local
ma	1x1	Double	local
R	1x1	Double	local
T	1x1	Double	local
pi	1x1	Double	local
afr	1x1	Double	local
Pc	1x1	Double	local
C	1x1	Double	local
N	1x1	Double	local
BP	1x1	Double	local
vsi	1x1	Double	local
n	1x1	Double	local

```
// -- 19/05/2013 15:02:20 -- //
  //A program
// -- 19/05/2013 15:03:54 -- //
// -- 19/05/2013 16:03:30 -- //
// -- 19/05/2013 16:04:00 -- //
// -- 20/05/2013 22:32:20 -- //
  57/4
  60/7
// -- 21/05/2013 12:46:19 -- //
  u(1)=1
  for n=1:10
     u(n+1)=2*u(n)-3
     disp([n,u(n)]})
  end
  u(1)=1
  for n=1:10
     u(n+1)=2*u(n)-3
     disp([n,u(n)]})
  end
// -- 21/05/2013 14:34:11 -- //
// -- 21/05/2013 15:53:53 -- //
```

Figure 7.5: Brake Torque

```
afr = 13/1;.......//air fuel ratio
pi=0.88*(10^5);..............//Intake pressure in pa
T=300;...........//Intake temperature in Kelvin
R = 287;.........//gas constant in J/kg.K
//calculations
ma = (Pc*afr)/60;...........//air comsumed
rhoa = pi/(R*T);.......//Density of air
etaV=ma/(rhoa*vsi*n*(N/2));
disp(etaV*100,"The volumetric efficiency is (%):")
mf = Pc/3600;...............//Fuel consumed per sec
etaBT = (BP*1000)/(mf*C);
disp (etaBT*100,"The brake thermal efficiency is (%)
   :")
T=(BP*60*1000)/(2*(%pi)*N);
disp (T,"The brake torque (Nm):")
```



```
The volumetric efficiency is (%):

   81.435234

Percentage Reduction in Output (%):

   4.6080984

-->
```

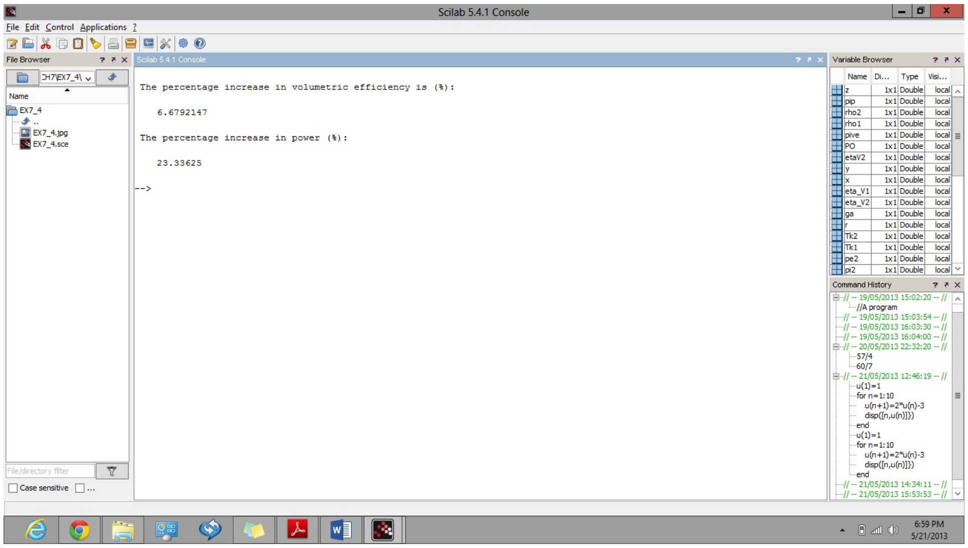
Name	Di...	Type	Visi...
PO	1x1	Double	local
etaV2	1x1	Double	local
y	1x1	Double	local
x	1x1	Double	local
eta_V1	1x1	Double	local
eta_V2	1x1	Double	local
ga	1x1	Double	local
r	1x1	Double	local
Tk2	1x1	Double	local
Tk1	1x1	Double	local
pe2	1x1	Double	local
pi2	1x1	Double	local
pe1	1x1	Double	local
pi1	1x1	Double	local
etaV1	1x1	Double	local
etaBT	1x1	Double	local
mf	1x1	Double	local

```
// -- 19/05/2013 15:02:20 -- //
  //A program
// -- 19/05/2013 15:03:54 -- //
// -- 19/05/2013 16:03:30 -- //
// -- 19/05/2013 16:04:00 -- //
// -- 20/05/2013 22:32:20 -- //
  57/4
  60/7
// -- 21/05/2013 12:46:19 -- //
  u(1)=1
  for n=1:10
     u(n+1)=2*u(n)-3
     disp([n,u(n)]})
  end
  u(1)=1
  for n=1:10
     u(n+1)=2*u(n)-3
     disp([n,u(n)]})
  end
// -- 21/05/2013 14:34:11 -- //
// -- 21/05/2013 15:53:53 -- //
```

Figure 7.6: Percentage change in output

Scilab code Exa 7.6 `Percentage change in output`

```
clc;funcprot(0)//EXAMPLE 7.6

//Initializing the variables
etaV1 = 0.8;.........//Volumetric efficiency
pi1 = 1.013;.......//Inlet pressure
 pe1= 1.013;pi2= 1.013;
pe2 = 1.15;.........//Exhaust pressure
Tk1 = 298;...........//Temperature in Kelvin
Tk2 = 318;...........//Temperature in Kelvin
r = 7.5;........//compression ratio
ga=1.4;..........//degree of freedom for gas
//calculations
//For pressure change
eta_V2 = r - (pe2/pi2)^(1/ga);
eta_V1 = r - (pe1/pi1)^(1/ga);
x=eta_V2/eta_V1;
//For inlet temperature change
y = sqrt(Tk2/Tk1);
```



```
The percentage increase in volumetric efficiency is (%):

   6.6792147

The percentage increase in power (%):

   23.33625

-->
```

Figure 7.7: Percentage change in output

```
//For volumetric efficiency , considering both
    pressure and temperature
etaV2 = etaV1*x*y;
disp(etaV2*100,"The volumetric efficiency is (%):")
PO=((etaV1/Tk1)-(etaV2/Tk2))/(etaV1/Tk1);
disp(PO*100,"Percentage Reduction in Output (%): ")
```

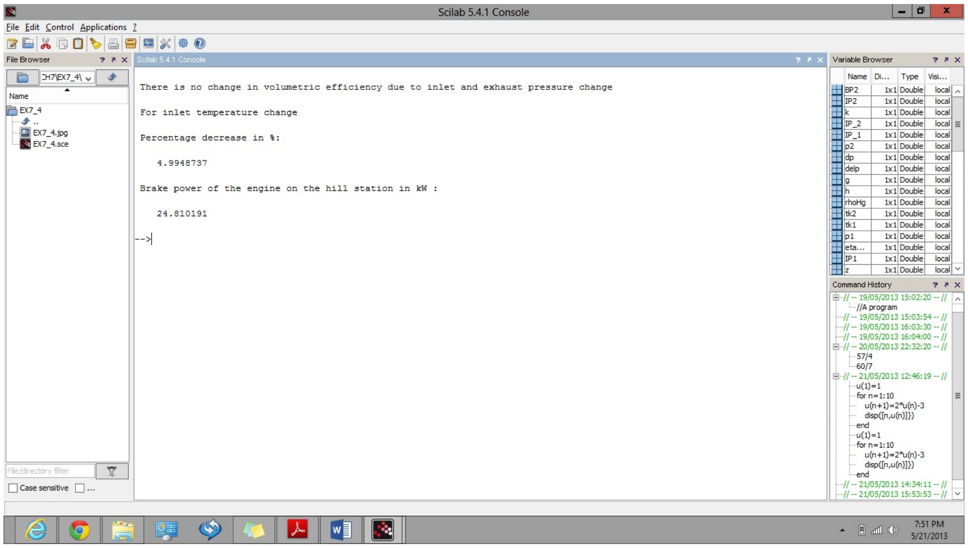
Scilab code Exa 7.7 `Percentage change in output`

```
clc;funcprot(0)//EXAMPLE 7.7

//Initializing the variables
pi1 = 1.013;.......//Inlet pressure
 pe1= 1.013;pi2= 1.3;
pe2 = 1.013;.........//Exhaust pressure
Tk1 = 300;...........//Temperature in Kelvin
```

```
Tk2 = 333;...........//Temperature in Kelvin
r = 14;........//compression ratio
ga=1.4;..........//degree of freedom for gas
R=287;...........//gas constant in J/kg.K
//calculations
//For pressure change
eta_V2 = r - (pe2/pi2)^(1/ga);
eta_V1 = r - (pe1/pi1)^(1/ga);
x=eta_V2/eta_V1;
//For inlet temperature change
y = sqrt(Tk2/Tk1);
//For volumetric efficiency , considering both pressure and temperature
pive = ((x*y)-1);.........//percentage increase in volumetric efficiency
disp(pive*100,"The percentage increase in volumetric efficiency is (%):")
rho1 = (pi1*10^5)/(R*Tk1);
rho2 = (pi2*10^5)/(R*Tk2);
z = (rho2/rho1)*x*y;
pip = (z-1);
disp (pip*100,"The percentage increase in power (%):")
```

Scilab code Exa 7.8 Percentage change in Volumetric efficiency and Brake Power

```
clc;funcprot(0)//EXAMPLE 7.8

//Initializing the variables
IP1 = 32;...............//Indicated power output in kW
etamech=80;............//Mechanical efficiency at sea level
```



```
There is no change in volumetric efficiency due to inlet and exhaust pressure change

For inlet temperature change

Percentage decrease in %:

   4.9948737

Brake power of the engine on the hill station in kW :

   24.810191

-->
```

Variable Browser

	Name	Di...	Type	Visi...
▦	BP2	1x1	Double	local
▦	IP2	1x1	Double	local
▦	k	1x1	Double	local
▦	IP_2	1x1	Double	local
▦	IP_1	1x1	Double	local
▦	p2	1x1	Double	local
▦	dp	1x1	Double	local
▦	delp	1x1	Double	local
▦	g	1x1	Double	local
▦	h	1x1	Double	local
▦	rhoHg	1x1	Double	local
▦	tk2	1x1	Double	local
▦	tk1	1x1	Double	local
▦	p1	1x1	Double	local
▦	eta...	1x1	Double	local
▦	IP1	1x1	Double	local
▦	z	1x1	Double	local

Command History

```
// -- 19/05/2013 15:02:20 -- //
    //A program
// -- 19/05/2013 15:03:54 -- //
// -- 19/05/2013 16:03:30 -- //
// -- 19/05/2013 16:04:00 -- //
// -- 20/05/2013 22:32:20 -- //
    57/4
    60/7
// -- 21/05/2013 12:46:19 -- //
    u(1)=1
    for n=1:10
        u(n+1)=2*u(n)-3
        disp([n,u(n)]})
    end
    u(1)=1
    for n=1:10
        u(n+1)=2*u(n)-3
        disp([n,u(n)]})
    end
// -- 21/05/2013 14:34:11 -- //
// -- 21/05/2013 15:53:53 -- //
```

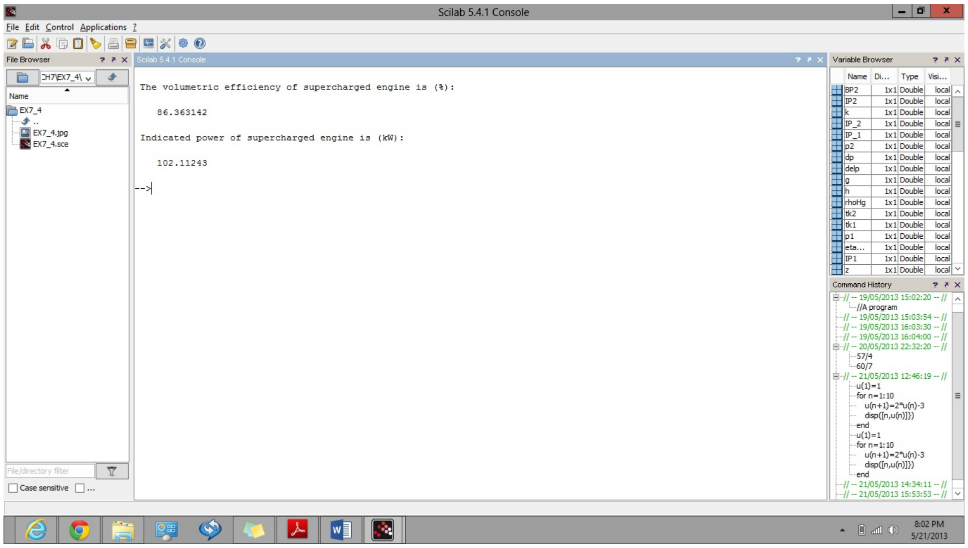
Figure 7.8: Percentage change in Volumetric efficiency and Brake Power

```
p1=1.013;..............//initial pressure at sea level in bar
tk1 = 308;...............//Initial temperature at sea level in Kelvin
tk2 = 278;...................//temperature atop the hill in Kelvin
rhoHg=13600;..............//Density of mercury in kg/m^3
h=2000;.....................//Hill altitude
g = 9.81;................//Acceleration due to gravity
delp = 10;..............//drop of mercury in mm Hg per every 100 m climb
//calculations

disp("There is no change in volumetric efficiency due to inlet and exhaust pressure change")
disp ("For inlet temperature change")
x = sqrt (tk2/tk1);................//for inlet temperature change
```

```
//x is the ratio of the efficiencies at the beginning and on hill top
disp ((1-x)*100,”Percentage decrease in %:”)
dp = rhoHg*g*((delp/1000)*(h/100))*(10^(-5));........//Drop in pressure at hill station
p2=p1-dp;
IP_1 = p1/tk1;
IP_2 = (x*p2)/tk2;
k = IP_2/IP_1;..............//Ratio of indicative power output during initial and final conditions
IP2 = (IP1 * k)/(etamech/100);
//Since the engine speed is the same at two places, the friction and hence mechanical efficiency remains unchanged
BP2 = IP2*(etamech/100);
disp(BP2,”Brake power of the engine on the hill station in kW :”)
```

Scilab code Exa 7.9 `Volumetric Efficiency and Indicated Power for Supercharged Eng`

```
clc;funcprot(0)//EXAMPLE 7.9

//Initializing the variables
etaV1 = 0.81;.........//Volumetric efficiency
pi1 = 1.01;.......//Inlet pressure before supercharger
pe1= 1.01;...........//Exhaust pressure before supercharger
pi2= 1.38;............//Inlet pressure after supercharger
pe2 = 1.01;.........//Exhaust pressure in bar after addition of super charger
Tk1 = 300;...........//Temperature in Kelvin
```



```
The volumetric efficiency of supercharged engine is (%):

   86.363142

Indicated power of supercharged engine is (kW):

   102.11243

-->
```

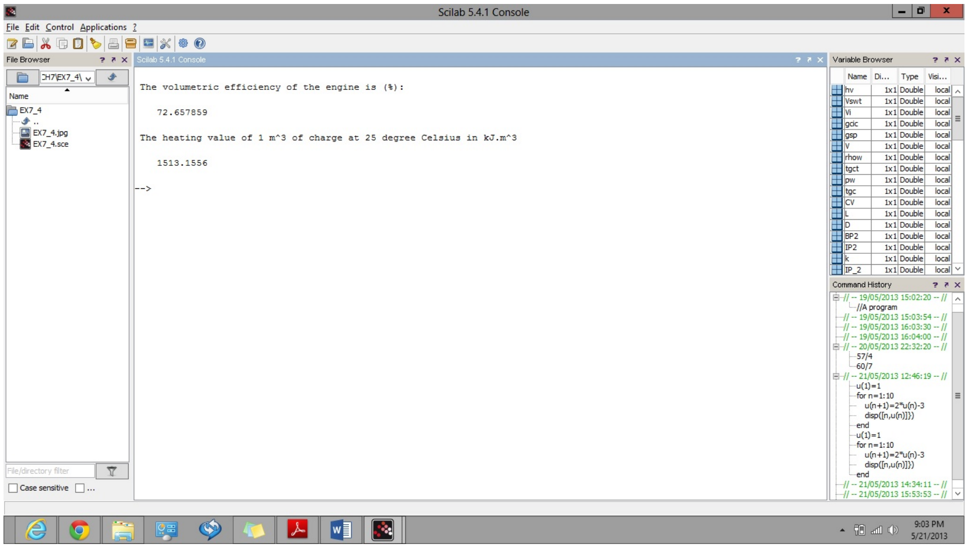
Figure 7.9: Volumetric Efficiency and Indicated Power for Supercharged Engine

```
Tk2 = 321;...........//Temperature in Kelvin
r = 7.5;........//compression ratio
ga=1.4;..........//degree of freedom for gas
R=287;.............//Gas constant for air in J/kgK
IP1=75;...............//Indicated power output before addition of supercharger
//calculations
//For pressure change
eta_V2 = r - (pe2/pi2)^(1/ga);
eta_V1 = r - (pe1/pi1)^(1/ga);
x=eta_V2/eta_V1;
//For inlet temperature change
y = sqrt(Tk2/Tk1);
//For volumetric efficiency , considering both pressure and temperature
etaV2 = etaV1*x*y;
disp(etaV2*100,”The volumetric efficiency of supercharged engine is (%):”)
rho1 = (pi1*10^5)/(R*Tk1);....//density of air
```

```
before addition of supercharger
rho2 = (pi2*10^5)/(R*Tk2);..//density of air after addition of supercharger
IP2 = IP1 * (etaV2*rho2)/(etaV1*rho1);
disp(IP2,"Indicated power of supercharged engine is (kW):")
```

Scilab code Exa 7.10 Volumetric Efficiency and Heating Value

```
clc;funcprot(0)//EXAMPLE 7.10

//Initializing the variables
n=1;.....//No of cylinders
D=0.32;.....//Bore of the cylinder in m
L=0.38;......//Stroke of the cylinder in m
N = 280;....//Engine rpm
CV = 18600;....//calorific value of fues in kJ/m^3
Tk1 = 300;....//Initial temperature in Kelvin
p1 = 1.013;.....//Initial pressure in bar
ma = 3.36;.......//mass of air consumed per min
tgc = 0.25;......//test gas consumption in m^3/min
pw = 120;.........//pressure of water in mm during the test gas consumption
tgct = 300;.......//Temperature in Kelvin during test gas consumption
rhow = 1000;.....//density of water in kg/m^3
R=287;...........//Gas constant in J/kg.K
//calculations
V= (ma*R*Tk1)/(p1*(10^5));...//Volume of air consumed at inlet condition

gsp = p1 +(pw/rhow)/10.2;....................//Gas supply pressure
//1 bar = 10.2 m
gcic = tgc*(gsp/p1);..........//Gas consumption at
```



```
The volumetric efficiency of the engine is (%):

   72.657859

The heating value of 1 m^3 of charge at 25 degree Celsius in kJ.m^3

   1513.1556

-->
```

Name	Di...	Type	Visi...
hv	1x1	Double	local
Vswt	1x1	Double	local
Vi	1x1	Double	local
gcic	1x1	Double	local
gsp	1x1	Double	local
V	1x1	Double	local
rhow	1x1	Double	local
tgct	1x1	Double	local
pw	1x1	Double	local
tgc	1x1	Double	local
CV	1x1	Double	local
L	1x1	Double	local
D	1x1	Double	local
BP2	1x1	Double	local
IP2	1x1	Double	local
k	1x1	Double	local
IP_2	1x1	Double	local

```
// -- 19/05/2013 15:02:20 -- //
    //A program
// -- 19/05/2013 15:03:54 -- //
// -- 19/05/2013 16:03:30 -- //
// -- 19/05/2013 16:04:00 -- //
// -- 20/05/2013 22:32:20 -- //
    57/4
    60/7
// -- 21/05/2013 12:46:19 -- //
    u(1)=1
    for n=1:10
        u(n+1)=2*u(n)-3
        disp([n,u(n)]})
    end
    u(1)=1
    for n=1:10
        u(n+1)=2*u(n)-3
        disp([n,u(n)]})
    end
// -- 21/05/2013 14:34:11 -- //
// -- 21/05/2013 15:53:53 -- //
```

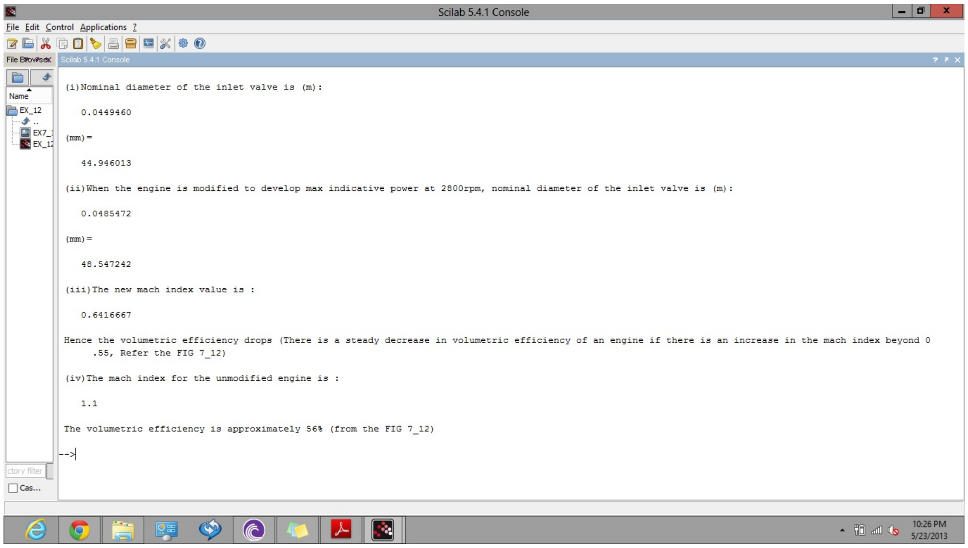
9:03 PM
5/21/2013

Figure 7.10: Volumetric Efficiency and Heating Value

```
   inlet condition
Vi = gcic+V;.....//Volume of mixture at inlet
   condition
Vswt = (%pi/4)*(D^2)*L*(N/2);......//Swept volume
etaV = Vi/Vswt;.....//Volumetric efficiency
disp(etaV*100,"The volumetric efficiency of the
   engine is (%):")
hv = (gcic/Vi)*CV;......//Heating value
disp(hv,"The heating value of 1 m^3 of charge at 25
   degree Celsius in kJ.m^3")
```

Scilab code Exa 7.12 Nominal Diameter of Inlet Valve and Volumetric Efficiency vs

```
clc;funcprot(0)//EXAMPLE 7.12
```



```
(i)Nominal diameter of the inlet valve is (m):

   0.0449460

(mm) =

   44.946013

(ii)When the engine is modified to develop max indicative power at 2800rpm, nominal diameter of the inlet valve is (m):

   0.0485472

(mm) =

   48.547242

(iii)The new mach index value is :

   0.6416667

Hence the volumetric efficiency drops (There is a steady decrease in volumetric efficiency of an engine if there is an increase in the mach index beyond 0
     .55, Refer the FIG 7_12)

(iv)The mach index for the unmodified engine is :

   1.1

The volumetric efficiency is approximately 56% (from the FIG 7_12)

-->
```

Figure 7.11: Nominal Diameter of Inlet Valve and Volumetric Efficiency vs Mach Index

```

//Initializing the variables
Z=0.55;.............//Mach Index
Dcy=0.11;............//Engine Bore in m
L = 0.14;............//stroke length in m
N = 2400;.............//Engine rpm
N1 = 2800;............//Engine rpm after modification
N2=4800;.............//Max rpm for unmodified engine
p = 0.88;.........//pressure at intake valve in bar
t=340;...............//temperature at intake valve in Kelvin
ki = 0.33;...........//Inlet flow co-efficient
ga = 1.4;...............//degree of freedom of the gas
R = 287;.................//Gas constant for air in J/kg.K
//calculations

```

```
Us = sqrt(ga*R*t);......//sonic velocity of air-fuel mixture at the inlet valve
Up = (2*L*N)/60;...........//piston speed
Div = sqrt(((Dcy^2)*Up)/(Z*ki*Us));................//Nominal diameter of the inlet valve in m
disp(Div,"(i)Nominal diameter of the inlet valve is (m):")
disp(Div*1000,"(mm)=")
Div1 = sqrt(((Dcy^2)*2*L*N1)/(Z*ki*Us*60));.......//Nominal diameter of inlet valve for the modified engine in m
disp(Div1,"(ii)When the engine is modified to develop max indicative power at 2800rpm, nominal diameter of the inlet valve is (m):")
disp(Div1*1000,"(mm)=")
Up1=(2*L*N1)/60;............//New piston speed for modified engine
Z1 = ((Dcy/Div)^2)*(Up1/(ki*Us));
disp(Z1,"(iii)The new mach index value is :")
disp("Hence the volumetric efficiency drops (There is a steady decrease in volumetric efficiency of an engine if there is an increase in the mach index beyond 0.55, Refer the FIG 7_12)")
Up2 = (2*L*N2)/60;..............//Piston speed at max rpm for unmodified engine
Z2 = ((Dcy/Div)^2)*(Up2/(ki*Us));
disp(Z2,"(iv)The mach index for the unmodified engine is :")
disp("The volumetric efficiency is approximately 56% (from the FIG 7_12)")
```

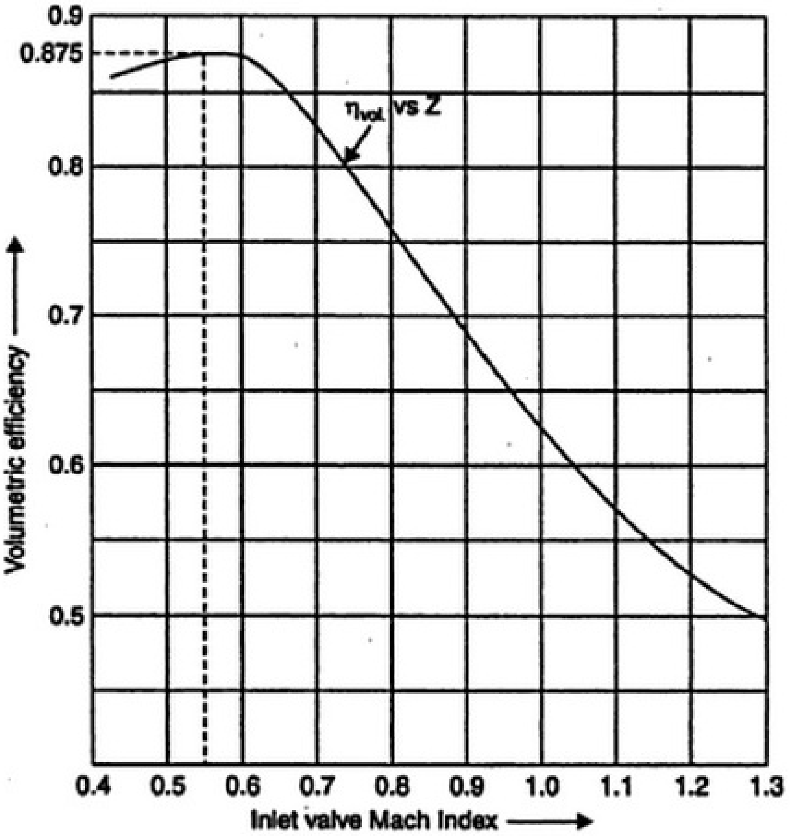


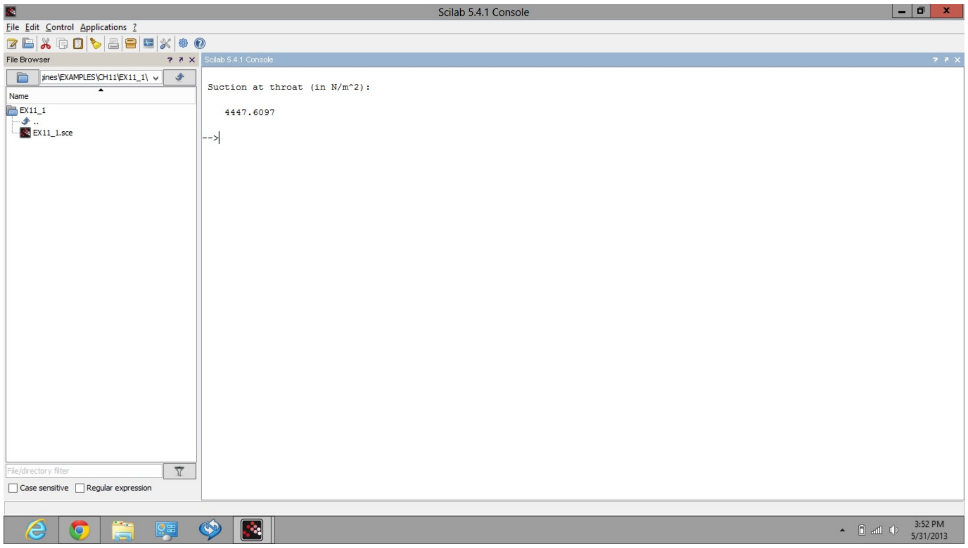
Figure 7.12: Nominal Diameter of Inlet Valve and Volumetric Efficiency vs Mach Index

Chapter 11

Carburation and carburettors

Scilab code Exa 11.1 `Suction at throat`

```
clc;funcprot(0);//EXAMPLE 11.1
// Initialisation of Variables
d=0.1;..................//Cylinder bore in m
l=0.12;................//Cylinder stroke in m
N=1800;.................//Engine rpm
d2=0.028;...............//Throat diameter in m
Cda=0.8;................//Co efficient of air flow
etaV=0.75;..................//Volumetric efficiency
rhoa=1.2;................//Density of air in kg/m^3
n=4;....................//No of cylinders
//Calculations
Vs=(%pi/4)*d*d*l*n;.................//Stroke Volume
   in m^3
Va=etaV*Vs;.......................//Actual volume
   per stroke in m^3
Vas=Va*(N/2)*(1/60);.............//Actual volume
   sucked per second
ma=Vas*rhoa;........................//Air consumed
   in kg/sec
```



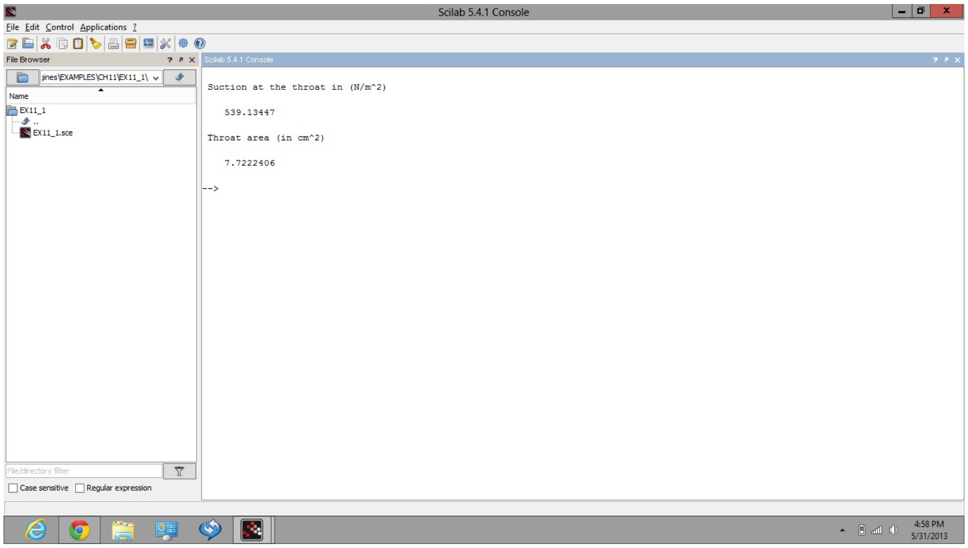
```
Suction at throat (in N/m^2):

   4447.6097

-->
```

Figure 11.1: Suction at throat

```
delp=((ma/(Cda*(%pi/4)*d2*d2))^2)/(2*rhoa);.............//Suction at throat in N/m^2
disp(delp,"Suction at throat (in N/m^2):")
```

Scilab code Exa 11.2 `Depression in Venturi throat and throat area`

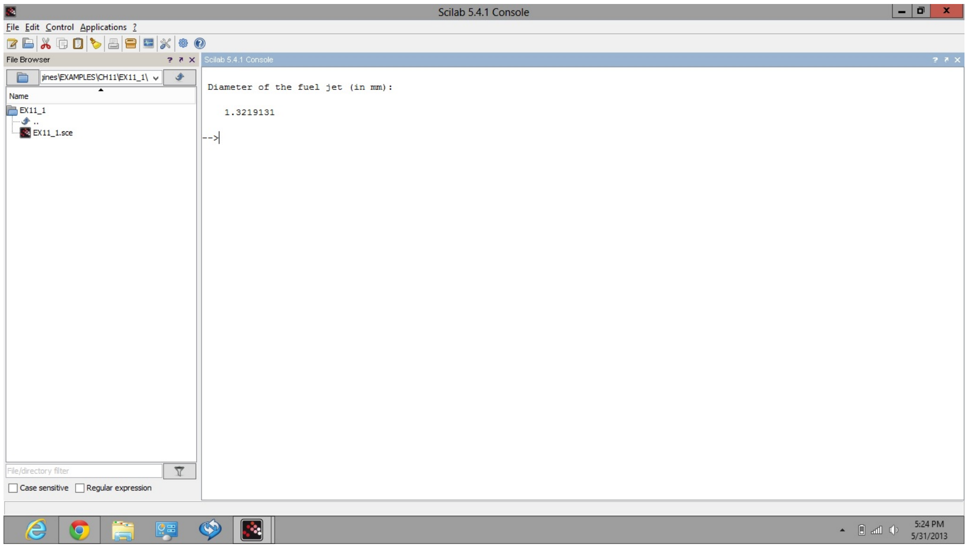
```
clc;funcprot(0);//EXAMPLE 11.2
// Initialisation of Variables
cp=5;..................//Consumption of petrol in kg/h
afr = 16;...............//Air fuel ratio
Af=2*10^(-6);...............//Fuel orifice area in m^2
z=0.005;...............//Distance between tip of jet and level of petrol in float chamber in m
```



```
Suction at the throat in (N/m^2)

   539.13447

Throat area (in cm^2)

   7.7222406

-->
```

Figure 11.2: Depression in Venturi throat and throat area

```
spgrp=0.75;..............//Specific gravity of petrol
rhow=1000;.................//Density of water in kg/m^3
rhoa=1.2;....................//Density of air in kg/m^3
Cda=0.8;...............//Coefficient of discharge for venturi throat
g=9.81;...............//Acceleration due to gravity in m/sec^2
//Calculations
mf=cp/3600;.................//Fuel consumed in kg/sec
delp=(((mf/(Af*Cda))^2)*(1/(2*spgrp*rhow)))+(g*z*spgrp*rhow);
disp(delp,"Suction at the throat in (N/m^2)")
ma=mf*afr;................//Air flow rate
Atsqr=((ma/Cda)^2)*(1/(2*rhoa*delp));....................//Throat area in m^2
disp(sqrt(Atsqr)*10^4,"Throat area (in cm^2)")
```



```
Diameter of the fuel jet (in mm):

   1.3219131

-->
```

Figure 11.3: Diameter of the fuel jet

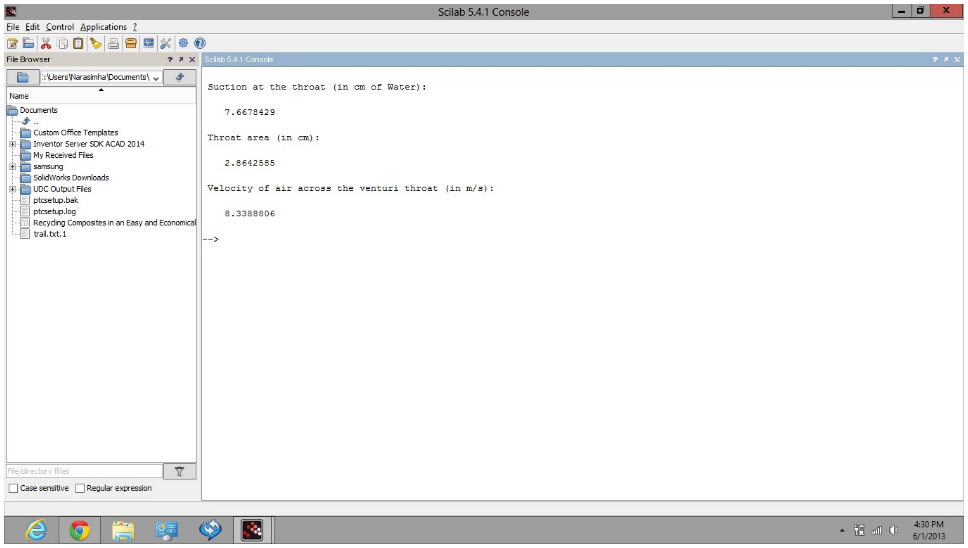
Scilab code Exa 11.3 `Diameter of the fuel jet`

```
clc;funcprot(0);//EXAMPLE 11.3
// Initialisation of Variables
pc=7.2;.................//Petrol consumed in kg/h
spgrp=0.75;................//Specific gravity of fuel
rhow=1000;.................//Density of water in kg/m^3
t1=300;...................//Temperature of air in Kelvin
afr=15;....................//Air fuel ratio
d2=0.024;....................//Diameter of choke tube in m
z=0.0042;...................//The height of the jet
```

```
   above petrol level in float chamber in m
Cda=0.8;.....................//Coefficient of
   discharge for air
Cdf=0.7;......................//Coefficient of
   discharge for fuel
p1=1.013;......................//Atmospheric pressure
    in bar
g=9.81;........................//Acceleration due to
   gravity in m/s^2
R=287;.........................//Gas constant in J/kg
   .K
//calculations
mf=pc/3600;.....................//Rate of fuel
   consumption in kg/sec
rhof=spgrp*rhow;................//Density of fuel in
   kg/m^3
rhoa=(p1*10^5)/(R*t1);.............//Density of air
   in kg/m^3
ma=mf*afr;........................//Air flow rate
delpa=((ma/(Cda*(%pi/4)*d2^2))^2)*(1/(2*rhoa))
   ;....................//Suction in N/m^2
df=sqrt((mf/sqrt(2*rhof*(delpa-(g*z*rhof))))*(1/(Cdf
   *(%pi/4))));...................//Diameter of fuel
   jet in m
disp(df*1000,"Diameter of the fuel jet (in mm):")
```

Scilab code Exa 11.4 Venturi depression and diameter and velocity of air across ve

```
clc;funcprot(0);//EXAMPLE 11.4
// Initialisation of Variables
pc=5.45;.......................//Petrol consumption
   in kg/h
afr=15;.......................//Air fuel ratio
```



```
Suction at the throat (in cm of Water):

   7.6678429

Throat area (in cm):

   2.8642585

Velocity of air across the venturi throat (in m/s):

   8.3388806

-->
```

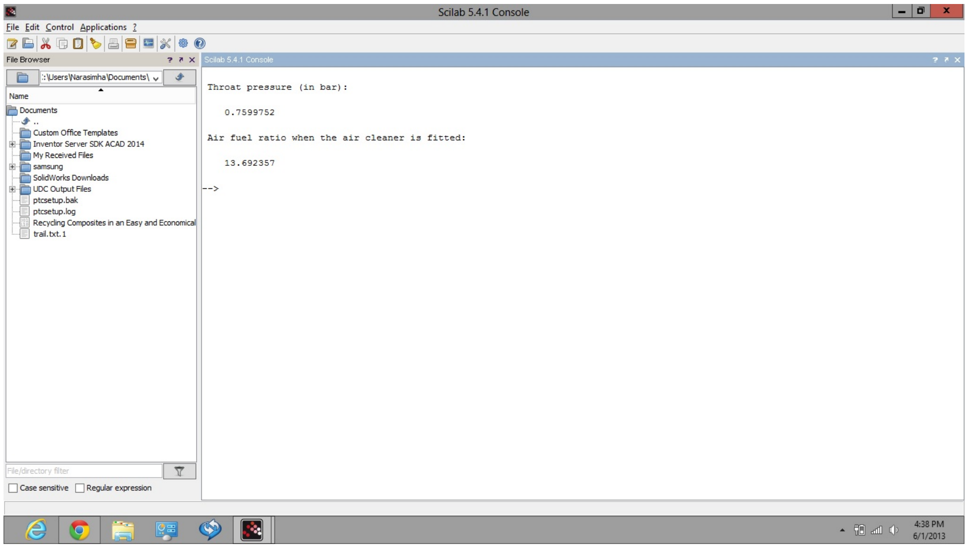
Figure 11.4: Venturi depression and diameter and velocity of air across venturi

```
af=2*10^(-6);................//Fuel jet orifice area in m^2
z=0.00635;...................//Distance between tip of fuel jet and level of petrol in the float chamber in m
Cda=0.8;............................//Coefficient of discharge of venturi throat
rhoa=1.29;........................//Density of air in kg/m^3
spgrp=0.72;........................//Specific gravity of fuel
rhow=1000;.........................//Density of water in kg/m^3
g=9.81;..............................//Acceleration due to gravity in m/s^2
Cdf=0.75;........................//Coefficient of discharge of the fuel
//calculations
mf=pc/3600;....................//Fuel consumed in kg
```

```
   /sec
rhof=spgrp*rhow;...............//Density of fuel in
   kg/m^3
delp=(((mf/(af*Cdf))^2)*(1/(2*rhof)))+(g*z*rhof)
   ;......................//Depression in venturi
   throat in N/m^2
h2odep=delp/(g*1000)
   ;................................//Depression in
   venturi throat in cm of Water
disp(h2odep*100,"Suction at the throat (in cm of
   Water):")
ma=mf*afr;................//Air flow rate
At=sqrt(((ma/Cda)^2)*(1/(2*rhoa*delp)))
   ;....................//Throat area in m^2
dt=sqrt(At/(%pi/4))
   ;........................................//Throat
    diameter in m
disp(dt*100,"Throat area (in cm):")
Ct=sqrt((2*g*z*rhof)/rhoa)
   ;..........................//Velocity of air
   across the venturi throat in m/sec
disp(Ct,"Velocity of air across the venturi throat (
   in m/s):")
```

Scilab code Exa 11.5 `Throat pressure with respct to air cleaner`

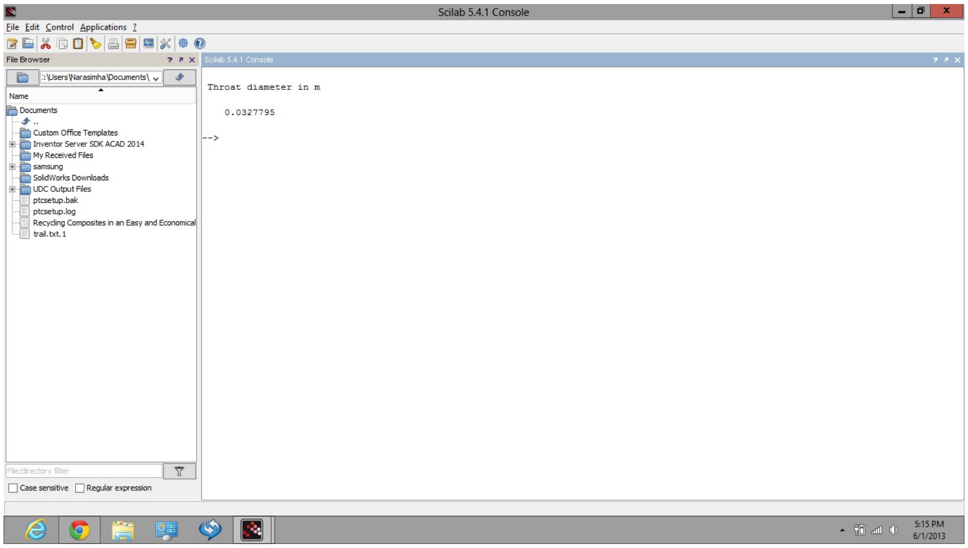
```
clc;funcprot(0);//EXAMPLE 11.5
// Initialisation of Variables
afr=15;.....................//Air fuel ratio
p1=1;.........................//Atmospheric pressure
    in bar
p2=0.8;.......................//Pressure at venturi
   throat in bar
```



```
Throat pressure (in bar):

   0.7599752

Air fuel ratio when the air cleaner is fitted:

   13.692357

-->
```

Figure 11.5: Throat pressure with respct to air cleaner

```
pd=30;......................//Pressure drop to air cleaner in mm of Hg
rhohg=13600;.....................//Density of Hg in kg/m^3
af=240;........................//Air flow at sea level in kg/h
g=9.81;......................//Acceleration due to gravity in m/s^2
//calculations
delpa=p1-p2;.........................//When there is no air cleaner
pt=1-(rhohg*g*(pd/1000)*10^(-5))-delpa;...........................//Throat pressure in bar
disp(pt,"Throat pressure (in bar):")
afrn=afr*sqrt(delpa/(p1-pt));................................//Air fuel ratio when the air cleaner is fitted
disp(afrn,"Air fuel ratio when the air cleaner is fitted:")
```

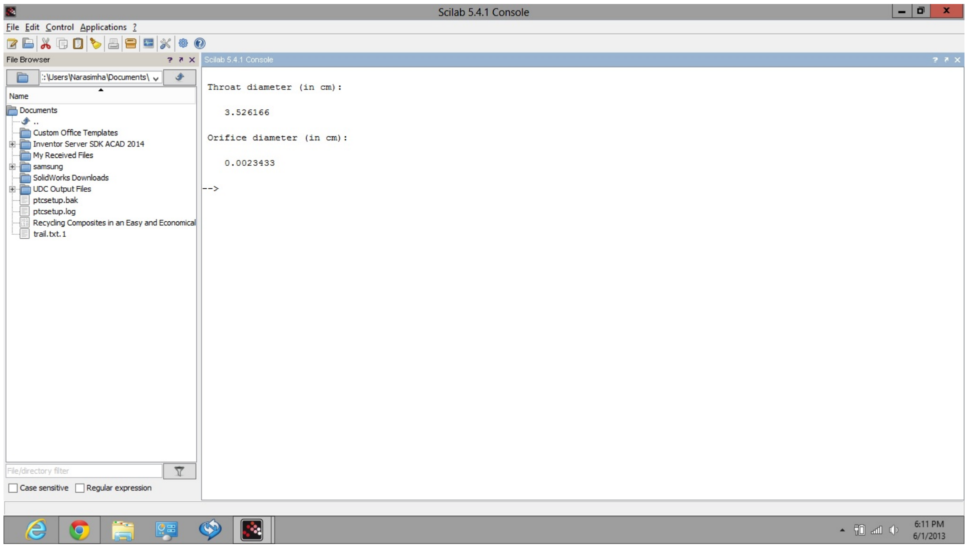


```
Throat diameter in m

   0.0327795

-->
```

Figure 11.6: Throat diameter

Scilab code Exa 11.6 `Throat diameter`

```
clc;funcprot(0);//EXAMPLE 11.6
// Initialisation of Variables
as=4.6;.........................//Air supply in kg/min
p1=1.013;.......................//Atmospheric pressure in bar
t1=298;.........................//Atmospheric temperature in Kelvin
C2=80;..........................//Air flow velocity in m/s
Cv=0.8;.....................//Velocity co efficient
ga=1.4;.........................//Degree of freedom of gas
```



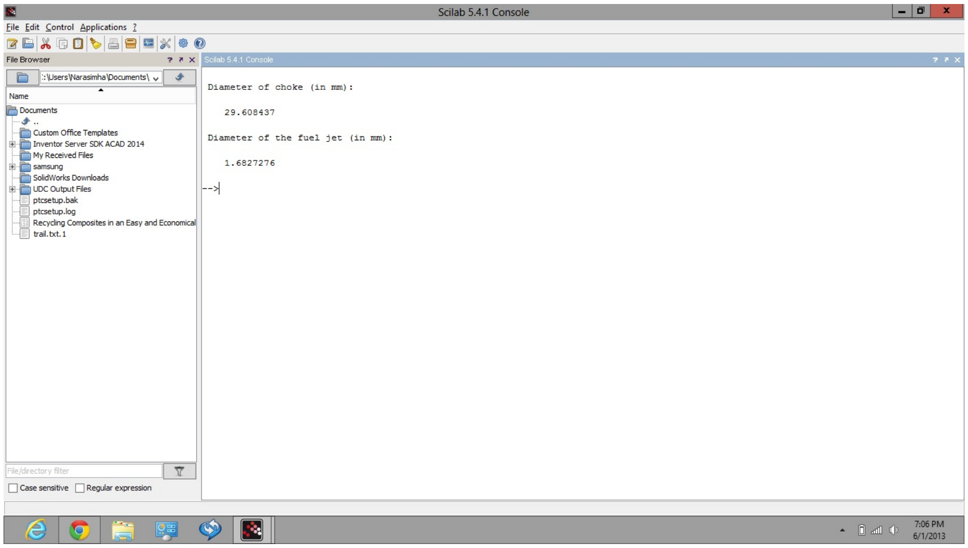
```
Throat diameter (in cm):

   3.526166

Orifice diameter (in cm):

   0.0023433

-->
```

Figure 11.7: Throat diameter and orifice diameter

```
R=0.287;........................//Gas constant in kJ/kgK
//Calculations
cp=R*(ga/(ga-1));.......................//Specific heat capacity of air in kJ/kgK
p2=((1-((((C2/Cv)^2)*(1/(2*cp*1000*t1))))^(ga/(ga-1)))*p1;...................//Throat pressure in bar
rho1=(p1*10^5)/(R*1000*t1);
rho2=rho1*(p2/p1)^(1/ga);
ma=as/60;...................//Air flow in kg/s
A2=ma/(rho2*C2);.................//Throat area in m^2
d2=sqrt((4*A2)/%pi);................//Throat diameter in m
disp(d2,"Throat diameter in m")
```

Scilab code Exa 11.7 `Throat diameter and orifice diameter`

```
clc;funcprot(0);//EXAMPLE 11.7
// Initialisation of Variables
as=6;.......................//Air supply in kg/min
fs=0.45;..........................//Fuel supply in kg/min
p1=1.013;.......................//Atmospheric pressure in bar
t1=300;......................//Atmospheric temperature in Kelvin
rhof=740;......................//Density of fuel in kg/m^3
C2=92;........................//Air flow velocity in m/s
Cda=0.8;....................//Velocity co efficient
Cdf=0.6;.........................//Coefficient of discharge for fuel
ga=1.4;........................//Degree of freedom of gas
r=0.75;......................//ratio of pressure drop across venturi and of that of choke
R=0.287;........................//Gas constant in kJ/kgK
//Calculations
ma=as/60;.................................//Air flow in kg/s
mf=fs/60;.................................//Fuel flow in kg/s
cp=R*(ga/(ga-1));.......................//Specific heat capacity of air in kJ/kgK
p2=((1-(((C2/Cda)^2)*(1/(2*cp*1000*t1))))^(ga/(ga-1)))*p1;....................//Throat pressure in bar
v1=(R*t1*1000)/(p1*10^5);
v2=v1*(p1/p2)^(1/ga);................//specific volume in m^3/kg
A2=(ma*v2)/(C2);.................//Throat area in m^2
```



```
Diameter of choke (in mm):

   29.608437

Diameter of the fuel jet (in mm):

   1.6827276

-->
```

Figure 11.8: Choke diameter and fuel jet diameter

```
d2=sqrt((4*A2)/%pi);.................//Throat diameter in m
disp(d2*100,"Throat diameter (in cm):")
pdv=p1-p2;..........//Pressure drop at venturi in bar
pdj=r*pdv;.............//Pressure drop at jet in bar
Af=((mf/Cdf)*(1/sqrt(2*rhof*pdj*10^5)))
   ;.............//Area of orifice in m^2
df=sqrt((4*Af)/%pi);.................//Orifice diameter in m
disp(df,"Orifice diameter (in cm):")
```

Scilab code Exa 11.8 `Choke diameter and fuel jet diameter`

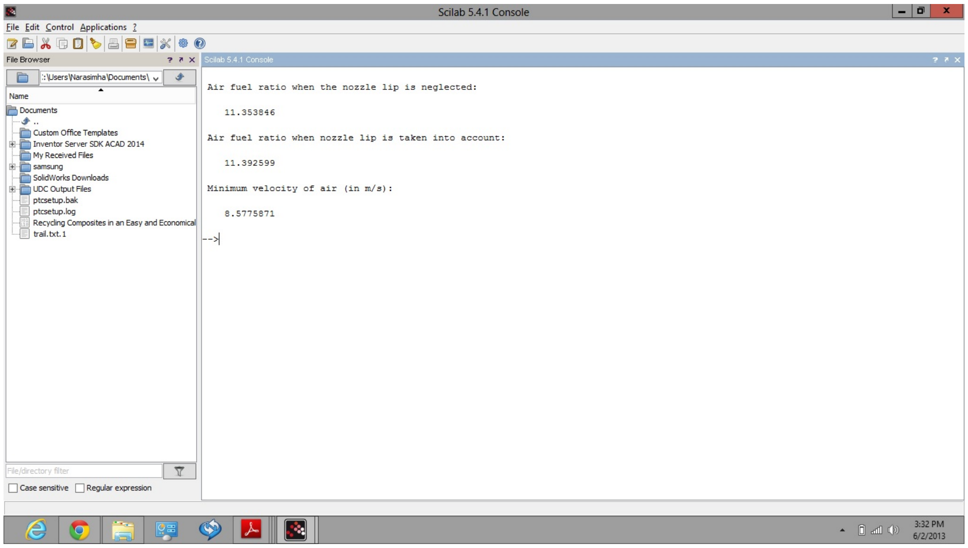
```
clc;funcprot(0);//EXAMPLE 11.8
// Initialisation of Variables
```

```
Vs=1489*10^(-6);.......................//Capacity of engine in m^3
N=4200;...............//Engine rpm at which max speed is developed
etaV=0.75;.....................//Volumetric efficiency
afr=13;........................//air fuel ratio
Ct=85;..........................//Theoretical air speed at peak power in m/s
C2=Ct;
Cda=0.82;....................//Coefficient of discharge for the venturi
Cdf=0.65;....................//Coefficient of discharge of main petrol jet
spgr=0.74;..................//Specific gravity of petrol
z=0.006;.................................//Level of petrol surface below choke
p1=1.013;......................//Atmospheric pressure in bar
t1=293;.........................//Atmospheric temperature in Kelvin
r=0.4;.............................//Ratio of diameter of emulsion tube to choke diameter
R=0.287;.............................//Gas constant in kJ/kgK
ga=1.4;..............................//Degree of freedom for air
g=9.81;..............................//Acceleration due to gravity in m/s^2
rhow=1000;...........................//Density of water in kg/m^3
//calculations
rhof=rhow*spgr;............................//Density of fuel in kg/m^3
Va=(etaV*Vs*N)/(60*2);.....................//Volume of air induced in m^3/s
ma=(p1*10^5*Va)/(R*t1*1000);...............//mass
```

```
flow of air in kg/s
cp=R*(ga/(ga-1));........................//Specific heat capacity of air in kJ/kgK
p2=((1-(((C2)^2)*(1/(2*cp*1000*t1))))^(ga/(ga-1))*p1;...................//Throat pressure in bar
pt=p2;
vt=Va*(p1/p2)^(1/ga);.....................//Volume flow of air at choke in m^3/s
At=vt/(Ct*Cda);....................//Area of emulsion tube in m
D=sqrt((4*At*10^6)/(%pi*(1-r^2)));...................//Diameter of choke in mm
disp(D,"Diameter of choke (in mm):")
mf=ma/afr;..................//Mass flow of fuel in kg/s
delpa=(p1-p2)*10^5;
df=sqrt((mf/sqrt(2*rhof*(delpa-(g*z*rhof))))*(1/(Cdf*(%pi/4))));.................//Diameter of fuel jet in m
disp(df*1000,"Diameter of the fuel jet (in mm):")
```

Scilab code Exa 11.9 `Air fuel ratio with respect to nozzle lip`

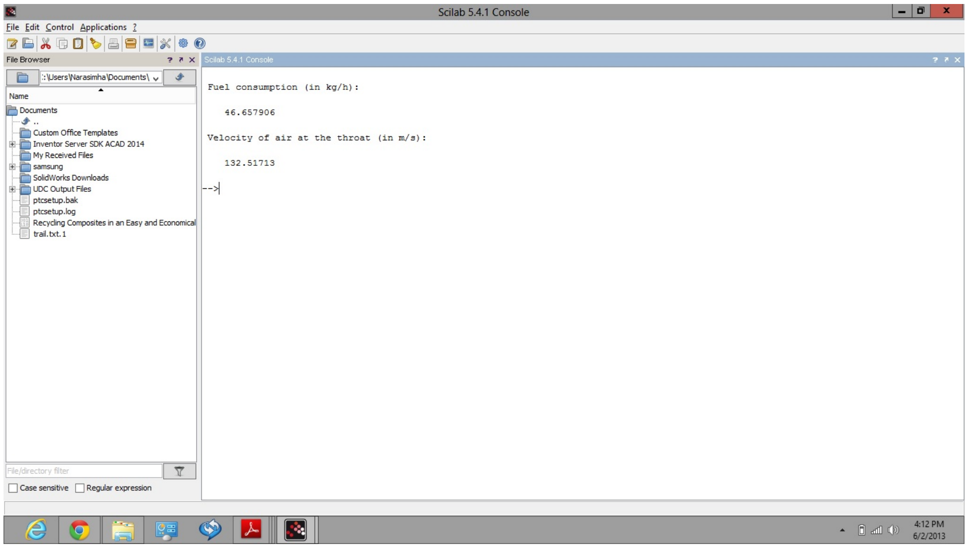
```
clc;funcprot(0);//EXAMPLE 11.9
// Initialisation of Variables
da=0.018;..........................//Throat Diameter in m
df=0.0012;......................//Diameter of fuel orifice in m
Cda=0.82;.................//Coefficient of air flow
Cdf=0.65;.......................//Coefficient of fuel flow
z=0.006;.........................//Level of petrol
```



```
Air fuel ratio when the nozzle lip is neglected:

   11.353846

Air fuel ratio when nozzle lip is taken into account:

   11.392599

Minimum velocity of air (in m/s):

   8.5775871

-->
```

Figure 11.9: Air fuel ratio with respect to nozzle lip

```
    surface below the throat
rhoa=1.2;........................//density of air in
    kg/m^3
rhof=750;.........................//density of fuel
    in kg/m^3
g=9.81;.........................//Acceleration due to
     gravity in m/s^2
delp=0.065*10^5;....................//Pressure drop
    in N/m^2
//Calculations
afr1=(Cda/Cdf)*((da/df)^2)*sqrt(rhoa/rhof)
    ;..................//Air fuel ratio when the
    nozzle lip is neglected
disp(afr1,"Air fuel ratio when the nozzle lip is
    neglected:")
afr2=afr1*sqrt(delp/(delp-(g*z*rhof)))
    ;......................//Air fuel ratio when
    nozzle lip is taken into account
disp(afr2,"Air fuel ratio when nozzle lip is taken
    into account:")
```



```
Fuel consumption (in kg/h):

   46.657906

Velocity of air at the throat (in m/s):

   132.51713

-->
```

Figure 11.10: Fuel consumption and air velocity through tube

```
C2=sqrt((2*g*z*rhof)/rhoa);.........................//Minimum velocity of air in m/s
disp(C2,"Minimum velocity of air (in m/s):")
```

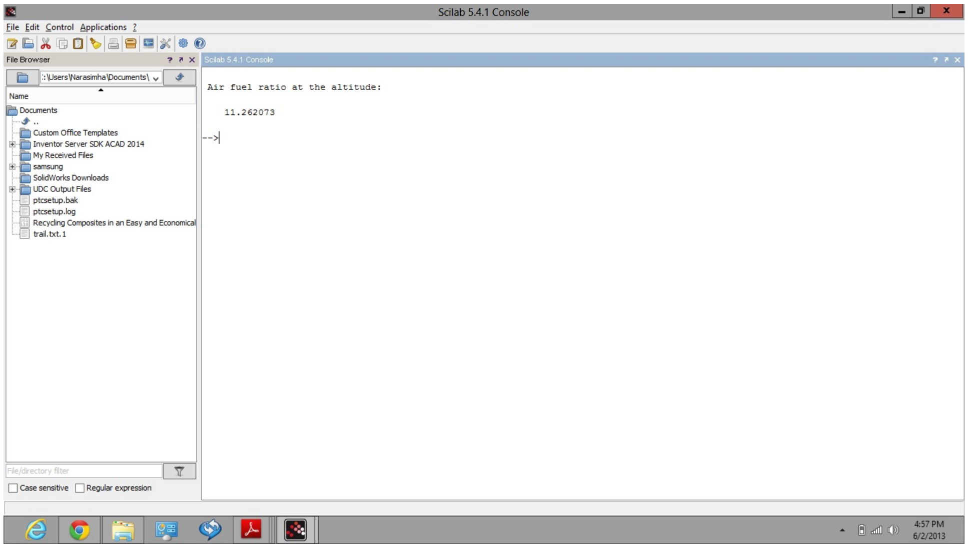
Scilab code Exa 11.10 `Fuel consumption and air velocity through tube`

```
clc;funcprot(0);//EXAMPLE 11.10
// Initialisation of Variables
d=0.11;..................//Engine bore in m
l=0.11;..................//Engine length in m
da=0.042;................//Throat diameter of the choke tube in m
N=3000;..................//Engine rpm
etaV=0.75;...............//Volumetric efficiency
Ra=287;..................//Gas constant for air in J/kgK
```

```
Rv=97;...................//Gas constant for fuel vapour in J/kgK
t=273;....................//Temperature in Kelvin
p=1.013;...................//Pressure in bar
delpa=0.12;.................//Pressure depression in bar
t2=273+15;...................//Temperature at throat
n=8;........................//No of cylinders
mO=32;.......................//Mass of Oxygen molecule in amu
mC=12;........................//Mass of Carbon molecule in amu
mH=1;.......................//Mass of Hydrogen molecule in amu
cC=84;......................//Composition of carbon in %
cH2=16;.....................//Composition of Hydrogen in %
//Calculations
Vfm=(%pi/4)*d*d*l*n*(N/2)*etaV;.....................//Volume of fuel mixture supplied in m^3/min
afr=((cC*(mO/mC))+(cH2*(mO/(4*mH))))/23;..................//Air fuel ratio
va=(Ra*t)/(p*10^5);.....................//Volume of 1 kg of air in m^3/kg
vf=(Rv*t)/(p*10^5);......................//Volume of 1 kg of fuel vapour in m^3/kg
fc=(Vfm/((afr*va)+vf))*60;...............//Fuel consumption in kg/h
disp(fc,"Fuel consumption (in kg/h):")
rhoa=((p-delpa)*10^5)/(Ra*t2);...............//Density of air at the throat in kg/m^3
Ca=(afr*(fc/3600))/((%pi/4)*da*da*rhoa);.................//Velocity of air at the throat in m/s
disp(Ca,"Velocity of air at the throat (in m/s):")
```

Scilab code Exa 11.11 `Air fuel ratio at a given altitude`

```
clc;funcprot(0);//EXAMPLE 11.11
// Initialisation of Variables
a=4500;.................//Altitude
afr=14;...............//Air fuel ratio at sea level
t1=25;...........//Temperature at sea level in Celsius
p1=1.013;...........//Pressure at sea level in bar
//Calculations
t2=t1-(0.0064*a);........................//Temperature at the given altitude using the given formula in Celsius
p2=p1/(10^(a/19300));...................//Pressure at the given altitude using the given formula in bar
afr2=afr*sqrt((p2*(t1+273))/(p1*(t2+273)));..................//Air fuel ratio at the altitude
disp(afr2,"Air fuel ratio at the altitude:")
```



```
Air fuel ratio at the altitude:

   11.262073

-->
```

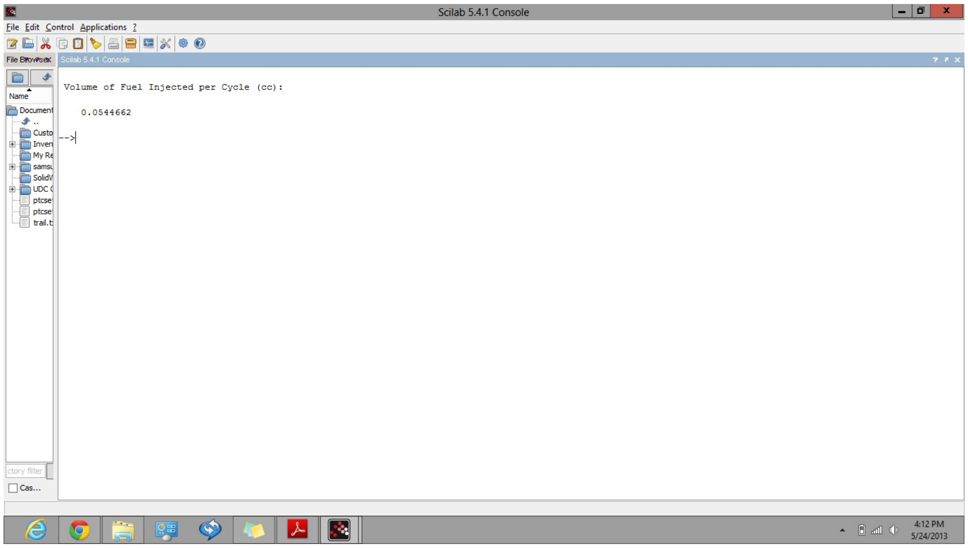
Figure 11.11: Air fuel ratio at a given altitude

Chapter 12

Fuel Injection Systems for CI Engines

Scilab code Exa 12.1 `Quantity of fuel injected per cycle`

```
clc;funcprot(0);//EXAMPLE 12.1
// Initialisation of Variables

n=6;...............//No of cylinders
BP=125;...............//Brake Power in kW
N=3000;..............//Engine rpm
bsfc=200;............//Brake Specific Fuel Consumption g/kWh
spgr=0.85;.............//Specific Gravity

//Calculations

fc=(bsfc/1000)*BP;.........//Fuel consumption in kg/h
fcpc=fc/n;..................//Fuel consumption per cylinder
FCPC=(fcpc/60)/(N/2);................//Fuel
```



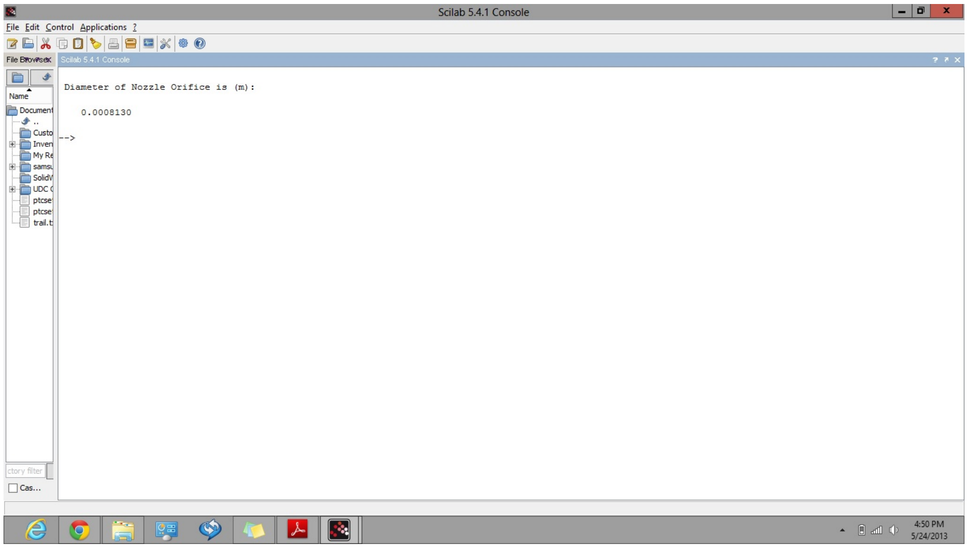
```
Volume of Fuel Injected per Cycle (cc):

   0.0544662

-->
```

Figure 12.1: Quantity of fuel injected per cycle

```
    Consumption per cycle in kg
VFIC = (FCPC*1000)/spgr;....................//Volume
    of fuel injected per cycle in cc
disp(VFIC,"Volume of Fuel Injected per Cycle (cc):")
```

Scilab code Exa 12.2 `Diameter of injector nozzle`

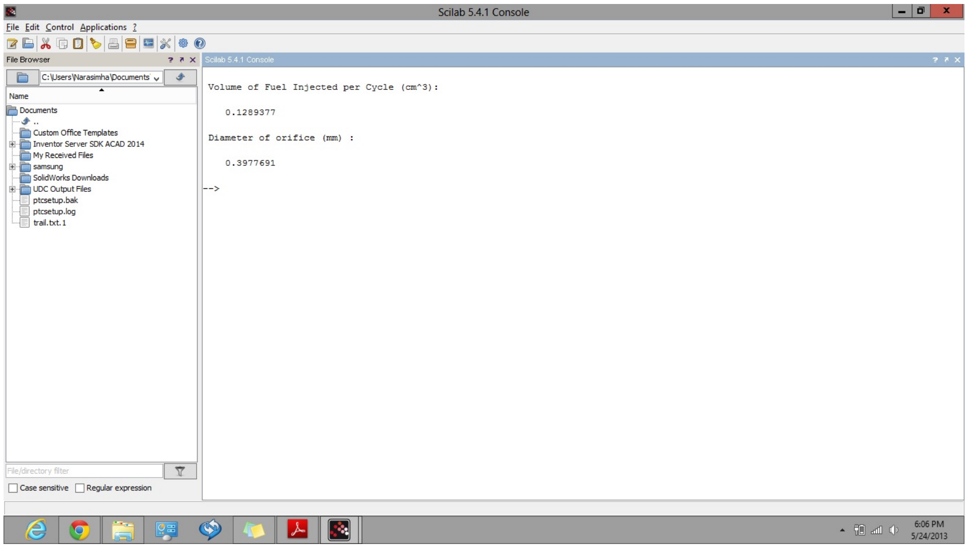
```
clc;funcprot(0);//EXAMPLE 12.2
// Initialisation of Variables
n=6;................//No of cylinders
N=1500;............//Engine rpm
BP=220;.............//Brake Power in kW
bsfc=0.273;..........//Brake Specific Fuel
    Consumption in kg/kWh
theta=30;.............//The Period of Injection in
    degrees of crank angle
```



```
Diameter of Nozzle Orifice is (m):

    0.0008130

-->
```

Figure 12.2: Diameter of injector nozzle

```
spgr=0.85;............//Specific Gravity of fuel
Cf=0.9;.................//Orifice discharge co-efficient
ip=160;...............//Injection pressure in bar
cp=40;.................//Pressure in combustion chamber in bar
rhow=1000;................//Density of water in kg/m^3
//Calculations
vf = Cf*sqrt((2*(ip-cp)*10^5)/(spgr*rhow));.............//Actual fuel velocity of injection in m/sec
qf=(bsfc*BP)/(spgr*rhow*3600);..................//Volume of fuel injected per sec in m^3
d=sqrt (qf/((%pi/4)*n*vf*(theta/360)*(60/N)*(N/120)));...........//Diameter of nozzle orifice
disp(d,"Diameter of Nozzle Orifice is (m):")
```

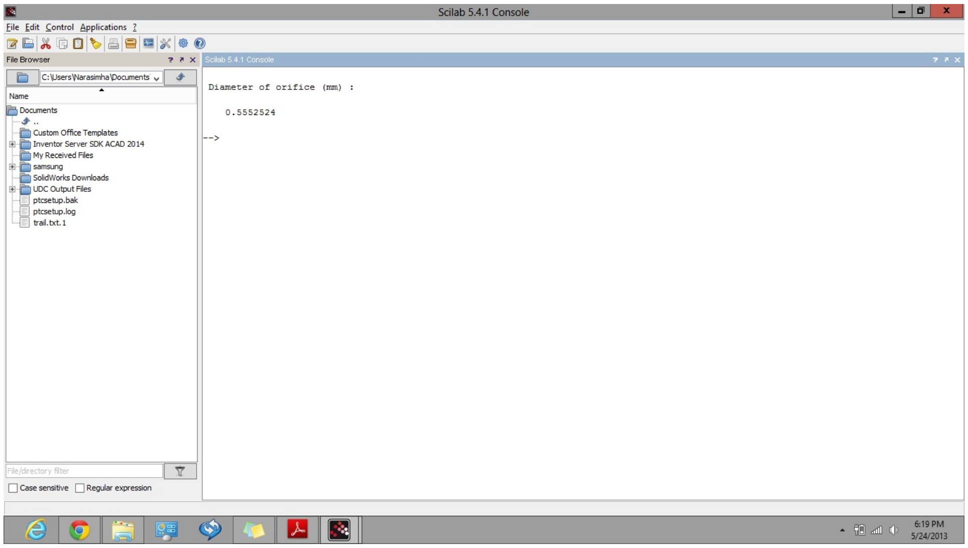


```
Volume of Fuel Injected per Cycle (cm^3):

   0.1289377

Diameter of orifice (mm) :

   0.3977691

-->
```

Figure 12.3: Volume of fuel injected and diameter of Injector

Scilab code Exa 12.3 `Volume of fuel injected and diameter of Injector`

```
clc;funcprot(0);//EXAMPLE 12.3
// Initialisation of Variables
n=1;............//No of cylinders
N=650;............//Engine rpm
theta=28;...........//Crank Travel in degree
fc=2.2;...........//Fuel consumption in kg/h
spgr=0.875;............//Specific Gravity
ip=150;................//Injection Pressure in bar
cp=32;.................//Combustion chamber Pressure
    in bar
Cd=0.88;...............//co-efficient of discharge
   of orifice
rhow=1000;...........//Density of water in kg/m^3
//Calculation
fcpc = fc/60;..............//Fuel consumption per
```



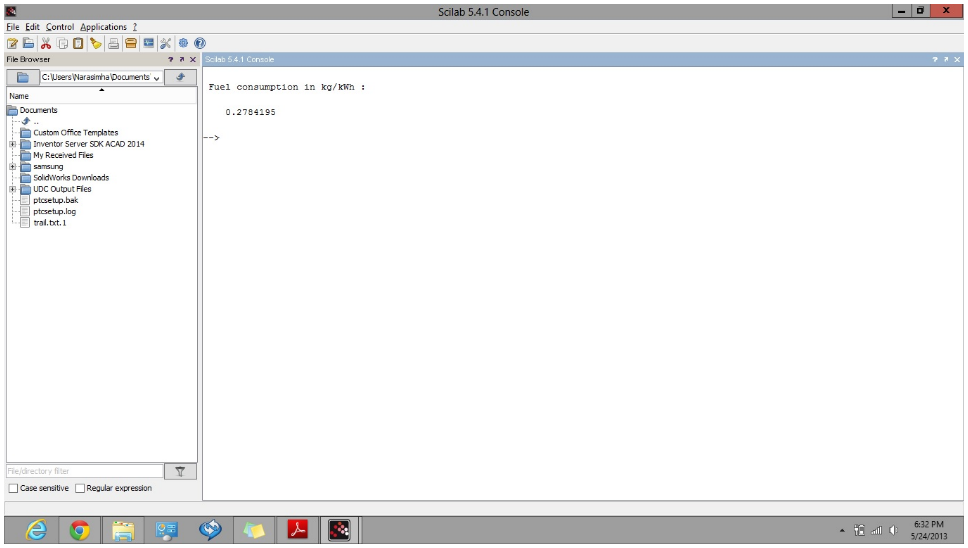
```
Diameter of orifice (mm) :

   0.5552524

-->
```

Figure 12.4: Diameter of injector nozzle

```
    cylinder
fipc = fcpc/(N/2);.........//Fuel Injected per cycle
     in kg
vfpc = fipc/(spgr*rhow);....//volume of fuel
    injected per cycle
disp(vfpc*10^6,"Volume of Fuel Injected per Cycle (
    cm^3):")
tfic=(theta/360)*(60/N);....//Time for Fuel
    Injection per Cycle in sec
mf = fipc/tfic;...............//Mass of fuel
    injected per cycle in kg/s
vf = Cd*sqrt((2*(ip-cp)*10^5)/(spgr*rhow))
    ;.............//Actual fuel velocity of injection
     in m/sec
d=sqrt((mf*4)/(%pi*vf*spgr*rhow))
disp(d*1000,"Diameter of orifice (mm) :")
```

Scilab code Exa 12.4 `Diameter of injector nozzle`

```
clc;funcprot(0);//EXAMPLE 12.4
// Initialisation of Variables
N=2000;............//Engine rpm
theta=30;...........//Crank Travel in degree
sfc=0.272;...........//Fuel consumption in kg/kWh
ip=120;................//Injection Pressure in bar
cp=30;.................//Combustion chamber Pressure in bar
Cd=0.9;...............//co-efficient of discharge of orifice
rhow=1000;...........//Density of water in kg/m^3
api = 32;.............//API in degree
pw=15;.................//Power Output in kW
//Calculation
spgr= 141.5/(131.5+api);...........//Specific Gravity
fcpc = (sfc*pw)/((N/2)*60);.............//Fuel consumption per cycle in kg
tfic=(theta/360)*(60/N);....//Time for Fuel Injection per Cycle in sec
mf = fcpc/tfic;...............//Mass of fuel injected per cycle in kg/s
vf = Cd*sqrt((2*(ip-cp)*10^5)/(spgr*rhow));.............//Actual fuel velocity of injection in m/sec
d=sqrt((mf*4)/(%pi*vf*spgr*rhow))
disp(d*1000,"Diameter of orifice (mm) :")
```

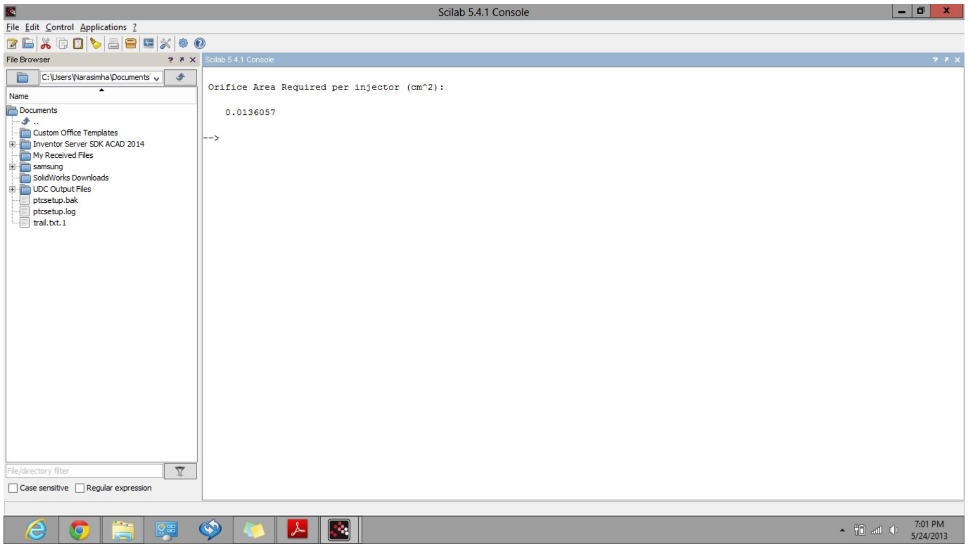


```
Fuel consumption in kg/kWh :

   0.2784195

-->
```

Figure 12.5: Fuel consumption

Scilab code Exa 12.5 `Fuel consumption`

```
clc;funcprot(0);//EXAMPLE 12.5
// Initialisation of Variables
N=1800;............//Engine rpm
theta=32;...........//Crank Travel in degree
ip=118.2;................//Injection Pressure in bar
cp=31.38;.................//Combustion chamber Pressure in bar
Cd=0.9;...............//co-efficient of discharge of orifice
rhow=1000;...........//Density of water in kg/m^3
api = 32;..............//API in degree
pw=11;..................//Power Output in kW
d=0.47;...................//Fuel Injection orifice diameter in mm
//Calculation
spgr= 141.5/(131.5+api);............//Specific Gravity
tfic=(theta/360)*(60/N);....//Time for Fuel
```



```
Orifice Area Required per injector (cm^2):

   0.0136057

-->
```

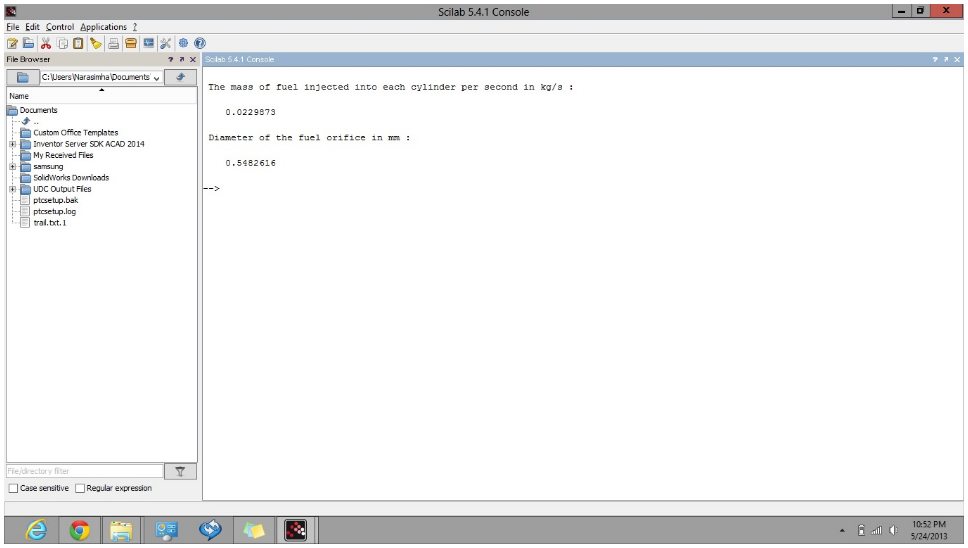
Figure 12.6: Injector orifice area

```
Injection per Cycle in sec
vf = Cd*sqrt((2*(ip-cp)*10^5)/(spgr*rhow));.............//Actual fuel velocity of injection in m/sec
mf=vf*spgr*rhow*(%pi/4)*(d/1000)^2;
tncp=(N/2)*60;...............//Total no of cycles per hour
FIPC=mf*tfic;.................//Mass of fuel injected per cycle in kg/cycle
fc=FIPC*tncp*(1/pw);....................//Fuel consumption in kg/kWh
disp(fc,"Fuel consumption in kg/kWh :")
```

Scilab code Exa 12.6 `Injector orifice area`

```
clc;funcprot(0);//EXAMPLE 12.6
```

```
// Initialisation of Variables
n=8;......//No of cylinders
pw=386.4;...........//Power output in kW
N=800;.............//Engine rpm
fc=0.25;.............//Fuel Consumption in kg/kWh
theta=12;..............//Crank Travel in degree (for injection)
spgr=0.85;...........//Specific Gravity
patm=1.013;............//Atmospheric pressure
cf=0.6;................//Co-efficient of discharge for injector
pcB=32;................//Pressure in cylinder in beginning in bar
piB=207;...............//Pressure in injector in beginning in bar
pcE=55;...............//Pressure in cylinder at the end in bar
piE=595;................//Pressure in injector at the end in bar
rhow=1000;..............//density of water in kg/m^3
//calculations
pwpc = pw/n;......................//Output per cylinder
fcpc = (pwpc*fc)/60;.............//Fuel consumption per cylinder in kg/min
fipc = fcpc/(N/2);................//Fuel injected per cycle in kg
tfic = (theta*60)/(360*N);...........//Time for fuel Injection per cycle
mf = fipc/tfic;......................//Mass of fuel injected per second
pdb = piB-pcB;....................//Pressure difference at beginning
pde = piE-pcE;...................//Pressure difference at end
apd = (pdb+pde)/2;
Ao=mf/(cf*sqrt(2*apd*10^5*spgr*rhow));
disp(Ao*10000,"Orifice Area Required per injector (
```



```
The mass of fuel injected into each cylinder per second in kg/s :

   0.0229873

Diameter of the fuel orifice in mm :

   0.5482616

-->
```

Figure 12.7: Amount of fuel injected and injector diameter

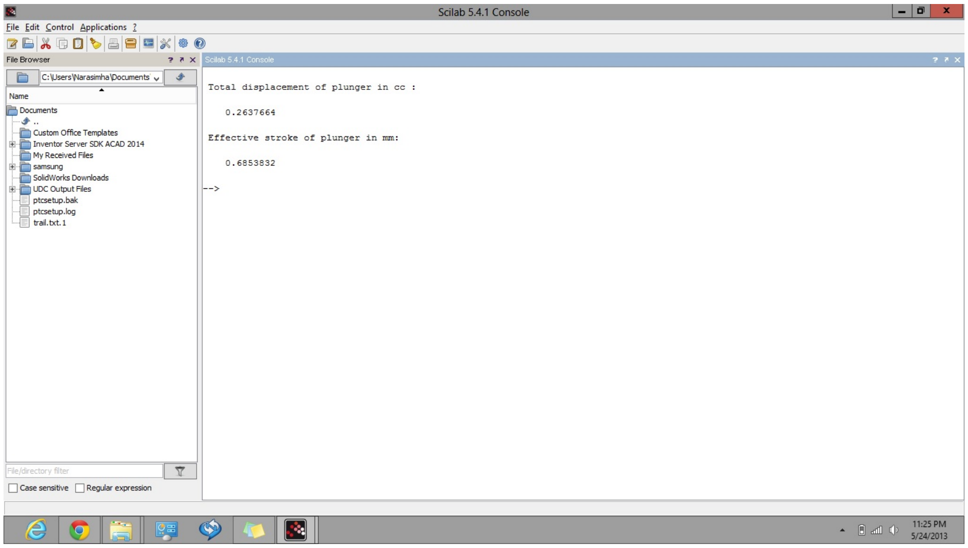
```
    cm^2):")
```

Scilab code Exa 12.7 `Amount of fuel injected and injector diameter`

```
clc;funcprot(0);//EXAMPLE 12.7
// Initialisation of Variables
n=6;...............//No of cylinders
afr=20;...........//Air fuel ratio
d = 0.1;...............//cylinder bore in mm
l=0.14;..............//Cylinder length in mm
etav=0.8;............//Volumetric Efficiency
pa=1;.................//Pressure at the beginning of the compression in bar
ta = 300;.............//Temperature at the beginning of the compression in Kelvin
```

```
theta = 20;................//Crank travel in degree for injection
N = 1500;....................//engine rpm
rhof=960;..................//Fuel density in kg/m^3
cf=0.67;..................//Co efficient of discharge for injector
pi=150;....................//injection pressure in bar
pc=40;....................//combustion pressure in bar
R=287;.......................//gas constant for air in kJ/kg.K
//calculations
V=(%pi/4)*d^2*l*etav;......................//Volume of air supplied per cylinder per cycle in m^3
ma=(pa*10^5*V)/(R*ta);....................//Mass of this air at suction conditions in kg/cycle
mf=ma/afr;............................//Mass of fuel in kg/cycle
fipc = (theta*60)/(360*N);...........//Time taken for fuel injection per cycle in seconds
MF = mf/fipc;........................//Mass of fuel injected into each cylinder per second
disp(MF,"The mass of fuel injected into each cylinder per second in kg/s :")
vf=cf*sqrt((2*(pi-pc)*10^5)/rhof);.............//fuel velocity injection in m/s
d0=sqrt((MF*4)/(%pi*vf*rhof));..................//diameter of fuel orifice in m
disp(d0*1000,"Diameter of the fuel orifice in mm :")
```

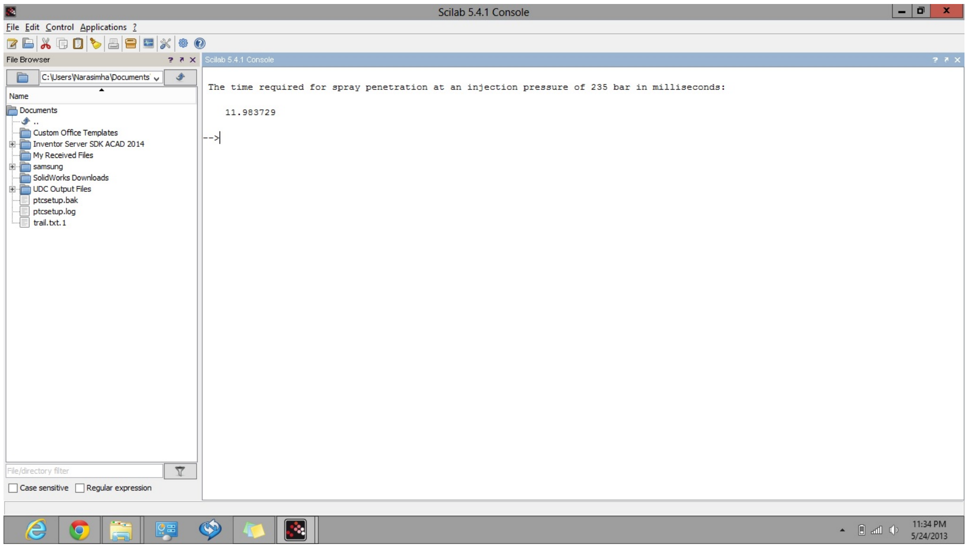
Scilab code Exa 12.8 `Plunger displacement and effective stroke`



```
Total displacement of plunger in cc :

   0.2637664

Effective stroke of plunger in mm:

   0.6853832

-->
```

Figure 12.8: Plunger displacement and effective stroke

```
clc;funcprot(0);//EXAMPLE 12.8
// Initialisation of Variables
Vpbes=7;.................//Volume of fuel in the pump barrel before commencement of effective stroke in cc
df=3;.................//Diameter of fuel line from pump to injector in mm
lf=700;.................//Length of fuel line from pump to injector in mm
Vfiv=2;................//Volume of fuel in the injection valve in cc
Vfd=0.1;.................//Volume of fuel to be delivered in cc
p1=150;..............//Pressure at which fuel is delivered in bar
p2=1;.................//atmospheric pressure in bar
cc=78.8*10^(-6);..........//Co - efficient of compressibility per bar
dp=7;..............//Diameter of plunger in mm
//calculations
```



```
The time required for spray penetration at an injection pressure of 235 bar in milliseconds:

   11.983729

-->
```

Figure 12.9: Calculation of fuel spray time

```
V1=Vpbes+(%pi/4)*((df/10)^2)*(lf/10)+Vfiv;....................//Total initial fuel volume
delV=cc*(p1-p2)*V1;................//Change in volume due to compression
displu=delV+Vfd;......................//Total displacement of plunger
disp(displu,"Total displacement of plunger in cc :")
lp=(displu*4)/(%pi*(dp/10)^2);.............//Effective stroke of plunger
disp(lp,"Effective stroke of plunger in mm:")
```

Scilab code Exa 12.9 `Calculation of fuel spray time`

```
clc;funcprot(0);//EXAMPLE 12.9
// Initialisation of Variables
p1=145;...........//injection pressure in bar
```

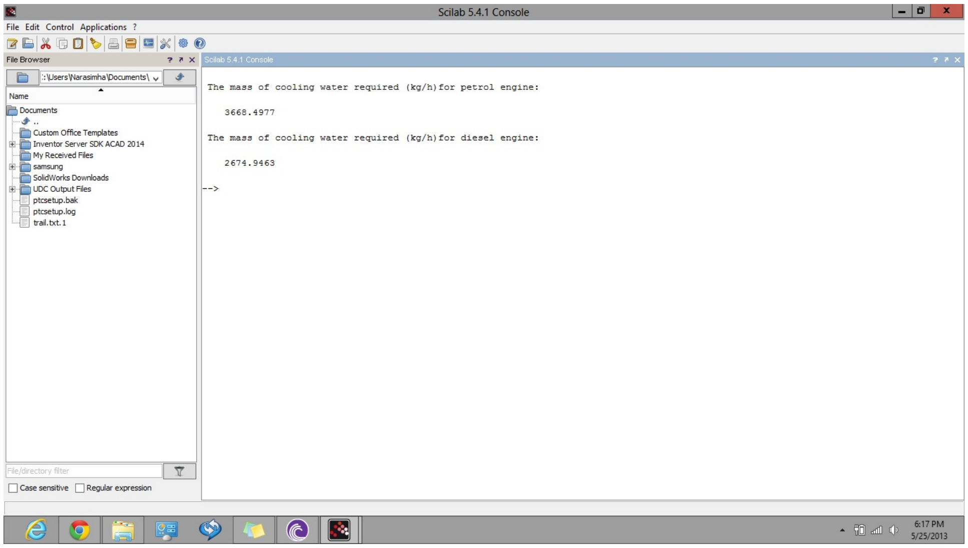
```
p2=235;.........//Injection pressure in bar (2nd
   case)
t1=16;.............//spray penetration time in
   milliseconds
s1=22;................//spray penetration length in
   cm
s2=22;.................//spray penetration length in
    cm (2nd case)
pc=30;.................//combustion chamber pressure
    in bar
//calculations
delp1=p1-pc;
delp2=p2-pc;
t2=(s2/s1)*t1*sqrt(delp1/delp2);..........//Spray
   time in seconds for 2nd case
//Given that s=t*sqrt(delp)
disp(t2,"The time required for spray penetration at
   an injection pressure of 235 bar in milliseconds:
   ")
```

Chapter 15

Engine Cooling

Scilab code Exa 15.1 `Coolant required for petrol and diesel engine`

```
clc;funcprot(0);//EXAMPLE 15.1
// Initialisation of Variables
BP=90;..................//Brake Power in kW
deltw=27;..................//Raise in temperature of water
etaP=0.25;...................//Efficiency of petrol engine
etaD=0.3;....................//Efficiency od diesel engine
Pec=32;......................//Percentage of energy going to coolant in petrol engine
Dec=28;......................//Percentage of energy going to coolant in diesel engine
cp=4.187;..........//specific heat of water at constant pressure
//Calculations
hsP = BP/etaP;...........//Heat supplied in kW or kJ/s
ecP=hsP*(Pec/100);.............//Energy going to
```

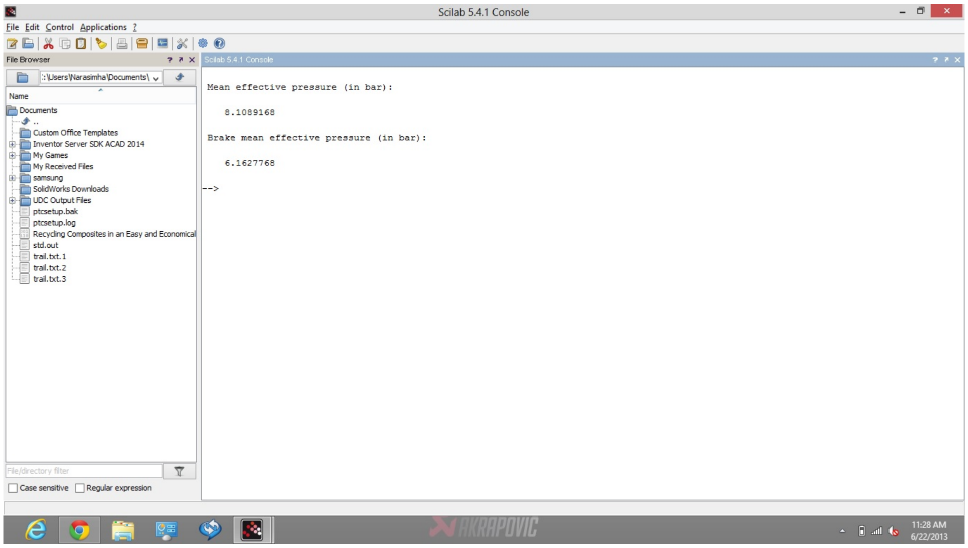


```
The mass of cooling water required (kg/h)for petrol engine:

   3668.4977

The mass of cooling water required (kg/h)for diesel engine:

   2674.9463

-->
```

Figure 15.1: Coolant required for petrol and diesel engine

```
    cooling water in kg/s
mwP=ecP/(cp*deltw);.............//Mass of cooling
    water required
hsD = BP/etaD;............//Heat supplied in kW or
    kJ/s
ecD=hsD*(Dec/100);.............//Energy going to
    cooling water in kg/s
mwD=ecD/(cp*deltw);.............//Mass of cooling
    water required
disp(mwP*3600,"The mass of cooling water required (
    kg/h)for petrol engine:")
disp(mwD*3600,"The mass of cooling water required (
    kg/h)for diesel engine:")
```

Scilab code Exa 17.28 `Indicated mean effective pressure and brake mean effective p`



```
Mean effective pressure (in bar):

   8.1089168

Brake mean effective pressure (in bar):

   6.1627768

-->
```

Figure 15.2: Indicated mean effective pressure and brake mean effective pressure

```
clc;funcprot(0);//EXAMPLE 17.28
// Initialisation of Variables
D=0.2;.................//Engine bore in m
L=0.25;...............//Engine stroke in m
n=2;.......................//No of cylinders
r=13;.....................//Compression ratio
fc=14;..................//Fuel consumption in kg/h
N=300;...................//Engine rpm
etarel=0.65;..............//Relative efficiency
etamech=0.76;.............//Mechanical efficiency
co=0.05;.....................//Cut off of the stroke
C=41800;.....................//Calorific value of fuel in kJ/kg
k=1;.........................//Two stroke engine
ga=1.4;........................//Degree of freedom
//calculations
rho=1+(co*(r-1));
etast=1-((1/(r^(ga-1)))*(1/ga)*((rho^ga)-1)*(1/(rho-1)));............//Air standard efficiency
```

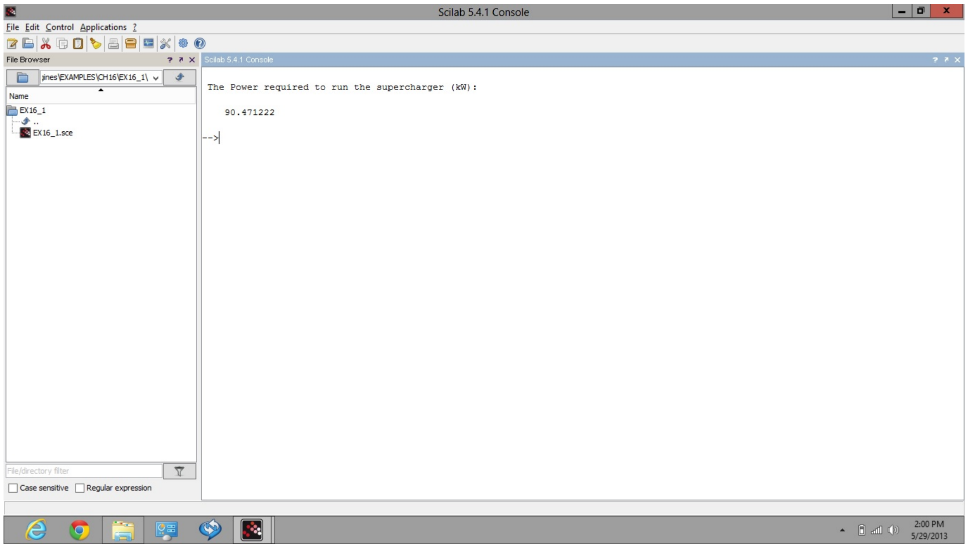
```
etath=etarel*etast;........................//Thermal efficiency
IP=etath*(fc/3600)*C;........................//Indicated power in kW
BP=etamech*IP;................................//Brake power in kW
pmi=(6*IP)/(n*N*L*(%pi/4)*D*D*k*10);............//mean effective pressure in bar
disp(pmi,"Mean effective pressure (in bar):")
pmb=pmi*etamech;...........................//Brake mean effective pressure in bar
disp(pmb,"Brake mean effective pressure (in bar):")
```

Chapter 16

Supercharging of IC Engines

Scilab code Exa 16.1 Power supplied to supercharger

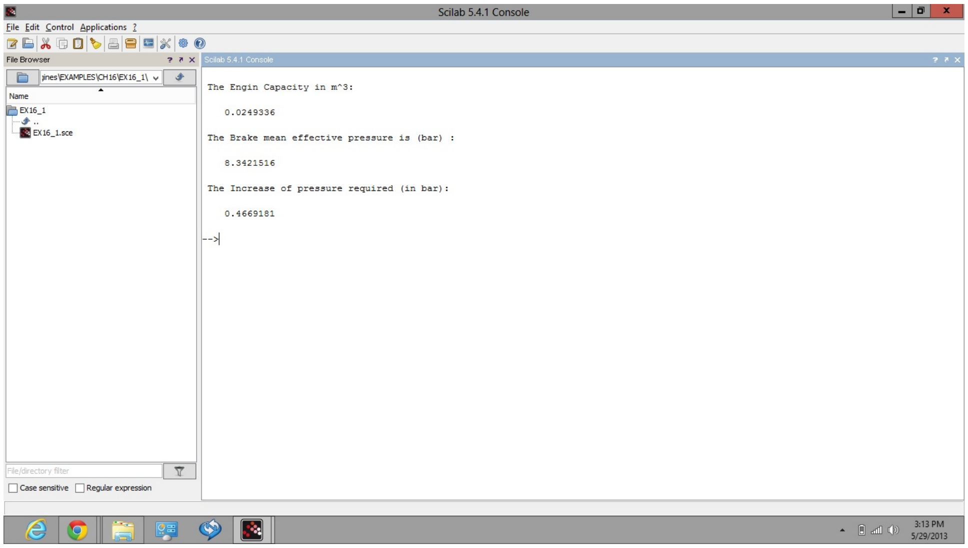
```
clc;funcprot(0);//EXAMPLE 16.1
// Initialisation of Variables
pwu=735;............//Power developed by naturally aspirated engine in kW
afru=12.8;.............//Air fuel ratio for naturally aspirated engine
bsfc=0.350;......//Brake specific fuel consumption in kg/kWh
metau=0.86;..........//Mechanical efficiency of naturally aspirated engine
pi=730;...........//Inlet pressure in mm of Hg absolute
tm=325;...........//Mixture temperature in Kelvin
pr=1.6;.............//Pressure ratio of supercharged engine
etaa=0.7;.............//Adiabatic efficiency of supercharged engine
metas=0.9;..............//Mechanical efficiency of supercharged engine
```



```
The Power required to run the supercharger (kW):

   90.471222

-->
```

Figure 16.1: Power supplied to supercharger

```
afrs=12.8;.............//Air fuel ratio for supercharged engine
rhohg=13600;.............//Density of mercury in kg/mˆ3
R=0.287;...................//Gas constant in kJ/kgK
ga=1.4;................//Degree of freedom for gas
cp=1.005;..................//Specific heat of the fuel
g=9.81;................//Acceleration due to gravity in m/sˆ2
//calculations
t2=tm*(pr)^((ga-1)/ga);..............//Ideal temperature for the supercharged engine
t2a=tm+(t2-tm)/etaa;................//Actual temperature for the supercharged engine
wa=cp*(t2a-tm);.....................//Work of the supercharger
wsup=cp*(t2a-tm)/metas;..............//Work required to drive the supercharger in kJ/kg of air
//When unsupercharged
```



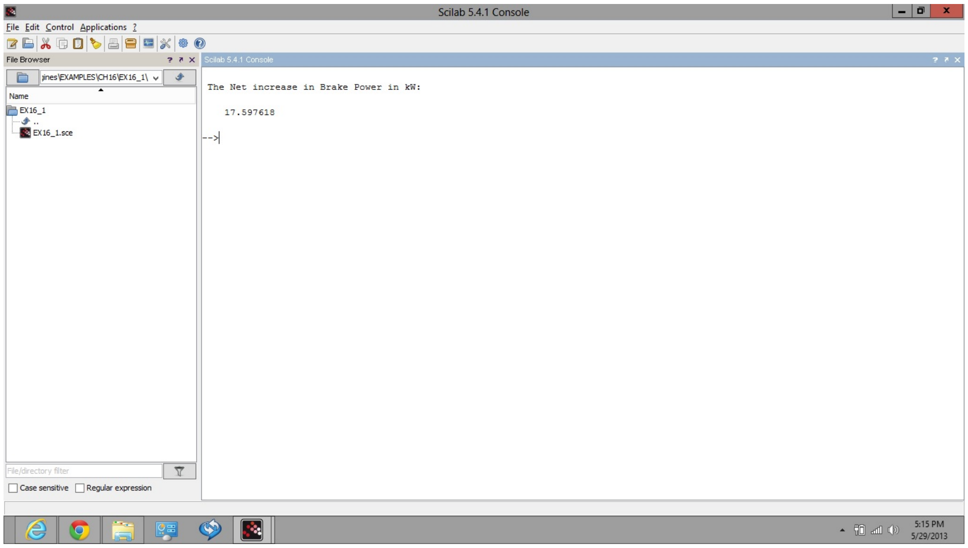
```
The Engin Capacity in m^3:

   0.0249336

The Brake mean effective pressure is (bar) :

   8.3421516

The Increase of pressure required (in bar):

   0.4669181

-->
```

Figure 16.2: Engine Capacity and Brake Mean effective Pressure

```
p1=(pi/1000)*((g*rhohg)/1000);...............//Inlet pressure in kN/m^2
rhounsup=p1/(R*tm);
maunsup=(bsfc*pwu*afrs)/3600;....................//Air consumption in kg/s for unsupercharged engine
//When supercharged
rhosup=(pr*p1)/(R*t2a);
masup=maunsup*(rhosup/rhounsup);...................//Air consumption in kg/s
Psup=masup*wsup;................//Power required to run the supercharger in kW
disp(Psup,"The Power required to run the supercharger (kW):")
```

Scilab code Exa 16.2 `Engine Capacity and Brake Mean effective Pressure`

```
clc;funcprot(0);//EXAMPLE 16.2
// Initialisation of Variables
p1=1.0132;..............//Mean pressure at sea level in bar
t1=283;.................//Mean temperature at sea level in Kelvin
BP=260;.....................//Brake Power output in kW
etaV=0.78;..................//Volumetric efficiency at sea level free air condition
sfc=0.247;............//Specific Fuel consumption in kg/kW.h
afr=17;...................//Air fuel ratio
N=1500;...................//Engine rpm
at=2700;.................//Altitude in mts
p2=0.72;.................//Pressure in bar at the given altitude
Psup=0.08;.................//8% power of engine is taken by the supercharger
R=287;..................//Gas constant in J/kgK
t2=32+273;..............//Temperature in Kelvin at the given altitude
//calculations
mf=(sfc*BP)/60;............//Fuel consumption in kg/min
ma = mf*afr;..................//Air consumption in ig/min
acps = ma/(N/2);...........//Air consumption per stroke in kg
Vs=(acps*R*t1)/(etaV*p1*10^5);................//Engine capacity in m^3
disp(Vs,"The Engin Capacity in m^3:")
pmb=(BP*6)/(Vs*10*(N/2));........//Brake Mean Effective Pressure in bar
disp(pmb,"The Brake mean effective pressure is (bar):")
gp=BP/(1-Psup);.................//Gross power produced by supercharged engine in kW
```



```
The Net increase in Brake Power in kW:

   17.597618

-->
```

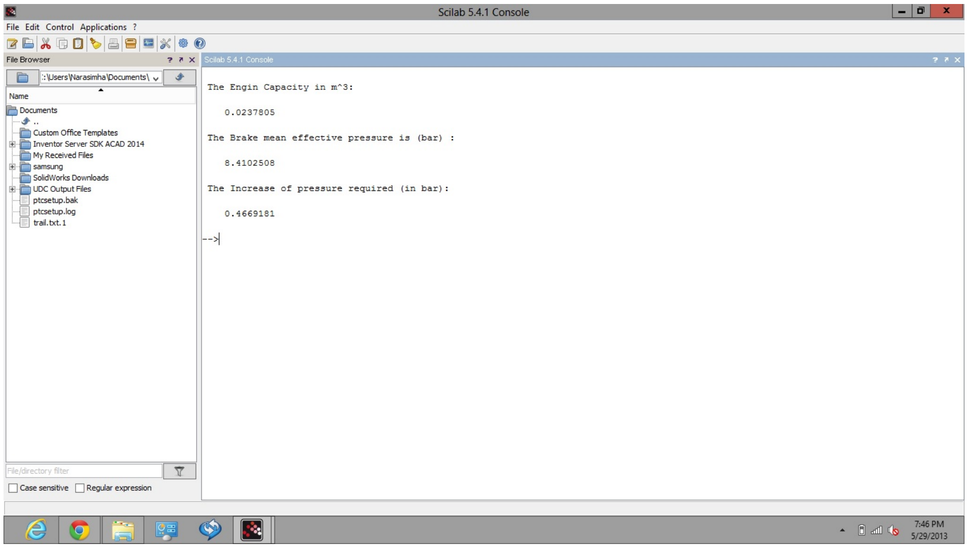
Figure 16.3: Increase in Brake Power due to supercharger

```
masup=ma*gp/BP;......................//Mass of air required for supercharged engine in kg
matc=masup/(N/2);..............//Mass of air taken per cycle
pressure=(matc*R*t2)/(etaV*10^5*Vs);
disp(pressure-p2,"The Increase of pressure required (in bar):")
```

Scilab code Exa 16.3 `Increase in Brake Power due to supercharger`

```
clc;funcprot(0);//EXAMPLE 16.3
// Initialisation of Variables
ec=3600*10^(-6);.............//Engine capacity in m^3
pw=13;...............//Power developed in kW per m^3 of free air induced per minute
```

```
etaV=0.82;............//Volumetric Efficiency
N=3000;................//Engine rpm
p1=1.0132;...........................//Initial Air pressure in bar
t1=298;........................//Initial Temperature in Kelvin
pr=1.8;.....................//Pressure ratio in rotary compressor
etaC=0.75;.................//Isentropic efficiency of compressor
etaM=0.8;....................//Mechanical efficiency
ga=1.4;.....................//Degree of freedom for the gas
td=4;.......................//The amount by which the temperature is kess than delivery temperature from compressor
R=287;......................//Gas constant in J/kg.K
cp=1.005;.....................//Specific heat capacity
//Calculations
Vs=(ec*N)/2;....................//Swept volume in m^3/min
Vu=Vs*etaV;....................//Unsupercharged volume induced per min
rcdp=pr*p1;........//Rotary compressor delivery pressure
t2=t1*(pr)^((ga-1)/ga);..............//Ideal temperature for the supercharged engine
t2a=t1+(t2-t1)/etaC;................//Actual temperature for the supercharged engine
ta=t2a-td;............................//Temperature of air at intake to the engine cylinder
V1=(rcdp*Vs*t1)/(p1*ta);.................//Equivalent volume at 1.0132 bar and 298 K
Vinc=V1-Vs;...........................//Increase in induced Volume of air in m^3/min
ipincai=pw*Vinc;.......................//Increase in IP from air induced in kW
```



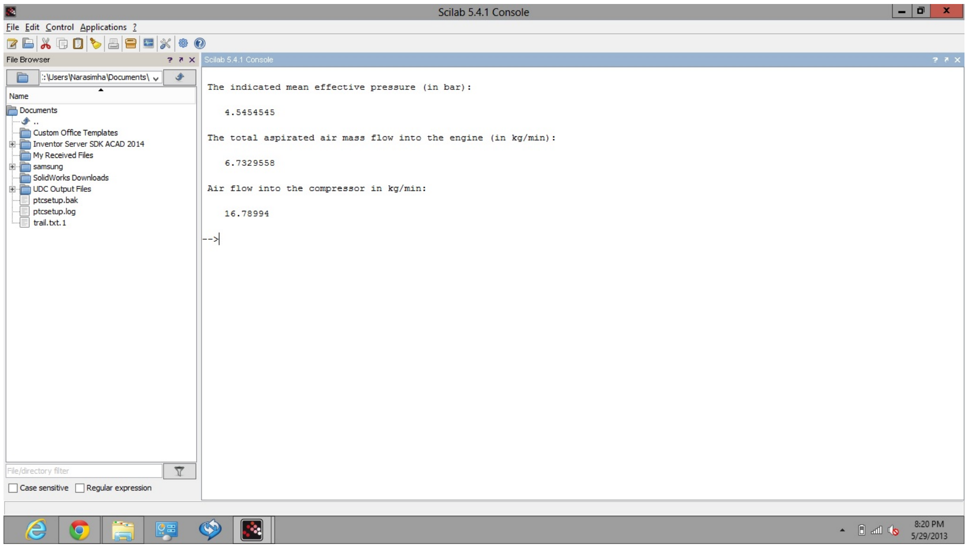
```
The Engin Capacity in m^3:

   0.0237805

The Brake mean effective pressure is (bar) :

   8.4102508

The Increase of pressure required (in bar):

   0.4669181

-->
```

Figure 16.4: Engine Capacity and Brake Mean effective Pressure

```
ipinciip=((rcdp-p1)*10^5*Vs)/(60*1000);...........//Increase in IP due to increased induction pressure kW
ipinctot=ipincai+ipinciip;...............//Total increase in Input Power in kW
bpinc=ipinctot*etaM;....................//Increase in Brake Power of the engine in kW
ma=(rcdp*10^5*Vs)/(60*R*ta);...................//Mass of air delivered by the compressor kg/s
pc=(ma*cp*(t2a-t1))/etaM;....................//Power required by the compressor
bpincnet=bpinc-pc;..........................//Net Increase in BP
disp(bpincnet,"The Net increase in Brake Power in kW :")
```

Scilab code Exa 16.4 Engine Capacity and Brake Mean effective Pressure

```
clc;funcprot(0);//EXAMPLE 16.4
// Initialisation of Variables
p1=1.0132;..............//Mean pressure at sea level in bar
t1=283;................//Mean temperature at sea level in Kelvin
BP=250;....................//Brake Power output in kW
etaV=0.78;..................//Volumetric efficiency at sea level free air condition
sfc=0.245;............//Specific Fuel consumption in kg/kW.h
afr=17;...................//Air fuel ratio
N=1500;...................//Engine rpm
at=2700;..................//Altitude in mts
p2=0.72;................//Pressure in bar at the given altitude
Psup=0.08;.................//8% power of engine is taken by the supercharger
R=287;...................//Gas constant in J/kgK
t2=32+273;..............//Temperature in Kelvin at the given altitude
//calculations
mf=(sfc*BP)/60;............//Fuel consumption in kg/min
ma = mf*afr;..................//Air consumption in ig/min
acps = ma/(N/2);............//Air consumption per stroke in kg
Vs=(acps*R*t1)/(etaV*p1*10^5);................//Engine capacity in m^3
disp(Vs,"The Engin Capacity in m^3:")
pmb=(BP*6)/(Vs*10*(N/2));........//Brake Mean Effective Pressure in bar
disp(pmb,"The Brake mean effective pressure is (bar):")
```



```
The indicated mean effective pressure (in bar):

   4.5454545

The total aspirated air mass flow into the engine (in kg/min):

   6.7329558

Air flow into the compressor in kg/min:

   16.78994

-->
```

Figure 16.5: Compressor run by supercharged Engine

```
gp=BP/(1-Psup);..................//Gross power produced by supercharged engine in kW
masup=ma*gp/BP;......................//Mass of air required for supercharged engine in kg
matc=masup/(N/2);..............//Mass of air taken per cycle
pressure=(matc*R*t2)/(etaV*10^5*Vs);
disp(pressure-p2,"The Increase of pressure required (in bar):")
```

Scilab code Exa 16.5 `Compressor run by supercharged Engine`

```
clc;funcprot(0);//EXAMPLE 16.5
// Initialisation of Variables
t1=298;.................//Temperature of the air while entering the compressor in Kelvin
```

```
qrej=1210;..............//Amount of heat rejected in cooler in kJ/min
t2=273+65;...............//Temperature of the air leaving the cooler in Kelvin
p2=1.75;.................//Pressure of the air leaving the cooler in bar
n=6;.....................//No of cylinders
d=0.1;...................//Bore of the cylinder in m
l=0.11;..................//Stroke of the cylinder in m
etaV=0.72;................//volumetric efficiency
N=2000;...............//Engine rpm
Tout=150;..................//Torque Output in Nm
etaM=0.8;..................//Mechanical efficiency
R=287;.......................//Gas constant for air in J/kgK
cp=1.005;...................//Specific capacity of air
//calculations
BP=(2*%pi*N*Tout)/(60*1000);...........//Brake power in kW
IP=BP/etaM;..........//Input Power in kW
Vc=(%pi/4)*d*d*l;...................//Cylinder Volume in m^3
pmi=(6*IP)/(n*Vc*(N/2)*10);................//Indicated mean effective pressure
disp(pmi,"The indicated mean effective pressure (in bar):")
Vs=Vc*6*(N/2);.........................//Engine Swept Volume in m^3/min
Vaa=Vs*etaV;..........................//Aspirated volume of air into engine in m^3/min
maa=(p2*10^5*Vaa)/(R*t2);..............//Aspirated air mass flow into the engine in kg/min
disp(maa,"The total aspirated air mass flow into the engine (in kg/min):")
t2a=((((BP/cp)/(qrej/(60*cp)))*t2)-t1)/(((BP/cp)/(qrej/(60*cp)))-1);
```

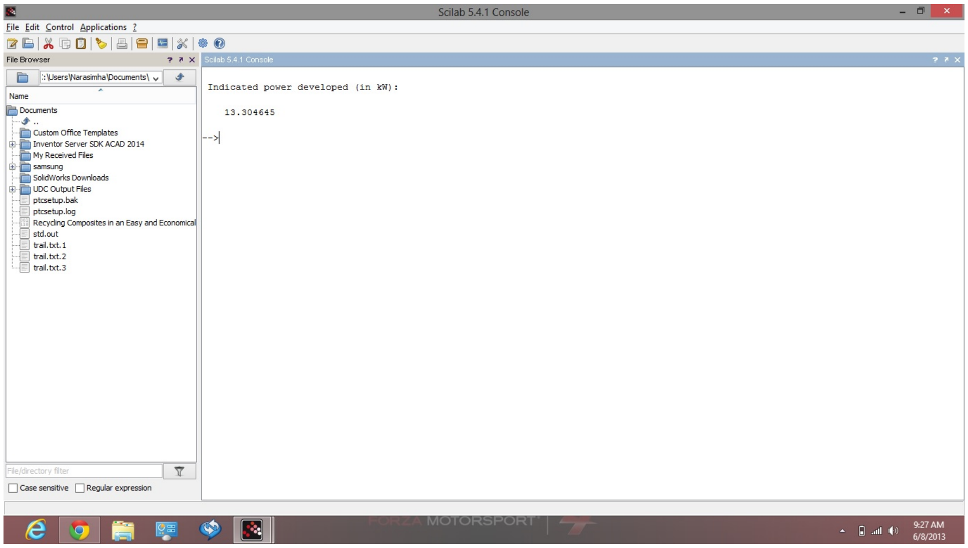
```
mc=((BP/cp)/(t2a-t1))*60;........................//Air flow into the compressor in kg/min
disp(mc,"Air flow into the compressor in kg/min:")
```

Chapter 17

Testing and Performance of IC Engines

Scilab code Exa 17.1 `Indicated power`

```
clc;funcprot(0);//EXAMPLE 17.1
// Initialisation of Variables
Pmi=6;......................//Mean effective pressure in bar
N=1000;....................//Engine rpm
d=0.11;....................//Diameter of piston in m
l=0.14;....................//Stroke length in m
n=1;.......................//No of cylinders
k=1;.......................//k=1 for two stroke engine
//Calculations
V=l*(%pi/4)*d*d;............//Volume of the cylinder in m^3
IP=(n*Pmi*V*k*10*N)/6;........//Indicated Power developed in kW
disp(IP,"Indicated power developed (in kW):")
```

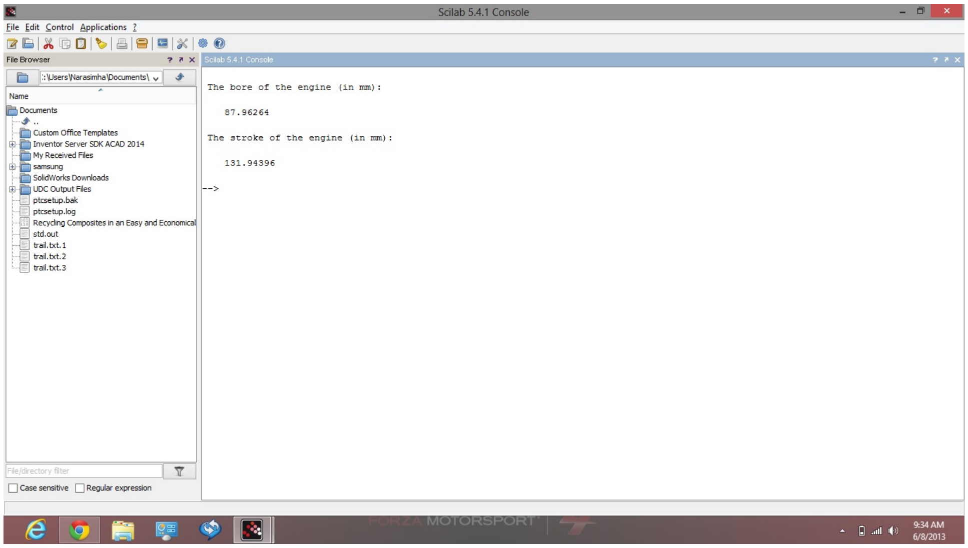


```
Indicated power developed (in kW):

   13.304645

-->
```

Figure 17.1: Indicated power

Scilab code Exa 17.2 `Bore and Stroke of engine`

```
clc;funcprot(0);//EXAMPLE 17.2
// Initialisation of Variables
n=4;........................//No of cylinders
P=14.7;....................//Power developed in kW
N=1000;....................//Engine speed in rpm
Pmi=5.5;....................//Mean effective pressure in bar
lbyd=1.5;...................//Ratio of stroke to bore
k=0.5;.......................//For four stroke engine
//Calculations
```



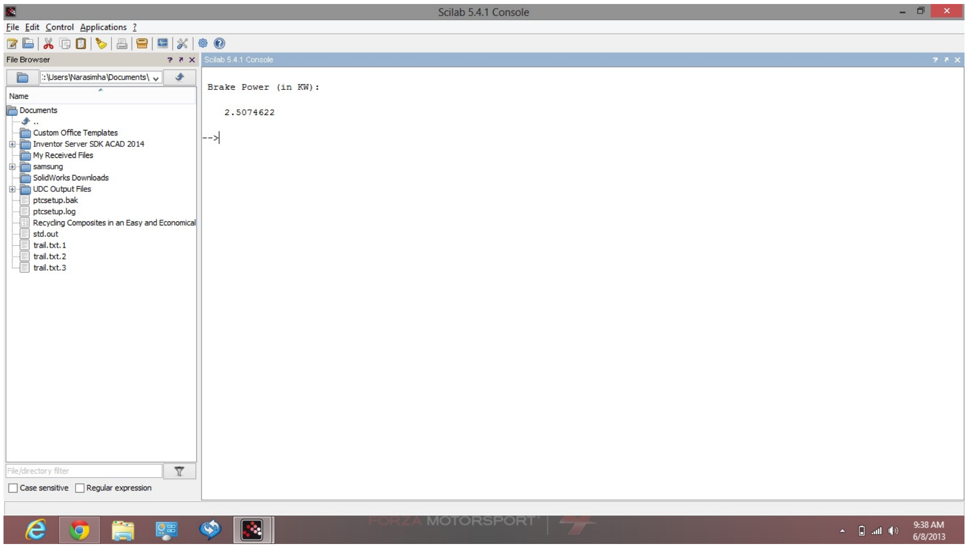
```
The bore of the engine (in mm):

   87.96264

The stroke of the engine (in mm):

   131.94396

-->
```

Figure 17.2: Bore and Stroke of engine

```
d=((P*6)/(n*Pmi*N*k*10*(%pi/4)*lbyd))^(1/3);......................//Calculation of bore in m
l=lbyd*d;...............................//Calculation of stroke in m
disp(d*1000,"The bore of the engine (in mm):")
disp(l*1000,"The stroke of the engine (in mm):")
```

Scilab code Exa 17.3 `Brake power`

```
clc;funcprot(0);//EXAMPLE 17.3
// Initialisation of Variables
Db=0.6;.....................//Diameter of the brake wheel in m
d=0.026;.....................//Diameter of the rope in m
```



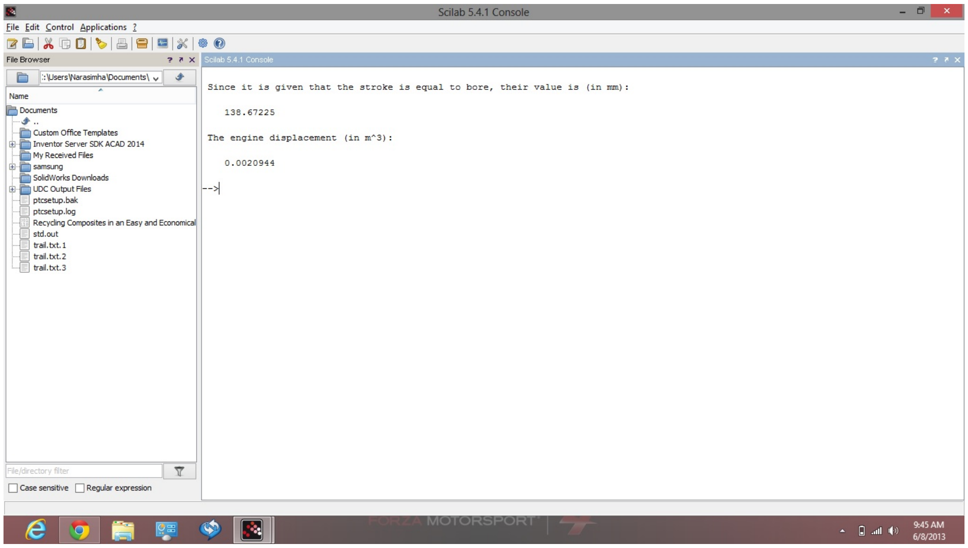
```
Brake Power (in KW):

   2.5074622

-->
```

Figure 17.3: Brake power

```
W=200;........................//Dead load on the brake in N
S=30;.......................//Spring balance reading in N
N=450;.......................//Engine speed in rpm
//Calculations
BP=((W-S)*%pi*(Db+d)*N)/(60*1000);...............//Brake Power in KW
disp(BP,"Brake Power (in KW):")
```

Scilab code Exa 17.4 `Engine displacement`

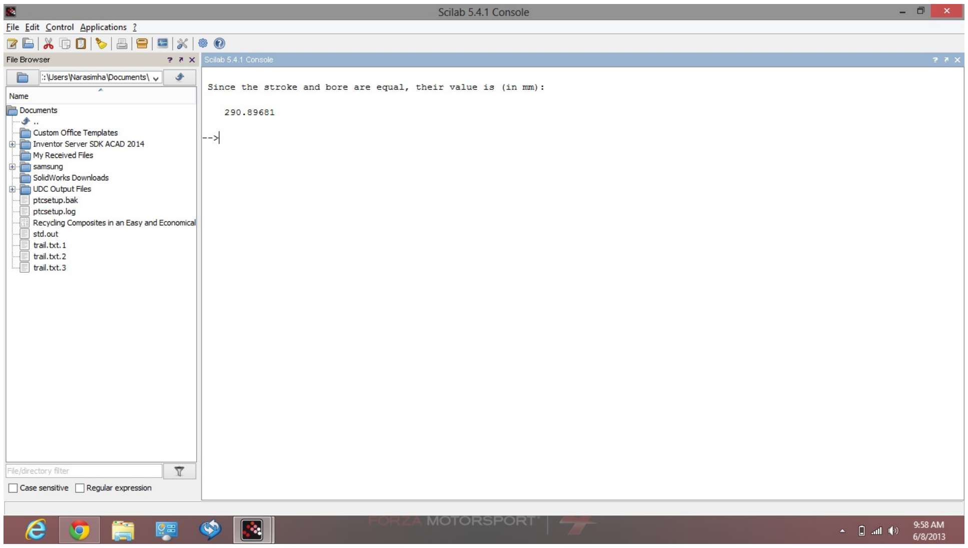
```
clc;funcprot(0);//EXAMPLE 17.4
// Initialisation of Variables
n=4;........................//No of cylinders
k=0.5;.......................//For four stroke engine
```



```
Since it is given that the stroke is equal to bore, their value is (in mm):

   138.67225

The engine displacement (in m^3):

   0.0020944

-->
```

Figure 17.4: Engine displacement

```
Tb=160;......................//Max brake torque in Nm
N=3000;.......................//Engine rpm
Pm=9.6;.....................//Brake mean effective pressure in bar
//Calculations
D=((2*%pi*N*Tb*6)/(60*1000*Pm*(%pi/4)*N*k*10))^(1/3);......................//Bore of engine in m
L=D;....................//Given that the stroke is equal to bore
Disp=(%pi/4)*D*D*L;.......................................//Displacement in m^3
disp(D*1000,"Since it is given that the stroke is equal to bore, their value is (in mm):    ")
disp(Disp,"The engine displacement (in m^3):")
```

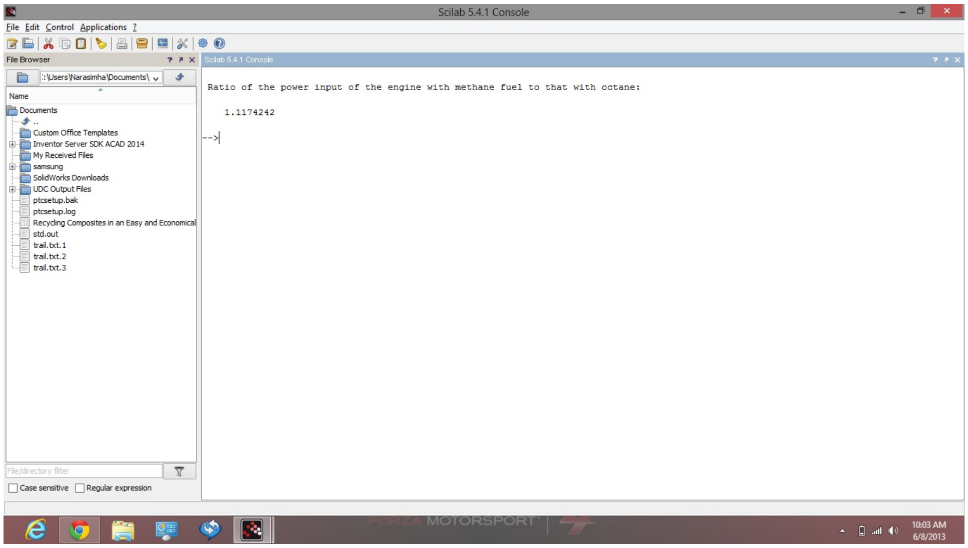


```
Since the stroke and bore are equal, their value is (in mm):

   290.89681

-->
```

Figure 17.5: Bore and stroke

Scilab code Exa 17.5 `Bore and stroke`

```
clc;funcprot(0);//EXAMPLE 17.5
// Initialisation of Variables
n=6;.....................//No of cylinders
Pmb=6;....................//Brake mean effective pressure in bar
N=1000;..................//Engine rpm
k=0.5;.......................//For four stroke engine
Wce=820;.................//Work during compression and expansion in kW
Wie=50;..................//Work during intake and exhaust in kW
f=150;......................//Rubbing friction in engiine in kW
WnetT=40;...................//Net work done by turbine in kW
//Calculations
BP=Wce-(Wie+f+WnetT);.....................//Net work
```



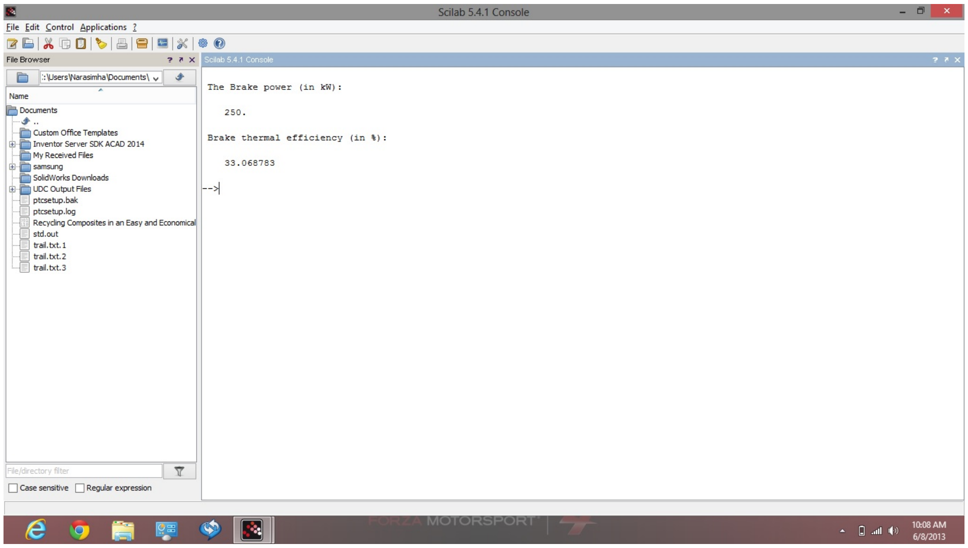
```
Ratio of the power input of the engine with methane fuel to that with octane:

   1.1174242

-->
```

Figure 17.6: Ratio of power output when using different fuels

```
     available or brake power in kW
D=((BP*6)/(n*Pmb*(%pi/4)*N*k*10))^(1/3)
    ;......................//Bore of engine in m
L=D;.........................................//Given
     that bore is equal to stroke
disp(D*1000,"Since the stroke and bore are equal,
    their value is (in mm):")
```

Scilab code Exa 17.6 `Ratio of power output when using different fuels`

```
clc;funcprot(0);//EXAMPLE 17.6
// Initialisation of Variables
Cm=50150;............................//Heating value
     of methane in kJ/kg
Co=44880;............................//Heating value
     of octane in kJ/kg
```



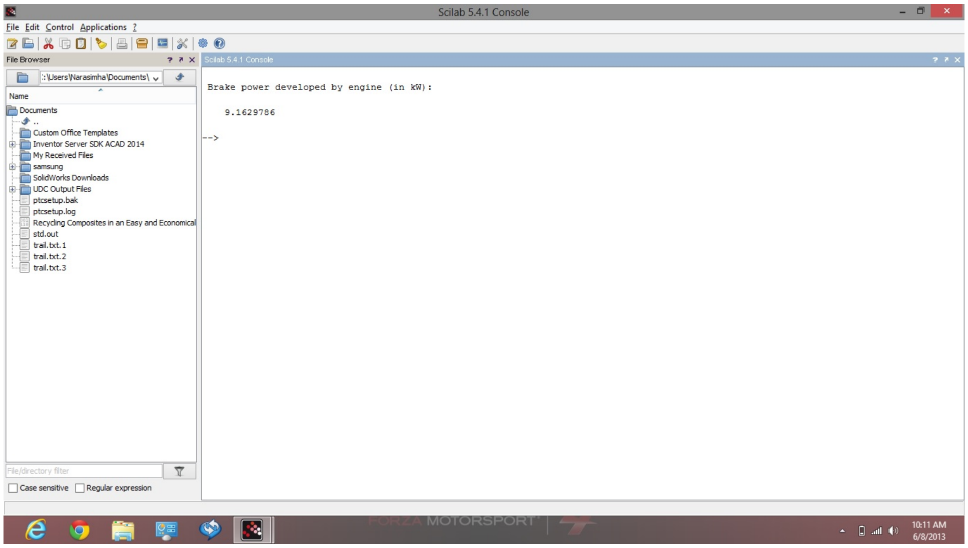
```
The Brake power (in kW):

   250.

Brake thermal efficiency (in %):

   33.068783

-->
```

Figure 17.7: Brake power and brake thermal efficiency

```
//Calculations
//Since Energy supplied is proportional to mass of fuel supplied time calorific value of the fuel supplied
ratioP=Cm/Co;.........................//Ratio of the power input of the engine with methane fuel to that with octane
disp(ratioP,"Ratio of the power input of the engine with methane fuel to that with octane:")
```

Scilab code Exa 17.7 `Brake power and brake thermal efficiency`

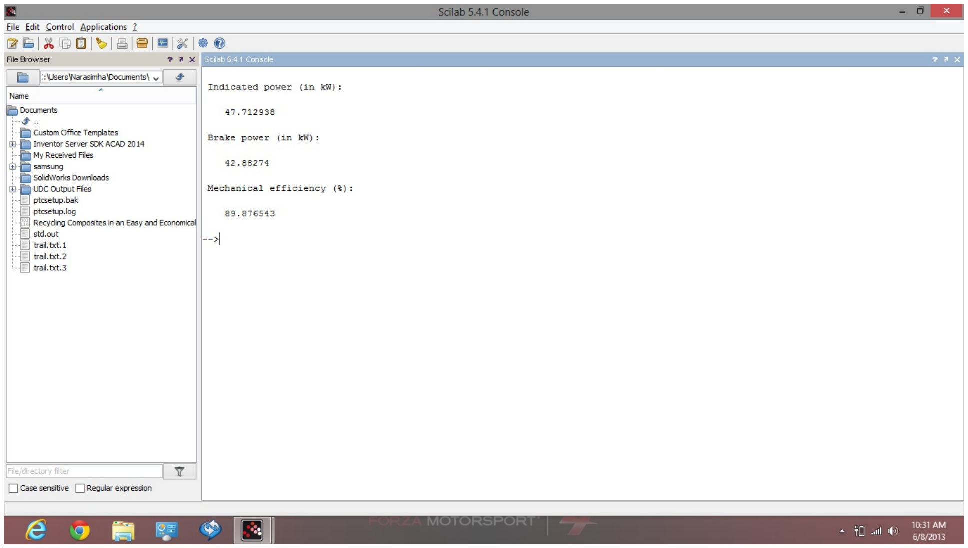
```
clc;funcprot(0);//EXAMPLE 17.7
// Initialisation of Variables
N=2000;...........................//Engine rpm
```



```
Brake power developed by engine (in kW):

   9.1629786

-->
```

Figure 17.8: Brake power

```
k=0.5;..............................//Four stroke engine
Disp=0.025;........................//Engine displacement in m^3
Pmb=6;..............................//Brake mean effective pressure in bar
mf=0.018;...........................//Fuel consumption in kg/s
Cf=42000;...........................//Calorific value of fuel in kJ/kg
//Calcuations
BP=(Pmb*Disp*N*k*10)/(6);................//Brake power in kW
etaBT=BP/(mf*Cf);.................//Brake thermal efficiency
disp(BP,"The Brake power (in kW):")
disp(etaBT*100,"Brake thermal efficiency (in %):")
```



```
Indicated power (in kW):

   47.712938

Brake power (in kW):

   42.88274

Mechanical efficiency (%):

   89.876543

-->
```

Figure 17.9: Indicated power and brake power and mechanical efficiency

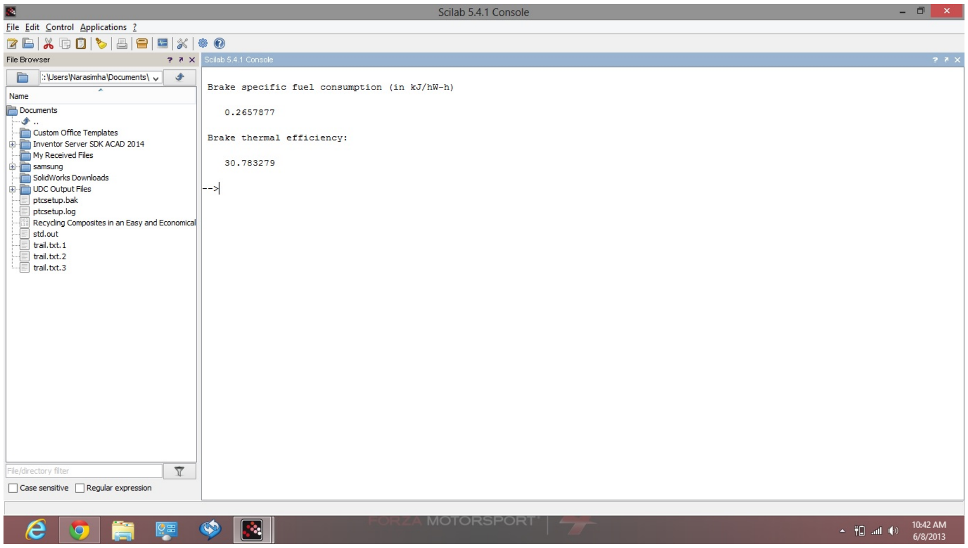
Scilab code Exa 17.8 Brake power

```
clc;funcprot(0);//EXAMPLE 17.8
// Initialisation of Variables
T=175;........................//Torque due to brake load in Nm
N=500;..........................//Engine speed in rpm
//calcuations
BP=(2*%pi*N*T)/(60*1000);.......................//Brake power developed by engine in kW
disp(BP,"Brake power developed by engine (in kW):")
```

Scilab code Exa 17.9 Indicated power and brake power and mechanical efficiency

```
clc;funcprot(0);//EXAMPLE 17.9
// Initialisation of Variables
D=0.3;.............................//Bore of engine cylinder in m
L=0.45;............................//Stroke of engine cylinder in m
N=300;.............................//Engine rpm
Pmi=6;.............................//Indicated mean effective pressure in bar
Nbl=1.5;...........................//Net brake load in kN
Db=1.8;............................//Diameter of brake drum in m
d=0.02;............................//Brake rope diameter
k=0.5;.............................//Four stroke engine
n=1;...............................//No of cylinders
//Calculations
IP=(n*Pmi*L*(%pi/4)*D*D*N*k*10)/6;......................//Indicated power in kW
BP=(Nbl*%pi*(Db+d)*N)/60;...............................//Brake power in kW
etam=BP/IP;.............................................//Mechanical efficiency
disp(IP,"Indicated power (in kW):")
disp(BP,"Brake power (in kW):")
disp(etam*100,"Mechanical efficiency (%):")
```

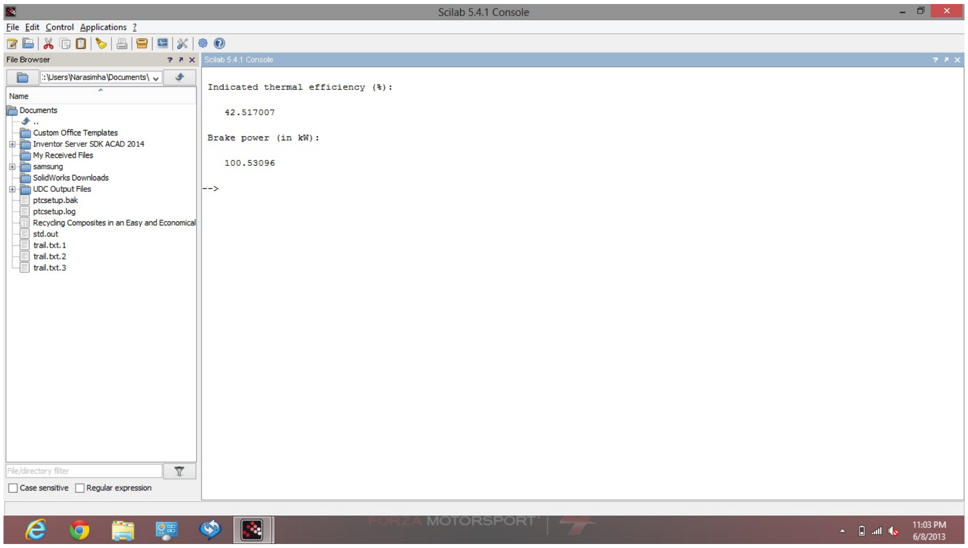
Scilab code Exa 17.10 `BSFC and brake thermal efficiency`



```
Brake specific fuel consumption (in kJ/hW-h)

   0.2657877

Brake thermal efficiency:

   30.783279

-->
```

Figure 17.10: BSFC and brake thermal efficiency

```
clc;funcprot(0);//EXAMPLE 17.10
// Initialisation of Variables
Db=0.7;..............................//Diameter of brake pulley in m
d=0.025;.............................//Diameter of the rope in m
W=50;................................//Load on the tight side of the rope in kg
S=50;................................//Spring balance reading in N
N=900;...............................//Engine rpm
mf=4;................................//Rate of fuel consumption in kg/h
C=44000;.............................//Calorific value of fuel in kJ/kg
g=9.81;..............................//Acceleration due to gravity in m/s^2
//Calculations
BP=(((W*g)-S)*%pi*(Db+d)*N)/(60*1000);........................//Brake power in kW
```



```
Indicated thermal efficiency (%):

   42.517007

Brake power (in kW):

   100.53096

-->
```

Figure 17.11: Indicated thermal efficiency and brake power

```
bsfc=mf/BP;.............................................//Brake specific fuel consumption in kJ/hW-h
disp(bsfc,"Brake specific fuel consumption (in kJ/hW-h)")
etathB=(BP*3600)/(mf*C);.........................................//Brake thermal efficiency
disp(etathB*100,"Brake thermal efficiency:")
```

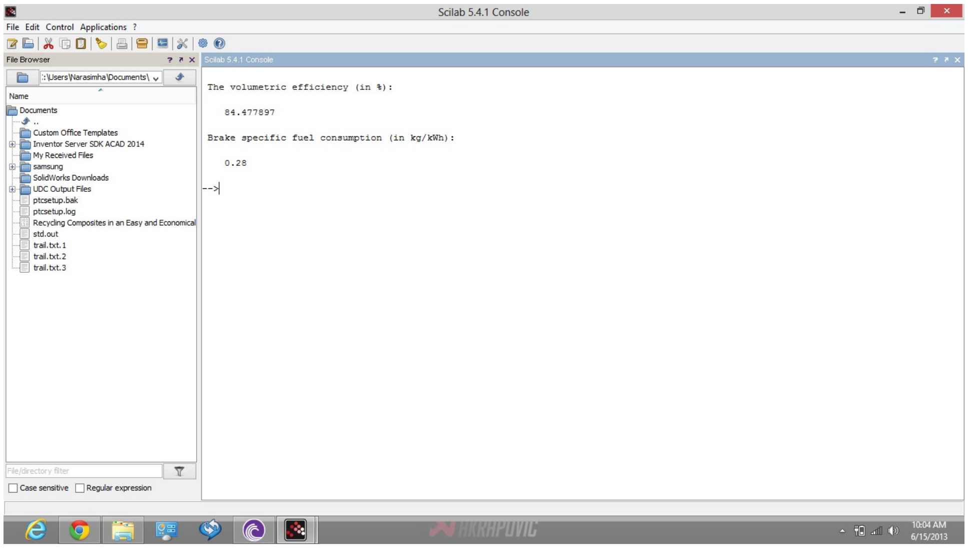
Scilab code Exa 17.11 `Indicated thermal efficiency and brake power`

```
clc;funcprot(0);//EXAMPLE 17.11
// Initialisation of Variables
n=4;......................//No of cylinders
k=0.5;....................//Four stroke engine
```

```
r=8;.......................//Compression ratio
d=0.1;.....................//Engine bore in m
l=0.1;.....................//Engine stroke in m
etaV=0.75;.................//Volumetric efficiency
N=4800;....................//Engine rpm
afr=15;....................//Air fuel ratio
C=42000000;................//Calorific value of fuel
rhoa=1.12;.................//Atmospheric density in
   kg/m^3
Pmi=10;....................//Mean effective pressure
    in bar
etamech=0.8;...............//Mechanical efficiency
//Calculations
IP=(n*Pmi*l*(%pi/4)*d*d*N*k*10)/6;.................
   //Indicated power in kW
Ac=n*(%pi/4)*d*d*l*(N/2)*(etaV/60)
   ;....................//Air consumption in m^3/s
ma=Ac*rhoa;.........................................
   //Mass flow of air in kg/s
mf=ma/afr;..........................................
   //Mass flow of fuel in kg/s
etath=(IP*1000)/(mf*C)
   ;...................................//Indicated
   thermal efficiency
disp(etath*100,"Indicated thermal efficiency (%):")
BP=IP*etamech;......................................
   //Brake Power in kW
disp(BP,"Brake power (in kW):")
```

Scilab code Exa 17.12 `Volumetric efficiency and BSFC`

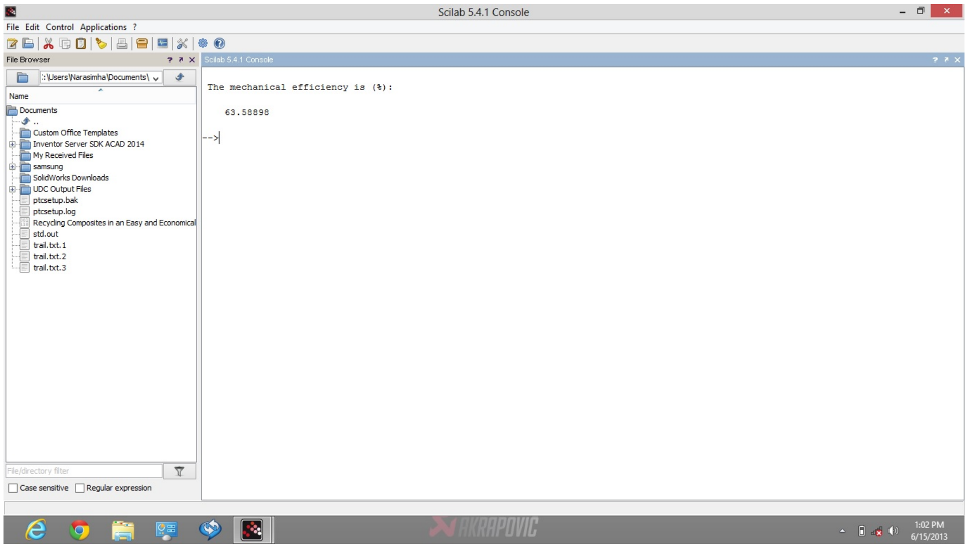
```
clc;funcprot(0);//EXAMPLE 7.12
// Initialisation of Variables
```



```
The volumetric efficiency (in %):

   84.477897

Brake specific fuel consumption (in kg/kWh):

   0.28

-->
```

Figure 17.12: Volumetric efficiency and BSFC

```
N=1800;..................//Engine rpm
l=0.11;..................//Engine stroke in m
d=0.085;.................//Engine bore in m
ma=0.56;.................//Air flow rate in kg/min
BP=6;....................//Brake power developed in kW
afr=20;..................//Air fuel ratio
C=42550;.................//Calorific value of fuel in kJ/kg
rhof=1.18;...............//Density of fuel in kg/m^3
//calculations
V=(%pi/4)*d*d*l*(N/2);.....................//Volume displacemt in m^3/min
Ma=V*rhof;.................................//Mass of air in kg/min
etaV=ma/Ma;................................//Volumetric efficiency
fc=ma/afr;.................................//Fuel concumption
```



```
The mechanical efficiency is (%):

   63.58898

-->
```

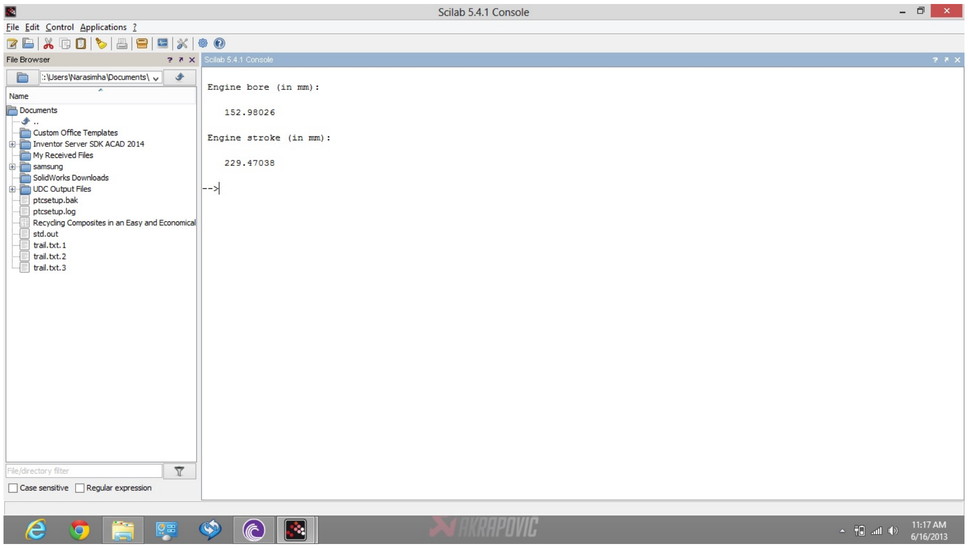
Figure 17.13: Mechanical efficiency

```
bsfc=(fc*60)/BP;...........................//Brake specific fuel consumption in kg/kWh
disp(etaV*100,"The volumetric efficiency (in %):")
disp(bsfc,"Brake specific fuel consumption (in kg/kWh):")
```

Scilab code Exa 17.13 `Mechanical efficiency`

```
clc;funcprot(0);//EXAMPLE 17.13
// Initialisation of Variables
pmicover=6.5;....................//Mean effective pressure on cover side in bar
pmicrank=7;......................//Mean effective pressure on crank side in bar
D=0.2;...........................//Engine bore in m
```

```
l=0.35;..........................//Engine stroke in m
drod=0.02;.........................//Diameter of piston rod in m
W=1370;............................//Dead load on the brake in N
S=145;.............................//Spring balance reading in N
Db=1.2;............................//Brake wheel diameter in m
d=0.02;............................//Brake rope diameter in m
k=0.5;.............................//Four stroke engine
N=420;.......................//Engine rpm
//calculations
Acover=(%pi/4)*D*D;......................//Area of cylinder on the cover side in m^2
Acrank=(%pi/4)*((D^2)-(drod^2));..........//Effective area of cylinder on the crank end side in m^2
IPcover=(pmicover*l*Acover*N*k*10)/6;................//Indicated power on the cover end side in kW
IPcrank=(pmicrank*l*Acrank*N*k*10)/6;................//Indicated power on the crank end side in kW
IPtotal=IPcover+IPcrank;....................//TOtal
BP=((W-S)*%pi*(Db+d)*N)/(60*1000);...................//Brake power in kW
etamech=BP/IPtotal;..................................//Mechanical efficiency
disp(etamech*100,"The mechanical efficiency is (%):")
```



```
Engine bore (in mm):

  152.98026

Engine stroke (in mm):

  229.47038

-->
```

Figure 17.14: Engine bore and stroke

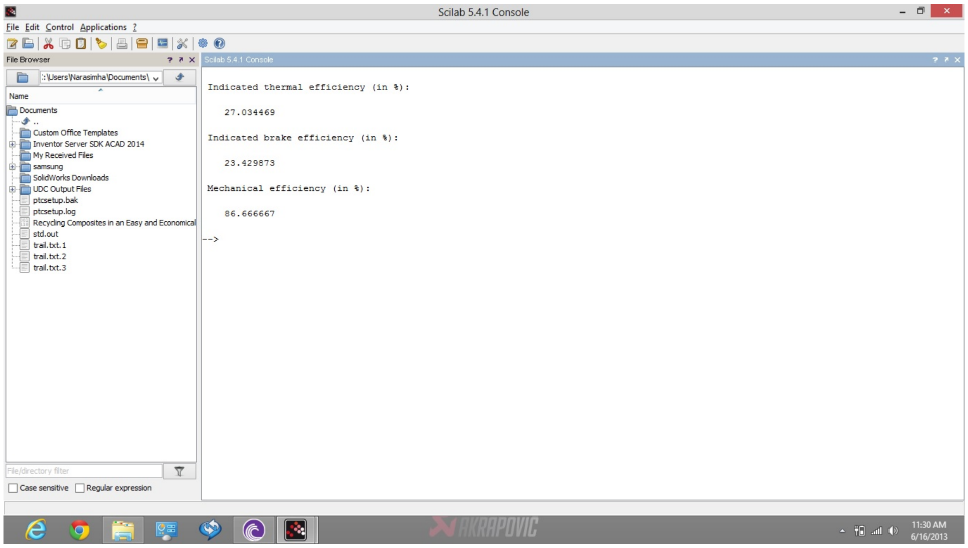
Scilab code Exa 17.14 `Engine bore and stroke`

```
clc;funcprot(0);//EXAMPLE 17.14
// Initialisation of Variables
BP=14.7;.........................//Brake power in kW
p1=0.9;.........................//Suction pressure in bar
etamech=0.8;....................//Mechanical efficiency
r=5;............................//Compression ratio
p3=24;..........................//maximum explosion pressure in bar
N=1000;.........................//Engine rpm
rld=1.5;........................//Ratio of length and stroke
```

```
ic=1.35;.........................//Index of compression curve
ie=1.3;..........................//Index of expansion curve
k=0.5;...........................//Four stroke engine
//calculations
p2=(r^ic)*p1;.......................//intermediate pressure (in bar) during compression
p4=p3/(r^ie);.......................//Intermediate pressure (in bar) during expansion
pm=((((p3-r*p4)/(ie-1))-((p2-p1*r)/(ic-1)))*(10^5))/(r-1);...........//Mean effective pressure in N/m^2
pmb=pm/100000;..........................................//Mean effective pressure in bar
IP=BP/etamech;..........................................//Indicated power in kW
D=((IP*6*4)/(pmb*rld*(%pi)*N*k*10))^(1/3);............//Engine bore in m
L=rld*D;................................................//Engine stroke in m
disp(D*1000,"Engine bore (in mm):")
disp(L*1000,"Engine stroke (in mm):")
```

Scilab code Exa 17.15 `Indicated thermal efficiency and brake thermal efficiency an`

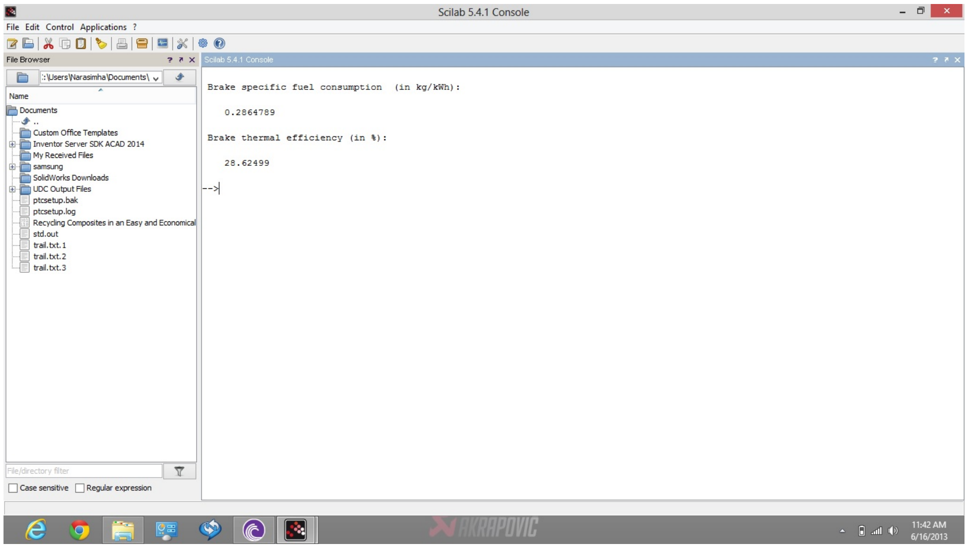
```
clc;funcprot(0);//EXAMPLE 17.15
//Initialisation of Variables
IP=30;..........................//Indicated power in kW
```



```
Indicated thermal efficiency (in %):

   27.034469

Indicated brake efficiency (in %):

   23.429873

Mechanical efficiency (in %):

   86.666667

-->
```

Figure 17.15: Indicated thermal efficiency and brake thermal efficiency and mechanical efficiency

```
BP=26;........................//Brake power in kW
N=1000;.......................//Engine rpm
fpbph=0.35;...................//Fuel per brake power hour in kg/B.P.h
C=43900;......................//Calorific value of fuel used in kJ/kg
//Calculations
mf=BP*fpbph;.............//Fuel consumption per hour in kg/h
etaIth=IP/((mf/3600)*C);.................//Indicated thermal efficiency
etaBth=BP/((mf/3600)*C);.................//Indicated brake efficiency
etamech=BP/IP;...........................//Mechanical efficiency
disp(etaIth*100,"Indicated thermal efficiency (in %):")
disp(etaBth*100,"Indicated brake efficiency (in %):")
```



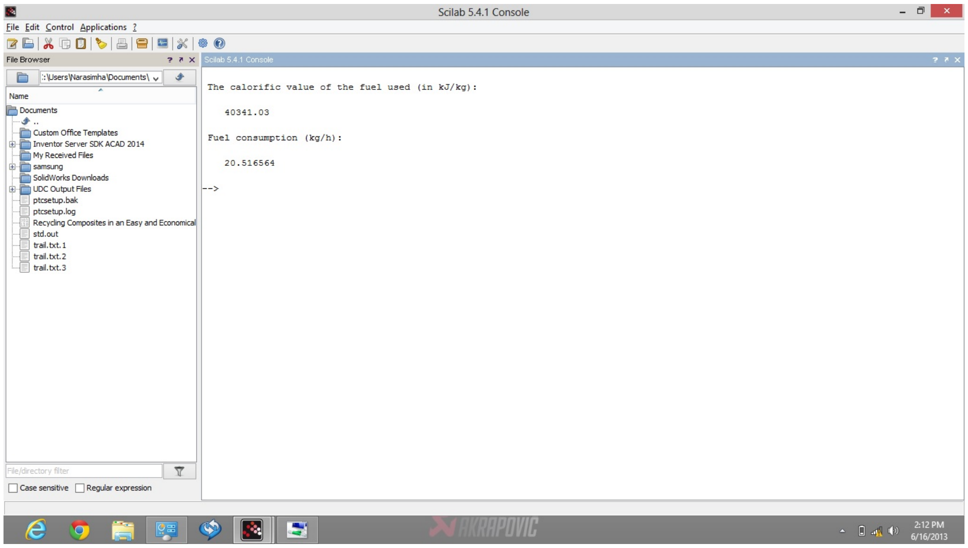
```
Brake specific fuel consumption  (in kg/kWh):

   0.2864789

Brake thermal efficiency (in %):

   28.62499

-->
```

Figure 17.16: BSFC and brake thermal efficiency

```
disp(etamech*100,"Mechanical efficiency (in %):")
```

Scilab code Exa 17.16 `BSFC and brake thermal efficiency`

```
clc;funcprot(0);//EXAMPLE 17.16
//Initialisation of Variables
Db=0.75;.....................//Diameter of brake pulley in m
d=0.05;......................//Rope diameter in m
W=400;.......................//Dead load in N
S=50;........................//Spring balance reading in N
cf=4.2;......................//Consumption of fuel in kg/h
N=1000;......................//Engine rpm
```



```
The calorific value of the fuel used (in kJ/kg):

   40341.03

Fuel consumption (kg/h):

   20.516564

-->
```

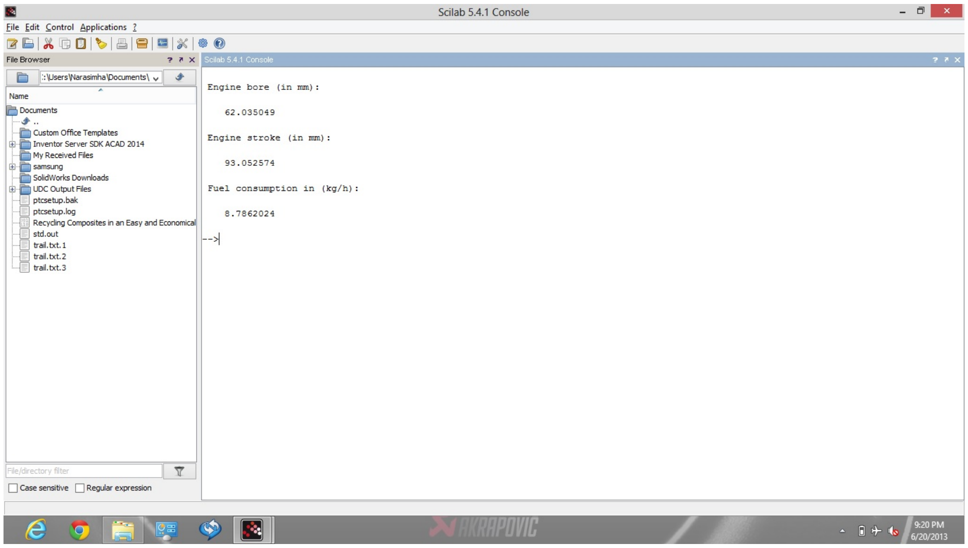
Figure 17.17: Fuel consumption and calorific value of fuel

```
C=43900;......................//Calorific value of fuel in kJ/kg
//Calculations
BP=((W-S)*%pi*(Db+d)*N)/(60*1000);...............//Brake power in kW
bsfc=cf/BP;......................................//Brake specific fuel consumption in kg/kWh
etabth=BP/((cf/3600)*C);.........................//Brake thermal efficiency
disp(bsfc,"Brake specific fuel consumption (in kg/kWh):")
disp(etabth*100,"Brake thermal efficiency (in %):")
```

Scilab code Exa 17.17 `Fuel consumption and calorific value of fuel`

```
clc;funcprot(0);//EXAMPLE 17.17
```

```
//Initialisation of Variables
n=6;.............................//No of cylinders
D=0.09;..........................//Bore of cylinder in m
L=0.1;...........................//Stroke length in m
r=7;.............................//Compression ratio
etarel=0.55;.....................//Relative efficiency
isfc=0.3;........................//Indicated specific fuel consumption in kg/kWh
imep=8.6;........................//Indicated mean effective pressure in bar
N=2500;..........................//Engine speed
ga=1.4;..........................//Degree of freedom for air
k=0.5;...........................//Four stroke engine
//calculations
etastan=1-1/(r^(ga-1));.......................//Air standard efficiency
etath=etarel*etastan;.........................//Indicated thermal efficiency
C=3600/(etath*isfc);...........................//Calorific value of fuel in kJ/kg
IP=(n*imep*L*D*D*(%pi/4)*N*k*10)/6;.....................//Indicated power in kW
fc=IP*isfc;.................................//Fuel consumption in kg/h
disp (C,”The calorific value of the fuel used (in kJ/kg):”)
disp(fc,”Fuel consumption (kg/h):”)
```

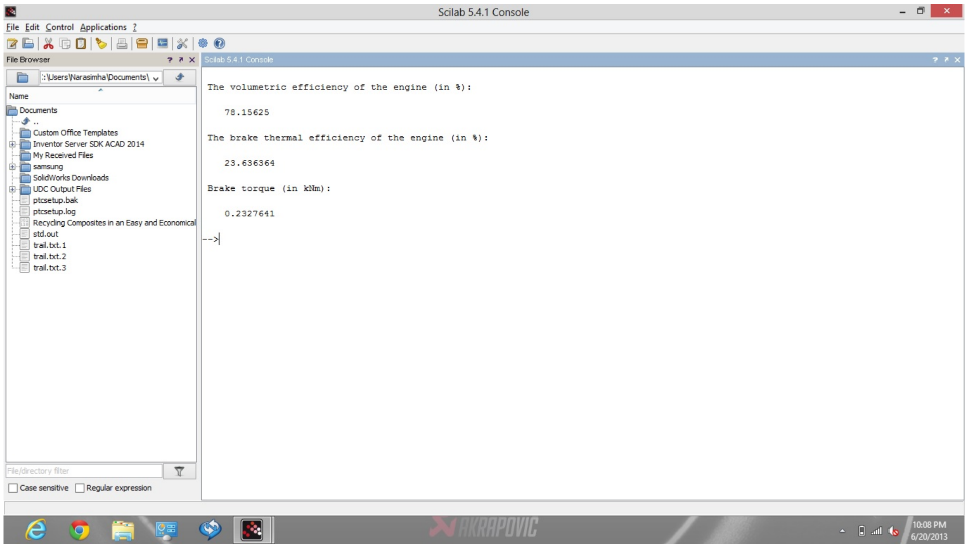


```
Engine bore (in mm):

   62.035049

Engine stroke (in mm):

   93.052574

Fuel consumption in (kg/h):

   8.7862024

-->
```

Figure 17.18: Engine bore and stroke and Fuel consumption

Scilab code Exa 17.18 `Engine bore and stroke and Fuel consumption`

```
clc;funcprot(0);//EXAMPLE 17.18
// Initialisation of Variables
BP=30;........................//Brake power in kW
pmi=8;........................//Mean effective
    pressure in bar
etamech=0.8;....................//Mechanical
    efficiency
n=4;...........................//No of cylinders
N=2500;........................//Engine rpm
rld=1.5;.......................//Ratio of length
    and stroke
etabth=0.28;.....................//Brake thermal
    efficiency
k=1;..........................//Two stroke engine
C=43900;.......................//Calorific value
    of fuel in kJ/kg
//calculations
IP=BP/etamech
```



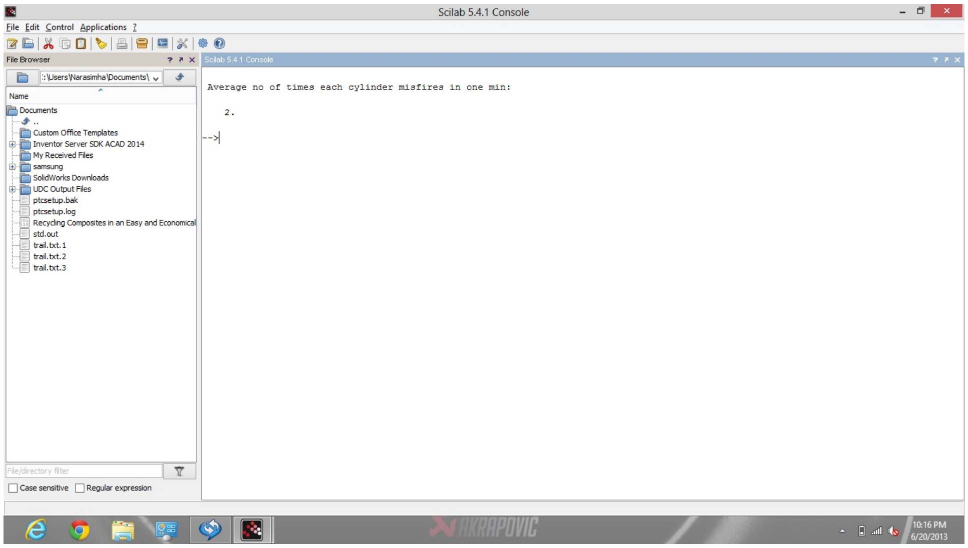
```
The volumetric efficiency of the engine (in %):

   78.15625

The brake thermal efficiency of the engine (in %):

   23.636364

Brake torque (in kNm):

   0.2327641

-->
```

Figure 17.19: Volumetric efficiency and brake thermal efficiency and brake torque

```
;.....................................//Indicated power in kW
D=((IP*6*4)/(pmi*n*rld*(%pi)*N*k*10))^(1/3);............//Engine bore in m
L=rld*D;...........................................//Engine stroke in m
disp(D*1000,"Engine bore (in mm):")
disp(L*1000,"Engine stroke (in mm):")
mf=BP/(etabth*C);.............................//Fuel consumption in kg/s
disp(mf*3600,"Fuel consumption in (kg/h):")
```

Scilab code Exa 17.19 `Volumetric efficiency and brake thermal efficiency and brake`

```
clc;funcprot(0);//EXAMPLE 17.19
// Initialisation of Variables
n=6;.......................//No of cylinders
pdpc=700*10^(-6);..................//Piston displacement per cylinder in m^3
P=78;.............................//Power developed in kW
N=3200;..............................//Engine rpm
mf=27;..............................//Fuel consumption in kg/h
C=44000;............................//Calorific value of fuel in kJ/kg
afr=12;...............................//Air fuel ratio
p1=0.9;...........................//Intake air pressure
pa=p1;
t1=305;................................//Intake air temperature
ta=t1;
R=0.287;......................//Gas constant in kJ/kgK
//Calculations
ma=afr*mf;.............................//maaa of air in kg/h
Va=(ma*R*t1)/(p1*100);.............//Volume of air intake in m^3/h
Vs=pdpc*n*(N/2)*60;......................//Swept volume in m^3/h
etaV=Va/Vs;..............................//Volumetric efficiency
disp(etaV*100,"The volumetric efficiency of the engine (in %):")
etabt=P/(mf*(C/3600));....................//Brake thermal efficiency
disp(etabt*100,"The brake thermal efficiency of the engine (in %):")
Tb=(P*60)/(2*%pi*N);...........................//
```



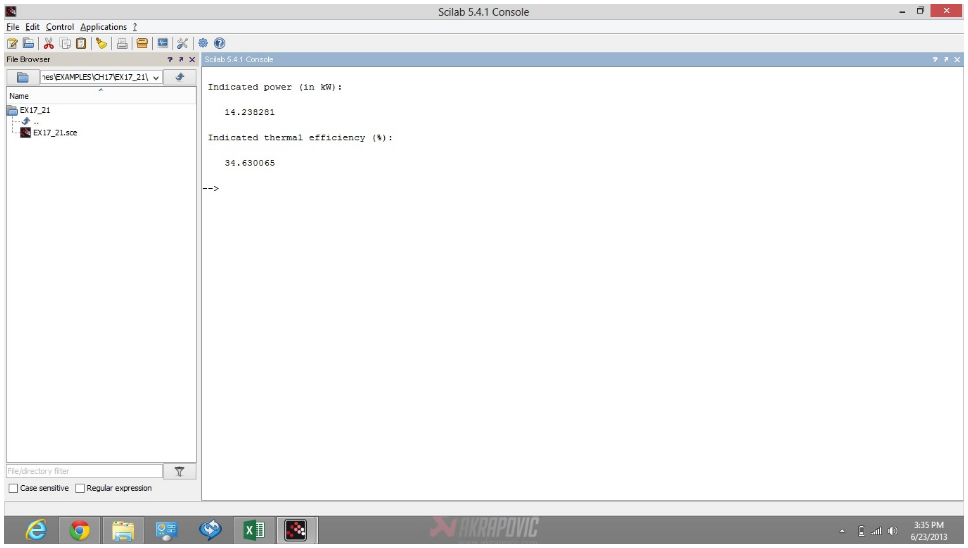
```
Average no of times each cylinder misfires in one min:

   2.

-->
```

Figure 17.20: Average no of misfires per min

```
   Brake torque in kNm
disp(Tb,"Brake torque (in kNm):")
```

Scilab code Exa 17.20 `Average no of misfires per min`

```
clc;funcprot(0);//EXAMPLE 17.20
// Initialisation of Variables
n=6;.......................//No of cylinders
Vs=1.75*10^(-3);.............//Stroke volume in m^3
IP=26.3;.....................//Indicated power in kW
Ne=504;......................//Expected Engine rpm
Pmi=6;.......................//Mean effective
   pressure in bar
k=0.5;.......................//Four stroke engine
//Calculations
```



```
Indicated power (in kW):

   14.238281

Indicated thermal efficiency (%):

   34.630065

-->
```

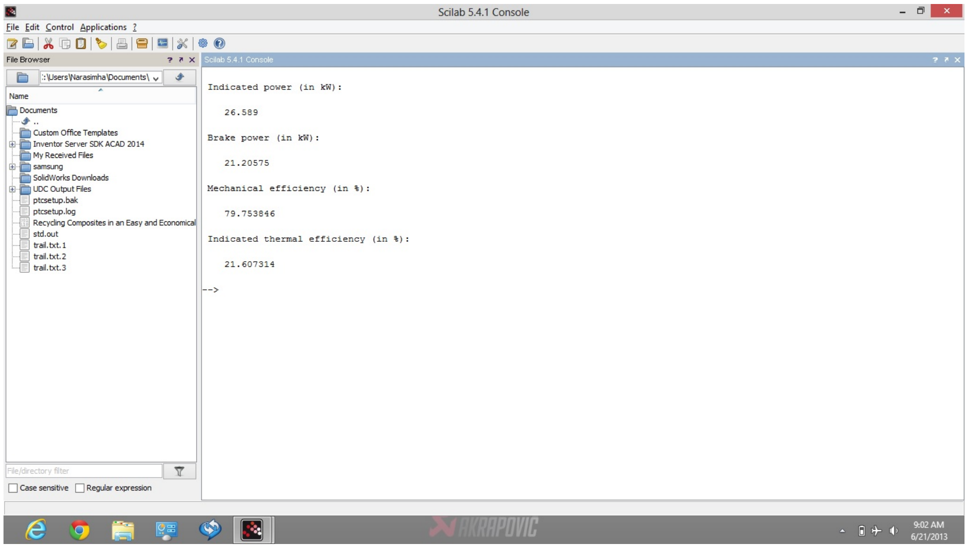
Figure 17.21: Indicated power and indicated thermal efficiency

```
Na=floor((IP*6)/(n*Pmi*Vs*k*10));.......................//Actual Engine rpm
af=(Na*n)/2;.......................//Actual no of fires in min
ef=(Ne*n)/2;.......................//Expected no of fires in min
Nm=ef-af;........................//No of misfires/min
nm=Nm/n;.....................//Average no of times each cylinder misfires in one min
disp(nm,"Average no of times each cylinder misfires in one min:")
```

Scilab code Exa 17.21 Indicated power and indicated thermal efficiency

```
clc;funcprot(0);//EXAMPLE 17.21
```

```
// Initialisation of Variables
n=4;.......................//No of cylinders
D=0.075;.......................//Engine bore in m
L=0.09;........................//Engine length in m
err=39/8;.......................//Engine to rear axle ratio
Dw=0.65;.........................//Wheel diameter in m
pc=0.227;.......................//Petrol consumption in kg
pmi=5.625;.........................//Mean effective pressure in bar
C=43470;..............................//Calorific value of petrol in kJ/kg
k=0.5;.............................//Four stroke engine
sc=48;............................//Speed of the car in km/h
d=3.2;.............................//Distance covered by car in km
//Calculations
sc1=sc*(1000/60);...................//Speed of the car in m/min
Nt=sc1/(%pi*Dw);......................//Revolutions made by tire per min
Ne=Nt*err;............................//Speed of engine shaft
IP=(n*pmi*L*(%pi/4)*D*D*Ne*k*10)/6;........//Indicated power in kW
disp(IP,"Indicated power (in kW):")
sc2=sc/60;.......................//Speed of the car in km/min
t=d/sc2;..........................//Time for covering 3.2 km in min
fc=pc/(t*60);.....................//Fuel consumed per second in kg
etait=IP/(fc*C);...............//Indicated thermal efficiency
```



```
Indicated power (in kW):

   26.589

Brake power (in kW):

   21.20575

Mechanical efficiency (in %):

   79.753846

Indicated thermal efficiency (in %):

   21.607314

-->
```

Figure 17.22: Finding all engine parameters

```
disp(etait*100,"Indicated thermal efficiency (%):")
```

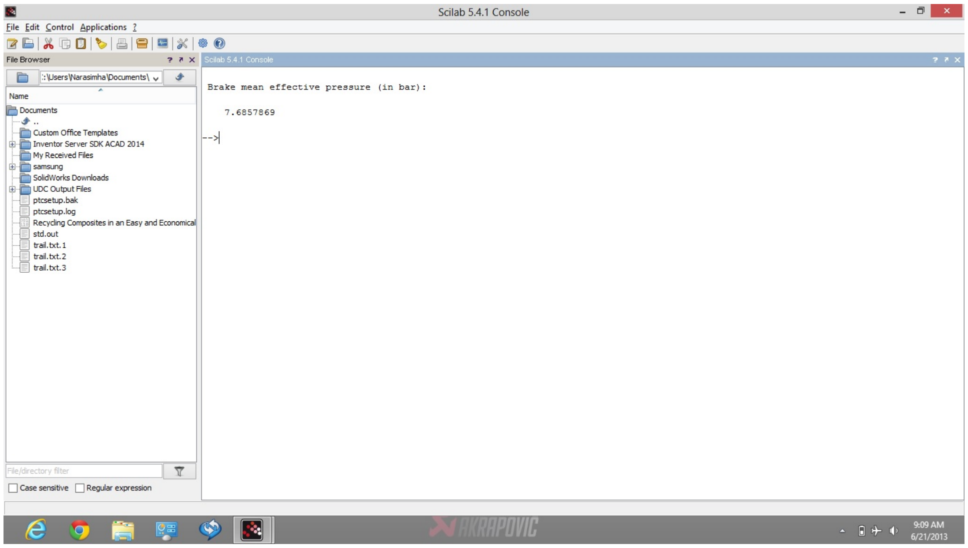
Scilab code Exa 17.22 `Finding all engine parameters`

```
clc;funcprot(0);//EXAMPLE 17.22
// Initialisation of Variables
n=1;..................//No of cylinders
D=0.25;................//Engine bore in m
L=0.4;.................//Engine stroke in m
pmg=7;.................//Gross mean effective pressure in bar
pmp=0.5;...............//Pumping mean effective pressure in bar
N=250;.................//Engine rpm
Db=1.5;................//Effective diameter of the brake in m
```

```
Nl=1080;..............//Net load on the brake in N
fh=10;.................//Fuel used per hour in kg
C=44300;...............//Calorific value of fuel in kJ/kg
k=0.5;.................//Four stroke engine
//Calculations
mf=fh/3600;.........................//Fuel used per second in kg
pm=pmg-pmp;......................//Net pressure
IP=(n*pm*L*(%pi/4)*D*D*N*k*10)/6;..........///Indicated power in kW
disp(IP,"Indicated power (in kW):")
BP=((Nl)*%pi*Db*N)/(60*1000);...............//Brake power in kW
disp(BP,"Brake power (in kW):")
etamech=BP/IP;...........................//Mechanical efficiency
disp(etamech*100,"Mechanical efficiency (in %):")
etath=IP/(mf*C);........................//Indicated thermal efficiency
disp(etath*100,"Indicated thermal efficiency (in %):")
```

Scilab code Exa 17.23 Brake mean effective pressure

```
clc;funcprot(0);//EXAMPLE 17.23
// Initialisation of Variables
etabth=0.3;....................//Brake thermal efficiency
afrw=20;........................//Air fuel ratio by weight
C=41800;........................//Calorific value of fuel used in kJ/kg
```



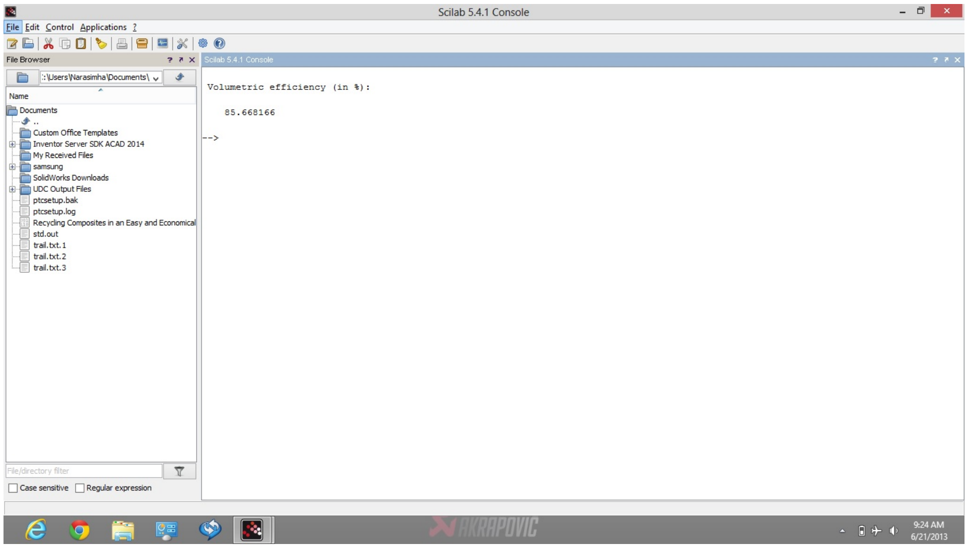
```
Brake mean effective pressure (in bar):

   7.6857869

-->
```

Figure 17.23: Brake mean effective pressure

```
R=287;.........................//Gas constant in J/kg
//Calculations
Wp=etabth*C;....................//Work produced per kg of fuel in kJ
p1=1.0132;t=273+15;.............//STP conditions in bar and Kelvin
V=(afrw*t*R)/(p1*10^5);........//Volume of air used in m^3
pmb=(Wp*1000)/(V*10^5);.........//Brake mean effective pressure in bar
disp(pmb,"Brake mean effective pressure (in bar):")
```

Scilab code Exa 17.24 `Volumetric efficiency`

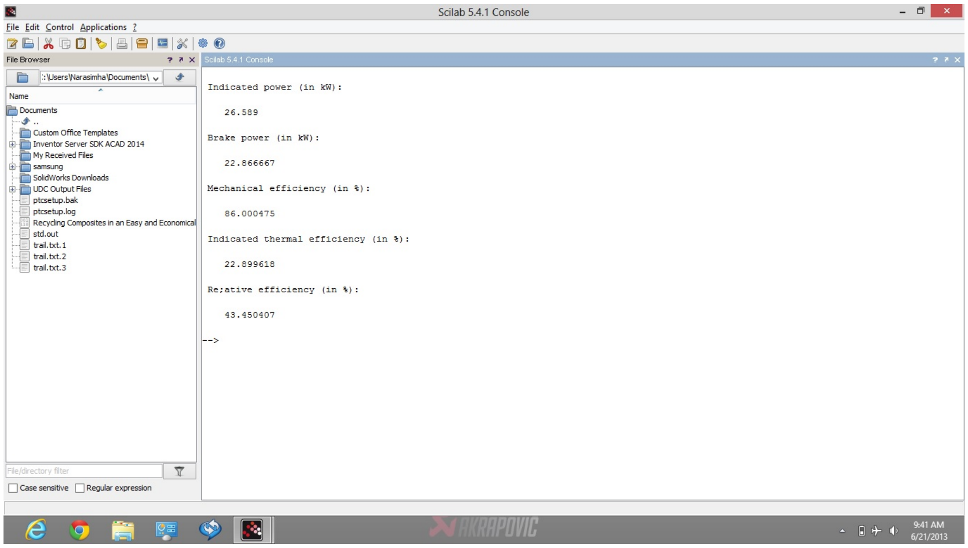
```
clc;funcprot(0);//EXAMPLE 17.24
// Initialisation of Variables
```



```
Volumetric efficiency (in %):

   85.668166

-->
```

Figure 17.24: Volumetric efficiency

```
v1=0.216;......................//Gas consumption in m^3/min
pw=75;.........................//Pressure of gas in mm of water
t1=290;......................//Temperature of gas in K
ac=2.84;.....................//Air consumption in kg/min
br=745;......................//Barometer reading in m of Hg
D=0.25;......................//Engine bore in m
L=0.475;.......................//Engine stroke in m
N=240;.........................//Engine rpm
R=287;.......................//Gas constant for air in J/kgK
//Calculations
p1=br+(pw/13.6);....................//Pressure of gas in mm of mercury
p2=760;t2=273;.....................//NTP conditions in mm of Hg and Kelvin
```



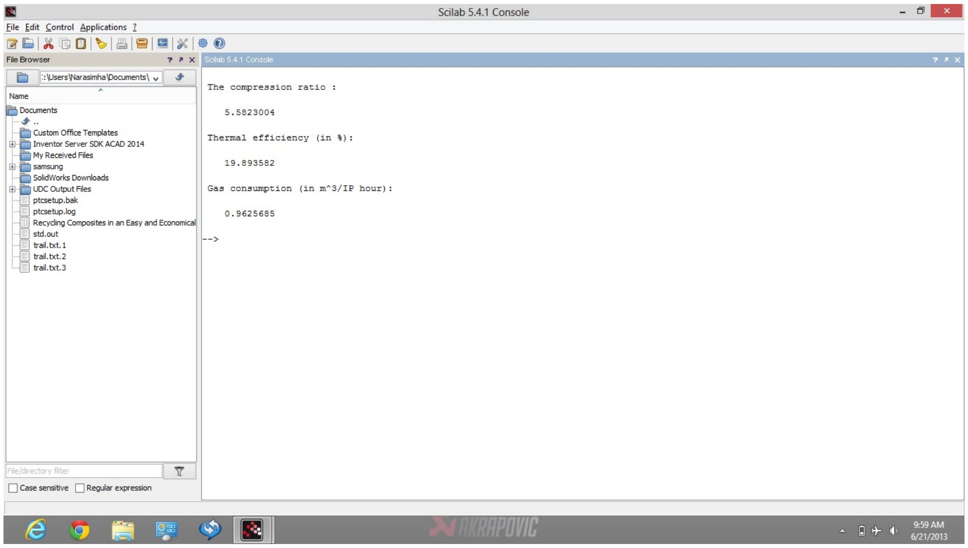
```
Indicated power (in kW):

   26.589

Brake power (in kW):

   22.866667

Mechanical efficiency (in %):

   86.000475

Indicated thermal efficiency (in %):

   22.899618

Re;ative efficiency (in %):

   43.450407

-->
```

Figure 17.25: finding all parameters of engine

```
v2=(p1*v1*t2)/(t1*p2);...............//Volume of gas used at NTP in m^3
gs=v2/(N/2);.........................//Gas used per stroke in m^3
v=(ac*R*t2)/(1.0132*10^5);...........//Volume occupied by air at NTP in m^3/min
aps=v/(N/2);...........................//Air used per stroke
Va=gs+aps;.....................//Actual volume of mixture in m^3 drawn per stroke at NTP
Vs=(%pi/4)*D*D*L;...............//Swept volume in mm^3
etaV=(Va/Vs);...................//Volumetric efficiency
disp(etaV*100,"Volumetric efficiency (in %):")
```

Scilab code Exa 17.25 `finding all parameters of engine`

```
clc;funcprot(0);//EXAMPLE 17.25
// Initialisation of Variables
t=1;...................//Duration of trial in hrs
Rev=14000;.............//Revolutions
nmc=500;...............//Number of missed cycles
bl=1470;................//Net Brake load in N
mep=7.5;................//Mean effective pressure in bar
gc=20000;...............//Gas consumption in litres
lcv=21;.................//LCV of gas at supply condition in kJ/litre
D=0.25;.................//Engine bore in m
L=0.4;..................//Engine stroke in m
r=6.5;..................//Compression ratio
n=1;......................//No of cylinders
Cb=4;......................//Effective brake Circumference
k=0.5;....................//Four stroke engine
ga=1.4;......................//Degree of freedom
//Calculations
N=Rev/60;..............//Engine rpm
Vg=gc/3600;.............//Fuel consumption in litres/s
Na=((Rev/2)-nmc)/60;...............//Working cycles per min
IP=(n*mep*L*(%pi/4)*D*D*Na*10)/6;............//indicated power in kW
disp(IP,"Indicated power (in kW):")
BP=((bl)*Cb*N)/(60*1000);...............//Brake power in kW
disp(BP,"Brake power (in kW):")
etamech=BP/IP;...........................//Mechanical efficiency
disp(etamech*100,"Mechanical efficiency (in %):")
etath=IP/(Vg*lcv);........................//Indicated thermal efficiency
```



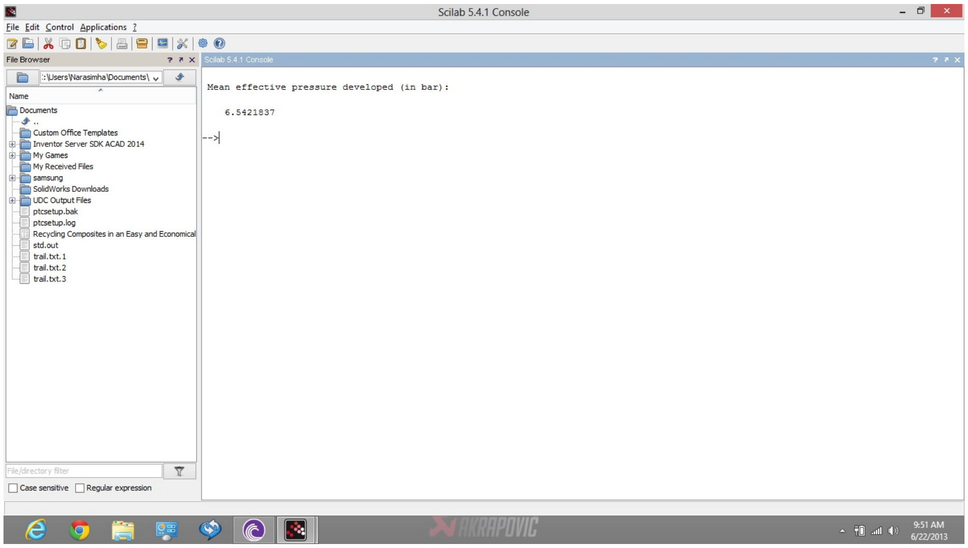
```
The compression ratio :

   5.5823004

Thermal efficiency (in %):

   19.893582

Gas consumption (in m^3/IP hour):

   0.9625685

-->
```

Figure 17.26: Compression ratio and thermal efficiency and gas consumption

```
disp(etath*100,"Indicated thermal efficiency (in %):")
etast=1-(1/r^(ga-1));............//Air standard efficiency
etarel=etath/etast;............//Relative efficiency
disp(etarel*100,"Relative efficiency (in %):")
```

Scilab code Exa 17.26 `Compression ratio and thermal efficiency and gas consumptio`

```
clc;funcprot(0);//EXAMPLE 17.26
// Initialisation of Variables
n=1.3;...................//Index of compression
pa=1.4;pb=3.6;posa=(1/4);..........//Point a - the position 1/4 of the stroke
posb=(3/4);..........//Point b - the position 3/4 of the stroke
```



```
Mean effective pressure developed (in bar):

   6.5421837

-->
```

Figure 17.27: Mean effective pressure developed

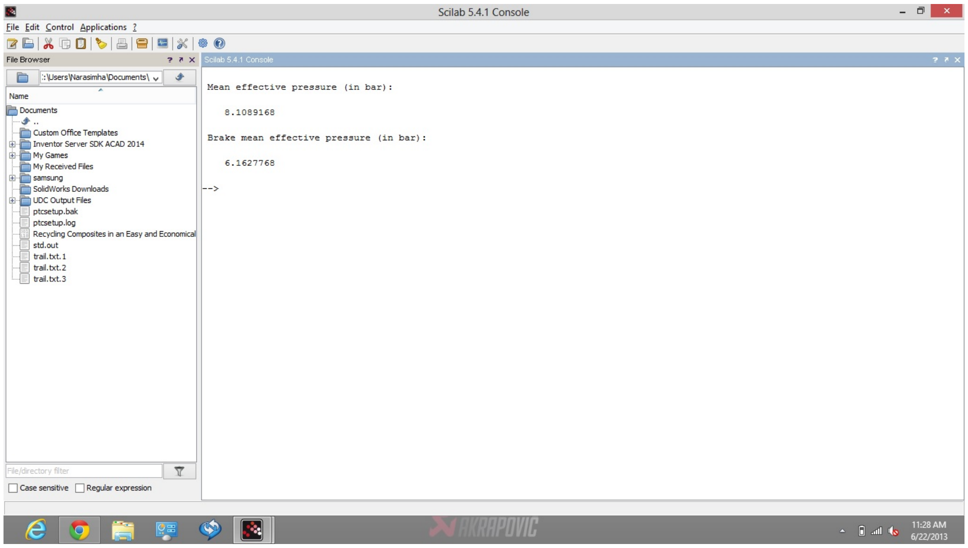
```
ga=1.4;................//Degree of freedom for gas
etarel=0.4;....................//Relative efficiency
C=18800;....................//Calorific value of fuel in kJ/m^3
//Calculations
r=1+((((pb/pa)^(1/n))-1)/(posb-(((pb/pa)^(1/n))*(posa))));.........//Compression ratio
disp(r,"The compression ratio :")
etast=1-(1/r^(ga-1));............//Air standard efficiency
etath=etarel*etast;...........//Thermal efficiency
disp(etath*100,"Thermal efficiency (in %):")
v=1/(etath*C);...............//Gas consumption per IP sec
disp(v*3600,"Gas consumption (in m^3/IP hour):")
```

Scilab code Exa 17.27 Mean effective pressure developed

```
clc;funcprot(0);//EXAMPLE 17.27
// Initialisation of Variables
n=6;.....................//No of cylinders
r=5;..................//Compression ratio
Vc=0.000115;................//Clearance volume of each cylinder in m^3
fc=10.5;.....................//Fuel consumed in kg/h
C=41800;......................//Calorific value of fuel in  kJ/kg
N=2500;.......................//Engine speed in rpm
er=0.65;.......................//Efficiency ratio
ga=1.4;........................//Degree of freedom
//calculations
etast=1-(1/r^(ga-1));...............................//Air standard efficiency
etath=etast*er;.................................//Thermal efficiency
IP=etath*(fc/3600)*C;..........................//Indicated power in kW
Wnet=(IP*(10^3)*60)/(n*(N/2));..............//Net work froom one cycle per cylinder in N-m
Vs=(r-1)*Vc;......................//Swept volume in m^3
pm=Wnet/(Vs*10^5);..................//Mean effective pressure developed
disp(pm,"Mean effective pressure developed (in bar):")
```

Scilab code Exa 17.28 Indicated mean effective pressure and brake mean effective p

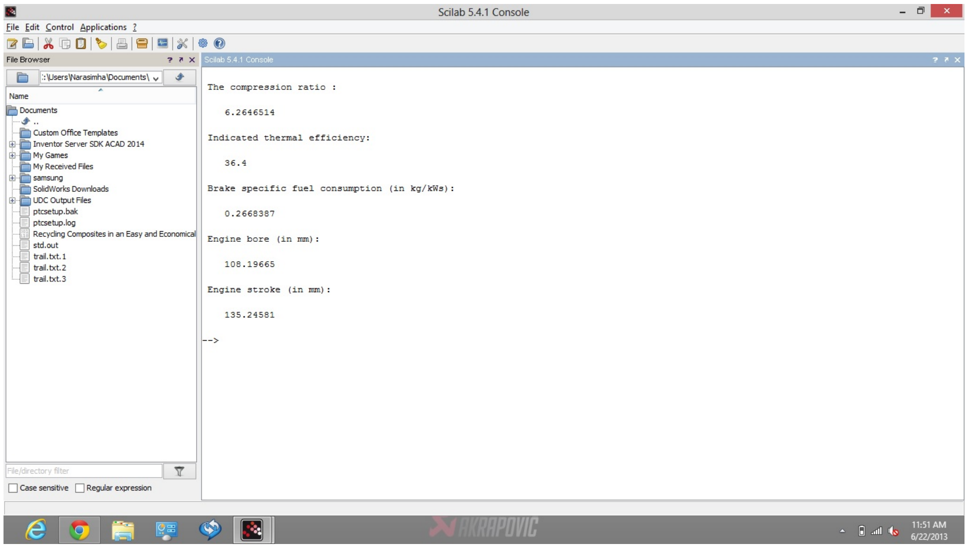
```
clc;funcprot(0);//EXAMPLE 17.28
```



```
Mean effective pressure (in bar):

   8.1089168

Brake mean effective pressure (in bar):

   6.1627768

-->
```

Figure 17.28: Indicated mean effective pressure and brake mean effective pressure

```
// Initialisation of Variables
D=0.2;................//Engine bore in m
L=0.25;...............//Engine stroke in m
n=2;.....................//No of cylinders
r=13;.....................//Compression ratio
fc=14;.................//Fuel consumption in kg/h
N=300;...................//Engine rpm
etarel=0.65;.............//Relative efficiency
etamech=0.76;............//Mechanical efficiency
co=0.05;....................//Cut off of the stroke
C=41800;....................//Calorific value of fuel in kJ/kg
k=1;.......................//Two stroke engine
ga=1.4;......................//Degree of freedom
//calculations
rho=1+(co*(r-1));
etast=1-((1/(r^(ga-1)))*(1/ga)*((rho^ga)-1)*(1/(rho-1)));............//Air standard efficiency
etath=etarel*etast;.......................//Thermal
```



```
The compression ratio :

   6.2646514

Indicated thermal efficiency:

   36.4

Brake specific fuel consumption (in kg/kWs):

   0.2668387

Engine bore (in mm):

   108.19665

Engine stroke (in mm):

   135.24581

-->
```

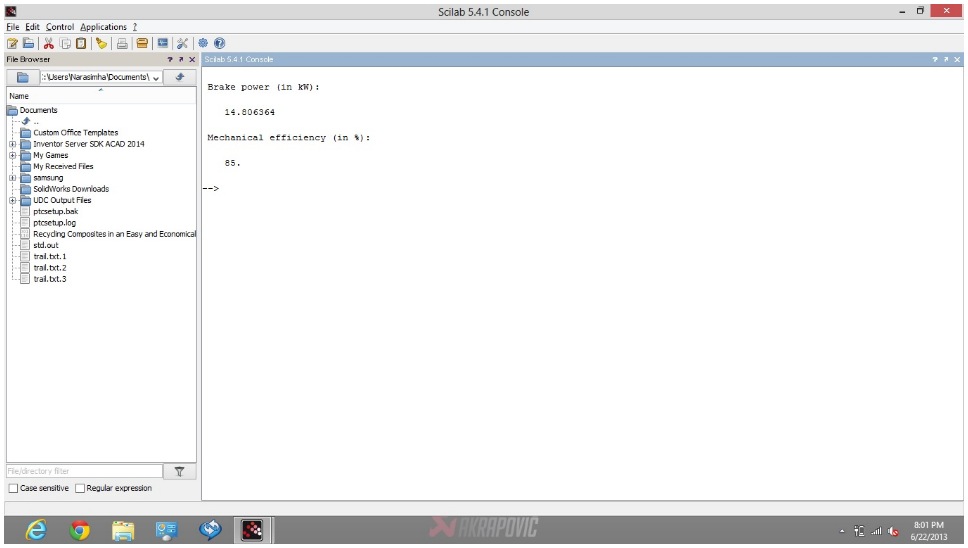
Figure 17.29: Finding all parameters of engine

```
    efficiency
IP=etath*(fc/3600)*C;........................//Indicated power in kW
BP=etamech*IP;................................//Brake power in kW
pmi=(6*IP)/(n*N*L*(%pi/4)*D*D*k*10);............//mean effective pressure in bar
disp(pmi,"Mean effective pressure (in bar):")
pmb=pmi*etamech;...........................//Brake mean effective pressure in bar
disp(pmb,"Brake mean effective pressure (in bar):")
```

Scilab code Exa 17.29 `Finding all parameters of engine`

```
clc;funcprot(0);//EXAMPLE 17.29
// Initialisation of Variables
```

```
n=4;..................//No of cylinders
C=45200;...................//calorific value of fuel in kJ/kg
etamech=0.82;................//Mechanical efficiency
etarel=0.7;..................//Relative efficiency
etast=0.52;................//Air standard efficiency
etav=0.78;................//Volumetric efficiency
sbr=1.25;....................//Stroke bore ratio
N=2400;....................//Engine rpm
p=1;........................//Suction pressure in bar
t=298;.....................//Suction temperature in bar
BP=72;....................//Brake power in kW
ga=1.4;.......................//Degree of freedom
afr=16;..................//Air fuel ratio
R=287;........................//Gas constant in J/kg
//calculations
r=(1/(1-etast))^(1/(ga-1));..............//Compression ratio
disp(r,"The compression ratio :")
etath=etast*etarel;.......................//Indicated thermal efficiency
disp(etath*100,"Indicated thermal efficiency:")
IP=BP/etamech;.....................//Indicated power in kW
mf=IP/(etath*C);........................//Fuel consumption in kg/s
bsfc=mf/BP;.......................//Brake specific fuel consumption in kg/kWs
disp(bsfc*3600,"Brake specific fuel consumption (in kg/kWs):")
mafm=afr+1;.......................//Mass of air fuel mixture in kg/kg of fuel
mafm1=mafm*mf;.....................//Mass of air fuel mixture when mf amount of fuel is supplied to engine per second
v=(mafm1*R*t)/(p*10^5);.........................///Volume of air fuel mixture supplied to the engine
```



```
Brake power (in kW):

   14.806364

Mechanical efficiency (in %):

   85.

-->
```

Figure 17.30: Full load brake power and mechanical efficiency

```
     in m^3
Vs=v/etav;..............................//Swept
   volume in m^3
D=((Vs)/((%pi/4)*sbr*n*(N/(2*60))))^(1/3)
   ;............//Engine bore in m
disp(D*1000,"Engine bore (in mm):")
disp(D*1000*sbr,"Engine stroke (in mm):")
```

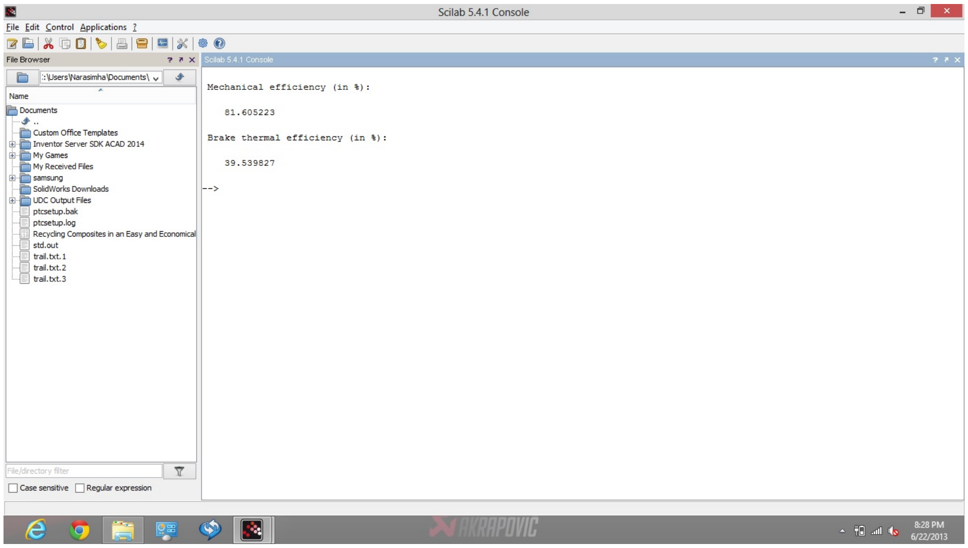
Scilab code Exa 17.30 `Full load brake power and mechanical efficiency`

```
clc;funcprot(0);//EXAMPLE 17.30
// Initialisation of Variables
n=1;.......................//No of cylinders
D=0.18;...................//Engine bore in m
L=0.34;....................//Engine stroke in m
N=400;......................//Engine rpm
```

```
mepw=6.4;.................//Mean effective pressure of working loop in bar
mepp=0.36;..................//Mean effective pressure of pumping loop in bar
mepd=0.64;.................//Mean effective pressure (dead cycle) iin bar
fs=46;................//Firing strokes per min
//calculations
pminet=mepw-mepp;..........//Net indicated mean effective pressure in bar
dc=(N/2)-fs;...............//Dead cycles per min
IPnet=(n*pminet*(%pi/4)*L*D*D*fs*4*10)/6;.............//Net indicated power output in kW
ppdc=(n*pminet*L*(%pi/4)*D*D*10*dc)/6;.............//Pumping power of dead cycles in kW
FP=IPnet-ppdc;...........................//Frictional power in kW
IP=(n*pminet*L*(%pi/4)*D*D*(N/2)*10)/6;...............//Indicated power in kW
BP=IP-FP;..................//Brake power in kW
disp(BP,"Brake power (in kW):")
etamech=BP/IP;.................//Mechanical efficiency
disp(etamech*100,"Mechanical efficiency (in %):")
```

Scilab code Exa 17.31 `Mechanical efficiency and brake thermal efficiency`

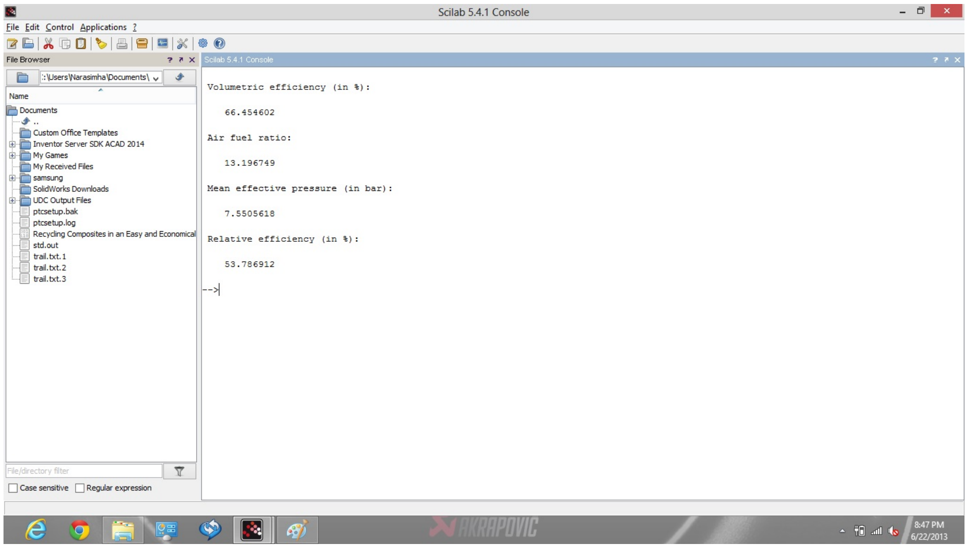
```
clc;funcprot(0);//EXAMPLE 17.31
// Initialisation of Variables
n=1;..............//No of cylinders
B=0.32;...............//Engine bore in m
L=0.42;..............//Engine stroke in m
```



```
Mechanical efficiency (in %):

   81.605223

Brake thermal efficiency (in %):

   39.539827

-->
```

Figure 17.31: Mechanical efficiency and brake thermal efficiency

```
N=200;................//Engine rpm
Nk=90;..................//No of explosions per min
v1=11.68;............//Gas used in m^3/h
pg=170;................//Pressure of gas in mm of water
br=755;................//Barometer reading in mm of Hg
pmi=6.2;.................//Mean effective pressure in bar
C=21600;.......................//Calorific value of gas in kJ/kg
bl=2040;......................//Net load on brake in N
Db=1.2;......................//Brake drum diameter in m
t1=298;.....................//Ambient temperature in Kelvin
//Calculations
IP=(n*pmi*L*(%pi/4)*B*B*Nk*10)/6;..........................//Indicated power in
```



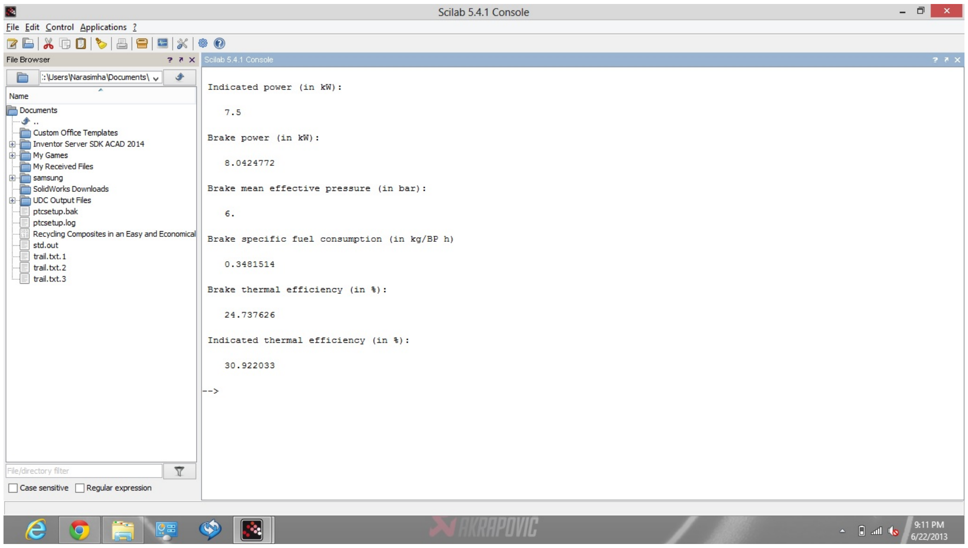
```
Volumetric efficiency (in %):

   66.454602

Air fuel ratio:

   13.196749

Mean effective pressure (in bar):

   7.5505618

Relative efficiency (in %):

   53.786912

-->
```

Figure 17.32: Finding all parameters of the engine

```
    kW
BP=(bl*%pi*Db*N)/(60*1000);.........................//Brake power in kW
etamech=(BP/IP);...................//Mechanical efficiency
disp(etamech*100,"Mechanical efficiency (in %):")
p1=br+(pg/13.6);.................//In mm of Hg
p2=760;t2=273;...................//NTP conditions in mm of Hg and Kelvin
v2=(p1*v1*t2)/(p2*t1);
etabth=BP/((v2/3600)*C);..............//Brake thermal efficiency
disp(etabth*100,"Brake thermal efficiency (in %):")
```

Scilab code Exa 17.32 `Finding all parameters of the engine`

```
clc;funcprot(0);//EXAMPLE 17.32
// Initialisation of Variables
n=1;...................//No of cylinders
d=0.032;................//Diameter of circular orifice in m
Cd=0.62;.............//Co efficient of discharge
hw=150;.................//Pressure across orfice in mm of water
t=20+273;..............//Temperature of air in the room in Kelvin
p=1.0132;.................//Ambient pressure in bar
pd=0.00178;............//Piston displacement in m^3
R=287;....................//Gas constant in J/kg
r=6.5;..................//Compression ratio
fc=0.135;................//Fuel consumption in kg/min
C=43900;.................//Calorific value of fuel in kJ/kg
BP=28;................//Brake power in kW
N=2500;...................//Engine rpm
k=0.5;....................//Four stroke engine
g=9.81;.......................//Acceleration due to gravity in m/s^2
rhow=1000;....................//Density of water in kg/m^3
ga=1.4;........................//Degree of freedom
//calculations
mbyv=(p*10^5)/(R*t);
pw=(hw/rhow)*rhow;....................//Pressure across orifice in kg/m^2
H=pw/mbyv;........................//Head of air column causing the flow in m
ma=Cd*(%pi/4)*d*d*sqrt(2*g*H);................//Air flow through orifice in m^3/s
maps=(ma*60)/(N/2);........................//Air consumption per stroke
etav=maps/pd;.................//Volumetric efficiency
```



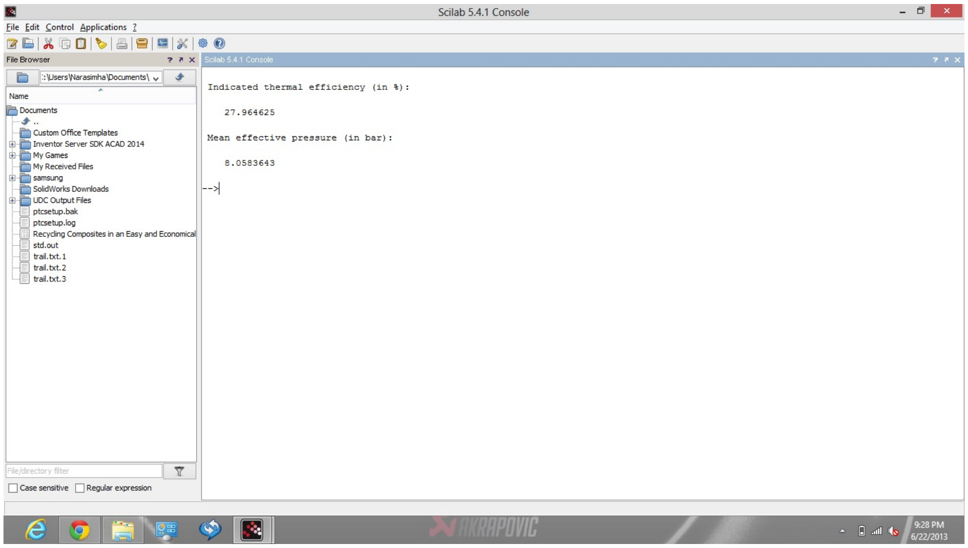
```
Indicated power (in kW):

   7.5

Brake power (in kW):

   8.0424772

Brake mean effective pressure (in bar):

   6.

Brake specific fuel consumption (in kg/BP h)

   0.3481514

Brake thermal efficiency (in %):

   24.737626

Indicated thermal efficiency (in %):

   30.922033

-->
```

Figure 17.33: Finding all parameters of the engine

```
disp(etav*100,"Volumetric efficiency (in %):")
ac=ma*60*mbyv;................//Mass of air drawn
    into cylinder per min in kg
afr=ac/fc;...................//Air fuel ratio
disp(afr,"Air fuel ratio:")
pmb=(6*BP)/(n*pd*N*k*10);...................//Mean
    effective pressure in bar
disp(pmb,"Mean effective pressure (in bar):")
etast=1-(1/(r^(ga-1)));...............//Air standard
     efficiency
etabth=BP/((fc/60)*C);...............//Brake thermal
     efficiency
etarel=etabth/etast;.................//Relative
    efficiency
disp(etarel*100,"Relative efficiency (in %):")
```

Scilab code Exa 17.33 Finding all parameters of the engine

```
clc;funcprot(0);//EXAMPLE 17.33
// Initialisation of Variables
N=400;.................//Engine rpm
n=1;....................//no of cylinders
W=370;.................//Load on the brake in N
S=50;..................//Spring balance readin in N
Db=1.2;.................//Diameter of the brake drum
mf=2.8;.................//Fuel consumption in kg/h
C=41800;.................//Calorific value of fuel in kJ/kg
D=0.16;..................//Engine bore in m
L=0.2;...................//Engine stroke in m
k=0.5;....................//Four stroke engine
Sc=1;....................//Spring constant in bar/mm
l=40;....................//Length of diagram in mm
aic=300;................//Area of indicator card in mm^2
//Calculations
pmi=aic*(Sc/l);.................//Mean effective pressure in bar
IP=(n*pmi*L*(%pi/4)*D*D*k*N*10)/6;..............//Indicated power in kW
disp(pmi,"Indicated power (in kW):")
BP=((W-S)*%pi*Db*N)/(60*1000);...........//Brake power in kW
disp(BP,"Brake power (in kW):")
pmb=(BP*6)/(n*L*D*D*(%pi/4)*k*N*10);..........//Brake mean effective pressure in bar
disp(pmb,"Brake mean effective pressure (in bar):")
bsfc=mf/BP;.................//Brake specific fuel consumption in kg/BP h
disp(bsfc,"Brake specific fuel consumption (in kg/BP h)")
etabth=BP/((mf/3600)*C);.................//Brake thermal efficiency
disp(etabth*100,"Brake thermal efficiency (in %):")
```



```
Indicated thermal efficiency (in %):

   27.964625

Mean effective pressure (in bar):

   8.0583643

-->
```

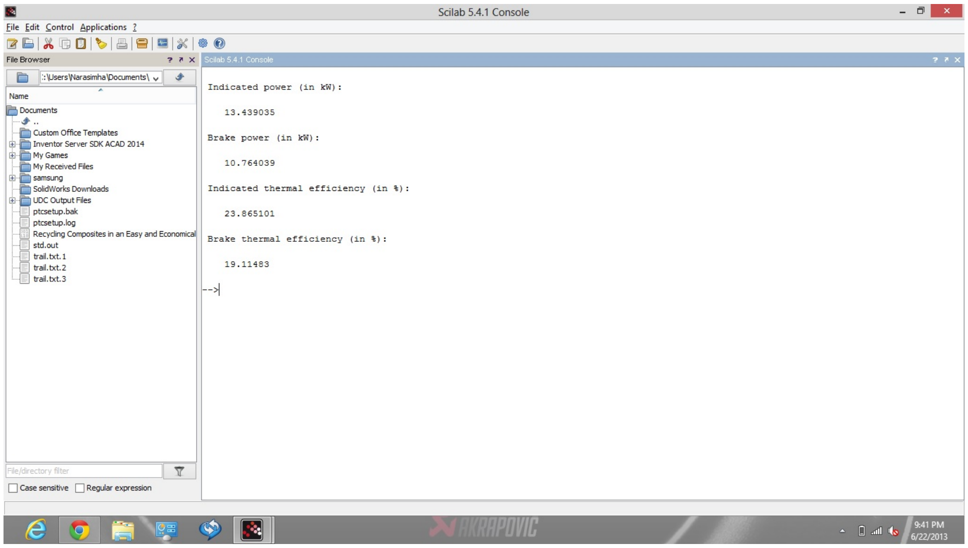
Figure 17.34: Indicated thermal efficiency and brake mean effective pressure

```
etaith=IP/((mf/3600)*C);....................//Indicated thermal efficiency
disp(etaith*100,"Indicated thermal efficiency (in %):")
```

Scilab code Exa 17.34 `Indicated thermal efficiency and brake mean effective pressu`

```
clc;funcprot(0);//EXAMPLE 17.34
// Initialisation of Variables
R=287;................//Gas constant in J/kg K
n=4;...................//No of cylinders
D=0.0825;..............//Engine bore in m
L=0.13;................//Engine stroke in m
BP=28;..................//Brake power in kW
N=1500;.................//Engine rpm
```

```
afrth=14.8;...............//theoretical air fuel ratio
C=45980;..................//Calorific value of fuel in kJ/kg
etamech=0.9;.............//Mechanical efficiency
ap=70;..................//Percentage of Volume of air in he cylinder
fr=20;..................//Percentage richness of the fuel
p1=1.0132;.................//Ambient pressure in bar
pc=762;...................//Pressure in the cylinder in mm of Hg
tc=273+15.5;...............//Temperature in the cylinder in Kelvin
k=0.5;..................//Four stroke engine
//Calculations
Vs=(%pi/4)*D*D*L;.......................//Swept volume in m^3
va=(ap/100)*Vs;.....................//Volume of air drawn in m^3
p=(pc/760)*p1;
m=(p*(10^5)*va)/(R*tc);...................//Mass of air per stroke per cylinder
tmau=m*(N/2)*n;...................//Theoretical mass of air used per minute in kg
tmfu=tmau/afrth;..................//Theoretical mass of fyel used per min in kg
mf=(tmfu/60)*((100+fr)/100);...............//Mass of fuel burnt per second in kg
IP=BP/etamech;.........................//Indicated power in kW
etaith=IP/(mf*C);.....................//Indicated thermal efficiency
disp(etaith*100,"Indicated thermal efficiency (in %):")
pmb=(BP*6)/(n*L*D*D*(%pi/4)*N*10*k);...............//Mean effective pressure in bar
disp(pmb,"Mean effective pressure (in bar):")
```



```
Indicated power (in kW):

   13.439035

Brake power (in kW):

   10.764039

Indicated thermal efficiency (in %):

   23.865101

Brake thermal efficiency (in %):

   19.11483

-->
```

Figure 17.35: Finding all parameters of IC engine

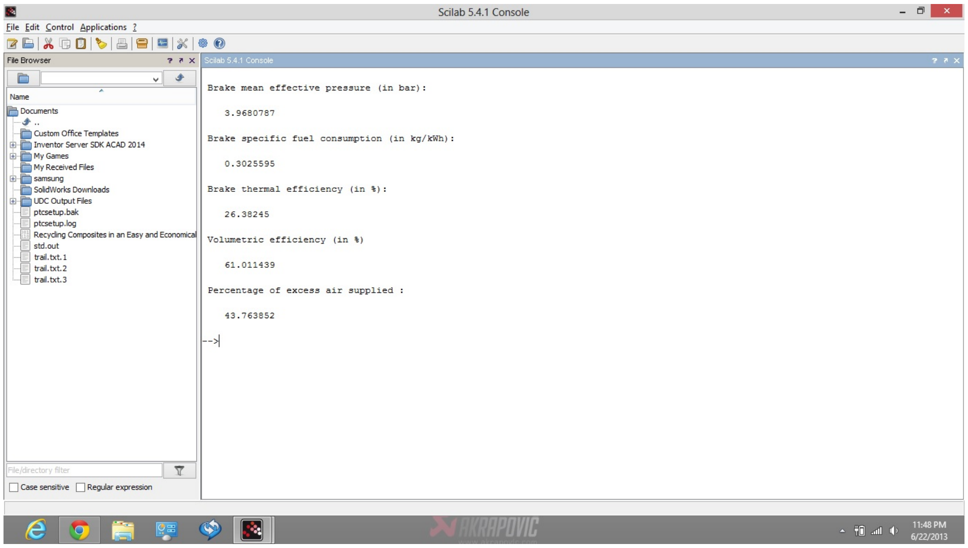
Scilab code Exa 17.35 `Finding all parameters of IC engine`

```
clc;funcprot(0);//EXAMPLE 17.35
// Initialisation of Variables
n=1;..................//No of cylinders
D=0.2;............//Engine bore in m
L=0.4;..............//Engine stroke in m
Nt=9400;...............//Total no of revolutions
Ne=4200;...............//Total no of explosions
t=40;...................//Duration of testing in min
Nk=Ne/t;...............//No of explosions
bl=540;...............//Brake load in N
Db=1.6;.................//Diameter of brake wheel in m
d=0.02;................//Diameter of rope in m
```

```
gu=8.5;..................//Gas used in m^3/sec
C=15900;...............//Calorific value of fuel in kJ/kg
Vg=(gu/(t*60));.................//Volume of gas used in m^3/sec
aic=550;......................//Area of indicator diagram mm^2
l=72;.......................//Length of indicator diagram in mm
s=0.8;.....................//Spring number in bar/mm
//calculations
pmi=(aic*s)/l;................//Mean effective pressure in bar
IP=(n*pmi*L*D*D*(%pi/4)*Nk*10)/6;............//Indicated power in kW
disp(IP,"Indicated power (in kW):")
BP=(bl*%pi*(Db+d)*(Nt/t))/(60*1000);...............//Brake power in kW
disp(BP,"Brake power (in kW):")
etaith=IP/(Vg*C);...............//Indicated thermal efficiency
disp(etaith*100,"Indicated thermal efficiency (in %):")
etabth=BP/(Vg*C);...............//Brake thermal efficiency
disp(etabth*100,"Brake thermal efficiency (in %):")
```

Scilab code Exa 17.36 `Finding all parameters of IC engine`

```
clc;funcprot(0);//EXAMPLE 17.36
// Initialisation of Variables
n=6;...................//No of cylinders
D=0.125;................//Engine bore in m
```

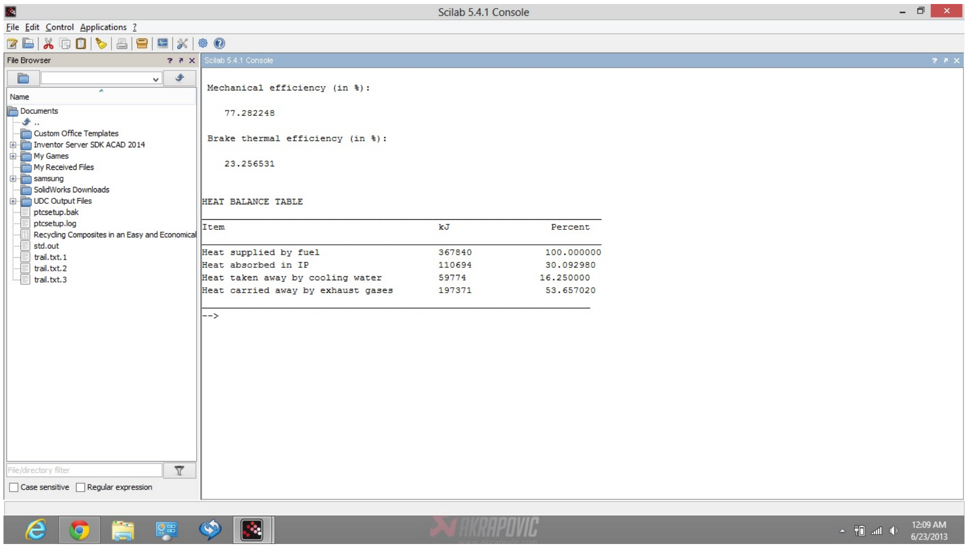


```
Brake mean effective pressure (in bar):

   3.9680787

Brake specific fuel consumption (in kg/kWh):

   0.3025595

Brake thermal efficiency (in %):

   26.38245

Volumetric efficiency (in %)

   61.011439

Percentage of excess air supplied :

   43.763852

-->
```

Figure 17.36: Finding all parameters of IC engine

```
L=0.125;...............//Engine stroke in m
N=2400;.................//Engine rpm
W=490;...............//Load on the dynamometer in N
CD=16100;...............//Dynamometer constant
d0=0.055;...................//Air orifice diameter
   in m
Cd=0.66;..................//Co efficient of
   discharge
hw=310;.................//Head causing flow through
   prifice in mm of water
br=760;................//Barometer reading in mm of
   Hg
t=298;.................//Ambient temperature in
   Kelvin
fc=22.1;..................//Fuel consumption per
   hour in kg
C=45100;..................//Calorific value of fuel
   used in kJ/kg
perc=85;..................//Percentage of carbon in
    the fuel
```

```
perh=15;...................//Percentage of hydrogen in the fuel
p1=1.013;....................//Pressure of air at the end of suction stroke in bar
t1=298;......................//Temperature of air the the end of suction stroke in Kelvin
k=0.5;.......................//Four stroke engine
R=287;.......................//Gas constant in J/kgK
//calculations
BP=W*(N/CD);................//Brake power in kW
pmb=(BP*6)/(L*D*D*k*10*N*n*(%pi/4));................//Brake mean effective pressure in bar
disp(pmb,"Brake mean effective pressure (in bar):")
bsfc=fc/BP;.......................//Brake specific fuel consumption in kg/kWh
disp(bsfc,"Brake specific fuel consumption (in kg/kWh):")
etathb=BP/((fc/3600)*C);......................//Brake thermal efficiency
disp(etathb*100,"Brake thermal efficiency (in %):")
Vst=(%pi/4)*D*D*L;..............//Stroke volume in m^3
Val=840*(%pi/4)*d0*d0*Cd*sqrt((hw/10)/((p1*10^5)/(R*t1)));............//Volume of air passing through orifice of air box per min
Vac=Val/n;.........................//Actual volume of air per cylinder in m^3/min
asps=Vac/(N/2);.......................//Air supplied per stroke per cylinder in m^3
etav=asps/Vst;....................//Volumetric efficiency
disp(etav*100,"Volumetric efficiency (in %)")
Qa=(100/23)*(((perc/100)*(8/3))+((perh/100)*(8/1)));.....................//Quantity of air required per kg of fuel combustion
aqas=(Val*((p1*10^5)/(R*t1))*60)/fc;....................//Actual quantity of air supplied per kg of fuel
```



```
 Mechanical efficiency (in %):

    77.282248

 Brake thermal efficiency (in %):

    23.256531


HEAT BALANCE TABLE
________________________________________________________________
Item                                      kJ                Percent
________________________________________________________________
Heat supplied by fuel                     367840          100.000000
Heat absorbed in IP                       110694           30.092980
Heat taken away by cooling water          59774           16.250000
Heat carried away by exhaust gases        197371           53.657020
________________________________________________________________
-->
```

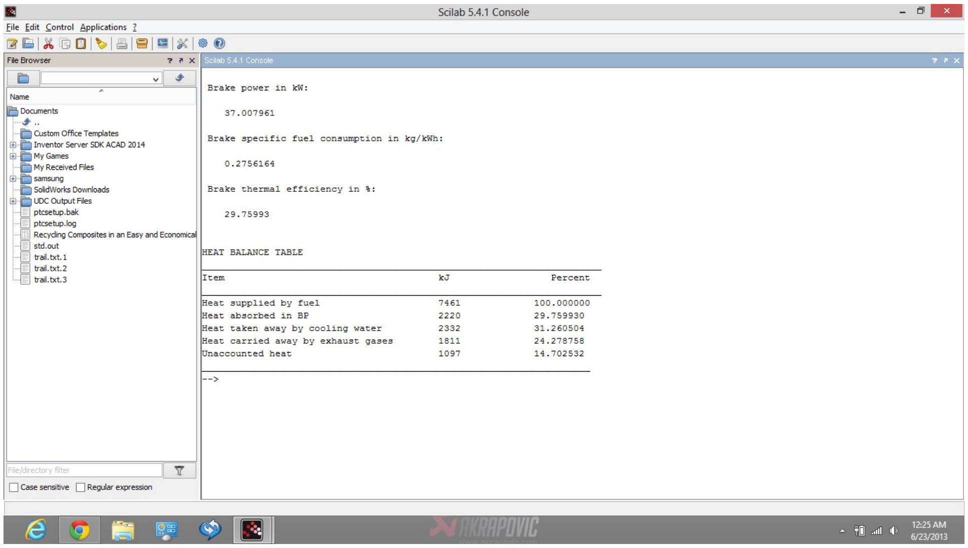
Figure 17.37: Heat balance sheet

```
pe=(aqas-Qa)/Qa;....................//Fraction of
   excess air supplied to engine
disp(pe*100,"Percentage of excess air supplied :")
```

Scilab code Exa 17.37 `Heat balance sheet`

```
clc;funcprot(0);//EXAMPLE 17.37
// Initialisation of Variables
n=1;......................//No of cylinders
D=0.3;....................//Engine bore in m
L=0.45;...................//Engine stroke in m
mf=8.8;...................//Fuel consumption in kg/h
C=41800;..................//Calorific value of fuel
    in kJ/kg
N=200;....................//Engine rpm
```

```
pmi=5.8;....................//Mean effective pressure in bar
bl=1860;....................//Brake load in N
Db=1.22;...................//Diameter of brake drum in m
k=0.5;........................//four stroke engine
mw=650;......................//Mass of cooling water in kg
cpw=4.18;....................//Specific heat capacity of water
delt=22;......................//Temperature rise
//Calculations
IP=(n*L*D*D*k*10*pmi*N*(%pi/4))/6;...............//Indicated power in kW
BP=(bl*%pi*Db*N)/(60*1000);..................//Brake power in kW
etamech=BP/IP;............//Mechanical efficiency
disp(etamech*100,”Mechanical efficiency (in %):”)
etathb=BP/((mf/3600)*C);...................//Brake thermal efficiency
disp(etathb*100,”Brake thermal efficiency (in %):”)
//Heat supplied
hip=IP*3600;...........//Heat equivalent of IP in kJ/h
hcw=mw*cpw*delt;..........//Heat carried away by cooling water
hf=mf*C;................//heat supplied by fuel
hex=hf-hip-hcw;..........//Heat carried by exhaust gasses
pf=100;pip=(hip/hf)*100;pcw=(hcw/hf)*100;pex=(hex/hf)*100
printf(”\n\n”)
printf(”HEAT BALANCE TABLE\n”)
printf(”-----------------------------------------------------------------\n”)
printf(”Item                                       kJ                  Percent\n”)
```



```
 Brake power in kW:

   37.007961

 Brake specific fuel consumption in kg/kWh:

   0.2756164

 Brake thermal efficiency in %:

   29.75993


HEAT BALANCE TABLE
_______________________________________________________________
Item                                    kJ                Percent
_______________________________________________________________
Heat supplied by fuel                   7461            100.000000
Heat absorbed in BP                     2220             29.759930
Heat taken away by cooling water        2332             31.260504
Heat carried away by exhaust gases      1811             24.278758
Unaccounted heat                        1097             14.702532
_____________________________________________________________
-->
```

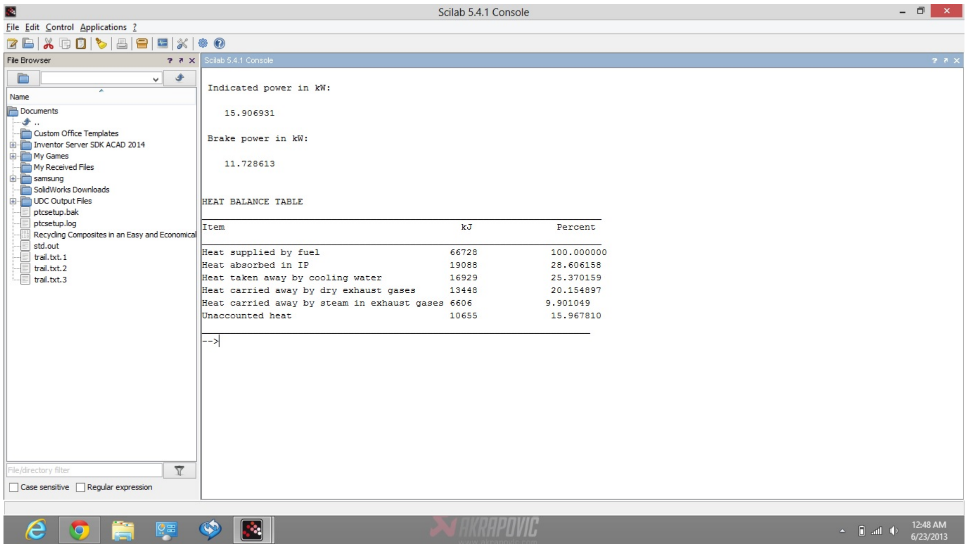
Figure 17.38: Heat balance sheet

```
printf("
    -----------------------------------------------------------------
   \n")
printf("Heat supplied by fuel                     %d
                  %f\n",hf,pf)
printf("Heat absorbed in IP                       %d
                  %f\n",hip,pip)
printf("Heat taken away by cooling water          %d
                  %f\n",hcw,pcw)
printf("Heat carried away by exhaust gases        %d
                  %f\n",hex,pex)
printf("
    -----------------------------------------------------------------
   ")
```

Scilab code Exa 17.38 `Heat balance sheet`

```
clc;funcprot(0);//EXAMPLE 17.38
// Initialisation of Variables
r=15;.................//Compression ratio
n=1;....................//No of cylinders
mf=10.2;...................//Fuel consumption in kg/h
C=43890;..................//Calorific value of fuel in kJ/kg
ma=3.8;..................//Consumption of air in kg/min
N=1900;....................//Engine rpm
T=186;.....................//Torque on brake drum in Nm
mw=15.5;..................//Mass of cooling water used in kg/min
delt=36;...................//temperature rise
tg=410;...................//Exhaust gas temperature in Celsius
tr=20;....................//Room temperature in Celsius
cp=1.17;..................//Specific heat capacity for exhaust gases kJ/kgK
cpw=4.18;...................//Specific heat capacity for water in kJ/kgK
//calculations
BP=(2*%pi*N*T)/(60*1000);.................//Brake power in kW
disp(BP,"Brake power in kW:")
bsfc=mf/BP;...............................//Brake specific fuel consumption in kg/kWh
disp(bsfc,"Brake specific fuel consumption in kg/kWh:")
etabth=BP/((mf/3600)*C);.....................//Brake thermal efficiency
disp(etabth*100,"Brake thermal efficiency in %:")
//Heat supplied
mg=(mf/60)+ma;.....................//Mass of exhaust gases in kg/min
hbp=BP*60;............//Heat equivalent of BP in kJ/
```

```
min
hcw=mw*cpw*delt;..........//Heat carried away by cooling water
hf=(mf/60)*C;................//heat supplied by fuel
hex=mg*cp*(tg-tr);..........//Heat carried by exhaust gasses
ha=round(hf)-round(hbp+hex+hcw);............//Unaccounted heat
pf=100;pbp=(hbp/hf)*100;pcw=(hcw/hf)*100;pex=(hex/hf)*100;pa=(ha/hf)*100;
printf("\n\n")
printf("HEAT BALANCE TABLE\n")
printf("-------------------------------------------------------------------------\n")
printf("Item                                              kJ                    Percent\n")
printf("-------------------------------------------------------------------------\n")
printf("Heat supplied by fuel                             %d          %f\n",hf,pf)
printf("Heat absorbed in BP                               %d          %f\n",hbp,pbp)
printf("Heat taken away by cooling water                  %d          %f\n",hcw,pcw)
printf("Heat carried away by exhaust gases                %d          %f\n",hex,pex)
printf("Unaccounted heat                                  %d          %f\n",ha,pa)
printf("-------------------------------------------------------------------------")
```



```
Indicated power in kW:

   15.906931

Brake power in kW:

   11.728613


HEAT BALANCE TABLE
______________________________________________________________________
Item                                           kJ                Percent
______________________________________________________________________
Heat supplied by fuel                          66728              100.000000
Heat absorbed in IP                            19088              28.606158
Heat taken away by cooling water               16929              25.370159
Heat carried away by dry exhaust gases         13448              20.154897
Heat carried away by steam in exhaust gases 6606                 9.901049
Unaccounted heat                               10655              15.967810
______________________________________________________________________
-->
```

Figure 17.39: heat balance sheet

Scilab code Exa 17.39 heat balance sheet

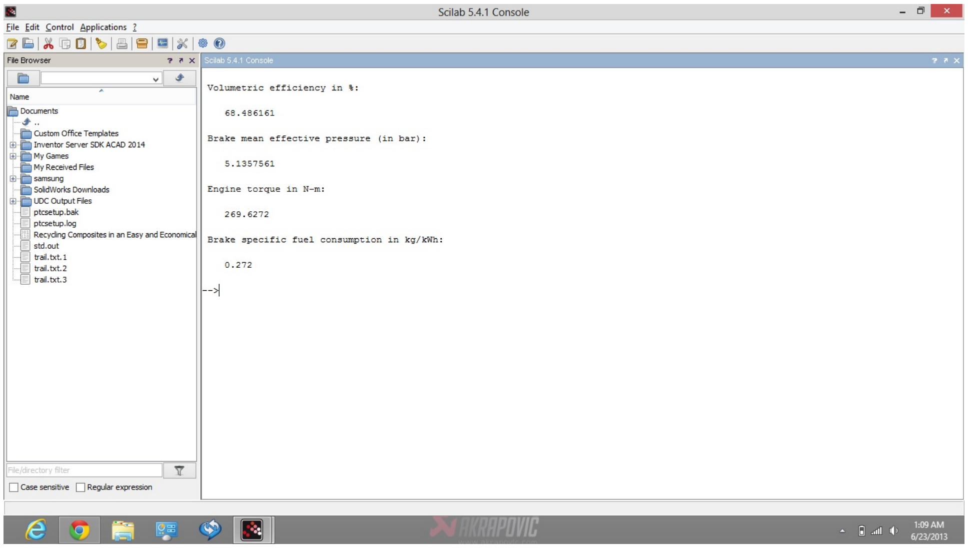
```
clc;funcprot(0);//EXAMPLE 17.39
// Initialisation of Variables
Cpw=4.18;..............//Specific heat of water in kJ/kgK
n=1;................//No of cylinders
N=350;.......//Engine rpm
pmi=3.1;..........//Mean effective pressure in bar
bl=640;..........//Brake load in N
mf=1.52;............//Fuel consumption in kg
mw=162;.............//Mass of cooling water
tw1=30;...............//Water inlet temperature in C
tw2=55;................//Water outlet temperature in C
ma=32;...................//Mass of air used per kg of fuel in kg
tr=25;.................//Room temperature in C
tg=305;.................//Exhaust temperature in C
D=0.2;..................//Engine bore in m
```

```
L=0.28;.................//Engine stroke in m
Db=1;......................//Brake drum diameter in m
ms=1.4;......................//Mass of steam formed per kg of fuel exhaust in kg
C=43900;...................//Calorirfic value of fuel in kJ/kg
Cps=2.09;..................//Specific heat of steamm in exhaust in kJ/kgK
Cpg=1.0;...................//Specific heat of dry exhaust gases in kJ/kgK
k=1;....................//Two stroke engiine
t=20;.....................//Duration of testing in min
//Calculations
IP=(n*pmi*N*D*D*L*k*10*(%pi/4))/6;...................//Indicated power in kW
disp(IP,"Indicated power in kW:")
BP=(bl*%pi*Db*N)/(60*1000);......................//Brake power in kW
disp(BP,"Brake power in kW:")
//Heat supplied
hf=mf*C;................//heat supplied by fuel
hip=IP*60*t;...........//Heat equivalent of BP in kJ/min
hcw=mw*Cpw*(tw2-tw1);..........//Heat carried away by cooling water
mg=mf+(ma*mf);....................//Mass of exhaust gases in kg/min
mst=mf*ms;..................//Mass of steam formed
hg=(mg-mst)*Cpg*(tg-tr);..........//Heat carried by exhaust gasses
hst=mst*(417.5+2257.9+(Cps*(305-99.6)));....................//Heat carried by exhaust steam, the obtained values are from steam table and hence are constants at NTP
ha=round(hf)-round(hip+hg+hst+hcw);............//Unaccounted heat
```

```
pf=100;pip=(hip/hf)*100;pcw=(hcw/hf)*100;pg=(hg/hf)
   *100;pa=(ha/hf)*100;pst=(hst/hf)*100;
printf("\n\n")
printf("HEAT BALANCE TABLE\n")
printf("
   -------------------------------------------------------------------
   \n")
printf("Item
                                                    kJ
                 Percent\n")
printf("
   -------------------------------------------------------------------
   \n")
printf("Heat supplied by fuel
   %d              %f\n",hf,pf)
printf("Heat absorbed in IP
   %d              %f\n",hip,pip)
printf("Heat taken away by cooling water
   %d              %f\n",hcw,pcw)
printf("Heat carried away by dry exhaust gases
   %d              %f\n",hg,pg)
printf("Heat carried away by steam in exhaust gases
   %d              %f\n",hst,pst)
printf("Unaccounted heat
   %d              %f\n",ha,pa)
printf("
   -------------------------------------------------------------------
   ")
```

Scilab code Exa 17.40 Finding the parameters for IC engine

```
clc;funcprot(0);//EXAMPLE 17.40
// Initialisation of Variables
```



```
Volumetric efficiency in %:

   68.486161

Brake mean effective pressure (in bar):

   5.1357561

Engine torque in N-m:

   269.6272

Brake specific fuel consumption in kg/kWh:

   0.272

-->
```

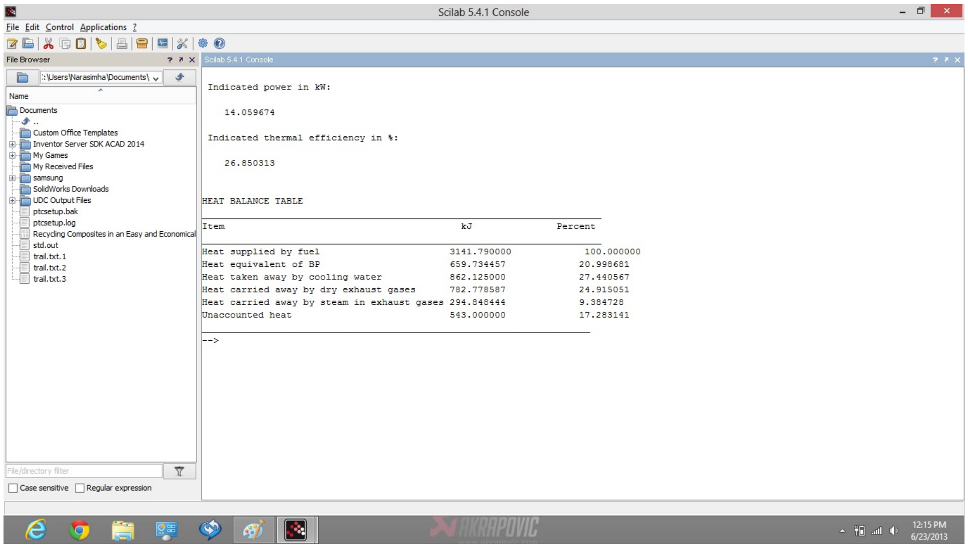
Figure 17.40: Finding the parameters for IC engine

```
n=6;................//No of cylinders
D=0.1;...............//Engine bore in m
L=0.14;...............//Engine stroke in m
N=2500;...............//Engine rpm
k=0.5;..................//Four stroke
bl=480;.................//Brake load in N
br=76;..................//Barometer reading in cm of
    Hg
d0=3.3/100;..............//Orifice diameter in m
Cd=0.62;.................//Co efficient of discharge
    of orifice
pd=14;...................//Pressure drop across
    orifice in cm of Hg
tr=25;...............//Room temperature in C
mf=0.32;................//Fuel consumption in kg/min
rhohg=13600;.................//Density of Hg in kg/m
    ^3
R=0.287;...................//gas constant in kJ/kgK
g=9.81;.................//Acceleration due to
    gravity in m/s^2
```

```
CD=17000;....................//dynamometer constant
//Calculations
Vs=(%pi/4)*D*D*L*(N/2)*(n/60);..............//Swept volume in m^3
br1=(br/100)*rhohg*g*(10^-3);.............//Barometer reading into kN/m^2
rhoa=br1/(R*(tr+273));...............//Density of air
pd1=(pd/100)*rhohg*g;......................//Conversion of pd into N/m^2
ha=pd1/(rhoa*g);.......................//Head of air causing flow in m
Va=Cd*(%pi/4)*d0*d0*sqrt(2*g*ha);............//Volume of air passing through orifice of air box per min
etav=Va/Vs;....................//Volumetric efficiency
disp(etav*100,"Volumetric efficiency in %:")
BP=bl*(N/CD);................//Brake power in kW
pmb=(BP*6)/(L*D*D*k*10*N*n*(%pi/4));...............//Brake mean effective pressure in bar
disp(pmb,"Brake mean effective pressure (in bar):")
T=(BP*60*1000)/(2*%pi*N);....................//Engine torque in N-m
disp(T,"Engine torque in N-m:")
bsfc=(mf*60)/BP;.......................//Brake specific fuel consumption in kg/kWh
disp(bsfc,"Brake specific fuel consumption in kg/kWh:")
```

Scilab code Exa 17.41 `Heat balance sheet`

```
clc;funcprot(0);//EXAMPLE 17.41
```



```
 Indicated power in kW:

   14.059674

 Indicated thermal efficiency in %:

   26.850313


HEAT BALANCE TABLE
______________________________________________________________________
Item                                          kJ                Percent
______________________________________________________________________
Heat supplied by fuel                       3141.790000          100.000000
Heat equivalent of BP                       659.734457          20.998681
Heat taken away by cooling water            862.125000          27.440567
Heat carried away by dry exhaust gases      782.778587          24.915051
Heat carried away by steam in exhaust gases 294.848444          9.384728
Unaccounted heat                            543.000000          17.283141
____________________________________________________________________
-->
```

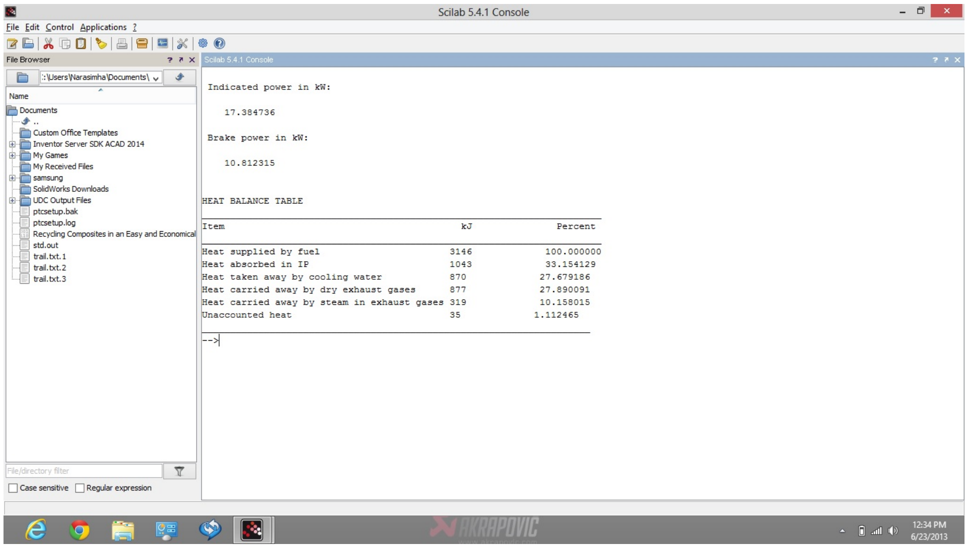
Figure 17.41: Heat balance sheet

```
// Initialisation of Variables
Cpw=4.18;..............//Specific heat of water in kJ/kgK
n=1;................//No of cylinders
N=350;.......//Engine rpm
pmi=2.74;..........//Mean effective pressure in bar
bl=600;..........//Brake load in N
mf=4.22;............//Fuel consumption in kg
mw=495;..............//Mass of cooling water
tw1=13;...............//Water inlet temperature in C
tw2=38;................//Water outlet temperature in C
ma=135;..................//Mass of air used in kg/h
tr=20;.................//Room temperature in C
tg=370;.................//Exhaust temperature in C
D=0.2;.................//Engine bore in m
L=0.28;.................//Engine stroke in m
Db=1;......................//Brake drum diameter in m
C=44670;...................//Calorirfic value of
```

```
fuel in kJ/kg
Cps=2.093;..................//Specific heat of steamm in exhaust in kJ/kgK
Cpg=1.005;...................//Specific heat of dry exhaust gases in kJ/kgK
k=1;....................//Two stroke engiine
t=60;....................//Duration of testing in min
perh=15;.................//Percentage of H2 in the fuel
//Calculations
IP=(n*pmi*N*D*D*L*k*10*(%pi/4))/6;...................//Indicated power in kW
disp(IP,"Indicated power in kW:")
BP=(bl*%pi*Db*N)/(60*1000);......................//Brake power in kW
etaith=(IP)/((mf/3600)*C);.................//Indicated thermal efficiency
disp(etaith*100,"Indicated thermal efficiency in %:")
//Heat supplied
hf=(mf/t)*C;................//heat supplied by fuel
hbp=BP*t;...........//Heat equivalent of BP in kJ/min
hcw=(mw/60)*Cpw*(tw2-tw1);..........//Heat carried away by cooling water
mg=(mf+ma)/t;....................//Mass of exhaust gases in kg/min
mst=9*(perh/100)*(mf/60);..................//Mass of steam formed
mdg=mg-mst;..............................//Mass of dry exhaust gases per min
hg=(mdg)*Cpg*(tg-tr);..........//Heat carried by exhaust gasses
hst=mst*(417.5+2257.9+(Cps*(305-99.6)));....................//Heat carried by exhaust steam, the obtained values are from steam table and hence are constants at NTP
```

```
ha=round(hf)-round(hbp+hg+hst+hcw);............//
   Unaccounted heat
pf=100;pbp=(hbp/hf)*100;pcw=(hcw/hf)*100;pg=(hg/hf)
   *100;pa=(ha/hf)*100;pst=(hst/hf)*100;
printf("\n\n")
printf("HEAT BALANCE TABLE\n")
printf("
   -----------------------------------------------------------------------
   \n")
printf("Item
                                                          kJ
                  Percent\n")
printf("
   -----------------------------------------------------------------------
   \n")
printf("Heat supplied by fuel
   %f              %f\n",hf,pf)
printf("Heat equivalent of BP
   %f              %f\n",hbp,pbp)
printf("Heat taken away by cooling water
   %f              %f\n",hcw,pcw)
printf("Heat carried away by dry exhaust gases
   %f              %f\n",hg,pg)
printf("Heat carried away by steam in exhaust gases
   %f              %f\n",hst,pst)
printf("Unaccounted heat
   %f              %f\n",ha,pa)
printf("
   -----------------------------------------------------------------------
   ")
```

Scilab code Exa 17.42 `Heat balance sheet`



```
 Indicated power in kW:

    17.384736

 Brake power in kW:

    10.812315


HEAT BALANCE TABLE
______________________________________________________________________
Item                                              kJ          Percent

______________________________________________________________________
Heat supplied by fuel                            3146          100.000000
Heat absorbed in IP                              1043           33.154129
Heat taken away by cooling water                 870           27.679186
Heat carried away by dry exhaust gases           877           27.890091
Heat carried away by steam in exhaust gases      319           10.158015
Unaccounted heat                                 35           1.112465
____________________________________________________________________
-->
```

Figure 17.42: Heat balance sheet

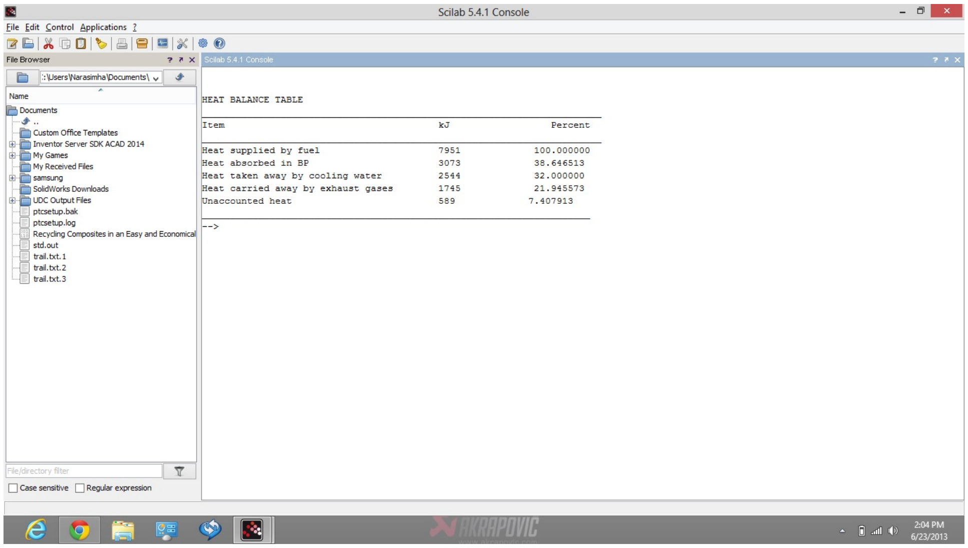
```
clc;funcprot(0);//EXAMPLE 17.42
// Initialisation of Variables
Cpw=4.18;...............//Specific heat of water in kJ/kgK
n=1;.................//No of cylinders
N=350;.......//Engine rpm
pmi=2.8;..........//Mean effective pressure in bar
bl=590;..........//Brake load in N
mf=4.3;.............//Fuel consumption in kg
mw=500;..............//Mass of cooling water
tw1=25;...............//Water inlet temperature in C
tw2=50;...............//Water outlet temperature in C
ma=33;..................//Mass of air used per kg of fuel in kg
tr=25;..................//Room temperature in C
tg=400;.................//Exhaust temperature in C
D=0.22;.................//Engine bore in m
L=0.28;.................//Engine stroke in m
Db=1;......................//Brake drum diameter in
```

```
m
C=43900;...................//Calorirfic value of fuel in kJ/kg
Cps=2.09;..................//Specific heat of steamm in exhaust in kJ/kgK
Cpg=1.0;...................//Specific heat of dry exhaust gases in kJ/kgK
k=1;....................//Two stroke engiine
perh=15;...................//Percentage of hydrogen
//Calculations
IP=(n*pmi*N*D*D*L*k*10*(%pi/4))/6;...................//Indicated power in kW
disp(IP,"Indicated power in kW:")
BP=(bl*%pi*Db*N)/(60*1000);......................//Brake power in kW
disp(BP,"Brake power in kW:")
//Heat supplied
hf=(mf/60)*C;................//heat supplied by fuel
hip=IP*60;...........//Heat equivalent of BP in kJ/min
hcw=(mw/60)*Cpw*(tw2-tw1);..........//Heat carried away by cooling water
mg=(mf+(mf*ma))/60;....................//Mass of exhaust gases in kg/min
mst=9*(perh/100)*(mf/60);..................//Mass of steam formed
mdg=mg-mst;..............................//Mass of dry exhaust gases per min
hg=(mdg)*Cpg*(tg-tr);..........//Heat carried by exhaust gasses
hst=mst*(417.5+2257.9+(Cps*(400-99.6)));....................//Heat carried by exhaust steam, the obtained values are from steam tables at NTP
mg=mf+(ma*mf);....................//Mass of exhaust gases in kg/min
ha=round(hf)-round(hip+hg+hst+hcw);............//Unaccounted heat
```

```
pf=100;pip=(hip/hf)*100;pcw=(hcw/hf)*100;pg=(hg/hf)*100;pa=(ha/hf)*100;pst=(hst/hf)*100;
printf("\n\n")
printf("HEAT BALANCE TABLE\n")
printf("---------------------------------------------------------------------
\n")
printf("Item                                              kJ                Percent\n")
printf("---------------------------------------------------------------------
\n")
printf("Heat supplied by fuel                    %d              %f\n",hf,pf)
printf("Heat absorbed in IP                      %d              %f\n",hip,pip)
printf("Heat taken away by cooling water         %d              %f\n",hcw,pcw)
printf("Heat carried away by dry exhaust gases   %d              %f\n",hg,pg)
printf("Heat carried away by steam in exhaust gases   %d              %f\n",hst,pst)
printf("Unaccounted heat                         %d              %f\n",ha,pa)
printf("---------------------------------------------------------------------
")
```

Scilab code Exa 17.43 `Heat balance sheet`

```
clc;funcprot(0);//EXAMPLE 17.43
// Initialisation of Variables
```

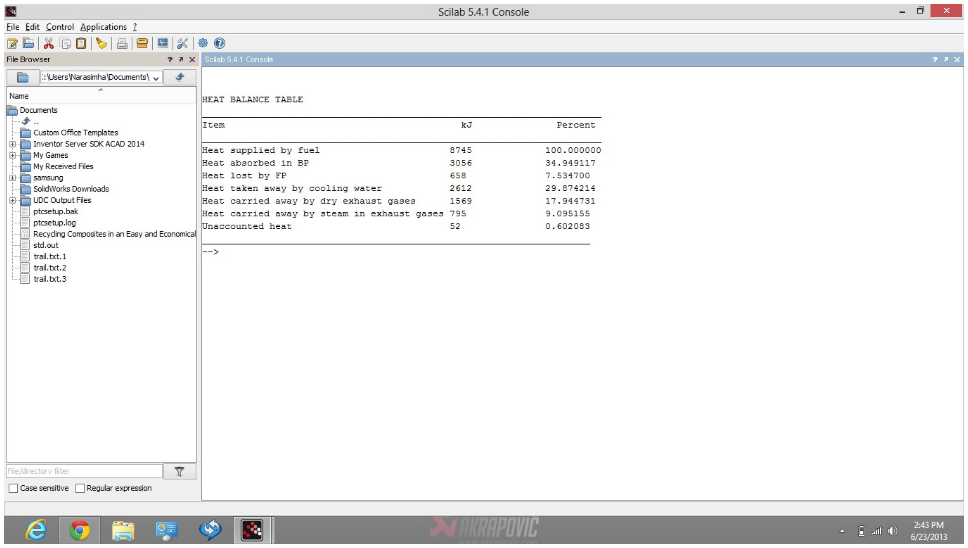


```
HEAT BALANCE TABLE

Item                                         kJ                  Percent

Heat supplied by fuel                        7951              100.000000
Heat absorbed in BP                          3073               38.646513
Heat taken away by cooling water             2544               32.000000
Heat carried away by exhaust gases           1745               21.945573
Unaccounted heat                             589               7.407913

-->
```

Figure 17.43: Heat balance sheet

```
I=210;.....................//Output of generator in A
V=200;.....................//Generator voltage in V
etag=0.82;.................//Generator efficiency
mf=11.2;...................//Fuel used in kg/h
C=42600;.....................//Calorific value of fuel in kJ/kg
afr=18;....................//Air fuel ratio
mc=580;....................//Mass of water through calorimeter in kg/h
delt=36;...................//Temperature raise in C
tg=98;.......................//Temperature of exhaust in C
ta=20;.......................//Ambient temperature in C
phcw=0.32;...................//Heat lost to cooling jacket is 32% of heat supplied
cpe=1.05;..................//Specific heat of exhause gases in kJ/kgK
cpw=4.18;..................//Specific heat of water
```

```
 in kJ/kgK
//Calculations
pow=V*I;.......................//Total power generated in W
BP=(pow/1000)/etag;..................//Brake power in kW
hf=(mf/60)*C;...................//Heat supplied to the engine
hbp=BP*60;.........................//Heat equivalent of BP
mg=(mf/60)*(afr+1);...............//Mass of exhaust gases formed per min in kg
hg=((mc/60)*cpw*(delt))+(mg*cpe*(tg-ta));..........//Heat carried by exhaust gases per min
hcw=phcw*hf;....................//Heat lost to cooling jacket
ha=hf-(hcw+hg+hbp);...................//Unaccounted heat
pf=100;pbp=(hbp/hf)*100;pcw=(hcw/hf)*100;pg=(hg/hf)*100;pa=(ha/hf)*100
printf("\n\n")
printf("HEAT BALANCE TABLE\n")
printf("---------------------------------------------------------------\n")
printf("Item                                         kJ                  Percent\n")
printf("---------------------------------------------------------------\n")
printf("Heat supplied by fuel                        %d                  %f\n",hf,pf)
printf("Heat absorbed in BP                          %d                  %f\n",hbp,pbp)
printf("Heat taken away by cooling water             %d                  %f\n",hcw,pcw)
printf("Heat carried away by exhaust gases           %d                  %f\n",hg,pg)
```



```
HEAT BALANCE TABLE
--------------------------------------------------------------
Item                                        kJ         Percent
--------------------------------------------------------------
Heat supplied by fuel                       8745       100.000000
Heat absorbed in BP                         3056       34.949117
Heat lost by FP                             658        7.534700
Heat taken away by cooling water            2612       29.874214
Heat carried away by dry exhaust gases      1569       17.944731
Heat carried away by steam in exhaust gases 795        9.095155
Unaccounted heat                            52         0.602083
------------------------------------------------------------
-->
```

Figure 17.44: Heat balance sheet

```
printf("Unaccounted heat                              %d
                    %f\n",ha,pa)
printf("
    ----------------------------------------------------------------------
    ")
```

Scilab code Exa 17.44 `Heat balance sheet`

```
clc;funcprot(0);//EXAMPLE 17.44
// Initialisation of Variables
D=0.34;..............//Engine bore in m
k=0.5;...............//Four stroke engine
n=1;..................//No of cylinders
L=0.44;...............//Engine stroke in m
Ne=400;...............//Engine rpm
```

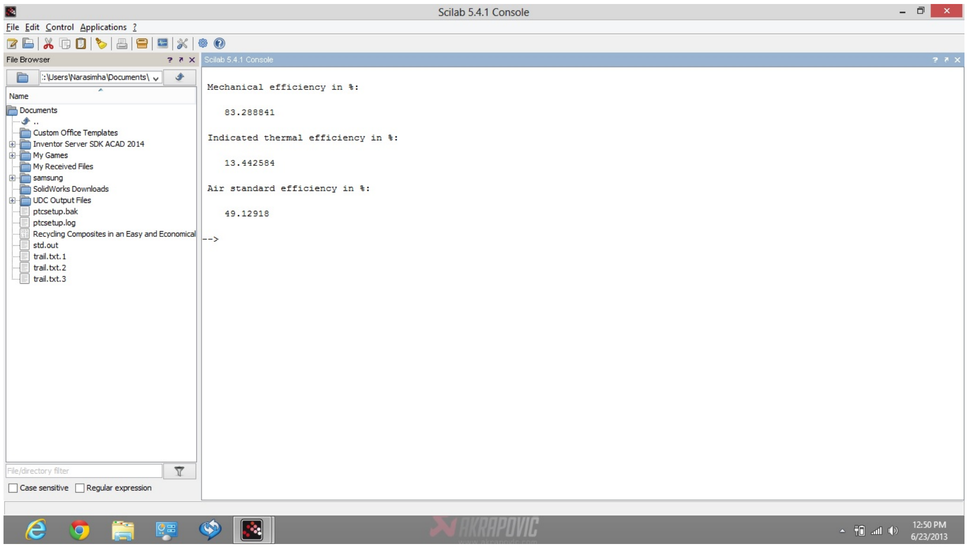
```
aic=465;..............//Area of indicator diagram in mm^2
l=60;..................//Length of diagram in mm
s=0.6;...............//Spring constant in bar/mm
W=950;.................//Load of dynamometer in N
CD=7460;................//Dynamometer constant
mf=10.6;................//Fuel used in kg/h
Ca=49500;.................//Calorific value of fuel in kJ/kg
mw=25;...................//Cooling water circulated in kg/min
cpw=4.18;..................//Specific heat capacity of water in kJ/kgC
delt=25;..................//Rise in temperature of water
//Mass analysis of fuel
C=84;..................//Percentage of carbon
H=15;..................//Percentage of hydrogen
In=1;..................//Percentage of incombustible
//Volume analysis of exhaust gases
CO2=9;..................//Percentage of caron dioxide
O=10;..................//Percentage of oxygen
N=81;..................//Percentage of nitrogen
tg=400;................//Temperature of exhaust gases in C
cpg=1.05;..............//Specific heat of exhaust gases in kJ/kgC
tr=25;.................//Temperature of room in C
ppst=0.03;..............//Partial pressure of steam in exhaust gases in bar
cpst=2.1;.................//Specific heat of superheated steam in kJ/kgC
//Calculations
pmi=(aic*s)/l;................//Mean effective pressure in bar
IP=(n*pmi*L*D*D*k*10*Ne*(%pi/4))/6;..............//Indicated power in kW
```

```
BP=(W*Ne)/CD;........................//Brake power in kW
FP=IP-BP;............................//Frictional power in kW
hf=(mf/60)*Ca;.......................//Heat supplied in kJ per min
hbp=BP*60;.......................//Heat equivalent of Brake power in kW
hfp=FP*60;.......................//heat equivalent of frictional power in kW
hcw=mw*cpw*delt;.................//Heat carried away by cooling water
ma1=(N*C)/(33*(CO2));...........//Mass of air supplied per kg of fuel
mg1=ma1+1;........................//Mass of exhaust gases per kg of fuel
mg=mg1*(mf/60);................//Mass of exhaust gas formed per min
mst1=9*(H/100);................//Mass of steam formed per kg of fuel
mst=mst1*(mf/60);.................//Mass of steam formed per min
mdg=mg-mst;......................//Mass of dry exhaust gas
hex=mdg*cpg*(tg-tr);..............//Heat carried by exhaust gases
hst=(2545.5+(cpst*(tg-24.1)))*mst;................//Heat carried by steam in exhaust gases in kJ/kg .....The values are from steam tables corresponding to the partial pressure 0.03 and temperature 400 Celsius
ha=hf-(hbp+hfp+hcw+hex+hst);....................//Unaccounted heat
pf=100;pbp=(hbp/hf)*100;pfp=(hfp/hf)*100;pcw=(hcw/hf)*100;pex=(hex/hf)*100;pa=(ha/hf)*100;pst=(hst/hf)*100;
printf(”\n\n”)
printf(”HEAT BALANCE TABLE\n”)
```

```
printf(”
    ----------------------------------------------------------------------
   \n”)
printf(”Item
                                                      kJ
                    Percent\n”)
printf(”
    ----------------------------------------------------------------------
   \n”)
printf(”Heat supplied by fuel
   %d              %f\n”,hf,pf)
printf(”Heat absorbed in BP
   %d              %f\n”,hbp,pbp)
printf(”Heat lost by FP
   %d               %f\n”,hfp,pfp)
printf(”Heat taken away by cooling water
   %d              %f\n”,hcw,pcw)
printf(”Heat carried away by dry exhaust gases
   %d              %f\n”,hex,pex)
printf(”Heat carried away by steam in exhaust gases
   %d               %f\n”,hst,pst)
printf(”Unaccounted heat
   %d                %f\n”,ha,pa)
printf(”
    ----------------------------------------------------------------------
   ”)
```

Scilab code Exa 17.45 Morse test

```
clc;funcprot(0);//EXAMPLE 17.45
// Initialisation of Variables
n=4;........................//No of cylinders
ga=1.4;...................//Degree of freedom
```



```
Mechanical efficiency in %:

   83.288841

Indicated thermal efficiency in %:

   13.442584

Air standard efficiency in %:

   49.12918

-->
```

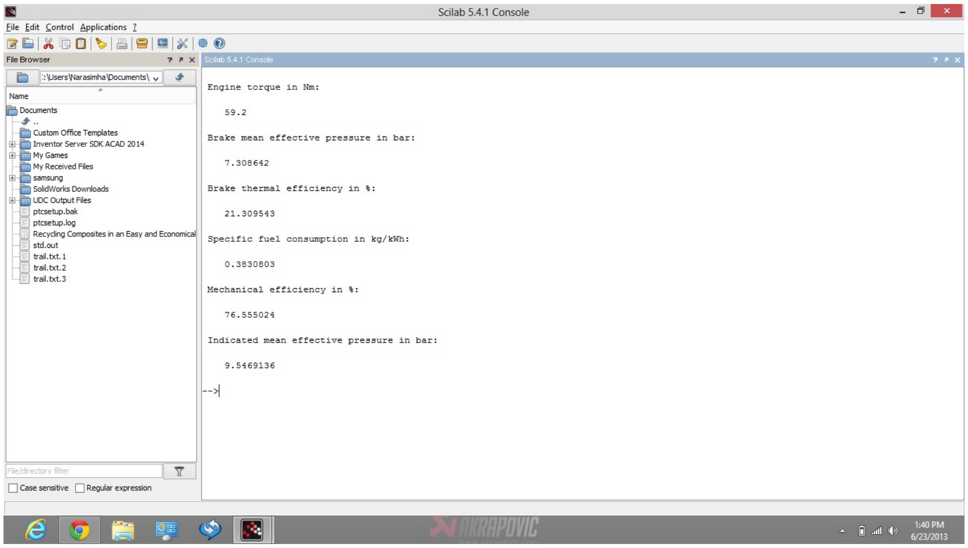
Figure 17.45: Morse test

```
D=0.075;..................//Engine bore in m
L=0.1;....................//Engine stroke in m
mf=6;.......................//Fuel consumption in kg/h
C=83600;..................//Calorific value of fuel used
Vc=0.0001;................//Clearence volume in m^3
BP=15.6;..................//Brake power wilh all cylinder working in kW
BP1=11.1;...................//Brake power wilh cylinder no 1 cutout in kW
BP2=11.03;..................//Brake power wilh cylinder no 2 cutout in kW
BP3=10.88;..................//Brake power wilh cylinder no 3 cutout in kW
BP4=10.66;..................//Brake power wilh cylinder no 4 cutout in kW
//Calculations
IP1=BP-BP1;...........................//Indicated power produced in cylinder 1 in kW
```

```
IP2=BP-BP2;...........................//Indicated
   power produced in cylinder 2 in kW
IP3=BP-BP3;...........................//Indicated
   power produced in cylinder 3 in kW
IP4=BP-BP4;...........................//Indicated
   power produced in cylinder 4 in kW
IP=IP1+IP2+IP3+IP4;............................//
   Total Indicated power produced in kW
etamech=BP/IP;..............................//
   Mechanical efficiency
disp(etamech*100,"Mechanical efficiency in %:")
etaith=IP/((mf/3600)*C);.....................//
   Indicated thermal efficiency
disp(etaith*100,"Indicated thermal efficiency in %:"
   )
Vs=(%pi/4)*D*D*L;..........................//Stroke
   volume in m^3
r=(Vs+Vc)/Vc;...............................//
   Compression ratio
etast=1-(1/(r^(ga-1)));...........................//
   Air standard efficiency
disp(etast*100,"Air standard efficiency in %:")
```

Scilab code Exa 17.46 `Morse test`

```
clc;funcprot(0);//EXAMPLE 17.46
// Initialisation of Variables
n=4;...........................//No of cylinders
D=0.06;........................//Engine bore in m
L=0.09;.........................//Engine stroke in m
N=2800;.........................//Engine rpm
Ta=0.37;.........................//Length of torque
   arm in m
```



```
Engine torque in Nm:

   59.2

Brake mean effective pressure in bar:

   7.308642

Brake thermal efficiency in %:

   21.309543

Specific fuel consumption in kg/kWh:

   0.3830803

Mechanical efficiency in %:

   76.555024

Indicated mean effective pressure in bar:

   9.5469136

-->
```

Figure 17.46: Morse test

```
spgr=0.74;.....................//Specific graviy of fuel
fc=8.986;......................//Fuel consumption in ltrs/h
mf=fc*spgr;.....................//Fuel consumed in kg/h
C=44100;......................//Calorific value of fuel in kJ/kg
BPnl=160;.................//Net brake load in N
BP1=110;...................//Brake load with cylinder no 1 cutout in N
BP2=107;...................//Brake load with cylinder no 2 cutout in N
BP3=104;...................//Brake load with cylinder no 3 cutout in N
BP4=110;...................//Brake load with cylinder no 4 cutout in N
k=0.5;.....................//Four stroke engine
//Calculations
T=BPnl*Ta;.......................//Engine torque in
```

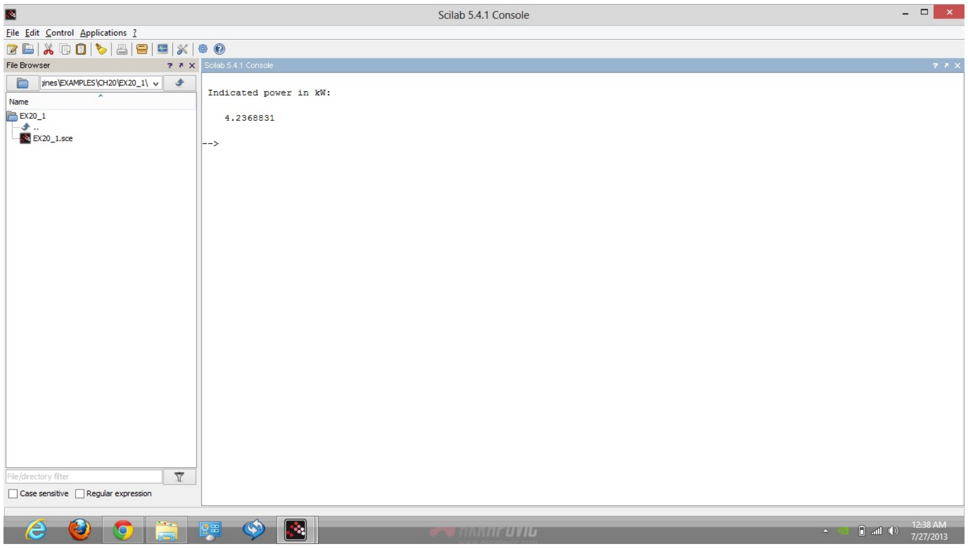
```
N-m
disp(T,"Engine torque in Nm:")
BP=(2*%pi*N*T)/(60*1000);..........................//Brake power in kW
pmb=(BP*6)/(n*D*D*L*N*10*(%pi/4)*k);...................//Brake mean effective pressure in bar
disp(pmb,"Brake mean effective pressure in bar:")
etabth=BP/((mf/3600)*C);...........................//Brake thermal efficiency
disp(etabth*100,"Brake thermal efficiency in %:")
sfc=mf/BP;.......................//Specific fuel consumption in kg/kWh
disp(sfc,"Specific fuel consumption in kg/kWh:")
IP1=BPnl-BP1;...........................//Indicated power produced in cylinder 1 in kW
IP2=BPnl-BP2;...........................//Indicated power produced in cylinder 2 in kW
IP3=BPnl-BP3;...........................//Indicated power produced in cylinder 3 in kW
IP4=BPnl-BP4;...........................//Indicated power produced in cylinder 4 in kW
IP=IP1+IP2+IP3+IP4;.............................//Total Indicated power produced in kW
etamech=BPnl/IP;..............................//Mechanical efficiency
disp(etamech*100,"Mechanical efficiency in %:")
pmi=pmb/etamech;............................//Indicated mean effective pressure in bar
disp(pmi,"Indicated mean effective pressure in bar:")
```

Chapter 20

Air Compressors

Scilab code Exa 20.1 `Single stage reciprocating compressor`

```
clc;funcprot(0);//EXAMPLE 20.1
// Initialisation of Variables
v1=1;.........//Volume of air taken in m^3/min
p1=1.013;...............//Intake pressure in bar
t1=288;...............//Intake temperature in K
p2=7;......................//Delivery pressure in
   bar
n=1.35;..............//Adiabatic index
R=287;..............//Gas constant in kJ/kgK
//Calculations
m=(p1*v1*10^5)/(R*t1);..............//Mass of air
   delivered per min in kg
t2=t1*((p2/p1)^((n-1)/n));..........//Delivery
   temperature in K
iw=(n/(n-1))*m*R*(t2-t1);...........//Indicated
   work in kJ/min
IP=iw/(60*1000);...................//Indicated
   power
disp(IP,"Indicated power in kW:")
```

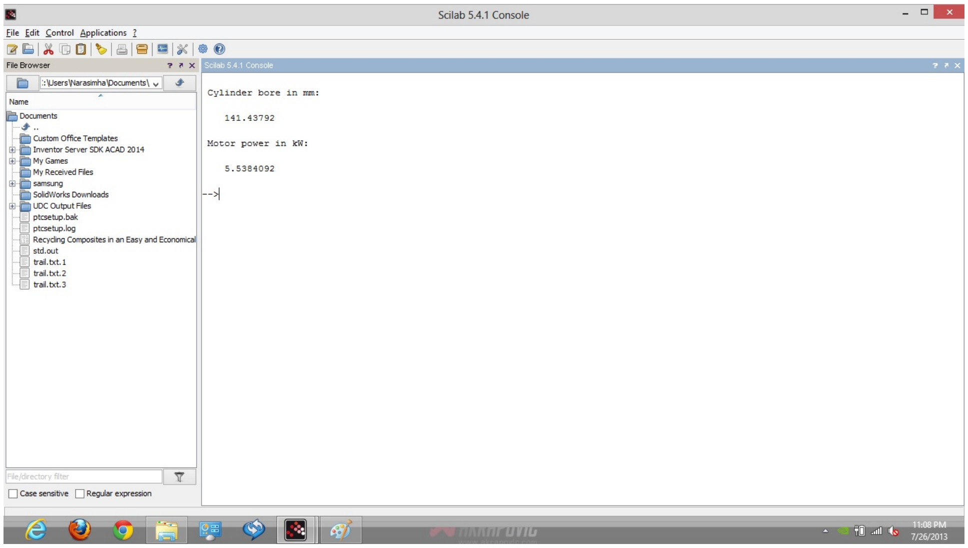


```
Indicated power in kW:

   4.2368831

-->
```

Figure 20.1: Single stage reciprocating compressor

Scilab code Exa 20.2 `Motor power and bore of single stage compressor`

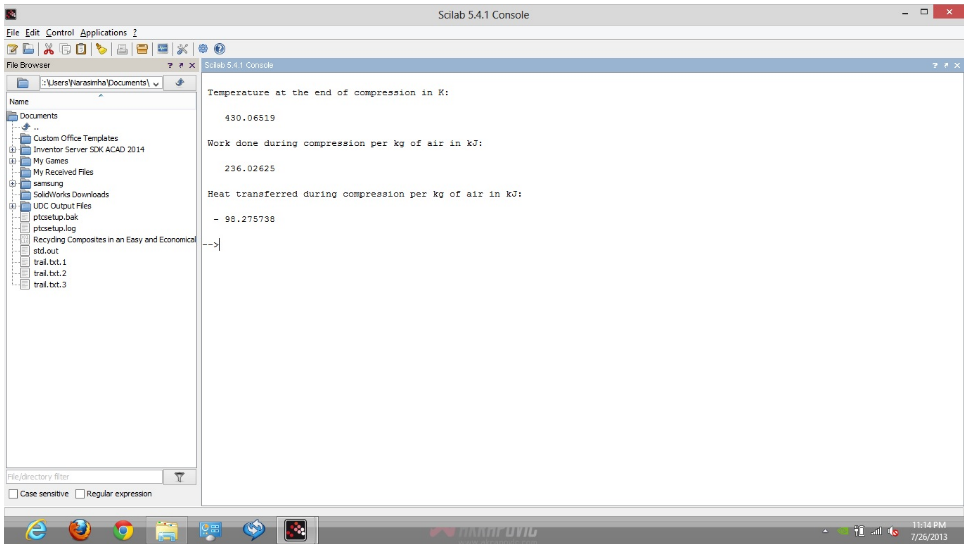
```
clc;funcprot(0);//EXAMPLE 20.2
// Initialisation of Variables
N=300;............//Compressor rpm
afr=15;.........//Air fuel ratio
etamech=0.85;....//Mechanical efficiency
etamt=0.9;.......//Motor transmission efficiency
v=1;............//Volume dealt with per min at inlet in m^3/min
rld=1.5;........//Ratio of stroke to diameter
v1=1;.........//Volume of air taken in m^3/min
p1=1.013;...............//Intake pressure in bar
t1=288;...............//Intake temperature in K
```



```
Cylinder bore in mm:

   141.43792

Motor power in kW:

   5.5384092

-->
```

Figure 20.2: Motor power and bore of single stage compressor

```
p2=7;......................//Delivery pressure in bar
n=1.35;..............//Adiabatic index
R=287;..............//Gas constant in kJ/kgK
//Calculations
m=(p1*v1*10^5)/(R*t1);..............//Mass of air delivered per min in kg
t2=t1*((p2/p1)^((n-1)/n));...........//Delivery temperature in K
iw=(n/(n-1))*m*R*(t2-t1);............//Indicated work in kJ/min
IP=iw/(60*1000);....................//Indicated power in kW
vdc=v/N;........//Volume drawn in per cycle in m^3
D=(vdc/((%pi/4)*rld))^(1/3);..........//Cylinder bore in m
disp(D*1000,"Cylinder bore in mm:")
pc=IP/etamech;.........//Power input to the compressor in kW
mp=pc/etamt;..........//Motor power in kW
```



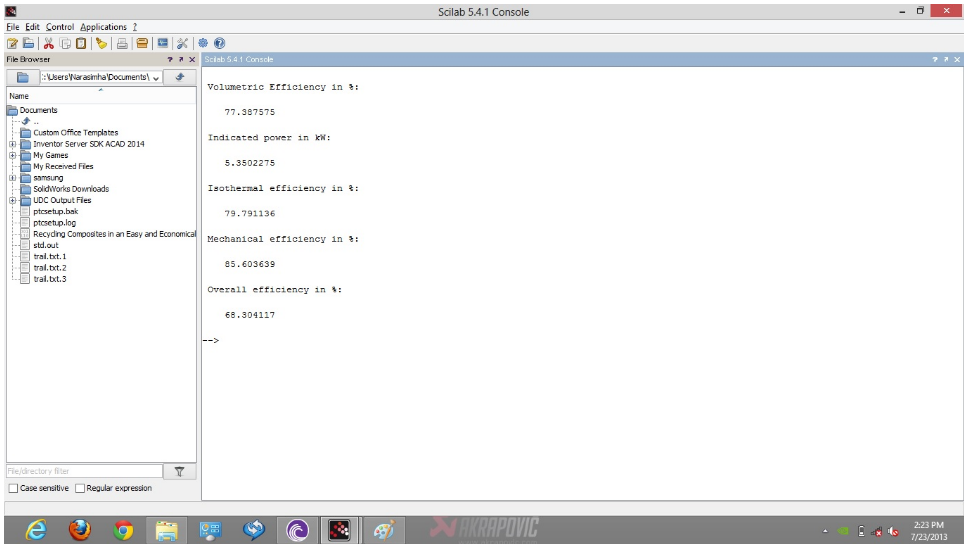
```
Temperature at the end of compression in K:

   430.06519

Work done during compression per kg of air in kJ:

   236.02625

Heat transferred during compression per kg of air in kJ:

 - 98.275738

-->
```

Figure 20.3: Work done and heat transferred during single stage compression

```
disp(mp,"Motor power in kW:")
```

Scilab code Exa 20.3 Work done and heat transferred during single stage compressio

```
clc;funcprot(0);//EXAMPLE 20.3
// Initialisation of Variables
p1=1;......//Suction pressure in bar
t1=293;.....//Suction temperature in K
n=1.2;......//Compression index
p2=10;......//Delivery pressure in bar
R=0.287;....//Gas constant in kJ/kgK
cv=0.718;...//Specific heat at constant volume in kJ/kgK
//Calculations
t2=t1*((p2/p1)^((n-1)/n));.....//Temperature at the end of compression in K
```



```
Volumetric Efficiency in %:

   77.387575

Indicated power in kW:

   5.3502275

Isothermal efficiency in %:

   79.791136

Mechanical efficiency in %:

   85.603639

Overall efficiency in %:

   68.304117

-->
```

Figure 20.4: Single stage compressor

```
disp(t2,"Temperature at the end of compression in K:")
W=1*R*t1*(n/(n-1))*(((p2/p1)^((n-1)/n))-1);.......//Work done during compression of air in kJ
disp(W,"Work done during compression per kg of air in kJ:")
Q=(t2-t1)*(cv-((R)/(n-1)));..........//Heat transferred during compression of air in kJ/kg
disp(Q,"Heat transferred during compression per kg of air in kJ:")
```

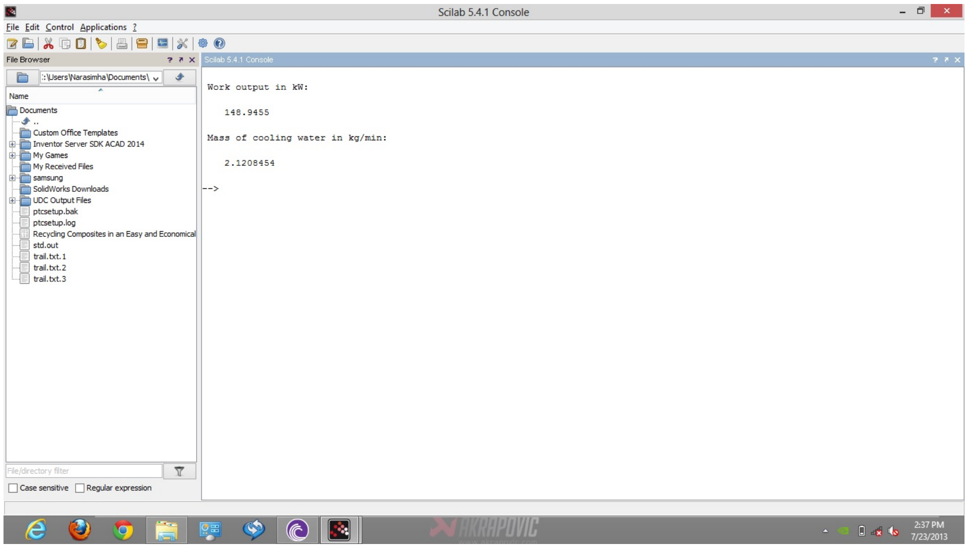
Scilab code Exa 20.4 Single stage compressor

```
clc;funcprot(0);//EXAMPLE 20.4
// Initialisation of Variables
p1=1;........//Suction pressure in bar
```

```
t1=293;.......//Suction temperature in K
p2=6;..........//Discharge pressure in bar
t2=453;.......//Discharge temperature in K
N=1200;.........//Compressor rpm
Ps=6.25;........//Shaft power in kW
ma=1.7;........//Mass of air delivered in kg/min
D=0.14;......//Engine bore in m
L=0.10;.......//Engine stroke in m
R=287;..........//Gas constant in kJ/kgK
//Calculations
Vd=(%pi/4)*D*D*L*N;.........//Displlacement volume in m^3/min
FAD=ma*R*t1/(p1*10^5);........//Free air delivered
etav=FAD/Vd;.....//Volumetric efficiency
disp(etav*100,"Volumetric Efficiency in %:")
n=1/(1-((log(t2/t1))/(log(p2/p1))));........//Index of compression
IP=(n/(n-1))*(ma/60)*(R/1000)*t1*(((p2/p1)^((n-1)/n))-1);..........//Indicated power in kW
disp(IP,"Indicated power in kW:")
Piso=((ma/60)*(R/1000)*t1*(log(p2/p1)));..........//Isothermal power
etaiso=Piso/IP;..............//Isothermal efficiency
disp(etaiso*100,"Isothermal efficiency in %:")
etamech=IP/Ps;...........//Mechanical efficiency
disp(etamech*100,"Mechanical efficiency in %:")
etao=Piso/Ps;........//Overall efficiency
disp(etao*100,"Overall efficiency in %:")
```

Scilab code Exa 20.5 `Low pressure water jacketed rotary compressor`

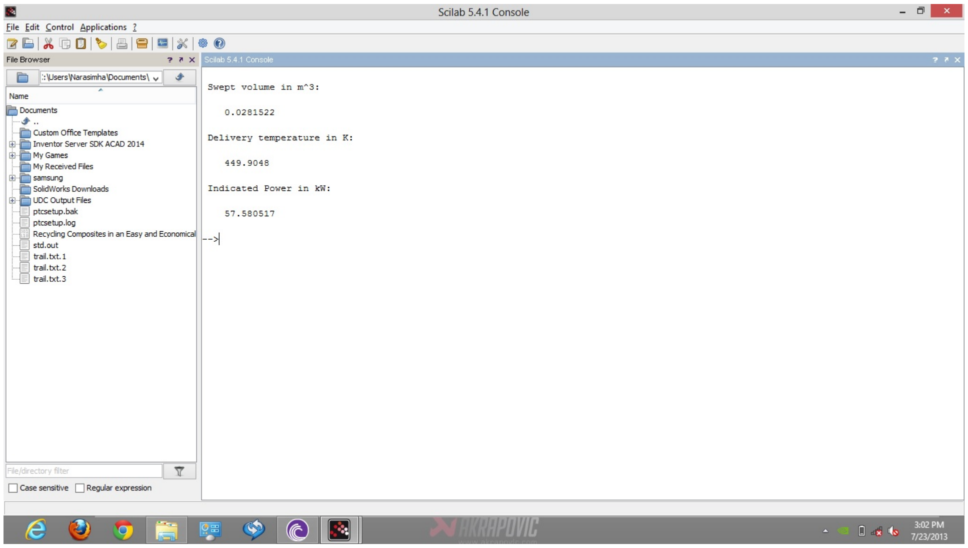
```
clc;funcprot(0);//EXAMPLE 20.5
// Initialisation of Variables
```



```
Work output in kW:

   148.9455

Mass of cooling water in kg/min:

   2.1208454

-->
```

Figure 20.5: Low pressure water jacketed rotary compressor

```
ma=6.75;.........//Mass of air compressed in kg/min
p1=1;............//Initial pressure in atm
cp=1.003;........//Specifc heat at constant vpressure in kJ/kgK
t1=21;...........//Initial temperature in Celsius
t2=43;..........//Final temperature in Celsius
rp=1.35;.........//Pressure ratio
ga=1.4;.........//Ratio os specific heats
delt=3.3;.......//Change in temperature
cpw=4.18;.......//Specific heat for water in kJ/kgK
//Calculations
W=ma*cp*(t2-t1);............//Work output in kJ
disp(W,"Work output in kW:")
t21=(t1+273)*(rp^((ga-1)/ga));...........//Final temperature if the compression had been isentropic
Qr=ma*cp*(t21-(t2+273));...........//Heat rejected in kJ
mw=Qr/(cpw*delt);........//Mass of cooling water in kg/min
```



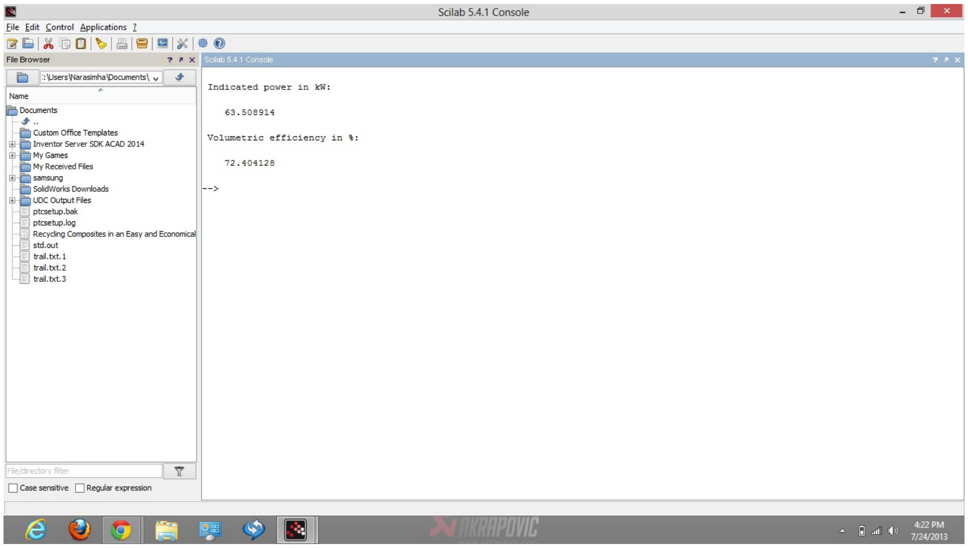
```
Swept volume in m^3:

   0.0281522

Delivery temperature in K:

   449.9048

Indicated Power in kW:

   57.580517

-->
```

Figure 20.6: Single stage double acting compressor

```
disp(mw,"Mass of cooling water in kg/min:")
```

Scilab code Exa 20.6 `Single stage double acting compressor`

```
clc;funcprot(0);//EXAMPLE 20.6
// Initialisation of Variables
ma=14;........//Quantity of air delivered in kg/min
p1=1.013;......//Intake pressure in bar
t1=288;.........//Intake temperature in K
p2=7;...........//Delivery pressure in bar
N=300;..........//Compressor rpm
pervc=0.05;.......//Percentage of clearance volume
    in the total stroke volume
n=1.3;............//Compressor and expansion index
//Calculations
V1byVs=pervc+1;
```



```
Indicated power in kW:

   63.508914

Volumetric efficiency in %:

   72.404128

-->
```

Figure 20.7: Single stage double acting compressor

```
v1minv4=ma/(N*2);v4byv3=((p2/p1)^(1/n));v4byvs=v4byv3*pervc;Vs=v1minv4/(V1byVs-v4byvs);.....//Swept volume in m^3
disp(Vs,”Swept volume in m^3:”)
t2=t1*((p2/p1)^((n-1)/n));........//Delivery Temperature in K
disp(t2,”Delivery temperature in K:”)
IP=((n)/(n-1))*p1*(10^5)*((ma)/(60*1000))*(((p2/p1)^((n-1)/n))-1);
disp(IP,”Indicated Power in kW:”)
```

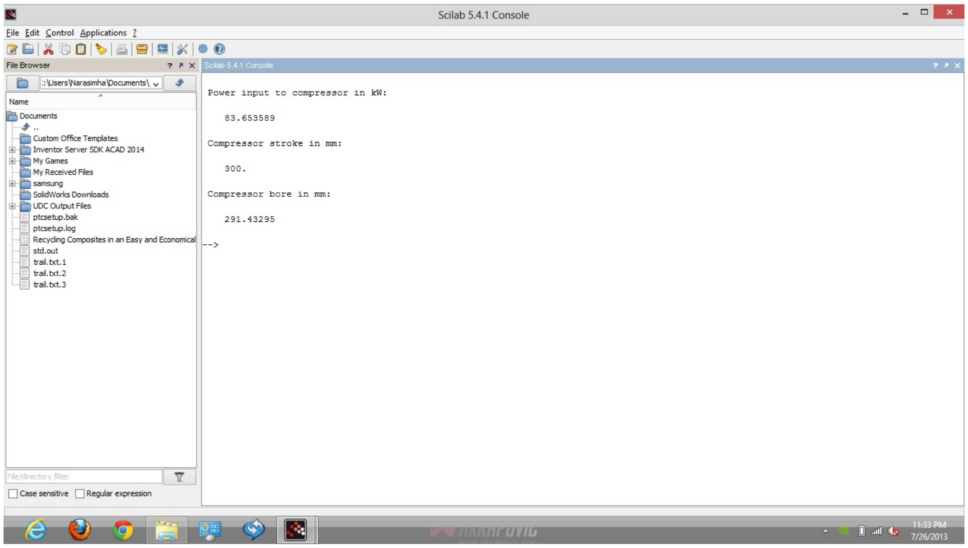
Scilab code Exa 20.7 `Single stage double acting compressor`

```
clc;funcprot(0);//EXAMPLE 20.7
// Initialisation of Variables
FAD=14;...........//Free air delivered in m^3/min
```

```
p1=0.95;.........//Induction pressure in bar
t1=305;........//Induction temperature in K
p2=7;...........//Delivery pressure in bar
n=1.3;...........//Adiabatic index
VcbyVs=0.05;........//Ratio of clearance volume and
   swept volume
R=287;...........//Gas constant in J/kgK
t=288;...........//free air temperature in K
p=1.013;.........//free air pressure in bar
//Calculations
m=(p*100000*FAD)/(R*t);..........//Mass delivered
   per min in kg
t2=t1*((p2/p1)^((n-1)/n));
IP=((n/(n-1))*m*(R/1000)*(t2-t1))/60;.........//
   Indicated power in kW
disp(IP,"Indicated power in kW:")
v4byv3=(p2/p1)^(1/n);v4byvs=v4byv3*VcbyVs;v1minv4
   =(1+VcbyVs)-v4byvs;
Vbyvs=v1minv4*(t/t1)*(p1/p);
etav=Vbyvs/1;.............//Volumetric efficiency
disp(etav*100,"Volumetric efficiency in %:")
```

Scilab code Exa 20.8 Single stage double acting compressor

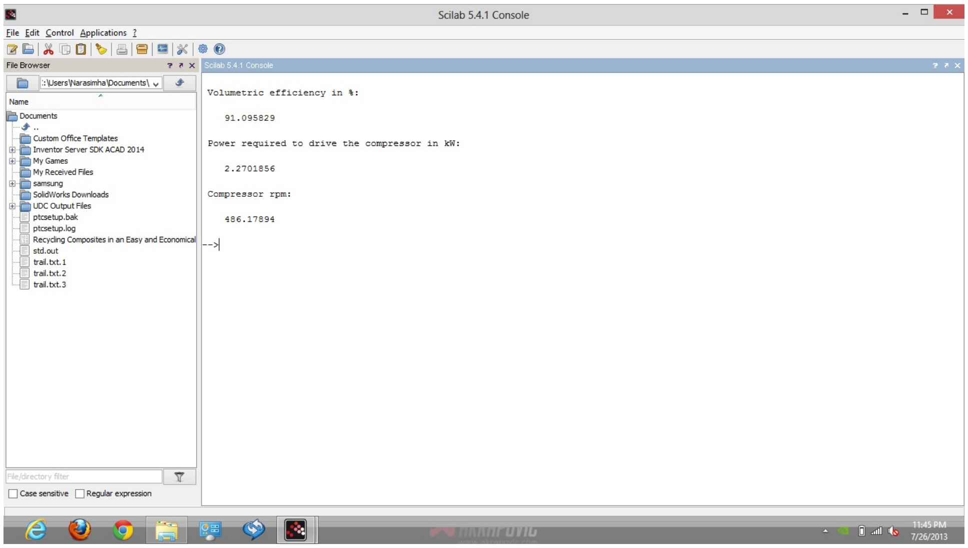
```
clc;funcprot(0);//EXAMPLE 20.8
// Initialisation of Variables
FAD=16;.......//Free air delivered in m^3/min
p1=0.96;......//Suction pressure in bar
t1=303;.......//Suction temperature in K
n=1.3;........//Compression index
k=0.04;........//Clearance ratio
p2=6;.........//Delivery pressure in bar
etamech=0.9;...//Mechanical efficiency
```



```
Power input to compressor in kW:

   83.653589

Compressor stroke in mm:

   300.

Compressor bore in mm:

   291.43295

-->
```

Figure 20.8: Single stage double acting compressor

```
vp=300;.......//Piston speed in m/min
N=500;........//Compressor rpm
p=1;.....//Ambient pressure in bar
t=288;.....//Ambient temperature in K
etac=0.85;...//Compressor efficiency
R=0.287;......//Universal gas constant
//Calculations
m=(p*10^5*FAD)/(R*1000*t);...........//Mass flow rate of compressor in kg/min
t2=t1*((p2/p1)^((n-1)/n));.....//Temperature at the end of compression in K
P=(n/(n-1))*(m/60)*R*(t2-t1)*(1/etamech)*(1/etac);..........//Power input to compressor in kW
disp(P,"Power input to compressor in kW:")
L=vp/(2*N);.........//Stroke in m
disp(L*1000,"Compressor stroke in mm:")
etav=((t/t1)*(p1/p)*(1+k-(k*((p2/p1)^(1/n)))));........//Volumetric efficiency
D=sqrt(FAD/((%pi/4)*L*N*2*etav));...........//Compressor bore in m
```



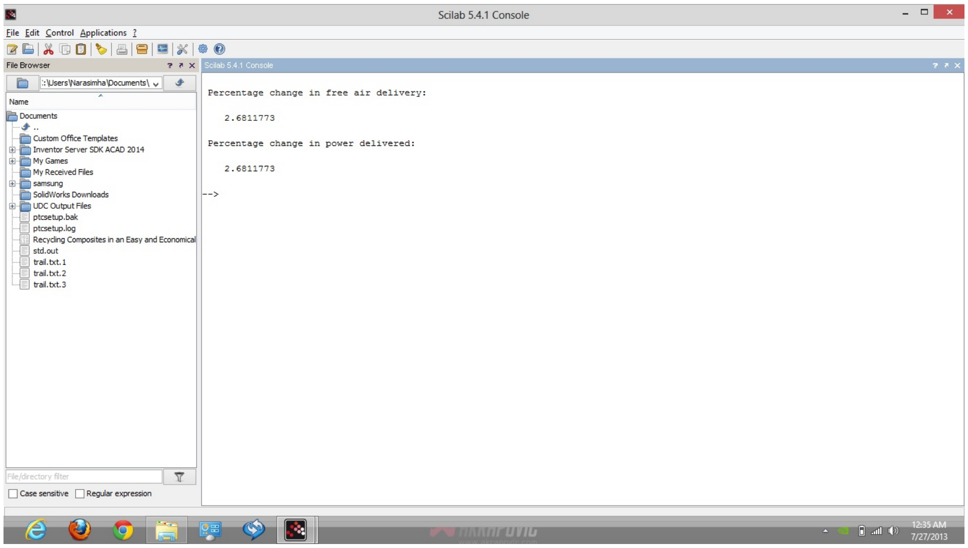
```
Volumetric efficiency in %:

   91.095829

Power required to drive the compressor in kW:

   2.2701856

Compressor rpm:

   486.17894

-->
```

Figure 20.9: Single stage single acting compressor

```
disp(D*1000,"Compressor bore in mm:")
```

Scilab code Exa 20.9 `Single stage single acting compressor`

```
clc;funcprot(0);//EXAMPLE 20.9
// Initialisation of Variables
m=0.6;..........//Mass of air delivered in kg/min
p2=6;.........//Delivery pressure in bar
p1=1;..........//Induction pressure in bar
t1=303;........//Induction temperature in K
D=0.1;.........//Compressor bore in m
L=0.15;........//Compressor stroke in m
k=0.03;........//Clearance ratio
etamech=0.85;....//Mechanical efficiency
R=0.287;.......//Gas constant in kJ/kgK
n=1.3;........//Compression index
```



```
Percentage change in free air delivery:

   2.6811773

Percentage change in power delivered:

   2.6811773

-->
```

Figure 20.10: Percentage change in volume and power

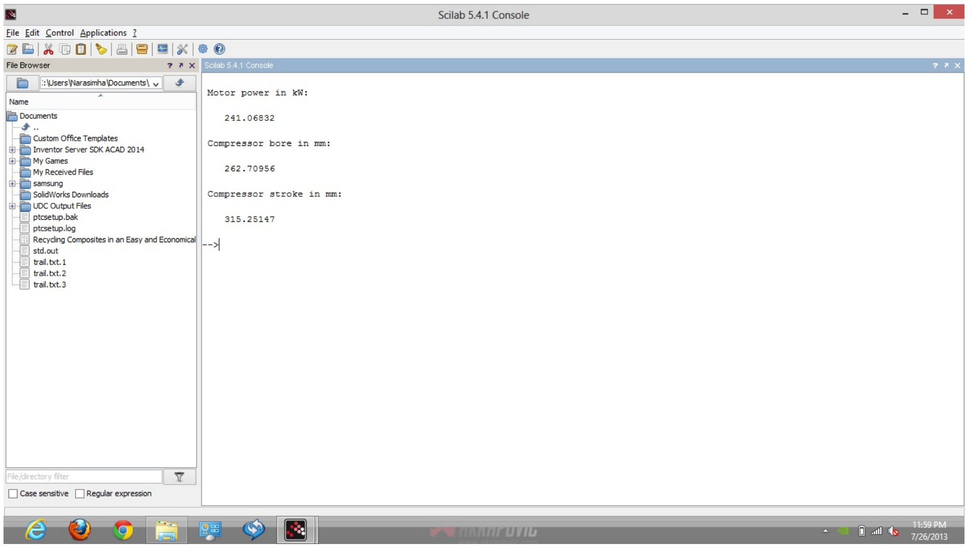
```
//Calculations
etav=(1+k)-(k*((p2/p1)^(1/n)));..........//Volumetric efficiency
disp(etav*100,"Volumetric efficiency in %:")
IP=(n/(n-1))*(m/60)*R*t1*(((p2/p1)^((n-1)/n))-1);.........//Indicated power in kW
P=IP/etamech;...........//Power required to drive the compressor in kW
disp(P,"Power required to drive the compressor in kW:")
FAD=(m*R*t1*1000)/(p1*10^5);...........//Free air delivery in m^3/min
Vd=FAD/etav;........//Displacement volume in m^3/min
N=Vd/((%pi/4)*D*D*L);.........//Compressor rpm
disp(N,"Compressor rpm:")
```

Scilab code Exa 20.10 Percentage change in volume and power

```
clc;funcprot(0);//EXAMPLE 20.10
// Initialisation of Variables
L=88;..........//Compressor stroke in cm
k=0.02;..........//Clearance ratio
p3=8.2;..........//Delivery pressure in bar
p4=1.025;.......//Suction pressure in bar
p1=p4;.......//Suction pressure in bar
n=1.3;.........//Compression index
lo=0.55;...//Length of distance piece fitted after
   overhaul in cm
//Calculations
pcfa=(((L+(L*k))-((L*k)*((p3/p4)^(1/n))))-(((k*L)+lo
   +L)-(((k*L)+lo)*((p3/p4)^(1/n)))))/((L+L*k)-((L*k
   )*((p3/p4)^(1/n))))
disp(pcfa*100,"Percentage change in free air
   delivery:")
pcpa=pcfa;......//Percentage change in power
   delivered
disp(pcpa*100,"Percentage change in power delivered:
   ")
```

Scilab code Exa 20.11 Single stage double acting compressor

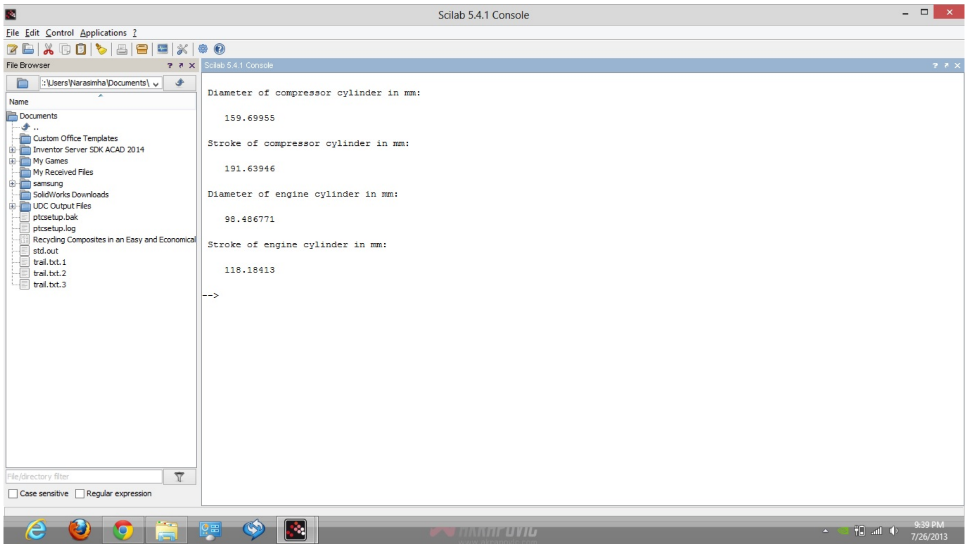
```
clc;funcprot(0);//EXAMPLE 20.11
// Initialisation of Variables
v=30;............//Suction volume in m^3/min
p1=1;..........//Suction pressure in bar
t1=300;.........//Suction temperature in K
p2=16;..........//Delivery pressure in bar
N=320;.........//Compressor rpm
k=0.04;.........//Clearance ratio
```



```
Motor power in kW:

   241.06832

Compressor bore in mm:

   262.70956

Compressor stroke in mm:

   315.25147

-->
```

Figure 20.11: Single stage double acting compressor

```
rld=1.2;.........//Ratio of stroke to bore
etamech=0.82;....//Mechanical efficiency
n=1.32;.........//Compression index
ti=39+273;......//Temperature inside the suction chamber in K
nc=4;.........//No of cylineders
//Calculations
W=(n/(n-1))*(p1/1000)*10^5*(v/60)*(((p2/p1)^((n-1)/n))-1);........//Work done in kW
mp=W/etamech;..........//Motor power in kW
disp(mp,"Motor power in kW:")
etav=((1+k)-(k*((p2/p1)^(1/n))))*(t1/ti);........//Volumetric efficiency
Vs=(v/nc)*(1/(2*N))*(1/etav);............//Swept volume of cylinder in m^3
D=(Vs/((%pi/4)*rld))^(1/3);.............//Compressor bore in m
L=D*rld;..............//Compresor stroke in m
disp(D*1000,"Compressor bore in mm:")
disp(L*1000,"Compressor stroke in mm:")
```



```
Diameter of compressor cylinder in mm:

   159.69955

Stroke of compressor cylinder in mm:

   191.63946

Diameter of engine cylinder in mm:

   98.486771

Stroke of engine cylinder in mm:

   118.18413

-->
```

Figure 20.12: Two cylinder single acting compressor

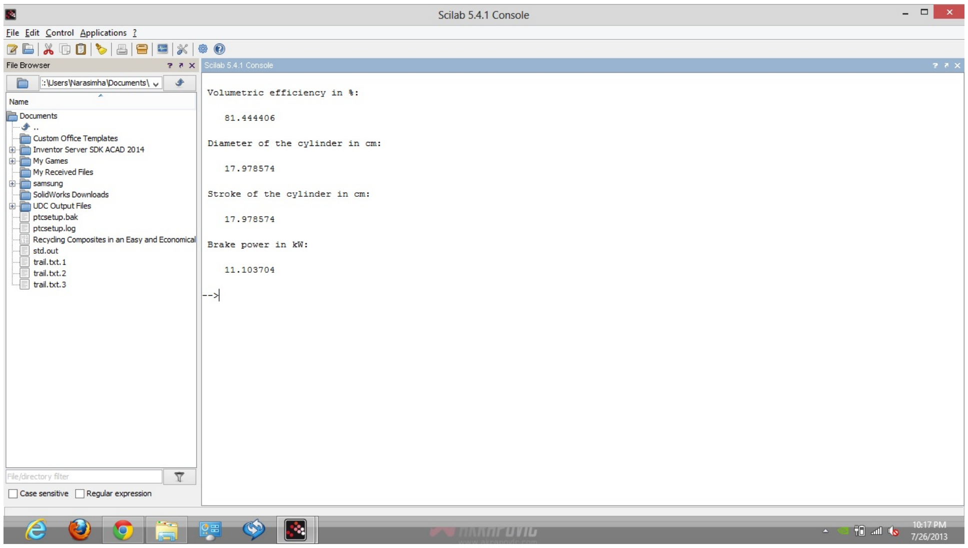
Scilab code Exa 20.12 `Two cylinder single acting compressor`

```
clc;funcprot(0);//EXAMPLE 20.12
// Initialisation of Variables
n=2;........//No of cylinders
ma=16;........//Mass of air supplied per min in kg
p1=1;........//Suction pressure in bar
t1=288;.......//Suction temperature in K
k=0.04;.......//Clearance ratio
ni=1.3;........//Compression index
R=0.287;........//Gas constant in kJ/kgK
N=2000;........//Engine rpm
p3=7;..........//Delivery pressure in bar
rld=1.2;...........//Ratio of stroke to bore for compressor cylinder and engine cylinder
```

```
etamech=0.82;.........//Mechanical efficiency of engine
pmb=5.5;..........//Mean effective pressure in bar in engine
ne=4;.............//No of engine cylinders
//Calculations
Vs=(((ma/n)*R*1000*t1)/(p1*10^5*N))/((1+k)-(k*((p3/p1)^(1/ni))));
Dc=(Vs/((%pi/4)*rld))^(1/3);.........//Diameter of compressor cylinder in m
Lc=rld*Dc;.............//Stroke of the compressor cylinder in m
disp(Dc*1000,"Diameter of compressor cylinder in mm:")
disp(Lc*1000,"Stroke of compressor cylinder in mm:")
IP=(ni/(ni-1))*(ma/60)*R*t1*(((p3/p1)^((ni-1)/ni))-1);......//Indicated power of the compressor in kW
BP=IP/etamech;..............//Brake power of the engine in kW
De=((BP*60*1000)/(ne*pmb*10^5*rld*(%pi/4)*N))^(1/3);......//Diameter of the engine cylinder in m
Le=rld*De;...........//Stroke of the engine cylinder in m
disp(De*1000,"Diameter of engine cylinder in mm:")
disp(Le*1000,"Stroke of engine cylinder in mm:")
```

Scilab code Exa 20.13 Single stage double acting compressor

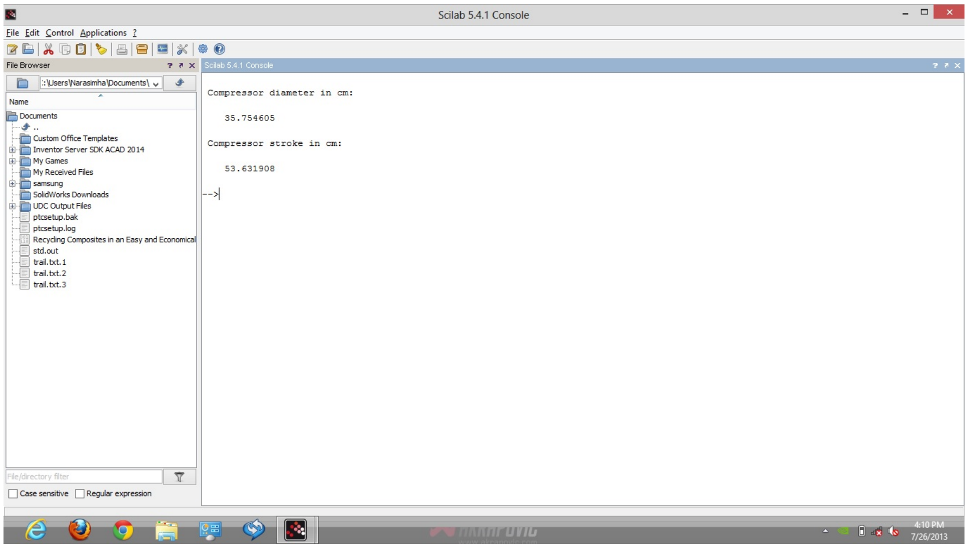
```
clc;funcprot(0);//EXAMPLE 20.13
// Initialisation of Variables
nc=1.25;......//Index of compression
ne=1.3;......//Index of expansion
```



```
Volumetric efficiency in %:

   81.444406

Diameter of the cylinder in cm:

   17.978574

Stroke of the cylinder in cm:

   17.978574

Brake power in kW:

   11.103704

-->
```

Figure 20.13: Single stage double acting compressor

```
etamech=0.85;.......//Mechanical efficiency
p1=1;.........//Suction pressure in bar
p2=7.5;.......//Delivery pressure in bar
t1=25+273;....//Suction temperature in bar
Vamb=2.2;.....//Volume of free air delivered in m^3
N=310;........//Engine rpm
k=0.05;.......//Clearance ratio
pamb=1.03;.....//Ambient pressure in bar
tamb=293;......//Ambient temperature in K
//Calculations
etav=(1+k-(k*((p2/p1)^(1/ne))));........//Volumetric efficiency
disp(etav*100,"Volumetric efficiency in %:")
v1=(pamb*Vamb*t1)/(p1*tamb);.......//Volume of air delivered at suction condition in m^3
vs=(v1/(etav*N*2));.........//Swept volume in m^3
D=(vs/(%pi/4))^(1/3);........//Diameter of the cylinder in m
L=D;
disp(D*100,"Diameter of the cylinder in cm:")
```



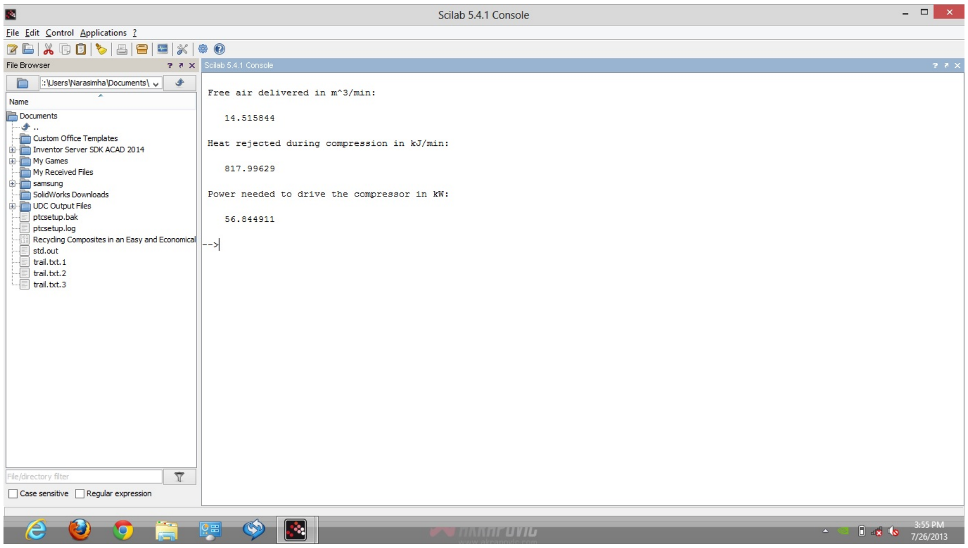
```
Compressor diameter in cm:

   35.754605

Compressor stroke in cm:

   53.631908

-->
```

Figure 20.14: Single stage single acting compressor

```
disp(L*100,”Stroke of the cylinder in cm:”)
W=2*vs*10^5*(((nc)/(nc-1))*p1*(1+k)*(((p2/p1)^((nc-1)/(nc)))-1)-((ne)/(ne-1))*p1*(k*((p2/p1)^(1/ne)))*(((p2/p1)^((ne-1)/(ne)))-1));..........//Work done per cycle of operation in Nm/cycle
IP=W*N/(60*1000);...............//Indicated power in kW
BP=IP/etamech;.............//Brake power in kW
disp(BP,”Brake power in kW:”)
```

Scilab code Exa 20.14 `Single stage single acting compressor`

```
clc;funcprot(0);//EXAMPLE 20.14
// Initialisation of Variables
v=14;..........//Volume of air delivered in m^3
p1=1;........//Suction pressure in bar
```



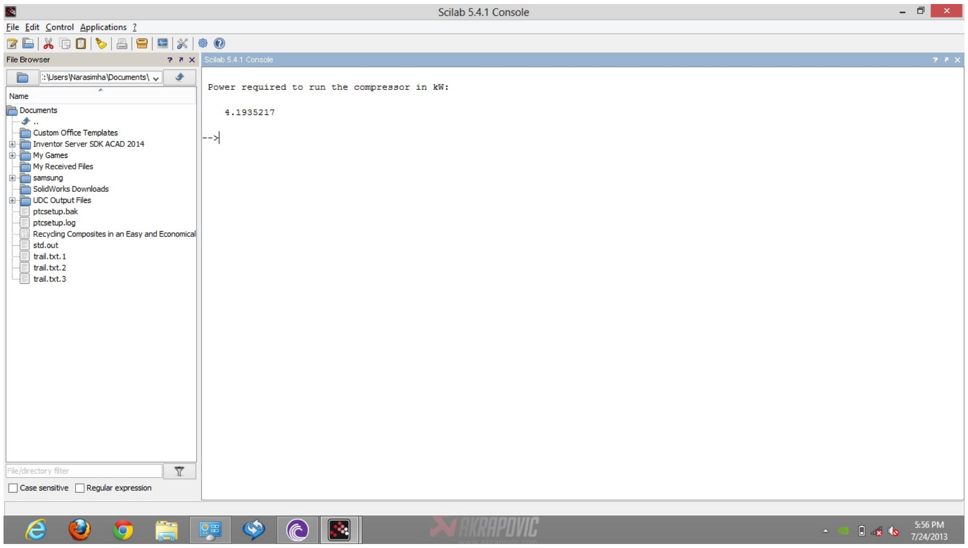
```
Free air delivered in m^3/min:

   14.515844

Heat rejected during compression in kJ/min:

   817.99629

Power needed to drive the compressor in kW:

   56.844911

-->
```

Figure 20.15: Double acting compressor

```
p2=7;........//Delivery pressure in bar
N=310;........//Compressor rpm
n=1.35;........//Compression index
k=0.05;........//Clearance ratio
rld=1.5;.........//Ratio of cylinder length and diameter
//Calculations
etav=(1+k)-(k*((p2/p1)^(1/n)));..........//Volumetric efficiency
Vs=v/(etav*N);.............//Swept volume in m^3
D=((Vs)/((%pi/4)*rld))^(1/3);......//Compressor diameter in m
L=rld*D;......................//Compressor stroke in m
disp(D*100,"Compressor diameter in cm:")
disp(L*100,"Compressor stroke in cm:")
```

Scilab code Exa 20.15 Double acting compressor

```
clc;funcprot(0);//EXAMPLE 20.15
// Initialisation of Variables
D=0.33;.........//Cylinder diameter in m
L=0.35;.........//Cylinder stroke in m
k=0.05;.........//Clearance ratio
N=300;..........//Compressor rpm
psuc=0.95;........//Suction pressure in bar
tsuc=298;.........//Suction temperature in K
pamb=1.013;......//Ambient pressure in bar
tamb=293;.........//Ambient temperature in K
p2=4.5;...........//Delivery pressure in bar
n=1.25;..........//Compression index
cv=0.717;...........//Specific heat at constant volume in kJ/kgK
ga=1.4;..........//Ratio of specific heats
etamech=0.8;......//Mechanical efficiency
R=0.287;.........//Gas constant in kJ/kgK
//Calculations
Vs=(%pi/4)*D*D*L*N*2;............//Swept volume in m^3
p1=psuc;etav=1-(k*(((p2/p1)^(1/n))-1));........//Volumetric efficiency
Vad=Vs*etav;................//Actual air drawn per min in m^3
FAD=(psuc/pamb)*(tamb/tsuc)*Vad;............//Free air delivered in m^3/min
disp(FAD,"Free air delivered in m^3/min:")
t1=tsuc;ma=(p1*10^5*Vad)/(R*1000*t1);.......//Mass of air delivered per min in kg
t2=t1*((p2/p1)^((n-1)/n));..........//Delivery temperature in K
Qr=ma*cv*((ga-n)/(n-1))*(t2-t1);..........//Heat
```



```
Power required to run the compressor in kW:

   4.1935217

-->
```

Figure 20.16: Two stage compressor

```
rejected during compression in kJ/min
disp(Qr,”Heat rejected during compression in kJ/min:”)
P=((n)/(n-1))*R*t1*(ma/60)*((((p2/p1)^((n-1)/(n)))-1)*(1/etamech);..........//Power needed to drive the compressor in kW
disp(P,”Power needed to drive the compressor in kW:”)
```

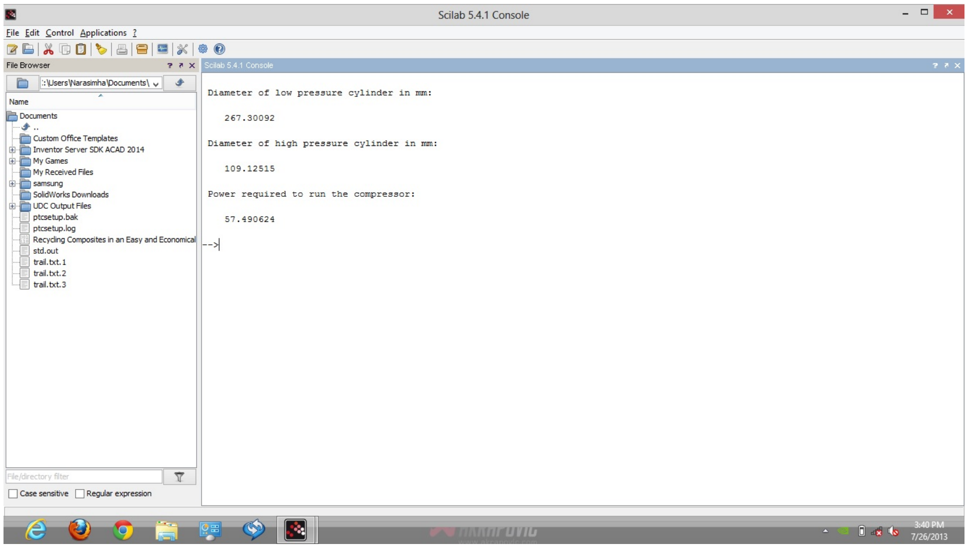
Scilab code Exa 20.16 Two stage compressor

```
clc;funcprot(0);...//Example 20.16
//Initialisation of variables
p1=1.03;...........//Intake pressure in bar
t1=300;............//Intake temperature in K
```

```
p2=7;.............//Intake pressure for High
   pressure cylinder in bar
t2=310;..............//Temperature of air entering
   high pressure cylinder in K
p3=40;...........//Pressure of air after
   compression in bar
V=30;.........//volume of air delivered in m^3/h
R=0.287;...........//Gas constant for air in kJ/kgK
ga=1.4;..........//Ratio of specific heats
//Calculations
m=p1*10^5*V/(R*1000*t1);.........//Mass of air
   compressed in kg/h
t21=t1*((p2/p1)^((ga-1)/ga));.......//Actual
   temperature of air entering high pressure
   cylinder in K
t3=t2*((p3/p2)^((ga-1)/ga));........//Actual
   temperature of air after compression in K
W=((ga)/(ga-1))*m*(R/3600)*(t21-t1+t3-t2);.........
   //Power required to run compressor in kW
disp(W,"Power required to run the compressor in kW:"
   )
```

Scilab code Exa 20.17 Two stage compressor

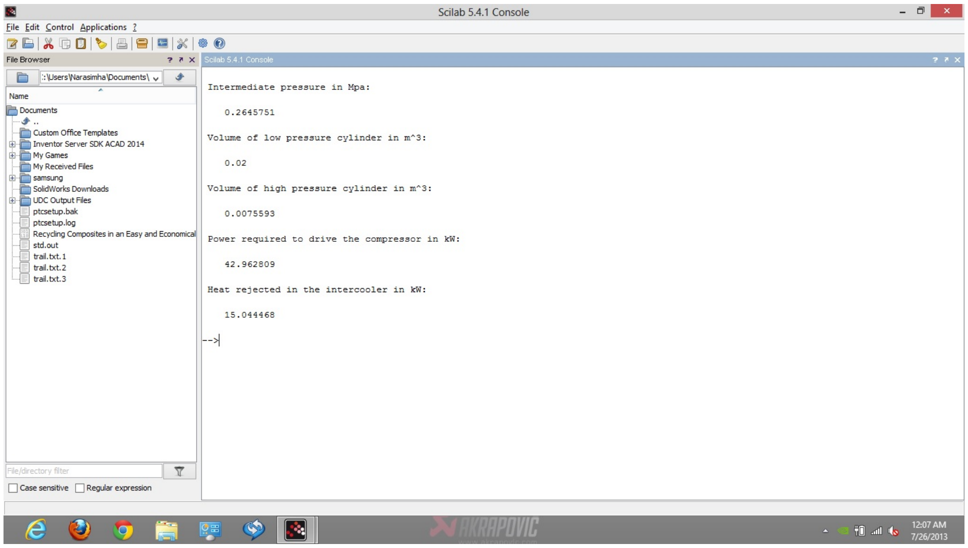
```
clc;funcprot(0);//EXAMPLE 20.17
// Initialisation of Variables
FAD=6;.......//Free air delivered in m^3/min
p1=1;........//suction pressure in bar
t1=300;......//Suction temperature in K
p3=40;.......//Delivery pressure in bar
p2=6;........//Intermediate pressure in bar
t3=300;........//Temperature at the inlet to 2nd
   stage in K
```



```
Diameter of low pressure cylinder in mm:

   267.30092

Diameter of high pressure cylinder in mm:

   109.12515

Power required to run the compressor:

   57.490624

-->
```

Figure 20.17: Two stage compressor

```
n=1.3;.........//Compression index
etamech=0.8;.....//Mechanical efficiency
N=400;............//Compressor rpm
R=0.287;.........//Gas constant in kJ/kgK
//Calculations
dlp=(FAD/(N*(%pi/4)))^(1/3);...............//Diameter of the low pressure cylinder in m
dhp=sqrt(1/(dlp*N*(%pi/4)));............//Diameter of high pressure cylinder in m
disp(dlp*1000,"Diameter of low pressure cylinder in mm:")
disp(dhp*1000,"Diameter of high pressure cylinder in mm:")
m=(p1*FAD*10^5)/(R*t1*1000*60);........//Mass flow of air in kg/s
W=n*(1/(n-1))*m*R*t1*(((p2/p1)^((n-1)/n))+((p3/p2)^((n-1)/n))-2);........//Indicated work in kJ/s
P=W/etamech;...............//Power required in kW
disp(P,"Power required to run the compressor:")
```



```
Intermediate pressure in Mpa:

   0.2645751

Volume of low pressure cylinder in m^3:

   0.02

Volume of high pressure cylinder in m^3:

   0.0075593

Power required to drive the compressor in kW:

   42.962809

Heat rejected in the intercooler in kW:

   15.044468

-->
```

Figure 20.18: Two stage compressor

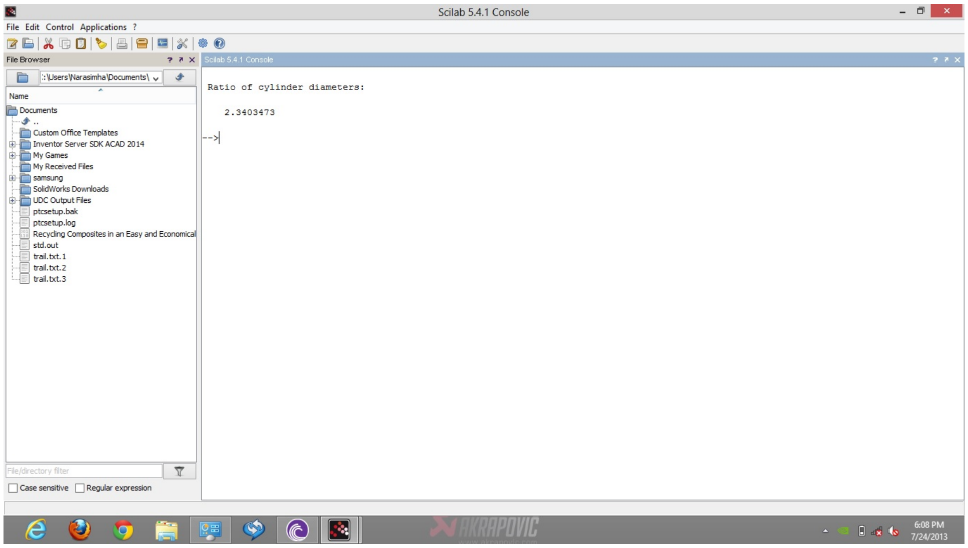
Scilab code Exa 20.18 `Two stage compressor`

```
clc;funcprot(0);//EXAMPLE 20.18
// Initialisation of Variables
ns=2;.............//No of stages
v1=0.2;.........//Intake volume in m^3/s
p1=1;..........//Intake pressure in bar
t1=289;...............//Intake temperature in K
p3=7;.........//Final pressure in bar
n=1.25;.......//Compression index
N=600;........//Compressor rpm
cp=1.005;.....//Specific heat at constant pressure in kJ/kgK
R=0.287;......//Gas constant in kJ/kgK
//Calculations
```

```
p2=sqrt(p1*p3);......//Intermediate pressure in bar
disp(p2/10,"Intermediate pressure in Mpa:")
vslp=60*v1/N;..........//Volume of low pressure
   cylinder in m^3
vshp=p1*vslp/p2;..........//Volume of high pressure
   cylinder in m^3
disp(vslp,"Volume of low pressure cylinder in m^3:")
disp(vshp,"Volume of high pressure cylinder in m^3:"
   )
W=(ns*(n/(n-1)))*p1*10^5*(v1/1000)*(((p3/p1)^((n-1)
   /(ns*n)))-1);...........//Power required to drive
    the compressor in kW
disp(W,"Power required to drive the compressor in kW
   :")
m=p1*10^5*v1/(R*t1*1000);.........//Mass of air
   handled in kg/s
t2=t1*((p2/p1)^((n-1)/n));.........//Temperature at
   the end of first stage compression in K
Qr=m*cp*(t2-t1);.......//Heat rejected in the
   intercooler in kW
disp(Qr,"Heat rejected in the intercooler in kW:")
```

Scilab code Exa 20.19 `Two stage compressor`

```
clc,funcprot(0);.......//Example 20.19
//initialisation of variables
p3=30;..........//delivery pressure in bar
p1=1;.........//suction pressure  in bar
t1=273+15;.......//suction temperature in K
n=1.3;.........//adiabatic index
//calculation
p2=sqrt(p1*p3);.....//Pressure before entering High
   pressure cylinder in bar
```



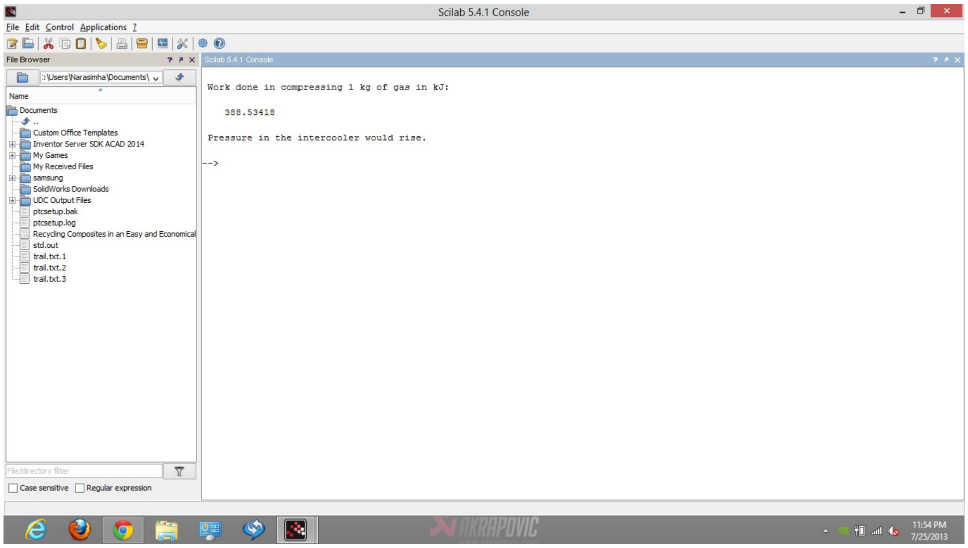
```
Ratio of cylinder diameters:

   2.3403473

-->
```

Figure 20.19: Two stage compressor

```
t21=t1*((p2/p1)^((n-1)/n));.........//Actual temperature before entering the high pressure turbine in K
r=sqrt((p2^(1/n))*(t21/t1));............//Ratio of cylinder diameters
disp(r,"Ratio of cylinder diameters:")
```

Scilab code Exa 20.20 `Two stage compressor`

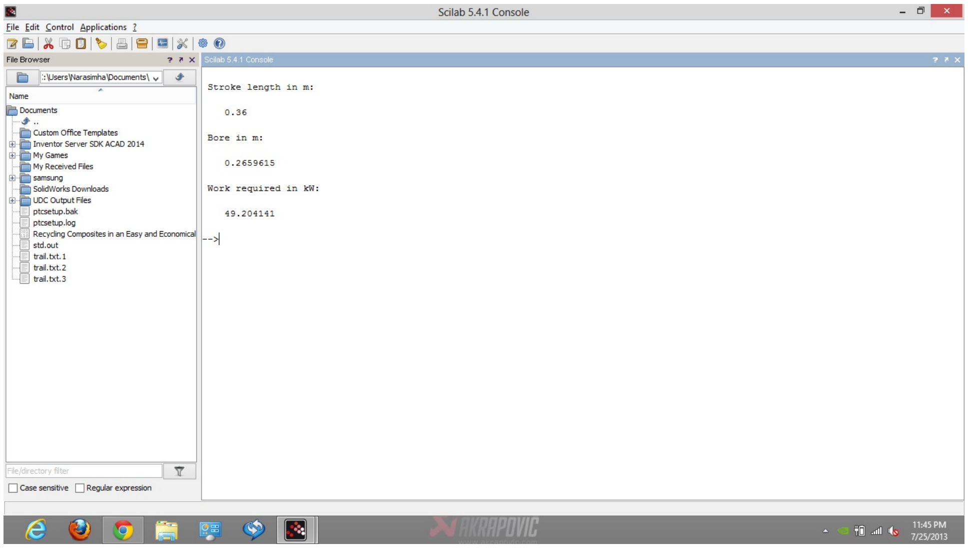
```
clc;funcprot(0);//EXAMPLE 20.20
// Initialisation of Variables
ns=2;.........//No of stages
p1=1;........//Suction pressure in bar
p2=7.4;.......//Intercooler pressure in bar
p3=42.6;.......//Delivery pressure in bar
t1=15+273;......//Suction temperature in K
```



```
Work done in compressing 1 kg of gas in kJ:

   388.53418

Pressure in the intercooler would rise.

-->
```

Figure 20.20: Two stage compressor

```
n=1.3;........//Compression index
R=0.287;.......//Gas constant in kJ/kgK
dlp=0.09;.......//Diameter of low pressure cylinder in m
dhp=0.03;.......//Diameter of high pressure cylinder in m
etav=0.9;.....//Volumetric efficiency
//Calculations
W=n*(1/(n-1))*R*t1*(((p2/p1)^((n-1)/n))+((p3/p2)^((n-1)/n))-2);
disp(W,"Work done in compressing 1 kg of gas in kJ:")
//Given that stroke length is same in both cases
rV=p2/p1;.........//Ratio of volumes
rECV=((dlp/dhp)^2)*etav;.........//Ratio of effective cylinder volumes
if (rECV>rV) then disp("Pressure in the intercooler would rise.")
else if (rECV<rV) then disp("Pressure in the intercooler would fall")
```



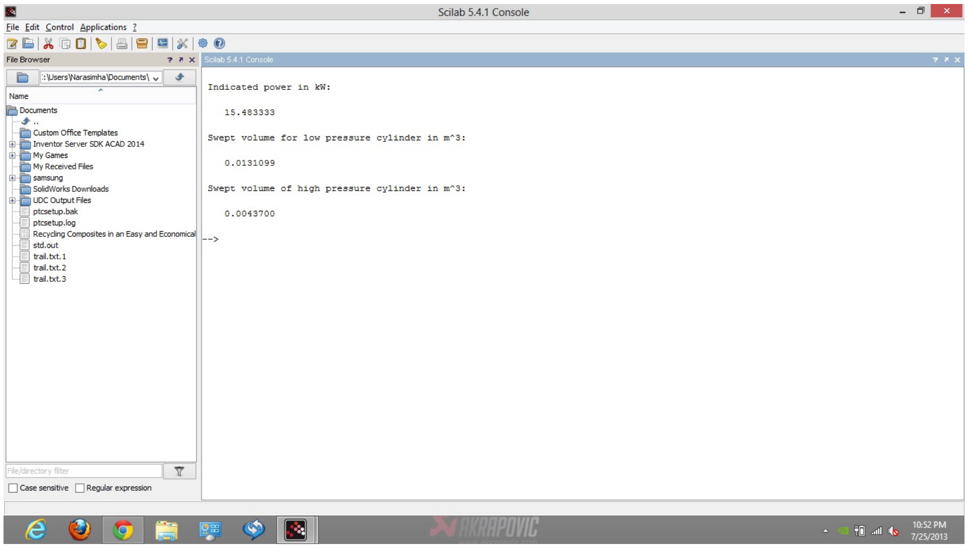
```
Stroke length in m:

   0.36

Bore in m:

   0.2659615

Work required in kW:

   49.204141

-->
```

Figure 20.21: Single acting two stage compressor

```
    end
end
```

Scilab code Exa 20.21 `Single acting two stage compressor`

```
clc;funcprot(0);//EXAMPLE 20.21
// Initialisation of Variables
V=4;...........//Volume of air handled in m^3/min
p1=1.016;.....//Suction pressure in bar
t1=288;........//Suction temperature in K
N=250;.........//Compressor rpm
p3=78.65;.....//Delivery pressure in bar
vp=3;........//Piston speed in m/s
etamech=0.75;.....//mechanical efficiency
etav=0.8;........//Volumetric efficiency
n=1.25;..........//Compression index
```



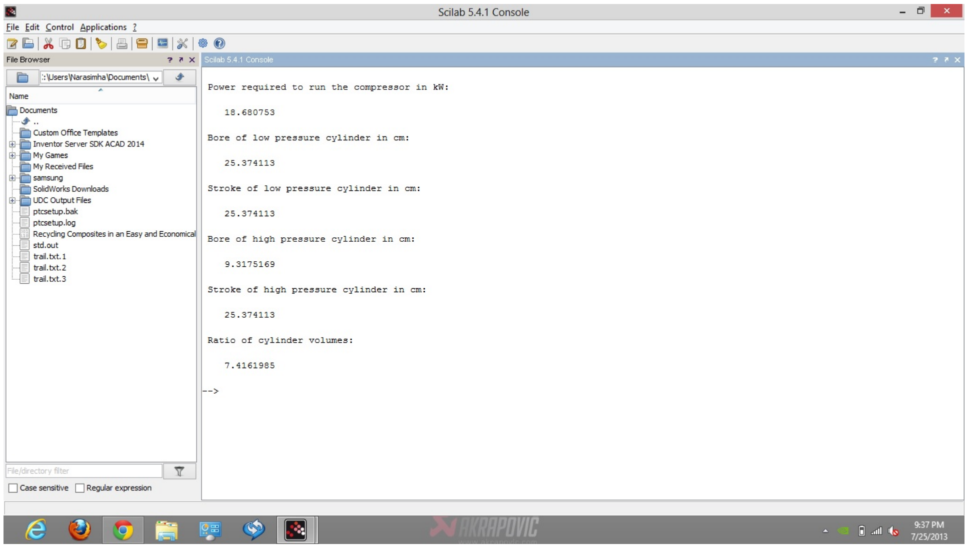
```
Indicated power in kW:

   15.483333

Swept volume for low pressure cylinder in m^3:

   0.0131099

Swept volume of high pressure cylinder in m^3:

   0.0043700

-->
```

Figure 20.22: Single acting two stage compressor

```
R=287;............//Gas constant in J/kgK
ns=2;.............//No of stages
//Calculations
l=(vp*60)/(2*N);...........//Stroke length in m
d=sqrt(V/((%pi/4)*l*N*etav));........//Bore in m
disp(l,"Stroke length in m:")
disp(d,"Bore in m:")
m=(p1*10^5*V)/(R*t1);........//Mass of air handled by the compressor in kg/min
p2=sqrt(p1*p3);..............//Intermediate pressure in bar
t2=t1*((p2/p1)^((n-1)/n));..........//Temperature at the end of first stage compression in K
W=ns*(n/(n-1))*(m/60)*(R/1000)*(t2-t1)*(1/etamech);...........//Work required in kW
disp(W,"Work required in kW:")
```

Scilab code Exa 20.22 `Single acting two stage compressor`

```
clc;funcprot(0);//EXAMPLE 20.22
// Initialisation of Variables
m=4.5;.........//Amount of air compressed in kg/min
ps=1.013;.......//Suction pressure in bar
ts=288;.........//Suction temperature in K
rp=9;...........//Pressure ratio
n=1.3;.........//Compression index
k=0.05;........//Clearance ratio
N=300;.........//Compressor rpm
R=287;.........//Gas constant in J/kgK
ns=2;...........//No of stages
//Calculations
ti=round(ts*((sqrt(rp))^((n-1)/n)));......//Intermediate temperature in K
W=round(ns*n*(1/(n-1))*m*(R/1000)*(ti-ts));..........//Work required per min in kJ
IP=W/60;.........//Indicated power in kW
disp(IP,"Indicated power in kW:")
mc=m/N;..........//Mass induced per cycle in kg
etav=(1+k)-(k*(sqrt(rp)^(1/n)));.......//Volumetric efficiency
Vs=(mc*R*ts)/(ps*10^5*etav);........//Swept volume for low pressure cylinder in m^3
disp(Vs,"Swept volume for low pressure cylinder in m^3:")
vdhp=(mc*ts*R)/(sqrt(rp)*ps*10^5);............//Volume of air drawn in high pressure cylinder per cycle in m^3
vshp=vdhp/etav;...............//Swept volume ofhigh pressure cylinder in m^3
disp(vshp,"Swept volume of high pressure cylinder in m^3:")
```



```
Power required to run the compressor in kW:

   18.680753

Bore of low pressure cylinder in cm:

   25.374113

Stroke of low pressure cylinder in cm:

   25.374113

Bore of high pressure cylinder in cm:

   9.3175169

Stroke of high pressure cylinder in cm:

   25.374113

Ratio of cylinder volumes:

   7.4161985

-->
```

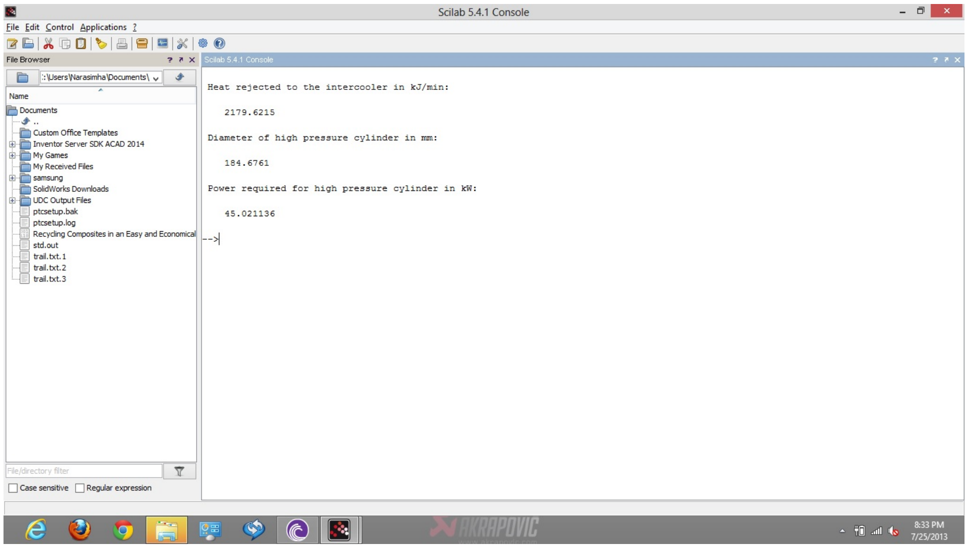
Figure 20.23: Two stage compressor

Scilab code Exa 20.23 `Two stage compressor`

```
clc;funcprot(0);//EXAMPLE 20.23
// Initialisation of Variables
v1=2.2;...........//free air delivered by the compressor in m^3/min
p1=1;........//Suction pressure in bar
t1=298;.......//Suction temperature in K
pd=55;........//Delivery pressure in bar
N=210;.......//Compressor rpm
n=1.3;........//Compression index
k=0.05;.......//Clearance ratio for high pressure and low pressure cylinders
R=287;.......//Gas constant in J/kgK
ns=2;.......//No of stages
```

```
//Calculations
ps=p1;
m =(p1*v1*10^5)/(R*t1);.........//Mass of air deivered in m^3/min
W=(ns*(n/(n-1)))*m*R*t1*(((pd/ps)^((n-1)/(ns*n)))-1);...........//Work done by compressor in Nm/min
P=W/(60*1000);...........//Power required to run the compressor
disp(P,"Power required to run the compressor in kW:")
pi=sqrt(ps*pd);........//Intermediate pressure in bar
etav1=(1+k)-(k*((pi/p1)^(1/n)));...........//Volumetric efficiency of the low pressure cylinder
Vs=(v1*10^6)/(etav1*N);............//Swept volume in cm^3
dlp=(Vs/((%pi/4)))^(1/3);..........//Diameter of low pressure cylinder in cm
llp=dlp;.................//Stroke of low pressure cylinder in cm
disp(dlp,"Bore of low pressure cylinder in cm:")
disp(llp,"Stroke of low pressure cylinder in cm:")
dhp=sqrt(dlp*dlp/pi);.........//Diameter of high pressure cylinder in cm
lhp=llp;
disp(dhp,"Bore of high pressure cylinder in cm:")
disp(lhp,"Stroke of high pressure cylinder in cm:")
rcv=pi/ps;.....//Ratio of cylinder volumes
disp(rcv,"Ratio of cylinder volumes:")
```

Scilab code Exa 20.24 `Two stage double acting compressor`



```
Heat rejected to the intercooler in kJ/min:

   2179.6215

Diameter of high pressure cylinder in mm:

   184.6761

Power required for high pressure cylinder in kW:

   45.021136

-->
```

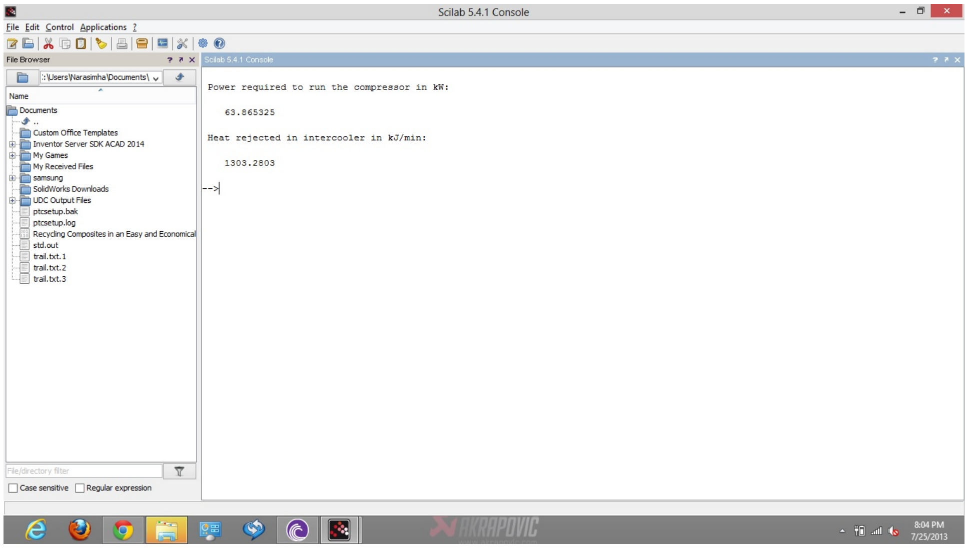
Figure 20.24: Two stage double acting compressor

```
clc;funcprot(0);//EXAMPLE 20.24
// Initialisation of Variables
p1=1;........//Suction pressure in bar
p2=4;.....//Intermediate pressure in bar
p5=3.8;.......//Pressure of air leaving the interooler in bar
p6=15.2;........//Delivery pressure in bar
t1=300;..........//Suction temperature in K
dlp=0.36;........//Diameter of low pressure cylinder in m
llp=0.4;........//Stroke of low pressure cylinder in m
N=220;........//Compressor rpm
k=0.04;........//Clearance ratio
cp=1.0035;.........//Specific heat at constant pressure in kJ/kgK
n=1.3;........//Compression index
R=0.287;........//Gas constant in kJ/kgK
p8=p5;p3=p2;p7=p6;t5=t1;
//Calculations
```

```
Vslp=(%pi/4)*dlp*dlp*llp*N*2;.......//Swept volume in m^3
etavlp=(1+k)-(k*((p2/p1)^(1/n)));.....//Volumetric efficiency
valp=Vslp*etavlp;................//Volume of air drawn in low pressure cylinder in m^3
m=(p1*10^5*valp)/(R*1000*t1);........//Mass of air drawin in kg/min
t2=round(t1*((p2/p1)^((n-1)/n)));
Qr=m*cp*(t2-t5);........//Heat rejected to the intercooler in kJ/min
disp(Qr,"Heat rejected to the intercooler in kJ/min:")
vahp=(m*R*t5*1000)/(p5*10^5);...//Volume of air drawn into high pressure cylinder per min in m^3
Vshp=vahp/etavlp;.........//Swept volume of high pressure cylinder in m^3/min
dhp=sqrt(Vshp/((%pi/4)*2*N*llp));..........//Diameter of high pressure cylinder in m
disp(dhp*1000,"Diameter of high pressure cylinder in mm:")
P=(n/(n-1))*m*(1/60)*R*(t2-t1);.......//Power required for high pressure cylinder in kW
disp(P,"Power required for high pressure cylinder in kW:")
```

Scilab code Exa 20.25 Two stage single acting compressor

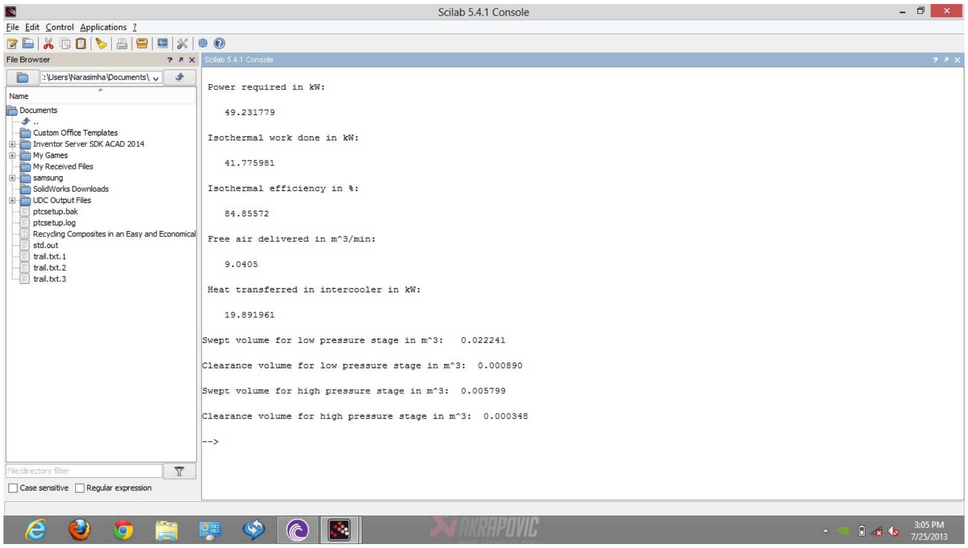
```
clc;funcprot(0);//EXAMPLE 20.25
// Initialisation of Variables
ps=1;........//Suction pressure in bar
pi=4.2;.....//Intermediate pressure in bar
pi1=4;.......//Pressure of air leaving the
```



```
Power required to run the compressor in kW:

   63.865325

Heat rejected in intercooler in kJ/min:

   1303.2803

-->
```

Figure 20.25: Two stage single acting compressor

```
    interooler in bar
pd=18;........//Delivery pressure in bar
t1=298;..........//Suction temperature in K
t5=t1;
dlp=0.4;........//Diameter of low pressure cylinder in m
llp=0.5;........//Stroke of low pressure cylinder in m
N=200;........//Compressor rpm
k=0.05;........//Clearance ratio
cp=1.004;.........//Specific heat at constant pressure in kJ/kgK
n=1.25;........//Compression index
R=0.287;........//Gas constant in kJ/kgK
//Calculations
Vslp=(%pi/4)*dlp*dlp*llp;..........//Swept volume of low pressure cylinder in m^3
etavlp=(1+k)-(k*((pi/ps)^(1/n)));.....//Volumetric efficiency
t2=round(t1*((pi/ps)^((n-1)/n)));
```



```
 Power required in kW:

    49.231779

 Isothermal work done in kW:

    41.775981

 Isothermal efficiency in %:

    84.85572

 Free air delivered in m^3/min:

    9.0405

 Heat transferred in intercooler in kW:

    19.891961

Swept volume for low pressure stage in m^3:   0.022241

Clearance volume for low pressure stage in m^3:  0.000890

Swept volume for high pressure stage in m^3:  0.005799

Clearance volume for high pressure stage in m^3:  0.000348

-->
```

Figure 20.26: Two stage single acting compressor

```
m=(ps*10^5*etavlp*Vslp)/(R*1000*t1);...//Mass of air in kg
wlp=((n)/(n-1))*R*1000*t1*m*(((pi/ps)^((n-1)/(n)))-1);..........//Work done per min in Nm in low pressure cylinder
whp=((n)/(n-1))*R*t5*m*1000*(((pd/pi1)^((n-1)/(n)))-1);..........//Work done per min in Nm in high pressure cylinder
W=wlp+whp;.........//Net work done in Nm
IP=(W*N)/(60*1000);............//Power required to run the compressor in kW
disp(IP,"Power required to run the compressor in kW:")
Qr=m*N*cp*(t2-t1);...........//Heat rejected in intercooler in kJ/min
disp(Qr,"Heat rejected in intercooler in kJ/min:")
```

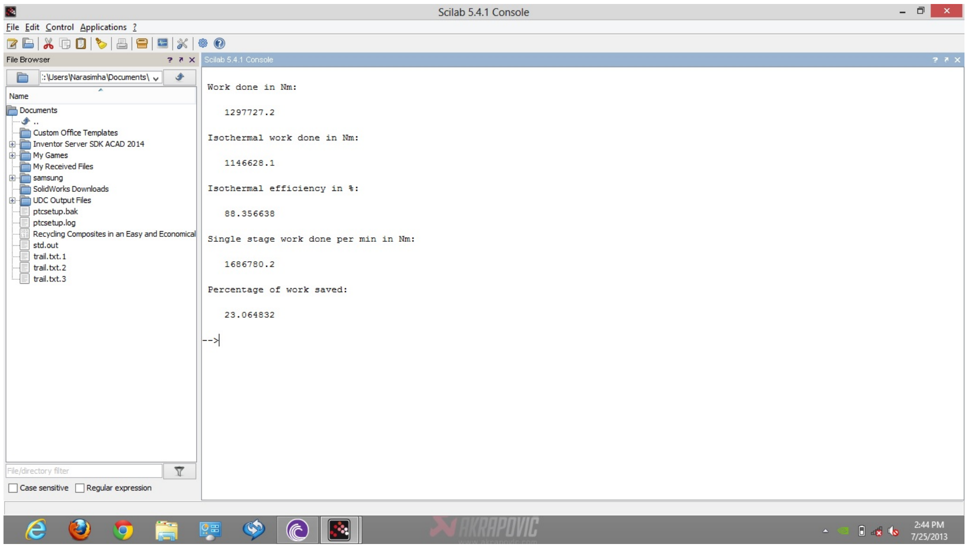
Scilab code Exa 20.26 `Two stage single acting compressor`

```
clc;funcprot(0);//EXAMPLE 20.26
// Initialisation of Variables
p1=1;............//Intake pressure in bar
p2=4;..............//Pressure after first stage in bar
p3=16;............//Final pressure in bar
ns=2;............//No of stages
t1=300;............//Intake temperature in K
n=1.3;............//Compression index
klp=0.04;.........//Clearance ratio for low pressure cylinder
khp=0.06;........//Clearance ratio for high pressure cylinder
N=440;............//Engine rpm
R=0.287;..........//Gas constant in kJ/kgK
m=10.5;.............//Mass of air delivered in kg/min
cp=1.005;.........//Specific heat at constant pressure in kJ/kgK
//Calculations
rp=sqrt(p1*p3);...........//Pressure ratio per stage
P=((ns*n)/(n-1))*R*t1*(m/60)*(((p3/p1)^((n-1)/(ns*n))-1);..........//Work done per min in Nm
disp(P,"Power required in kW:")
isoWd=(m/60)*R*t1*log(p3/p1);..........//Isothermal work done in Nm
disp(isoWd,"Isothermal work done in kW:")
etaiso=isoWd/P;...............//Isothermal efficiency
disp(etaiso*100,"Isothermal efficiency in %:")
FAD=(m*R*t1*1000)/(p1*10^5);.............//Free air delivered in m^3/min
```

```
disp(FAD,”Free air delivered in mˆ3/min:”)
t2=t1*((p2/p1)ˆ((n-1)/n));.....//Temperature at the end of compression in K
Qt=(m/60)*cp*(t2-t1);..............//Heat transferred in intercooler in kW
disp(Qt,”Heat transferred in intercooler in kW:”)
etavlp=(1+klp)-(klp*((p2/p1)ˆ(1/n)));..........//Volumetric efficiency of low pressure stage
etavhp=(1+khp)-(khp*((p2/p1)ˆ(1/n)));..........//Volumetric efficiency of high pressure stage
vslp=FAD/(N*etavlp);......//Swept volume for low pressure stage in mˆ3
vclp=klp*vslp;..............//Clearance volume for low pressure stage in mˆ3
printf(”\nSwept volume for low pressure stage in mˆ3:    %f\n”,vslp)
printf(”\nClearance volume for low pressure stage in mˆ3:   %f\n”,vclp)
vshp=FAD/(N*rp*etavhp);......//Swept volume for high pressure stage in mˆ3
vchp=khp*vshp;..............//Clearance volume for high pressure stage in mˆ3
printf(”\nSwept volume for high pressure stage in mˆ3:   %f\n”,vshp)
printf(”\nClearance volume for high pressure stage in mˆ3:   %f\n”,vchp)
```

Scilab code Exa 20.27 `Three stage compressor`

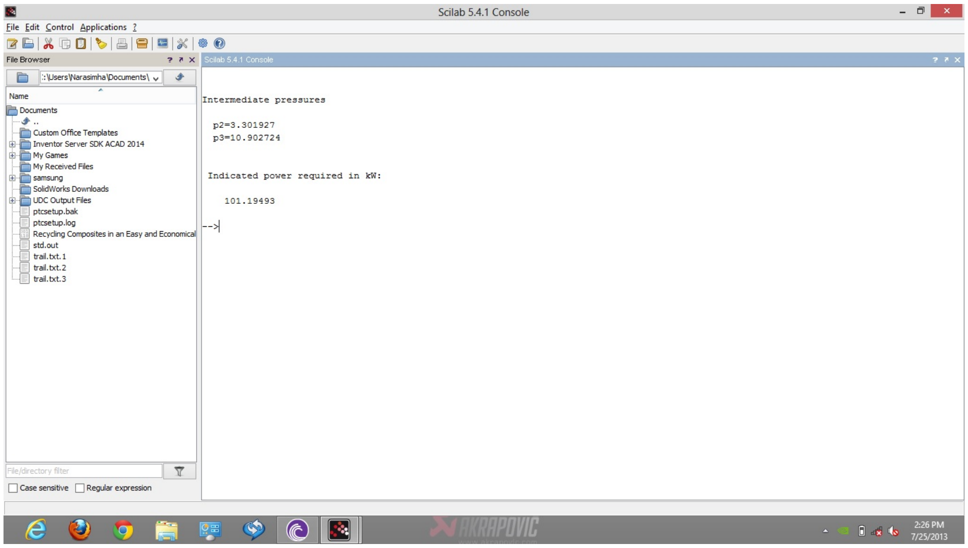
```
clc;funcprot(0);//EXAMPLE 20.27
// Initialisation of Variables
ns=3;......//No of stages
p1=1.05;......//Intake pressure in bar
```



```
Work done in Nm:

   1297727.2

Isothermal work done in Nm:

   1146628.1

Isothermal efficiency in %:

   88.356638

Single stage work done per min in Nm:

   1686780.2

Percentage of work saved:

   23.064832

-->
```

Figure 20.27: Three stage compressor

```
pd=40;..........//Delivery pressure in bar
V=3;...........//Volume of air xupplied per min in m^3
n=1.25;........//Compression index
//Calculations
Wd=((ns*n)/(n-1))*p1*V*10^5*(((pd/p1)^((n-1)/(ns*n)))-1);..........//Work done per min in Nm
disp(Wd,"Work done in Nm:")
isoWd=10^5*p1*V*log(pd/p1);..........//Isothermal work done in Nm
disp(isoWd,"Isothermal work done in Nm:")
etaiso=isoWd/Wd;...............//Isothermal efficiency
disp(etaiso*100,"Isothermal efficiency in %:")
wdss=((n)/(n-1))*p1*V*10^5*(((pd/p1)^((n-1)/(n)))-1);..........//Single stage Work done per min in Nm
disp(wdss,"Single stage work done per min in Nm:")
perws=(wdss-Wd)/wdss;.......//Percentage of work saved
disp(perws*100,"Percentage of work saved:")
```

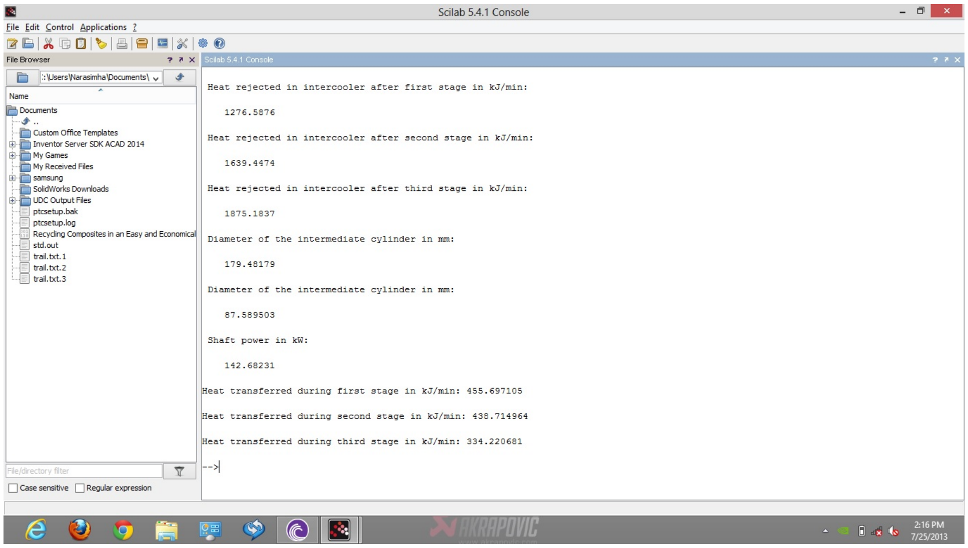


```
Intermediate pressures

  p2=3.301927
  p3=10.902724


 Indicated power required in kW:

    101.19493

-->
```

Figure 20.28: Three stage compressor

Scilab code Exa 20.28 `Three stage compressor`

```
clc;funcprot(0);//EXAMPLE 20.28
// Initialisation of Variables
p1=1;.............//Intake pressure in bar
p4=36;........//Final pressure in bar
n=1.25;.........//Compression index
R=0.287;.......//Gas constant in kJ/kgK
t1=300;..........//Intake temperature in K
ns=3;...........//No of stages
v=15;..........//Volume of air delivered in m^3
//Calculations
p2=p1*((p4/p1)^(1/ns));
p3=p2*((p4/p1)^(1/ns));
printf("\n\nIntermediate pressures\n\n  p2=%f\n  p3=
```



```
Heat rejected in intercooler after first stage in kJ/min:

   1276.5876

Heat rejected in intercooler after second stage in kJ/min:

   1639.4474

Heat rejected in intercooler after third stage in kJ/min:

   1875.1837

Diameter of the intermediate cylinder in mm:

   179.48179

Diameter of the intermediate cylinder in mm:

   87.589503

Shaft power in kW:

   142.68231

Heat transferred during first stage in kJ/min: 455.697105

Heat transferred during second stage in kJ/min: 438.714964

Heat transferred during third stage in kJ/min: 334.220681

-->
```

Figure 20.29: Three stage compressor

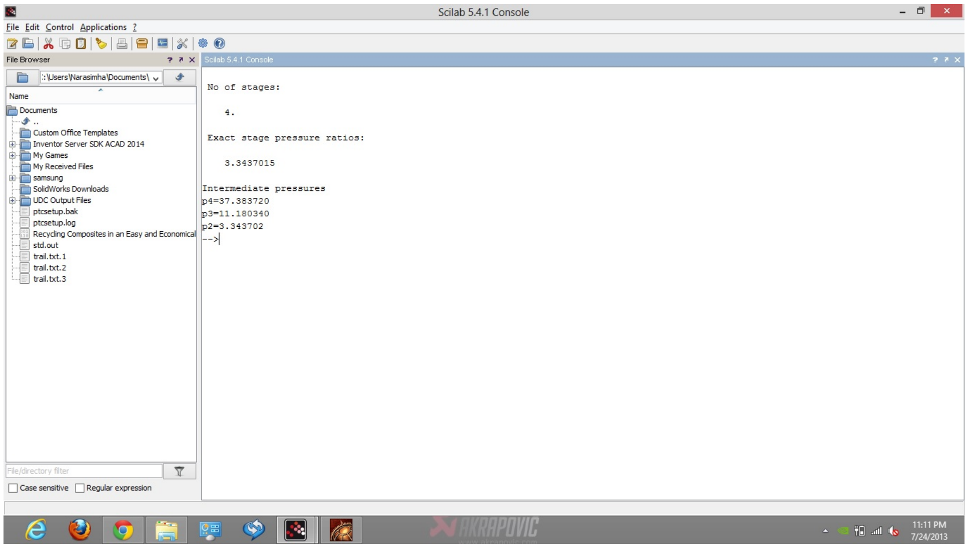
```
    %f\n\n",p2,p3)
t2=t1*((p4/p1)^(((n-1)/n)*(1/ns)));....//Delivery temperature in K
m=p1*10^5*v/(R*1000*t1);...........//Mass of air handled per min in kg
Wt=((n/(n-1))*m*R*(1/60)*(t2-t1)*ns);........//Total work done in three stages
disp(Wt,"Indicated power required in kW:")
```

Scilab code Exa 20.29 Three stage compressor

```
clc;funcprot(0);//EXAMPLE 20.29
// Initialisation of Variables
ns=3;........//No of stages
N=200;.......//Compressor rpm
p1=1;.......//Intake pressure in bar
```

```
t1=20+273;....//Intake temperature in K
D=0.35;......//Engine bore in m
L=0.4;.......//Engine stroke in m
p2=4;........//Discharge pressure from first stage in bar
p6=16;........//Discharge pressure from second stage in bar
p10=64;........//Discharge pressure from third stage in bar
pd=0.2;........//Loss of pressure between intercoolers in bar
R=0.287;......//Gas constant in kJ/kgK
k=0.04;.......//Clearence volume in 4% of the stroke volume
n1=1.2;.....//Compressor index for first stage
n2=1.25;.....//Compressor index for second stage
n3=1.3;.....//Compressor index for third stage
cp=1.005;......//Specific heat at constant pressure in kJ/kgK
etamech=0.8;.....//Mechanical efficiency
//Calculations
p5=p2-pd;p9=p6-pd;t5=t1;t9=t1;
Vs=(%pi/4)*D*D*L*N*2;............//Swept volume of low pressure cylinder per min in m^3
etav1=(1+k)-(k*((p2/p1)^(1/n1)));.....//Volumetric efficiency in first stage
etav2=(1+k)-(k*((p6/p5)^(1/n2)));.....//Volumetric efficiency in second stage
etav3=(1+k)-(k*((p10/p9)^(1/n3)));.....//Volumetric efficiency in third stage
vain1=Vs*etav1;.................//Volume of air taken in first stage in m^3/min
m=(p1*10^5)*vain1/(R*t1*1000);...........//Mass of air intake in kg/min in first stage
t2=round(t1*((p2/p1)^((n1-1)/n1)));
t6=t5*((p6/p5)^((n2-1)/n2));
t10=t9*((p10/p9)^((n3-1)/n3));
Qr1=m*cp*(t2-t5);........//Heat rejected in
```

```
intercooler after first stage in kJ/min
Qr2=m*cp*(t6-t9);........//Heat rejected in intercooler after second stage in kJ/min
Qr3=m*cp*(t10-t1);........//Heat rejected in intercooler after third stage in kJ/min
disp(Qr1,"Heat rejected in intercooler after first stage in kJ/min:")
disp(Qr2,"Heat rejected in intercooler after second stage in kJ/min:")
disp(Qr3,"Heat rejected in intercooler after third stage in kJ/min:")
vainip=m*R*t5*1000/(p5*10^5);.........//Volume drawn in intermediate pressure cylinder/min
Vsip=vainip/etav2;.............//Swept volume of intermediate cylinder in m^3/min
Dip=sqrt(Vsip/(2*N*L*(%pi/4)));............//Diameter of the intermediate cylinder in m
disp(Dip*1000,"Diameter of the intermediate cylinder in mm:")
vainhp=m*R*t9*1000/(p9*10^5);.........//Volume drawn in high pressure cylinder/min
Vshp=vainhp/etav3;.............//Swept volume of high pressure cylinder in m^3/min
Dhp=sqrt(Vshp/(2*N*L*(%pi/4)));............//Diameter of the intermediate cylinder in m
disp(Dhp*1000,"Diameter of the intermediate cylinder in mm:")
Ps=[{(n1/(n1-1))*m*R*(t2-t1)}+{(n2/(n2-1))*m*R*(t6-t5)}+{(n3/(n3-1))*m*R*(t10-t9)}]*(1/(60*etamech));...//Shaft power in kW
disp(Ps,"Shaft power in kW:")
cv=cp-R;..........//Specific heat at constant volume in kJ/kgK
ga=cp/cv;...........//Ratio of specific heats
Qt1=cv*((ga-n1)/(ga-1))*(t2-t1)*m;............//Heat transfer during first stage in kJ/min
Qt2=cv*((ga-n2)/(ga-1))*(t6-t1)*m;............//Heat transfer during second stage in kJ/min
```



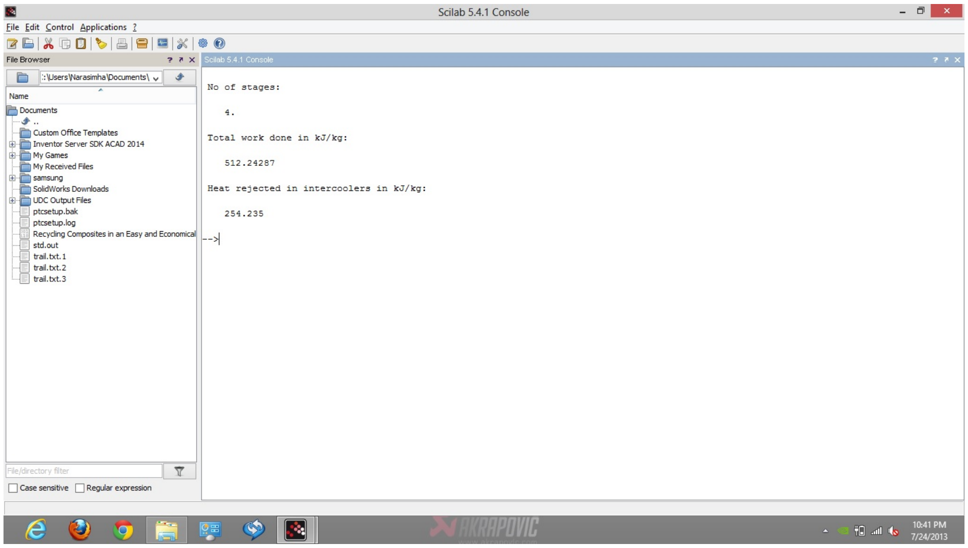
```
 No of stages:

    4.

 Exact stage pressure ratios:

    3.3437015

Intermediate pressures
p4=37.383720
p3=11.180340
p2=3.343702
-->
```

Figure 20.30: Multi stage compressor

```
Qt3=cv*((ga-n3)/(ga-1))*(t10-t1)*m;.............//Heat transfer during third stage in kJ/min
printf("\nHeat transferred during first stage in kJ/min: %f\n",Qt1)
printf("\nHeat transferred during second stage in kJ/min: %f\n",Qt2)
printf("\nHeat transferred during third stage in kJ/min: %f\n",Qt3)
```

Scilab code Exa 20.30 `Multi stage compressor`

```
clc;funcprot(0);//EXAMPLE 20.30
// Initialisation of Variables
p1=1;.....//Intake pressure in bar
p5=125;.....//Pressure of the compressed air in bar
rpr=4;.........//Pressure ratio is restricted to 4
```



```
No of stages:

   4.

Total work done in kJ/kg:

   512.24287

Heat rejected in intercoolers in kJ/kg:

   254.235

-->
```

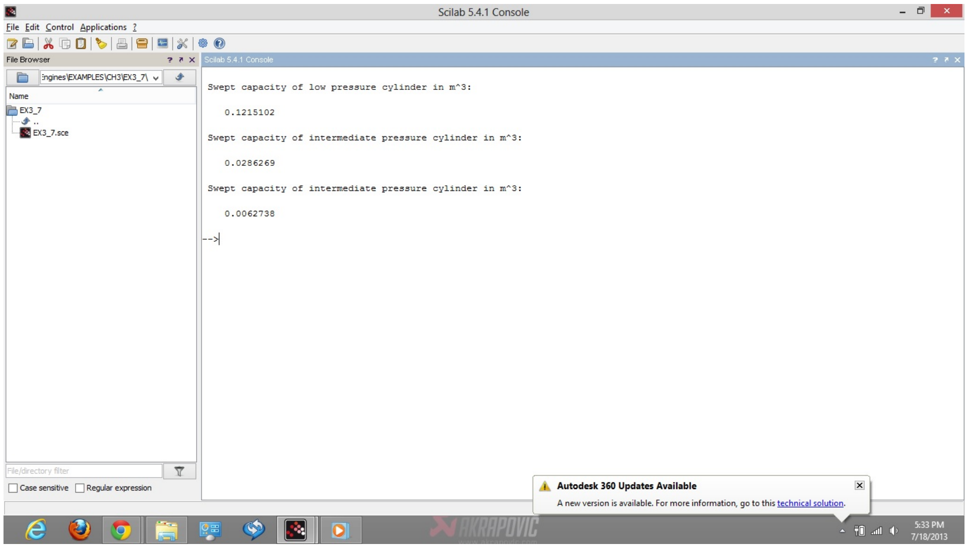
Figure 20.31: Multi stage compressor

```
//Calculations
X=(log(p5/p1)/log(rpr));
if(X>round(X))
x=round(X)+1;
else
    x=round(X);
end
disp(x,"No of stages:")
esrp=(p5/p1)^(1/x);
disp(esrp,"Exact stage pressure ratios:")
p4=p5/esrp;p3=p4/esrp;p2=p3/esrp;......//Intermediate pressures in bar
printf("\nIntermediate pressures\np4=%f\np3=%f\np2=%f",p4,p3,p2)
```

Scilab code Exa 20.31 `Multi stage compressor`

```
clc;funcprot(0);//EXAMPLE 20.31
// Initialisation of Variables
ps=1;.........//Suction pressure in bar
t1=273+125;.......//Delivery temperature in K
pd=160;...........//Delivery pressure in bar
tm=40+273;........//Min temperature
ts=298;........//Suction temperature in K
n=1.25;......//Adiabatic index
cv=0.71;.......//Specific heat at constant volume in kJ/kgK
R=0.287;......//Gas constant in kJ/kgK
ns=3;.......//No of stages
//Calculations
p1=ps*((t1/ts)^(n/(n-1)));
x=(log(pd/p1))/(((n/(n-1))*(log(t1/tm))));
disp(round(x)+1,"No of stages:")
rp1=p1;...........//Pressure ratio in 1st stage
rp=(pd/rp1)^(1/ns);.........//Pressure ratio in the following stage
W=(n/(n-1))*R*ts*(((rp1)^((n-1)/n))-1);.........//Work done in first stage in kJ
Wf=ns*(n/(n-1))*R*tm*(((rp)^((n-1)/n))-1);.........//Work done in next three stages in kJ
wt=W+Wf;............//Total work done per kg in kJ
disp(wt,"Total work done in kJ/kg:")
cp=cv+R;..............//Specific heat at constant pressure in kJ/kgK
Qr=ns*cp*(t1-tm);.............//Heat rejected in intercoolers in kJ/kg
disp(Qr,"Heat rejected in intercoolers in kJ/kg:")
```

Scilab code Exa 20.32 Three stage compressor



```
Swept capacity of low pressure cylinder in m^3:

   0.1215102

Swept capacity of intermediate pressure cylinder in m^3:

   0.0286269

Swept capacity of intermediate pressure cylinder in m^3:

   0.0062738

-->
```

Autodesk 360 Updates Available

A new version is available. For more information, go to this technical solution.

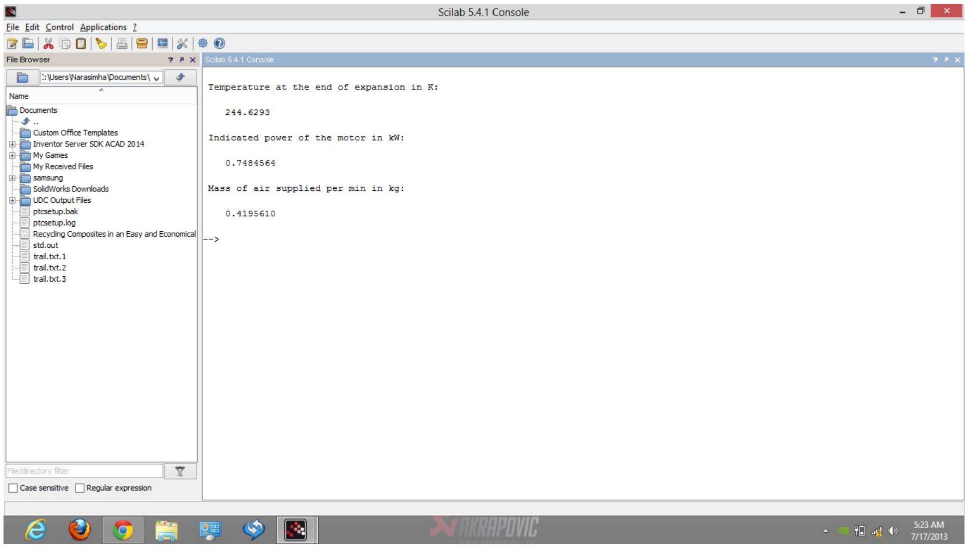
Figure 20.32: Three stage compressor

```
clc;funcprot(0);//EXAMPLE 20.32
// Initialisation of Variables
Vamb=10.5;........//Free air volume in m^3
Pamb=1.013;...........//Free air presssure in bar
Tamb=273+15;..........//Free air temperature in K
T1=(273+25);...........//Temperature at the end of suction in all cylinders in K
P1=1;............//Pressure at the suction in bar
pd=95;...........//Delivery presssure in bar
N=100;.........//Compressor rpm
n=1.25;..........//Adiabatic index
k=0.04;.........//Fractional clearances for LP
k1=0.07;.........//Fractional clearances for HP
//Calculations
z=(pd/P1)^(1/3);.........//Pressure ratio
pi1=z*P1;
pi2=z*pi1;
etavollp=1+k-(k*(z^(1/n)));
etavolhp=1+k1-(k1*(z^(1/n)));
v1=(Pamb*Vamb*T1)/(Tamb*P1);
```

```
sclp=(round(v1))/(etavollp*N);.........//Swept
   capacity of LP cylinder in m^3
disp(sclp,"Swept capacity of low pressure cylinder
   in m^3:")
vip=(Pamb*Vamb*T1)/(pi1*Tamb);.........//Volume of
   free air reduced to suction conditions of IP
   cylinder
scip=vip/(etavolhp*N);.........//Swept capacity of
   IP cylinder in m^3
disp(scip,"Swept capacity of intermediate pressure
   cylinder in m^3:")
vhp=(Pamb*Vamb*T1)/(pi2*Tamb);.........//Volume of
   free air reduced to suction conditions of HP
   cylinder
schp=vhp/(etavolhp*N);.........//Swept capacity of
   HP cylinder in m^3
disp(schp,"Swept capacity of intermediate pressure
   cylinder in m^3:")
```

Scilab code Exa 20.34 `Indicated power and air supplied per minute`

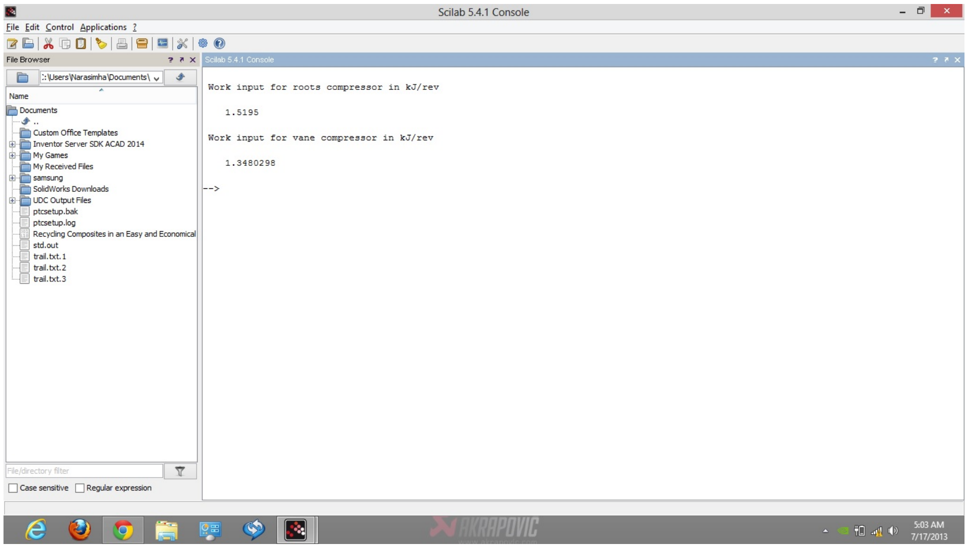
```
clc;funcprot(0);//EXAMPLE 20.34
// Initialisation of Variables
D=0.0635;.......//Engine bore in m
L=0.114;.........//Engine stroke in m
p1=6.3;..........//Supply pressure in bar
t1=273+24;.........//Supply temperature in K
p4=1.013;..........//Exhaust pressure in bar
cv=0.05;............//Clearance volume is 5% of the
   swept volume
cr=0.5;..........//Cut off ratio
n=1.3;...........//Adiabatic index
R=287;...............//gas constant in kJ/kgK
```



```
Temperature at the end of expansion in K:

   244.6293

Indicated power of the motor in kW:

   0.7484564

Mass of air supplied per min in kg:

   0.4195610

-->
```

Figure 20.33: Indicated power and air supplied per minute

```
N=300;..............//Engine rpm
ga=1.4;...........//Ratio of specific heats
//Calculations
Vs=(%pi*D*D*L)/4;........//Swept volume in m^3
Vc=cv*Vs;..........//Clearance volume in m^3
v6=Vc;v5=v6;
v1=(Vs/2)+Vc;v2=Vs+Vc;v3=v2;p3=p4;v4=v5+(cv*Vs);
p2=p1*((v1/v2)^n);.......//Pressure at the end of expansion
t2=t1*((v1/v2)^(n-1));........//Temperature at the end of expansion in K
disp(t2,"Temperature at the end of expansion in K:")
p5=p4*((v4/v5)^n);
w=((p1*(v1-v6))+(((p1*v1)-(p2*v2))/(n-1))-(p3*(v3-v4))-(((p5*v5)-(p4*v4))/(n-1)))*10^5;.......//Workk done per cycle in Nm
IP=(w*N)/(60*1000);..........//Indicated power in kW
disp(IP,"Indicated power of the motor in kW:")
t3=t2*((p3/p2)^((ga-1)/ga));
t4=t3;m4=(p4*v4*10^5)/(R*t4);m1=(p1*v1*10^5)/(R*t1);
```



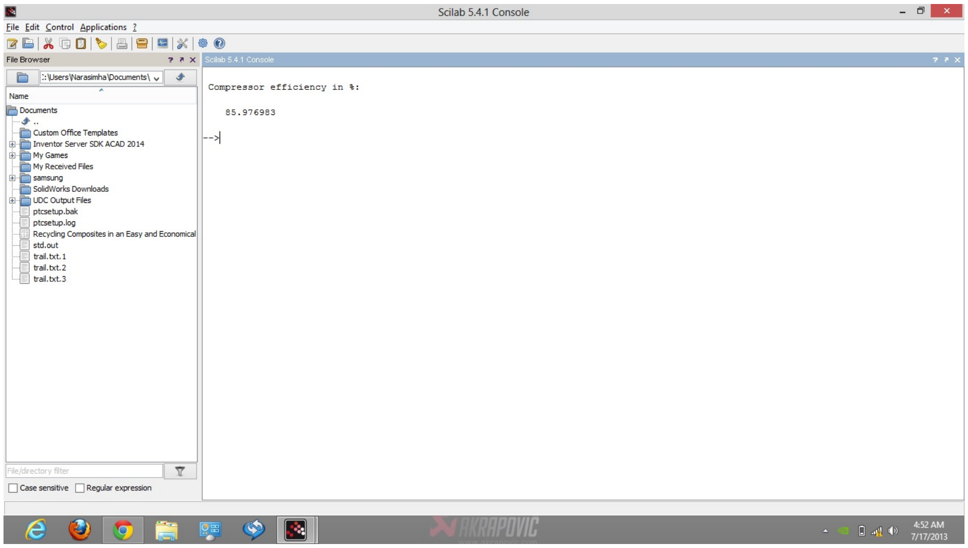
```
Work input for roots compressor in kJ/rev

   1.5195

Work input for vane compressor in kJ/rev

   1.3480298

-->
```

Figure 20.34: Comparison of roots blower and vane type compressor

```
ma=(m1-m4)*N;..........//Mass of air supplied per
    min
disp(ma,"Mass of air supplied per min in kg:")
```

Scilab code Exa 20.35 Comparison of roots blower and vane type compressor

```
clc;funcprot(0);//EXAMPLE 20.35
// Initialisation of Variables
v=0.03;..............//Induced volume in m^3/rev
p1=1.013;...........//Inlet pressure in bar
rp=1.5;............//Pressure ratio
ga=1.4;...........//Ratio of specific heats
//Calculations
p2=rp*p1;
wr=(p2-p1)*(10^5)*v/1000;.....//Work input for roots
     compressor in kJ
```



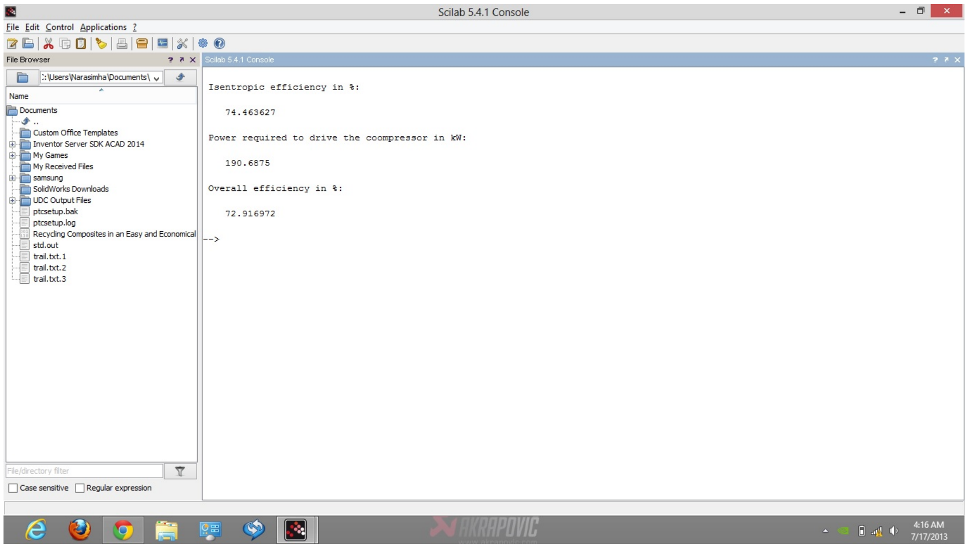
```
 Compressor efficiency in %:

    85.976983

-->
```

Figure 20.35: Roots blower

```
disp(wr,"Work input for roots compressor in kJ/rev")
pi=(p2+p1)/2;
wv=((p2-pi)*(10^5)*v*((p1/pi)^(1/ga))*(1/1000))+((ga
    /(ga-1))*p1*(10^5)*(v/1000)*(((pi/p1)^((ga-1)/ga)
    )-1));...//Work input required for vane type in
    kJ/rev
disp(wv,"Work input for vane compressor in kJ/rev")
```

Scilab code Exa 20.36 `Roots blower`

```
clc;funcprot(0);//EXAMPLE 20.36
// Initialisation of Variables
v=0.08;.........//Volume of air compressed in m^3
p1=1;..........//Intake pressure in bar
p2=1.5;........//Pressure after compression in in
    bar
```



```
Isentropic efficiency in %:

   74.463627

Power required to drive the coompressor in kW:

   190.6875

Overall efficiency in %:

   72.916972

-->
```

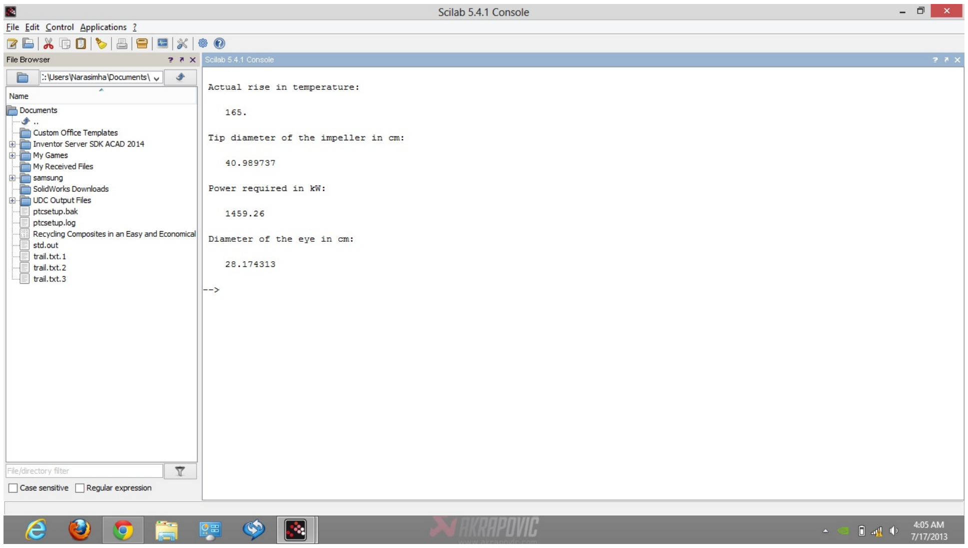
Figure 20.36: Centrifugal compressor

```
ga=1.4;.........//Ratio of specific heats
//Calculations
wac=v*(p2-p1)*10^5;........//Actual work done in Nm
wid=(ga/(ga-1))*p1*v*(10^5)*(((p2/p1)^((ga-1)/ga))
    -1);...........//Ideal work done per revolution
    in Nw
etac=wid/wac;................//Compressor efficiency
disp(etac*100,"Compressor efficiency in %:")
```

Scilab code Exa 20.37 `Centrifugal compressor`

```
clc;funcprot(0);//EXAMPLE 20.37
// Initialisation of Variables
m=2.5;..........//Air flow rate in kg/s
p1=1;........//Inlet pressure in bar
t1=290;............//Inlet temperature in bar
```

```
C1=80;..........//Inlet Velocity in m/s
p2=1.5;........//pressure after compression in bar
t2=345;............//temperature after compression in bar
C2=220;..........//Velocity after compression in m/s
cp=1.005;..........//Specific heat at constant pressure in kJ/kgK
ga=1.4;............//Ratio of specific heats
R=287;.............//Gas constant for air in kJ/kgK
//Calculations
t21=t1*((p2/p1)^((ga-1)/ga));
wisen=cp*(t21-t1)+((C2*C2)-(C1*C1))/(2*1000);.....//Isentropic work done in kJ/kg
w=cp*(t2-t1)+((C2*C2)-(C1*C1))/(2*1000);.....//Actual work done (in impeller) in kJ/kg
etaisen=wisen/w;...............//Isentropic efficiency
disp(etaisen*100,"Isentropic efficiency in %:")
P=m*w;.........//Power required to drive the coompressor in kW
disp(P,"Power required to drive the coompressor in kW:")
t3=(((C2*C2)-(C1*C1))/(2*1000*cp))+t2;....//Temperature of air after leaving the diffuser in K
p3=p2*((t3/t2)^(ga/(ga-1)));..........//Pressure of air after leaving the diffuser in bar
t31=t1*((p3/p1)^((ga-1)/ga));...........//Delivery temperature from diffuser in K
etao=(t31-t1)/(t3-t1);...............//Overall efficiency
disp(etao*100,"Overall efficiency in %:")
```



```
Actual rise in temperature:

   165.

Tip diameter of the impeller in cm:

   40.989737

Power required in kW:

   1459.26

Diameter of the eye in cm:

   28.174313

-->
```

Figure 20.37: Single inlet type centrifugal compressor

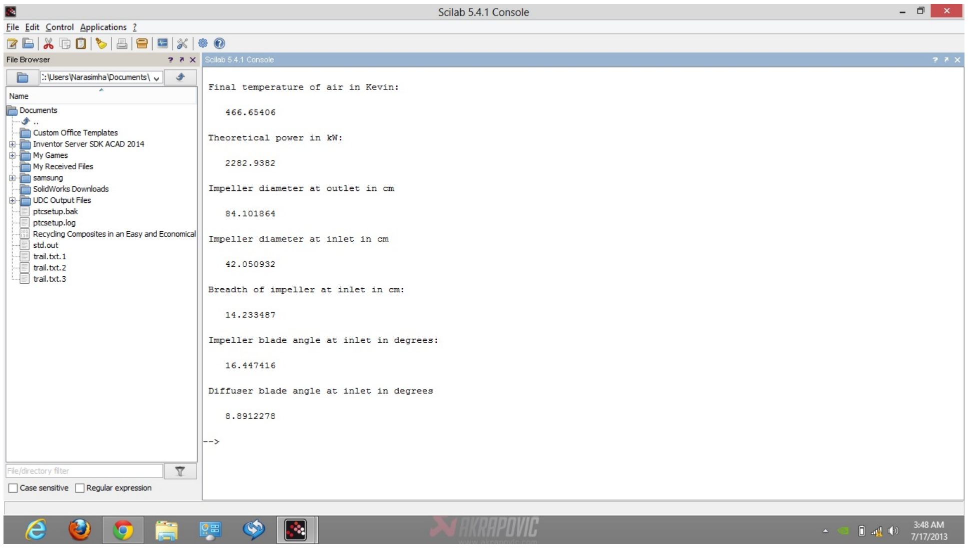
Scilab code Exa 20.38 `Single inlet type centrifugal compressor`

```
clc;funcprot(0);//EXAMPLE 20.38
// Initialisation of Variables
ma=528;.............//Air flow in kg/min
m=ma/60;.............//Air flow in kg/s
p1=1;........//Inlet pressure in bar
t1=293;............//Inlet temperature in bar
N=20000;..............//Compressor rpm
etaisen=0.8;.........//Isentropic efficiency
po1=1;.........//Static pressure in bar
p02=4;...........//Final total pressure in bar
C1=145;.........//Velocity of air when entering the impeller in m/s
rwt=0.9;..........//Ratio of whirl speed to tip speed
dh=0.12;........//Hub diameter in m
cp=1.005;...........//Specific heat at constant pressure in kJ/kgK
ga=1.4;............//Ratio of specific heats
```

```
R=287;..............//Gas constant for air in kJ/kgK
//Calculations
t01=t1+((C1*C1)/(2*cp*1000));..........//Stagnation temperature at the inlet to the machine in K
p01=p1*((t01/t1)^(ga/(ga-1)));.....//Stagnation pressure at the inlet to the machine in bar
t021=t01*((p02/p01)^((ga-1)/ga));
deltisen=t021-t01;.........//Isentropic rise in temperature in K
delt=round(deltisen/etaisen);........//Actual rise in temperature
disp(delt,"Actual rise in temperature:")
wc=cp*delt;.........//Work consumed by compressor in kJ/kg
Cbl2=sqrt(wc*1000/rwt);
d2=Cbl2*60/(%pi*N);..........//Tip diameter of the impeller in m
disp(d2*100,"Tip diameter of the impeller in cm:")
P=m*wc;............//Power required in kW
disp(P,"Power required in kW:")
rho1=(p1*10^5)/(R*t1);.......//Density at entry in kg/m^3
d1=sqrt(((m*4)/(C1*rho1*%pi))+(dh^2));.......//Eye diameter in m
disp(d1*100,"Diameter of the eye in cm:")
```

Scilab code Exa 20.39 `Centrifugal compressor`

```
clc;funcprot(0);//EXAMPLE 20.39
// Initialisation of Variables
N=10000;.................//Compressor rpm
v=660;............//Volume of air delivered in m^3/min
```



```
Final temperature of air in Kevin:

   466.65406

Theoretical power in kW:

   2282.9382

Impeller diameter at outlet in cm

   84.101864

Impeller diameter at inlet in cm

   42.050932

Breadth of impeller at inlet in cm:

   14.233487

Impeller blade angle at inlet in degrees:

   16.447416

Diffuser blade angle at inlet in degrees

   8.8912278

-->
```

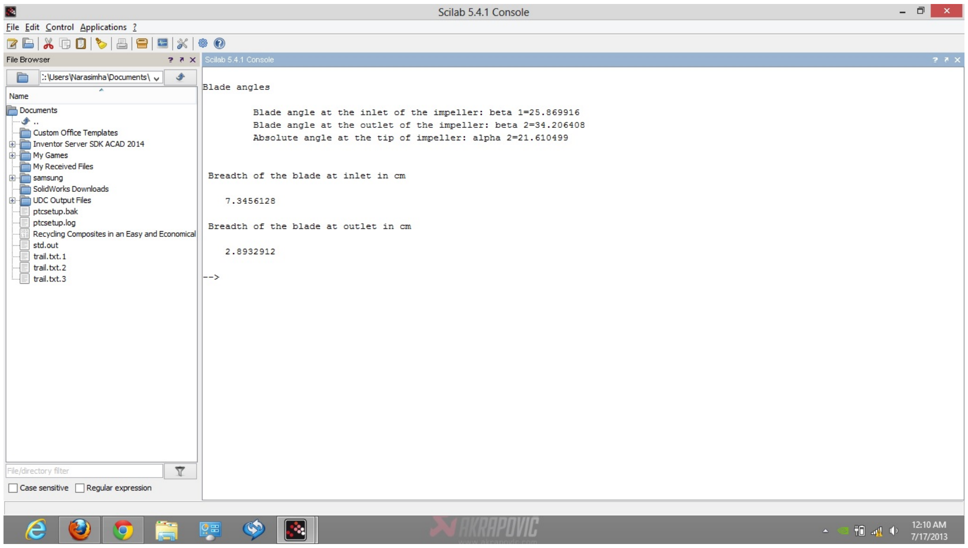
Figure 20.38: Centrifugal compressor

```
p1=1;..................//Inlet pressure in bar
t1=293;..............//Inlet temperature in K
rp=4;.............//Pressure ratio
etaisen=0.82;........//Isentropic efficiency
Cf2=62;...............//Flow velocity in m/s
rr=2;.............//Ratio of outer radius of impeller to inner radius of impeller
ka=0.9;..............//Blade area co efficient
fis=0.9;...........//Slip factor
cp=1.005;..............//Specific heat at constant pressure in kJ/kgK
ga=1.4;............//Ratio of specific heats
R=287;.............//Gas constant for air in kJ/kgK
//Calculations
t21=t1*(rp^((ga-1)/ga));Cf1=Cf2;
t2=t1+((t21-t1)/etaisen);..........//Final temperature of air
m=(p1*10^5*v/60)/(R*t1);...............//Mass flow rate in m^3/s
P=m*cp*(t2-t1);.........//Theoretical power in kW
```

```
disp(t2,"Final temperature of air in Kevin:")
disp(P,"Theoretical power in kW:")
Cbl2=sqrt(1000*cp*(t2-t1)/fis);
d2=60*Cbl2/(%pi*N);..........//Impeller diameter at
    outlet in m
d1=d2/rr;...............//Impeller diameter at inlet
     in m
disp(d2*100,"Impeller diameter at outlet in cm")
disp(d1*100,"Impeller diameter at inlet in cm")
b1=(v/60)/(2*%pi*(d1/2)*Cf1*ka);.........//Breadth
    of impeller at inlet in m
disp(b1*100,"Breadth of impeller at inlet in cm:")
Cbl1=Cbl2/rr;
beta1=(atan(Cf1/Cbl1))*180/%pi;
al2=(atan(Cf2/(fis*Cbl2)))*180/%pi;
disp(beta1,"Impeller blade angle at inlet in degrees
    :")
disp(al2,"Diffuser blade angle at inlet in degrees")
```

Scilab code Exa 20.40 `Centrifugal compressor`

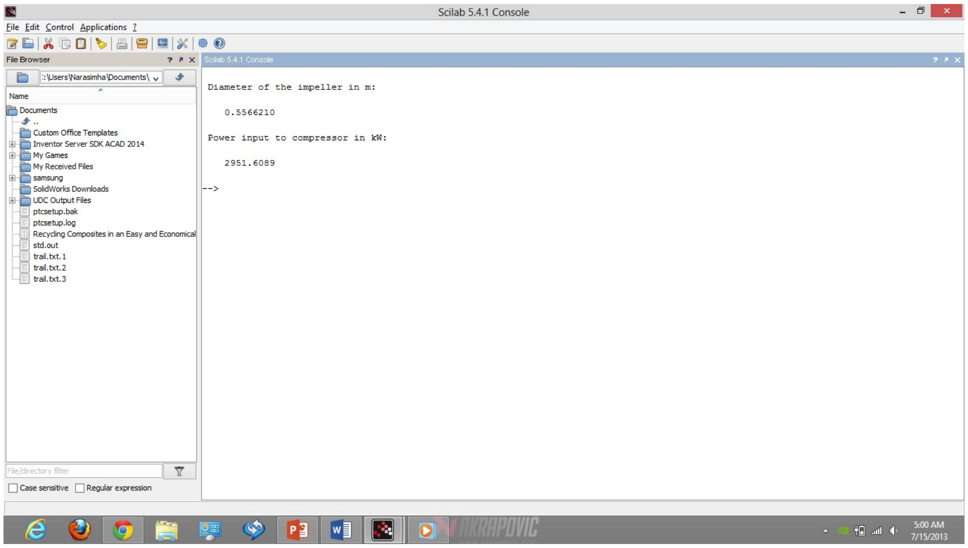
```
clc;funcprot(0);//EXAMPLE 20.40
// Initialisation of Variables
v1=4.8;......//Volume of air compressed in m^3/s
p1=1;....//Inlet pressure in bar
t1=293;........//Inlet pressure in K
n=1.5;........//Compression index
Cf1=65;......//Air flow velocity at inlet in m/s
Cf2=Cf1;......//Flow velocity is same at inlet and
    outlet
d1=0.32;..........//Inlet impeller diameter in m
d2=0.62;........//Outlet impeller diameter in m
N=8000;........//Blower rpm
```



```
Blade angles

        Blade angle at the inlet of the impeller: beta 1=25.869916
        Blade angle at the outlet of the impeller: beta 2=34.206408
        Absolute angle at the tip of impeller: alpha 2=21.610499


 Breadth of the blade at inlet in cm

    7.3456128

 Breadth of the blade at outlet in cm

    2.8932912

-->
```

Figure 20.39: Centrifugal compressor

```
cp=1.005;......//Specific heat at constant pressure in kJ/kgK
//Calculations
t21=t1*((n/p1)^((n-1)/n));....//Temperature at the outlet of compressor in K
Cbl1=(%pi*d1*N)/60;......//Peripheral velocity at inlet in m/s
Cbl2=(%pi*N*d2)/60;......//Tip peripheral velocity at outlet in m/s
Cw2=(cp*(t21-t1)*1000)/Cbl2;
be1=(atan(Cf1/Cbl1))*180/%pi;be2=(atan(Cf2/(Cbl2-Cw2)))*180/%pi;......//Blade angles at the tip of the impeller
al2= (atan(Cf2/Cw2))*180/%pi;
printf(”\nBlade angles  \n\n\t Blade angle at the inlet of the impeller: beta 1=%f \n\t Blade angle at the outlet of the impeller: beta 2=%f \n\t Absolute angle at the tip of impeller: alpha 2=%f \n\n”,be1,be2,al2)
b1=v1/(2*%pi*(d1/2)*Cf1);........//Breadth of blade
```



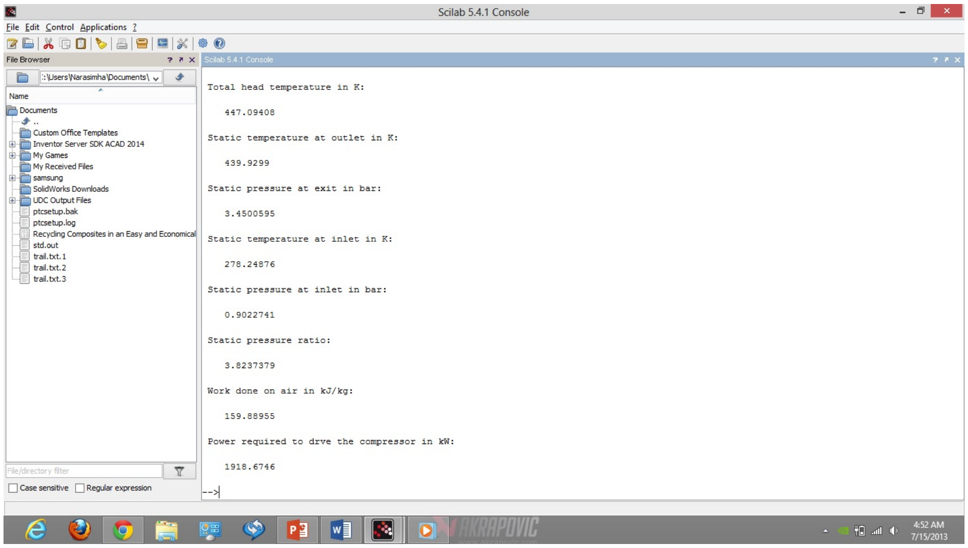
```
Diameter of the impeller in m:

   0.5566210

Power input to compressor in kW:

   2951.6089

-->
```

Figure 20.40: Centrifugal compressor

```
    at inlet in m
disp(b1*100,"Breadth of the blade at inlet in cm")
v2=(v1*t21*p1)/(n*t1);..............//Discharge at
    the outlet in m^3/s
b2=v2/(2*%pi*(d2/2)*Cf2);........//Breadth of blade
    at outlet in m
disp(b2*100,"Breadth of the blade at outlet in cm")
```

Scilab code Exa 20.41 `Centrifugal compressor`

```
clc;funcprot(0);//EXAMPLE 20.41
// Initialisation of Variables
m=16.5;.......//Air flow in kg/s
rp=4;........//Pressure ratio
N=15000;.........//Compressor rpm
t01=293;.........//Inlet head temperature
```



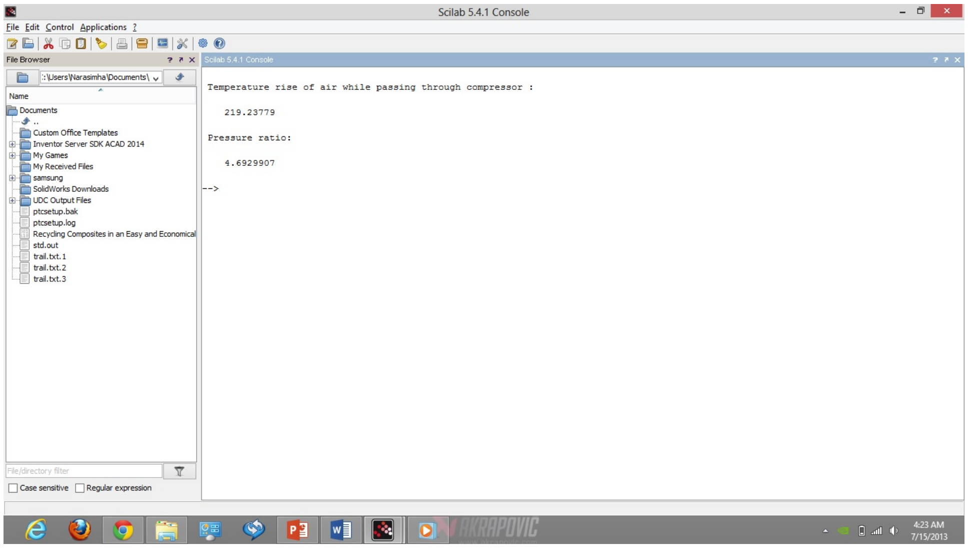
```
Total head temperature in K:

   447.09408

Static temperature at outlet in K:

   439.9299

Static pressure at exit in bar:

   3.4500595

Static temperature at inlet in K:

   278.24876

Static pressure at inlet in bar:

   0.9022741

Static pressure ratio:

   3.8237379

Work done on air in kJ/kg:

   159.88955

Power required to drve the compressor in kW:

   1918.6746

-->
```

Figure 20.41: Centrifugal compressor

```
fis=0.9;...........//Slip factor
fiw=1.04;.........//Power input factor
etaisen=0.8;.......//Isentropic efficiency
cp=1.005;........//Specific heat at constant pressure in kJ/kgK
ga=1.4;......//Ratio of specific heats
//Calculations
t021=t01*(rp^((ga-1)/ga));
delt=(t021-t01)/etaisen;Cbl2=sqrt((1000*cp*delt)/(fiw*fis));
D=(60*Cbl2)/(%pi*N);.............//Diameter of impeller
disp(D,"Diameter of the impeller in m:")
P=m*cp*delt;
disp(P,"Power input to compressor in kW:")
```

Scilab code Exa 20.42 `Centrifugal compressor`

```
clc;funcprot(0);//EXAMPLE 20.42
// Initialisation of Variables
rp=3.6;..........//Pressure ratio
die=0.35;.......//Diameter of inlet eye of compressor in m
Cf=140;..........//Axial velocity in m/s
m=12;.............//Mass flow in kg/s
Cbl2=120;.........//Velocity in the delivery duct in m/s
Ci=460;..........//The tip speed of the impeller in m/s
N=16000;............//Speed of impeller in rpm
etaisen=0.8;.......//Isentropic efficiency
pc=0.73;........//Pressure co efficient
pa=1.013;..........//Ambient pressure in bar
ta=273+15;................//Ambient temperature in K
ga=1.4;..........//Ratio of specific heats
cp=1.005;.........//Specific heat at constant pressure in kJ/kgK
R=0.287;........//Gas constant in kJ/kgK
//Calculations
delt=((ta*((rp^((ga-1)/ga))-1))/etaisen);.......//Rise in temperature
t02=ta+delt;............//Total head temperature in K
disp(t02,"Total head temperature in K:")
t2=t02-((Cbl2*Cbl2)/(2*cp*1000));..........//Static temperature at outlet in K
disp(t2,"Static temperature at outlet in K:")
p02=pa*rp;
p2=p02/(1+((Cbl2*Cbl2)/(2*R*t2*1000)));...........//Static pressure at exit in bar
disp(p2,"Static pressure at exit in bar:")
t1=ta-((Cf*Cf)/(2*cp*1000));.............//Static temperature at inlet in K
disp(t1,"Static temperature at inlet in K:")
```



```
Temperature rise of air while passing through compressor :

   219.23779

Pressure ratio:

   4.6929907

-->
```

Figure 20.42: Centrifugal compressor

```
p1=pa/(1+((Cf*Cf)/(2*R*t1*1000)));...........//Static pressure at inlet in bar
disp(p1,"Static pressure at inlet in bar:")
rp=p2/p1;.....//Static pressure ratio
disp(rp,"Static pressure ratio:")
W=cp*delt;...........//Work done on air in kJ/kg of air
disp(W,"Work done on air in kJ/kg:")
P=m*cp*delt;..........//Power required to drive the compressor in kW
disp(P,"Power required to drve the compressor in kW:")
```

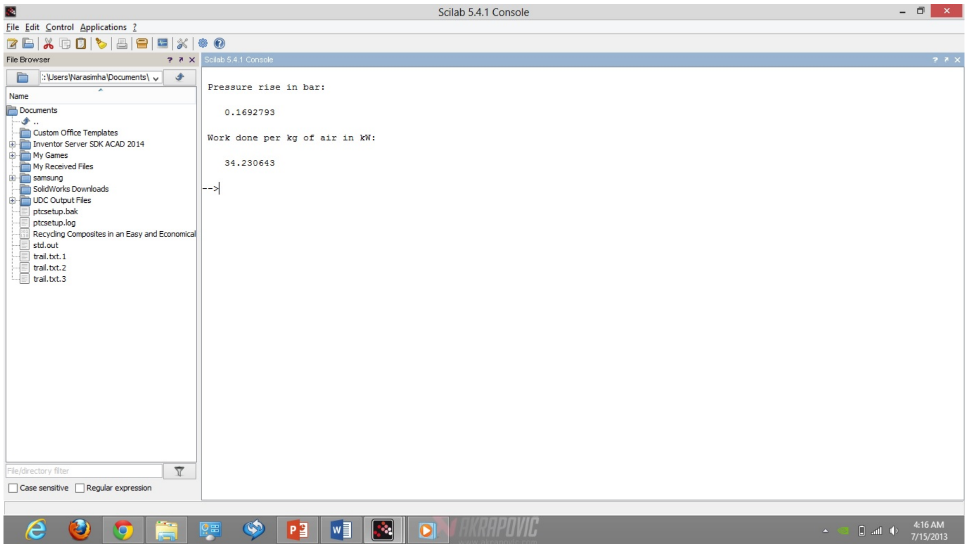
Scilab code Exa 20.43 `Centrifugal compressor`

```
clc;funcprot(0);//EXAMPLE 20.43
```

```
// Initialisation of Variables
t1=300;.........//Inlet temperature in K
N=18000;.............//Compressor rpm
etaisen=0.76;.......//Isentropic efficiency
od=0.55;......//Outer diameter of blade tip
sf=0.82;......//Slip factor
cp=1.005;.........//Specific heat capacity at
   constant pressure in kJ/kgK
ga=1.4;.............//Ratio of specific heats
//Calculations
Cbl2=(%pi*od*N)/60;W=Cbl2*Cbl2*sf/1000;...........//
   Work done per kg of air in kW
delt=W/cp;.............//Temperature rise of air
   while passing through compressor
disp(delt,"Temperature rise of air while passing
   through compressor :")
t21=(etaisen*delt)+t1;rp=((t21/t1)^(ga/(ga-1)))
   ;.....//Pressure ratio
disp(rp,"Pressure ratio:")
```

Scilab code Exa 20.44 `Axial flow compressor`

```
clc;funcprot(0);//EXAMPLE 20.44
// Initialisation of Variables
Cbl=240;........//Mean blade velocity in m/s
Cf=190;.........//Air flow velocity in m/s
al1=45;al2=14;.........//Blade angels in degrees
rho=1;.........//Density of air in kg/m^3
//Calculations
pr=(1/2)*(rho*Cf*Cf/(10^5))*(((tan(al1*%pi/180))^2)
   -((tan(al2*%pi/180))^2));.......//Pressure rise
   in bar
disp(pr,"Pressure rise in bar:")
```



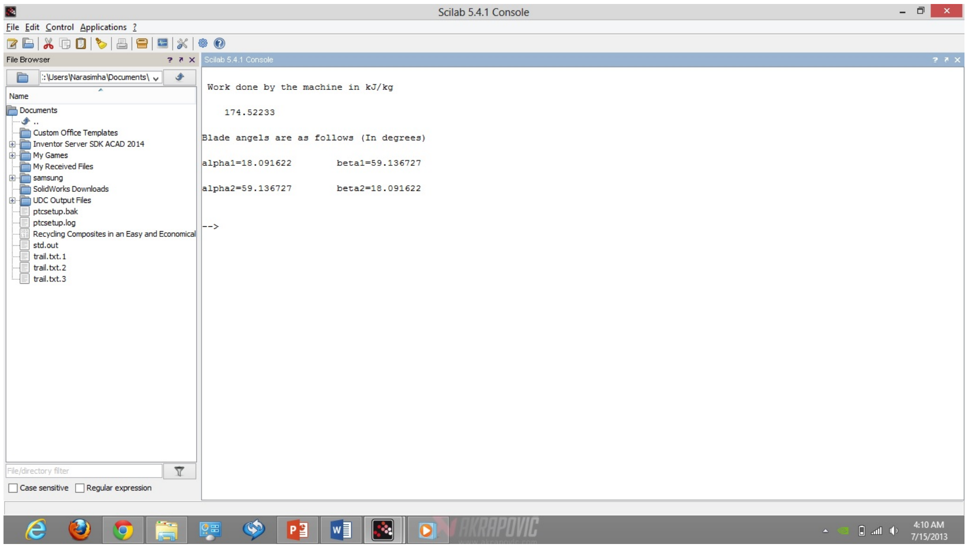
```
Pressure rise in bar:

   0.1692793

Work done per kg of air in kW:

   34.230643

-->
```

Figure 20.43: Axial flow compressor

```
W=Cbl*Cf/1000*((tan(al1*%pi/180))-(tan(al2*%pi/180))
   );..............//Work done per kg of air in kW
disp(W,"Work done per kg of air in kW:")
```

Scilab code Exa 20.45 `Axial flow compressor`

```
clc;funcprot(0);//EXAMPLE 20.45
// Initialisation of Variables
etaisen=0.82;.......//Overall isentropic efficiency
N=8;............//No of stages
t1=293;...........//Inlet temperature in K
ga=1.4;............//Ratio of specific heats
rp=4;.............//Pressure ratio
Rd=0.5;.................//Reaction factor
Cbl=180;..................//Mean blade speed in m/s
Cf=90;...............//Air flow velocity in m/s
```

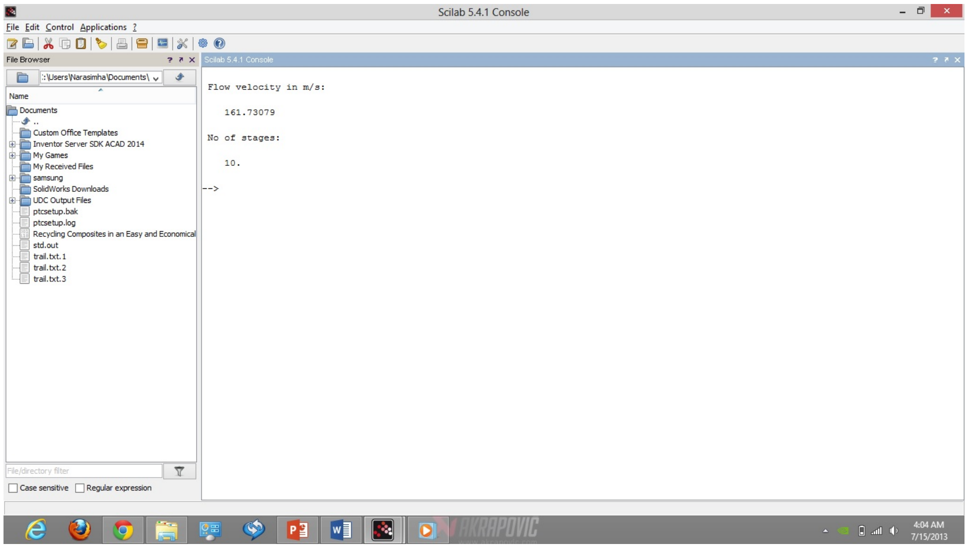


```
Work done by the machine in kJ/kg

   174.52233

Blade angels are as follows (In degrees)

alpha1=18.091622        beta1=59.136727

alpha2=59.136727        beta2=18.091622


-->
```

Figure 20.44: Axial flow compressor

```
cp=1.005;.........//Specific heat at constant pressure in kJ/kgK
//Calculations
t21=t1*(rp^((ga-1)/ga));
t2=((t21-t1)/etaisen)+t1;
wrt=cp*(t2-t1);.........//Work done by the machine in kJ/kg
disp(wrt,"Work done by the machine in kJ/kg")
be1=atan((((cp*(t2-t1)*1000/(Cf*Cbl*N))+(Cbl/Cf))/2))*180/%pi;
al1=atan((Cbl/Cf)-tan(be1*%pi/180))*180/%pi;
printf("\nBlade angels are as follows (In degrees)\n\nalpha1=%f\tbeta1=%f\n\nalpha2=%f\tbeta2=%f\n\n",al1,be1,be1,al1)
```

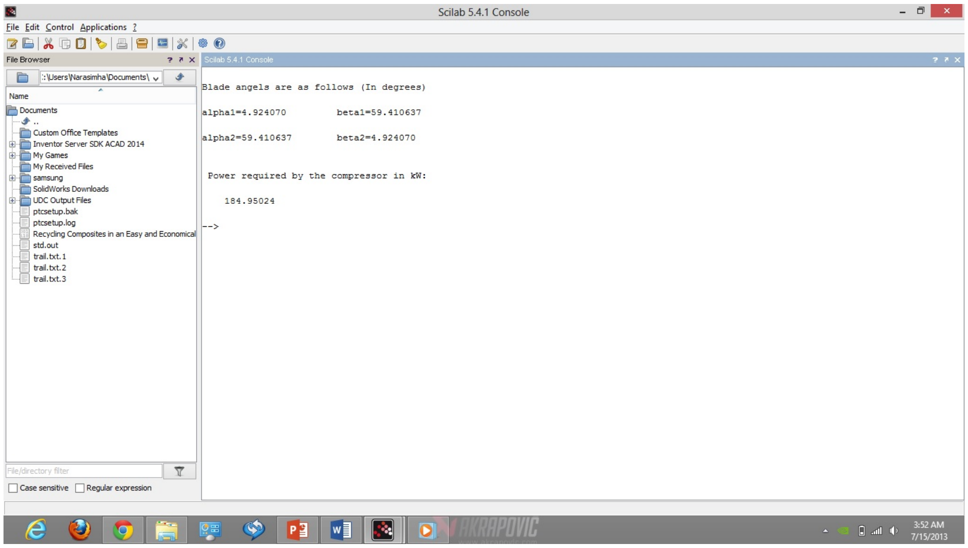
Scilab code Exa 20.46 `Axial flow compressor`



```
Flow velocity in m/s:

   161.73079

No of stages:

   10.

-->
```

Figure 20.45: Axial flow compressor

```
clc;funcprot(0);//EXAMPLE 20.46
// Initialisation of Variables
etaisen=0.85;.......//Overall isentropic efficiency
t1=293;...........//Inlet temperature in K
rp=4;.............//Pressure ratio
Rd=0.5;................//Reaction factor
Cbl=180;.................//Mean blade speed in m/s
wip=0.82;..............//Work input factor
al1=12;be1=42;......//Blade angels in degrees
ga=1.4;............//Ratio of specific heats
cp=1.005;.........//Specific heat at constant pressure in kJ/kgK
//Calculations
t21=t1*(rp^((ga-1)/ga));
t2=((t21-t1)/etaisen)+t1;
wrt=cp*(t2-t1);.........//Theoretical work required in kJ/kg
Cf=Cbl/(tan(al1*%pi/180)+tan(be1*%pi/180));
Cw1=Cf*tan(al1*%pi/180);Cw2=Cf*tan(be1*%pi/180);
wcps=Cbl*(Cw2-Cw1)*wip/1000;.............//Work
```



```
Blade angels are as follows (In degrees)

alphal=4.924070        beta1=59.410637

alpha2=59.410637       beta2=4.924070


 Power required by the compressor in kW:

    184.95024

-->
```

Figure 20.46: Eight stage axial flow compressor

```
   consumed per stage in kJ/kg
N=round(wrt/wcps);.......//No of stages
disp(Cf,"Flow velocity in m/s:")
disp(N,"No of stages:")
```

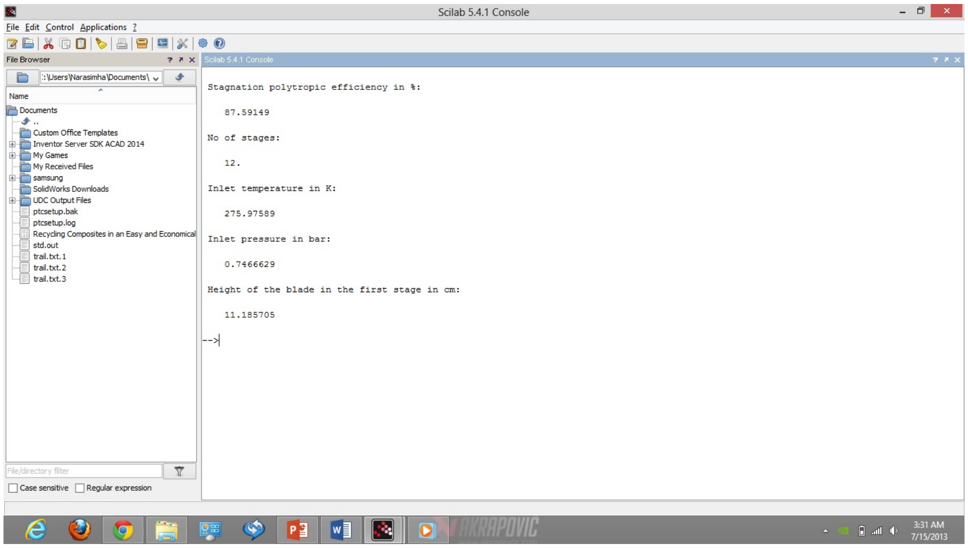
Scilab code Exa 20.47 `Eight stage axial flow compressor`

```
clc;funcprot(0);//EXAMPLE 20.47
// Initialisation of Variables
rp=5;..........//Stagnation pressure ratio ga
etaisen=0.92;.......//Overall isentropic efficiency
t1=290;.............//Inlet stagnation temperature
   in K
p1=1;...............//Inlet stagnation pressure in
   bar
Cbl=160;...........//Mean blade speed in m/s
```

```
ga=1.4;...........//Ratio of specific heats
Rd=0.5;............//Degree of reaction
Cf=90;...............//Axial velocity of air through compressor in m/s
N=8;............//No of stages
m=1;.........//Mass flow in kg/s
cp=1.005;...........//Specific heat at constant pressure in kJ/kgK
//Calculations
tN1=t1*(rp^((ga-1)/ga));......//Temperature at the end of compression stage due to isentropic expansion in K
tN=((tN1-t1)/etaisen)+t1;
be1=atan(((cp*(tN-t1)*1000/(Cf*Cbl*N))+(Cbl/Cf))/2)*180/%pi;
al1=atan((Cbl/Cf)-tan(be1*%pi/180))*180/%pi;
printf("\nBlade angels are as follows (In degrees)\n\nalpha1=%f\t\tbeta1=%f\n\nalpha2=%f\tbeta2=%f\n\n",al1,be1,be1,al1)
P=m*cp*(tN-t1);..........//Power required by the compressor in kW
disp(P,"Power required by the compressor in kW:")
```

Scilab code Exa 20.48 `Axial flow compressor`

```
clc;funcprot(0);//EXAMPLE 20.48
// Initialisation of Variables
rp=4;........//Stagnation pressure ratio
etaisen=0.85;.....//Stagnation isentropic efficiency
p1=1;.............//Inlet stagnation pressure in bar
t1=300;...........//Inlet stagnation temperature in K
Rd=0.5;............//Degree of reaction
```



```
Stagnation polytropic efficiency in %:

   87.59149

No of stages:

   12.

Inlet temperature in K:

   275.97589

Inlet pressure in bar:

   0.7466629

Height of the blade in the first stage in cm:

   11.185705

-->
```

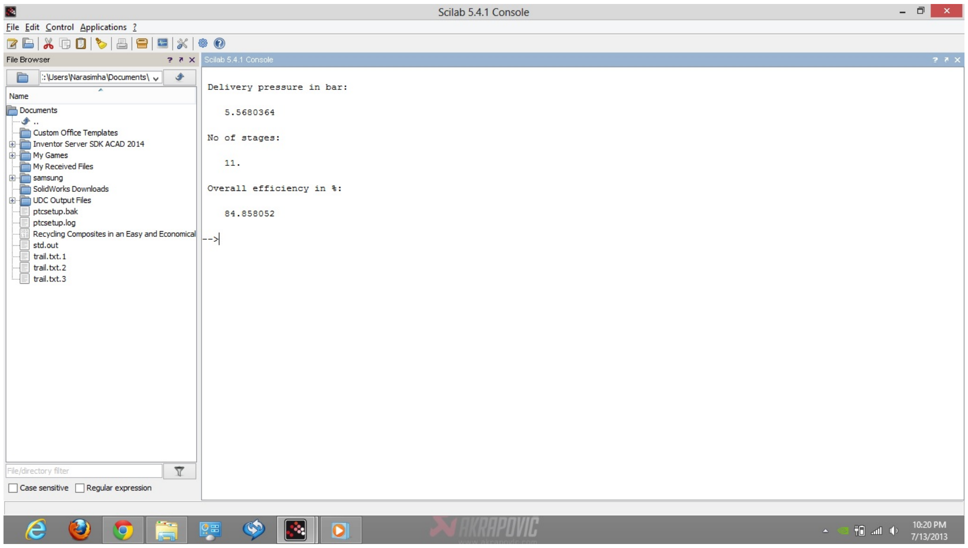
Figure 20.47: Axial flow compressor

```
Cu=180;...........//Mean blade speed in m/s
Wd=0.9;...........//Work done factor
htr=0.42;.......//Hub tip ratio
al1=12;be2=al1;.......//Relative air angle at rotor inlet in degrees
al2=32;be1=al2;........//Relative air angle at rotor at outlet in degrees
ga=1.4;...........//Ratio of specific heats
cp=1.005;..........//Specific heat capacity at constant pressure in kJ/kgK
R=287;..........//Gas constant in J/kgK
m=19.5;..........//Mass flow in kg/s
//Calculations
tN1=t1*(rp^((ga-1)/ga));......//Temperature at the end of compression stage due to isentropic expansion in K
tN=((tN1-t1)/etaisen)+t1;
etap=log(rp^((ga-1)/ga))/log(tN/t1);...........//Stagnation polytropic efficiency
disp(etap*100,"Stagnation polytropic efficiency in %
```

```
:")
Cf=Cu/(tan(al1*%pi/180)+tan(be1*%pi/180));
Cw1=Cf*tan(al1*%pi/180);Cw2=Cf*tan(al2*%pi/180);
wcps=Cu*(Cw2-Cw1)*Wd/1000;.............//Work consumed per stage in kJ/kg
wc=cp*(tN-t1);...............//Work consumed by compressor in kJ/kg
N=round(wc/wcps);.......//No of stages
disp(N,"No of stages:")
C1=Cf/cos(al1*%pi/180);.......//Absolute velocity at exit from guide vanes in m/s
ti=t1-((C1*C1)/(2*cp*1000));..........//Inlet temperature in K
disp(ti,"Inlet temperature in K:")
pi=p1*((ti/t1)^(ga/(ga-1)));......//Inlet pressure in bar
disp(pi,"Inlet pressure in bar:")
rho1=(pi*10^5)/(R*ti);.............//Density of air approaching the first stage
r1=sqrt(m/(rho1*%pi*Cf*(1-(htr^2))));rh=r1*htr;
l=r1-rh;............//Height of the blade in the first stage in m
disp(l*100,"Height of the blade in the first stage in cm:")
```

Scilab code Exa 20.49 Multi stage axial flow compressor

```
clc;funcprot(0);//EXAMPLE 20.49
// Initialisation of Variables
ma=20;..........//Air flow rate in kg/s
p1=1;.........//Inlet stagnation pressure in bar
t1=290;.........//Inlet stagnation temperature in Kelvin
```



```
Delivery pressure in bar:

   5.5680364

No of stages:

   11.

Overall efficiency in %:

   84.858052

-->
```

Figure 20.48: Multi stage axial flow compressor

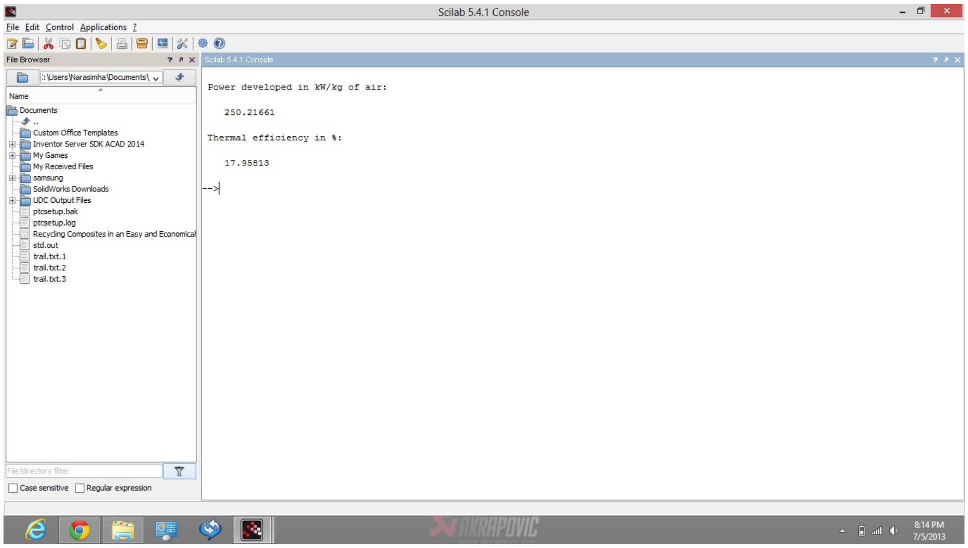
```
t2=305;.........//Temperature at the end of first stage in K
etapc=0.88;.....//Polytropic efficiency of compression
P=4350;......//Power consumed by compressor in kW
ga=1.4;.....//Ratio of specific heats
cp=1.005;......//Specific heat at constant pressure
//Calculations
p2byp1=(%e^(etapc*log(t2/t1)))^(ga/(ga-1));
tN=(P/(ma*cp))+t1;
pN=p1*((tN/t1)^((etapc*ga)/(ga-1)));......//Delivery pressure in bar
disp(pN,”Delivery pressure in bar:”)
N=log(pN/p1)/log(p2byp1);...........//No of stages
disp(round(N),”No of stages:”)
tN1=t1*((pN/p1)^((ga-1)/ga));
etao=(tN1-t1)/(tN-t1);...............//Overall efficiency
disp(etao*100,”Overall efficiency in %:”)
```

Chapter 21

Gas Turbines and Jet Propulsion

Scilab code Exa 21.1 `Open cycle gas turbine`

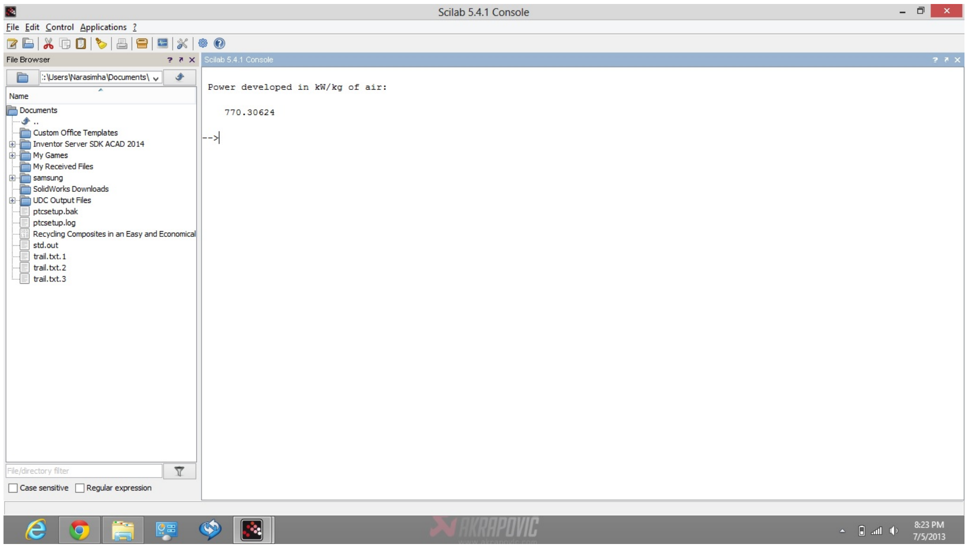
```
clc;funcprot(0);//EXAMPLE 21.1
// Initialisation of Variables
p1=1;.........//Pressure of air while entering the turbine in bar
t1=293;........//Temperature of air entering the turbine in K
p2=4;.........//Pressure of air after compression in bar
etac=0.8;....//Efficiency of compressor
etat=0.85;.....//Efficiency of turbine
afr=90;........//Air fuel ratio
ma=3;...........//Mass of air in kg/s
ga=1.4;........//Ratio of specific heats
cp=1;.............//Specific heat at constant pressure in kJ/kgK
C=41800;.............//Calorific value of fuel in kJ/kg
```



```
Power developed in kW/kg of air:

   250.21661

Thermal efficiency in %:

   17.95813

-->
```

Figure 21.1: Open cycle gas turbine

```
//Calculations
t2=t1*((p2/p1)^((ga-1)/ga));...............//Ideal temperature of air after compression in K
t21=((t2-t1)/etac)+t1;..............//Actual temperature of air after compression in K
t3=round((C/((afr+1)*cp))+t21);..............//Temperature before expansion in turbine in K
p4=p1;p3=p2;t4=t3*((p4/p3)^((ga-1)/ga));...........//Ideal temperature after expansion in turbine in K
t41=t3-(etat*(t3-t4));................//Actual temperature after expansion in turbine in K
wt=((afr+1)/afr)*cp*(t3-t41);........//Work done by turbine  in kJ/kg of air
wc=round(1*cp*(t21-t1));.................//Work done by compression in kJ/kg of air
wnet=wt-wc;..........//Net work done in kJ/kg
P=wnet*ma;.................//Power developed in kW/kg of air
disp(P,"Power developed in kW/kg of air:")
```



```
Power developed in kW/kg of air:

   770.30624

-->
```

Figure 21.2: Open cycle gas turbine

```
qs=(1/afr)*C;................//Heat supplied in kJ/kg of air
etath=wnet/qs;................//Thermal efficiency
disp(etath*100,"Thermal efficiency in %:")
```

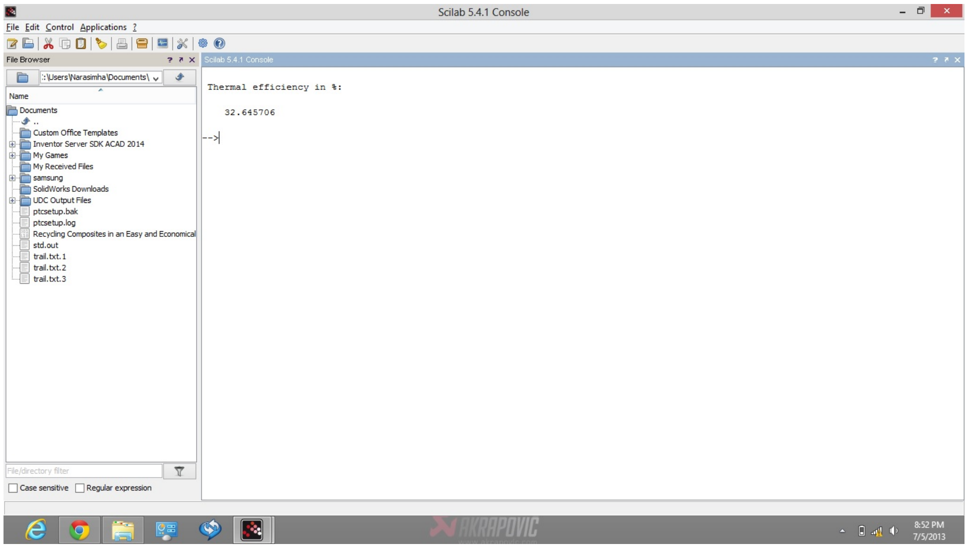
Scilab code Exa 21.2 `Open cycle gas turbine`

```
clc;funcprot(0);//EXAMPLE 21.2
// Initialisation of Variables
t1=288;........//Temperature of air entering the turbine in K
t3=883;..............//Temperature before expansion in turbine in K
etac=0.8;....//Efficiency of compressor
etat=0.82;.....//Efficiency of turbine
rp=6;...........//Pressure ratio
```

```
ma=16;...........//Mass of air in kg/s
gac=1.4;........//Ratio of specific heats for compression process
gae=1.333;............//Ratio of specific heats for expansion process
cpc=1.005;.............//Specific heat at constant pressure in kJ/kgK during compression process
cpe=1.11;.............//Specific heat at constant pressure in kJ/kgK during expansion process
C=41800;.............//Calorific value of fuel in kJ/kg
//Calculations
t2=t1*((rp)^((gac-1)/gac));...............//Ideal temperature of air after compression in K
t21=((t2-t1)/etac)+t1;..............//Actual temperature of air after compression in K
t4=t3/((rp)^((gae-1)/gae));............//Ideal temperature after expansion in turbine in K
t41=t3-(etat*(t3-t4));.................//Actual temperature after expansion in turbine in K
wt=cpe*(t3-t41);........//Work done by turbine in kJ/kg of air
wc=(1*cpc*(t21-t1));.................//Work done by compression in kJ/kg of air
wnet=wt-wc;..........//Net work done in kJ/kg
P=wnet*ma;.................//Power developed in kW/kg of air
disp(P,"Power developed in kW/kg of air:")
```

Scilab code Exa 21.3 `Thermal efficiency of Gas turbine`

```
clc;funcprot(0);//EXAMPLE 21.3
// Initialisation of Variables
```



```
Thermal efficiency in %:

   32.645706

-->
```

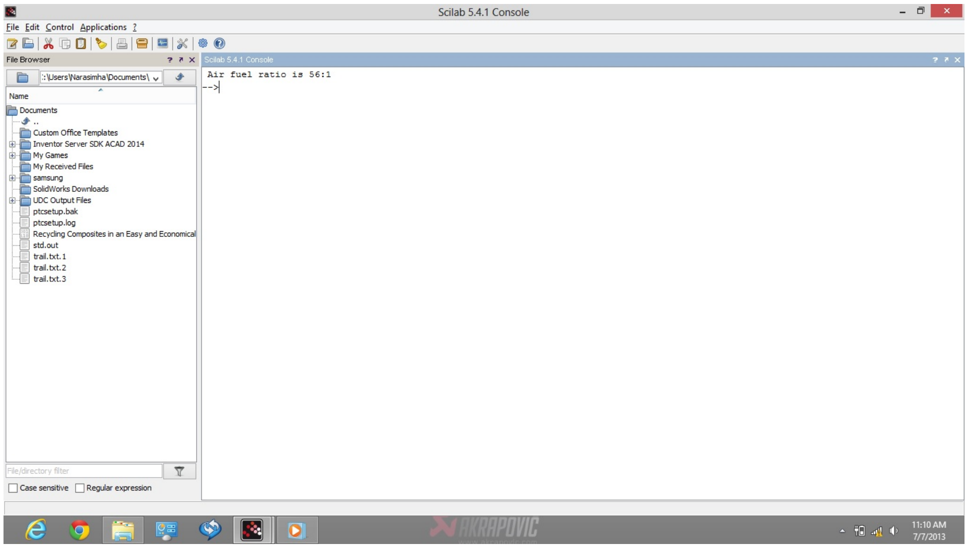
Figure 21.3: Thermal efficiency of Gas turbine

```
p1=1;.........//Pressure of air while entering the turbine in bar
t1=300;........//Temperature of air entering the turbine in K
p2=6.2;.........//Pressure of air after compression in bar
etac=0.88;....//Efficiency of compressor
etat=0.9;.....//Efficiency of turbine
far=0.017;........//Fuel air ratio
ga=1.4;........//Ratio of specific heats for compression
gae=1.333;........//Ratio of specific heats for expansion
cp=1.147;.............//Specific heat at constant pressure in kJ/kgK during expansion
cpc=1.005;.............//Specific heat at constant pressure in kJ/kgK during compression
C=44186;.............//Calorific value of fuel in kJ/kg
//Calculations
```

```
t2=t1*((p2/p1)^((ga-1)/ga));................//Ideal temperature of air after compression in K
t21=((t2-t1)/etac)+t1;..............//Actual temperature of air after compression in K
t3=(((C*far)/((far+1)*cpc))+t21);.............//Temperature before expansion in turbine in K
p4=p1;p3=p2;t4=t3*((p4/p3)^((gae-1)/gae));............//Ideal temperature after expansion in turbine in K
t41=t3-(etat*(t3-t4));.................//Actual temperature after expansion in turbine in K
wt=(cp*(t3-t41));........//Work done by turbine  in kJ/kg of air
wc=round(1*cpc*(t21-t1));.................//Work done by compression in kJ/kg of air
wnet=wt-wc;..........//Net work done in kJ/kg
qs=(far)*C;.................//Heat supplied in kJ/kg of air
etath=wnet/qs;................//Thermal efficiency
disp(etath*100,"Thermal efficiency in %:")
```

Scilab code Exa 21.4 `Air fuel ratio for gas turbine`

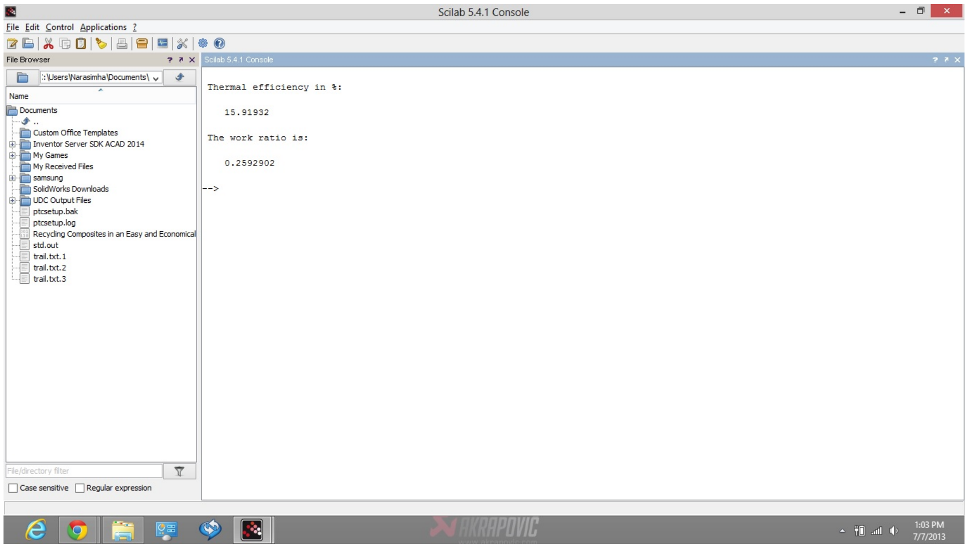
```
clc;funcprot(0);//EXAMPLE 21.4
// Initialisation of Variables
t1=300;........//Temperature of air entering the turbine in K
t3=1148;..............//Temperature before expansion in turbine in K
etac=0.8;....//Efficiency of compressor
etat=0.852;.....//Efficiency of turbine
rp=4;...........//Pressure ratio
p1=1;...............//Pressure of air before
```



```
Air fuel ratio is 56:1
-->
```

Figure 21.4: Air fuel ratio for gas turbine

```
    entering compressor
ga=1.4;........//Ratio of specific heats
cp=1.0;.............//Specific heat at constant pressure in kJ/kgK
C=42000;.............//Calorific value of fuel in kJ/kg
perlcc=10;...........//Percent loss of calorific value of fuel in combustion chamber
//Calculations
p2=p1*rp;.................//Pressure of air after compression in  bar
etacc=(100-perlcc)/100;.......//Efficiency of combustion chamber
t2=t1*((rp)^((ga-1)/ga));...............//Ideal temperature of air after compression in K
t21=((t2-t1)/etac)+t1;..............//Actual temperature of air after compression in K
afr=((C*etacc)/(cp*(t3-t21)))-1;........//Air fuel ratio
printf("Air fuel ratio is %d:1",round(afr))
```



```
Thermal efficiency in %:

   15.91932

The work ratio is:

   0.2592902

-->
```

Figure 21.5: Thermal efficiency of gas turbine

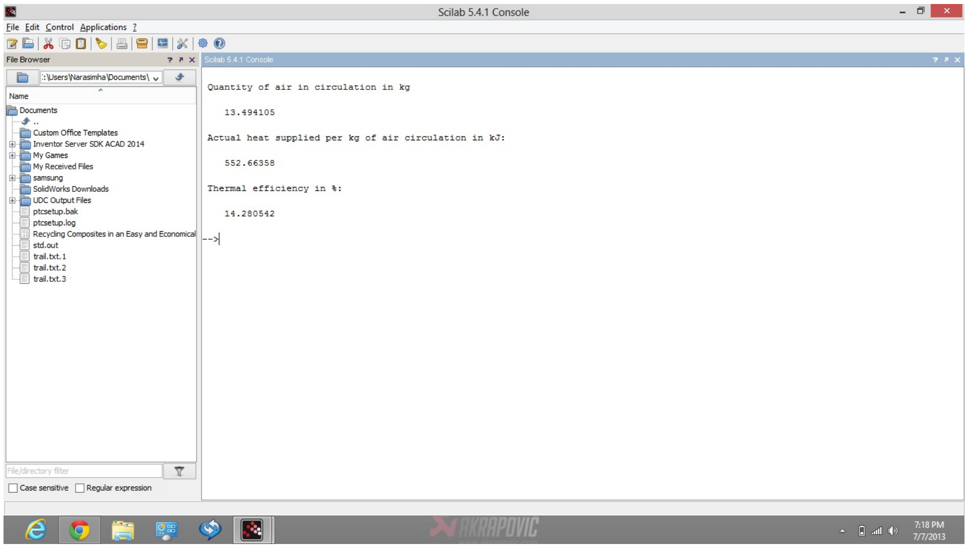
Scilab code Exa 21.5 `Thermal efficiency of gas turbine`

```
clc;funcprot(0);//EXAMPLE 21.5
// Initialisation of Variables
t1=300;........//Temperature of air entering the turbine in K
t3=883;..............//Temperature before expansion in turbine in K
etac=0.8;....//Efficiency of compressor
etat=0.852;.....//Efficiency of turbine
rp=4;...........//Pressure ratio
p1=1;...............//Pressure of air before entering compressor
ga=1.4;........//Ratio of specific heats
cp=1.11;.............//Specific heat at constant
```

```
pressure in kJ/kgK
C=42000;.............//Calorific value of fuel in kJ/kg
perlcc=10;............//Percent loss of calorific value of fuel in combustion chamber
//Calculations
p2=p1*rp;.................//Pressure of air after compression in  bar
etacc=(100-perlcc)/100;.......//Efficiency of combustion chamber
t2=t1*((rp)^((ga-1)/ga));...............//Ideal temperature of air after compression in K
t21=((t2-t1)/etac)+t1;..............//Actual temperature of air after compression in K
qs=cp*(t3-t21);...................//Heat supplied in  kJ/kg
t4=t3/((rp)^((ga-1)/ga));............//Ideal temperature after expansion in turbine in K
t41=t3-(etat*(t3-t4));.................//Actual temperature after expansion in turbine in K
wt=cp*(t3-t41);........//Work done by turbine  in kJ/kg of air
wc=(1*cp*(t21-t1));.................//Work done by compression in kJ/kg of air
wnet=wt-wc;..........//Net work done in kJ/kg
etath=wnet/qs;................//Thermal efficiency
disp(etath*100,"Thermal efficiency in %:")
wrr=wnet/wt;...................//Work ratio
disp(wrr,"The work ratio is:")
```

Scilab code Exa 21.6 `Open cycle gas turbine`

```
clc;funcprot(0);//EXAMPLE 21.6
```



```
Quantity of air in circulation in kg

   13.494105

Actual heat supplied per kg of air circulation in kJ:

   552.66358

Thermal efficiency in %:

   14.280542

-->
```

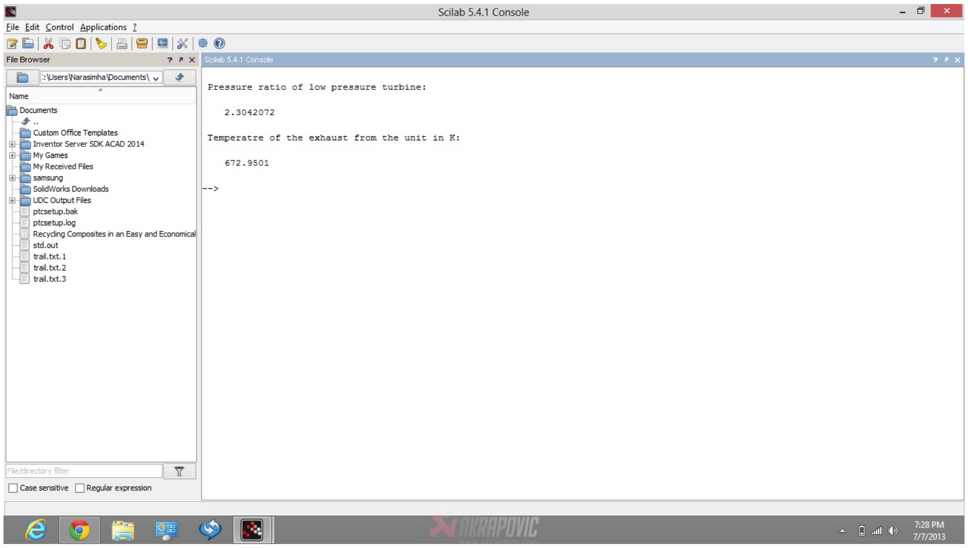
Figure 21.6: Open cycle gas turbine

```
// Initialisation of Variables
p1=1;.........//Pressure of air while entering the turbine in bar
t1=293;........//Temperature of air entering the turbine in K
p2=5;.........//Pressure of air after compression in bar
plcc=0.1;.....//Pressure loss in combustion chamber in bar
t3=953;............//Temperature before expansion in turbine in K
etac=0.85;....//Efficiency of compressor
etat=0.8;.....//Efficiency of turbine
etacc=0.85;......//Efficiency of combustion chamber
ga=1.4;........//Ratio of specific heats
cp=1.024;.............//Specific heat at constant pressure in kJ/kgK
P=1065;.............//Power developed by the plant in kW

```

```
//Calculations
p3=p2-plcc;........................//Pressure before expansion in turbine in bar
p4=p1;
t2=t1*((p2/p1)^((ga-1)/ga));...............//Ideal temperature of air after compression in K
t21=((t2-t1)/etac)+t1;..............//Actual temperature of air after compression in K
t4=t3*((p4/p3)^((ga-1)/ga));............//Ideal temperature after expansion in turbine in K
t41=t3-(etat*(t3-t4));.................//Actual temperature after expansion in turbine in K
wt=(cp*(t3-t41));........//Work done by turbine  in kJ/kg of air
wc=round(1*cp*(t21-t1));.................//Work done by compression in kJ/kg of air
wnet=wt-wc;..........//Net work done in kJ/kg
ma=P/wnet;.............//Quantity of air in circulation in kg
disp(ma,”Quantity of air in circulation in kg”)
qs=cp*(t3-t21)/etac;..................//Actual heat supplied per kg of air circulation in kJ
disp(qs,”Actual heat supplied per kg of air circulation in kJ:”)
etath=wnet/qs;.............//Thermal efficiency
disp(etath*100,”Thermal efficiency in %:”)
```

Scilab code Exa 21.7 Pressure ratio and temperature of the exhaust

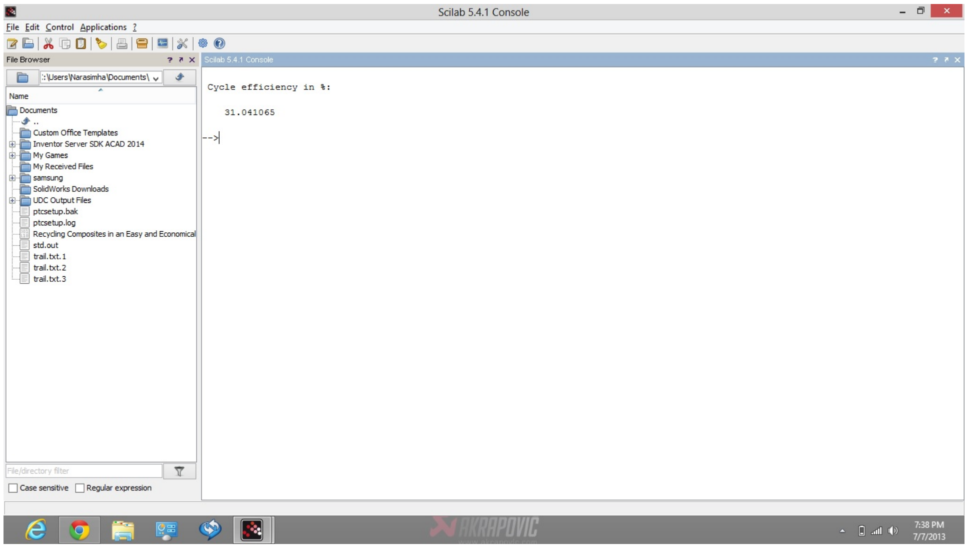
```
clc;funcprot(0);//EXAMPLE 21.7
// Initialisation of Variables
ma=20;..............//Air flow rate in kg/s
t1=300;........//Temperature of air entering the
```



```
Pressure ratio of low pressure turbine:

   2.3042072

Temperatre of the exhaust from the unit in K:

   672.9501

-->
```

Figure 21.7: Pressure ratio and temperature of the exhaust

```
    turbine in K
t3=1000;............//Temperature before expansion
    in turbine in K
rp=4;...............//Pressure ratio
cp=1;.............//Specific heat at constant
    pressure in kJ/kgK
ga=1.4;........//Ratio of specific heats
//Calculations
t2=t1*((rp)^((ga-1)/ga));...............//
    Temperature of air after compression in K
t4=t3-t2+t1;............//Temperature after
    expansion in turbine in K
prlp=rp/((t3/t4)^(ga/(ga-1)));.............//
    Pressure ratio of low pressure turbine
disp(prlp,"Pressure ratio of low pressure turbine:")
t5=t4/((prlp)^((ga-1)/ga));...........//Temperature
     of the exhaust from the unit in K
disp(t5,"Temperature of the exhaust from the unit in
     K:")
```

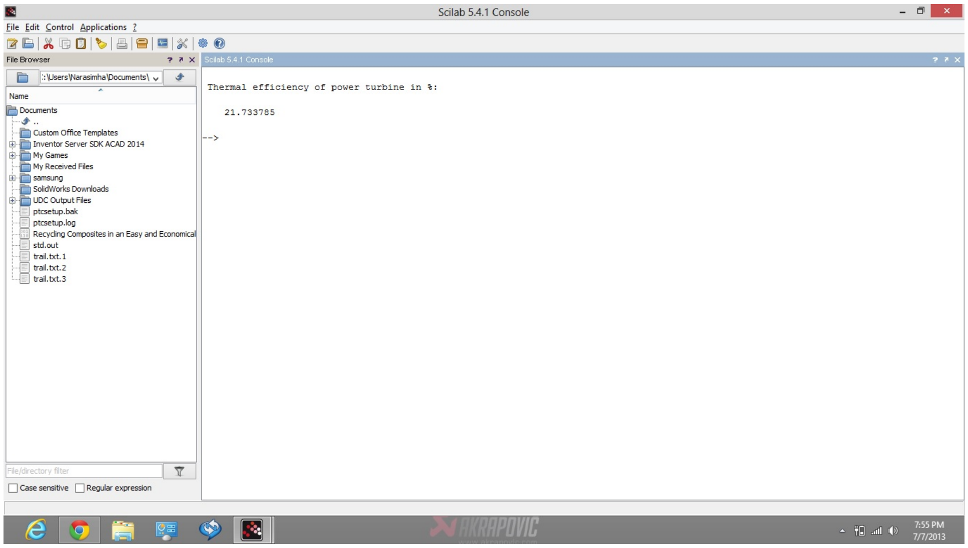


```
Cycle efficiency in %:

   31.041065

-->
```

Figure 21.8: Efficiency of open cycle gas turbine

Scilab code Exa 21.8 `Efficiency of open cycle gas turbine`

```
clc;funcprot(0);//EXAMPLE 21.8
// Initialisation of Variables
p1=1;.........//Pressure of air while entering the turbine in bar
t1=300;........//Temperature of air entering the turbine in K
t21=490;........//Actual temperature of air after compression in K
t3=1000;............//Temperature before expansion in turbine in K
rp=5;.............//Pressure ratio
etac=0.8;....//Efficiency of compressor
etat=0.8;.....//Efficiency of turbine
```



```
Thermal efficiency of power turbine in %:

   21.733785

-->
```

Figure 21.9: Multi stage gas turbine

```
ga=1.4;........//Ratio of specific heats
cp=1.005;.............//Specific heat at constant pressure in kJ/kgK
//Calculations
t4=t3/((rp)^((ga-1)/ga));...........//Ideal temperature after expansion in turbine in K
t41=t3-(etat*(t3-t4));................//Actual temperature after expansion in turbine in K
t5=((t41-t21)*etac)+t21;..........//Temperature of the exhaust from the unit in K
wc=cp*(t21-t1);.............//Work consumed by compressor in kJ/kg
wt=cp*(t3-t41);........//Work done by turbine in kJ/kg
qs=cp*(t3-t5);..........//Heat supplied in kJ/kg
etac=(wt-wc)/qs;.........//Cycle efficiency
disp(etac*100,"Cycle efficiency in %:")
```

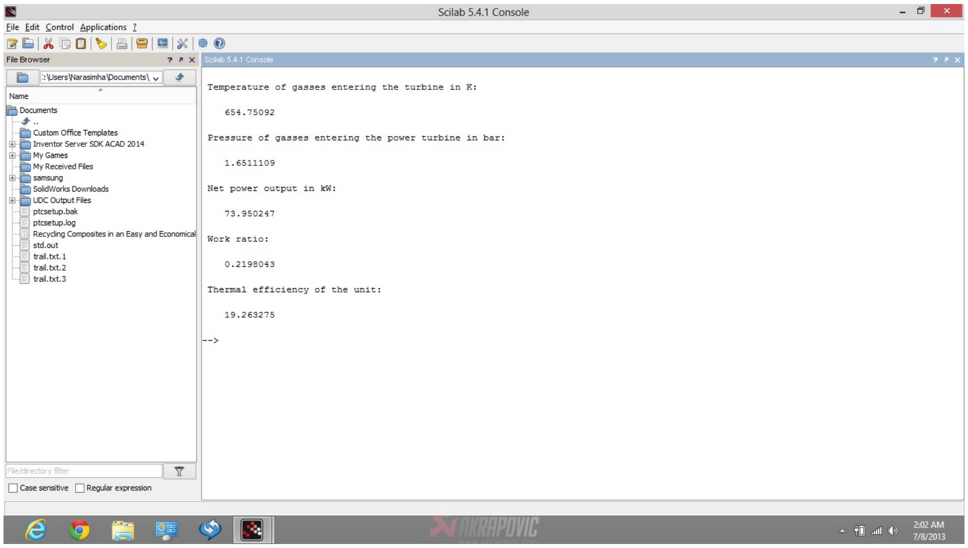
Scilab code Exa 21.9 `Multi stage gas turbine`

```
clc;funcprot(0);//EXAMPLE 21.9
// Initialisation of Variables
p1=1;.........//Pressure of air while entering the turbine in bar
t1=288;........//Temperature of air entering the turbine in K
p2=8;.........//Pressure of air after compression in bar
t3=1173;.............//Temperature before expansion in turbine in K
etac=0.76;....//Efficiency of compressor
etat=0.86;.....//Efficiency of turbine
ma=23;.........//Quantity of air circulation in kg/s
ga=1.4;........//Ratio of specific heats for compression
gag=1.34;........//Ratio of specific heats for expansion
cp=1.005;.............//Specific heat at constant pressure in kJ/kgK
cpg=1.128;.............//Specific heat at constant pressure in kJ/kgK
C=4200;.............//Calorific value of fuel in kJ/kg
etamech=0.95;........//Mechanical efficiency
etagen=0.96;.........//Generator efficiency
//Calculations
t2=t1*((p2/p1)^((ga-1)/ga));...............//Ideal temperature of air after compression in K
t21=((t2-t1)/etac)+t1;..............//Actual temperature of air after compression in K
p4=p1;p3=p2;.............//Isobaric processes
t4=t3*((p4/p3)^((gag-1)/gag));............//Ideal
```

```
temperature after expansion in turbine in K
t41=t3-(etat*(t3-t4));.................//Actual temperature after expansion in turbine in K
wc=cp*(t21-t1);................//Work dony by compressor
m1=(wc)/(cpg*(t3-t41));.............//Flow through compressor turbine in kg
m2=1-m1;..............//Flow through power turbine in kg
wpt=m2*(cpg*(t3-t41));.........//turbine work in kJ/kg
P=ma*wpt*etamech*etagen;.........//Power output in kW
qi=cpg*t3-cp*t21;.............//Input heat in kJ/kg of air
etath=wpt/qi;.............//Thermal efficiency of power turbine
disp(etath*100,"Thermal efficiency of power turbine in %:")
```

Scilab code Exa 21.10 `Multi stage gas turbine`

```
clc;funcprot(0);//EXAMPLE 21.10
// Initialisation of Variables
t1=288;........//Temperature of air entering the turbine in K
t3=883;..............//Temperature before expansion in turbine in K
etac=0.82;....//Efficiency of compressor
etathp=0.85;.....//Efficiency of high pressure turbine
etatlp=0.85;.....//Efficiency of low pressure turbine
```



```
Temperature of gasses entering the turbine in K:

   654.75092

Pressure of gasses entering the power turbine in bar:

   1.6511109

Net power output in kW:

   73.950247

Work ratio:

   0.2198043

Thermal efficiency of the unit:

   19.263275

-->
```

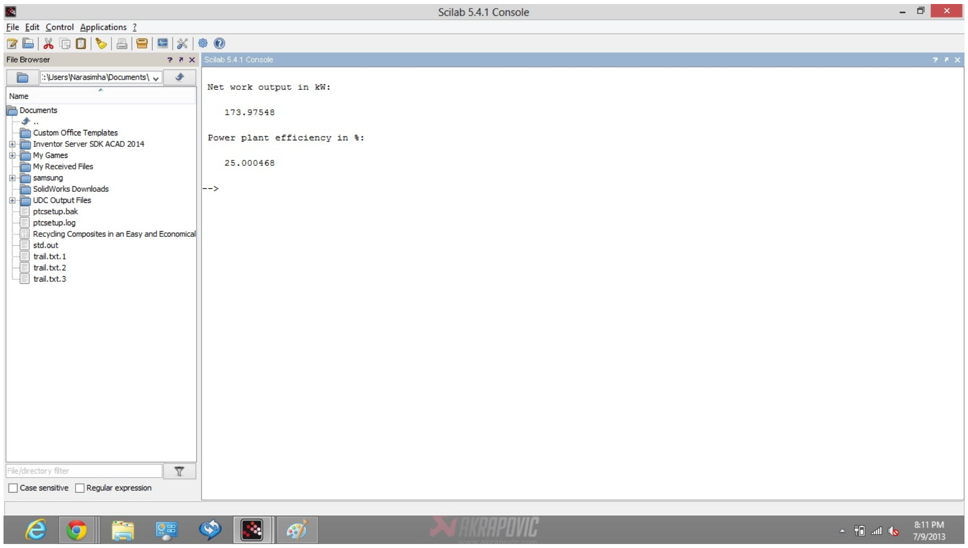
Figure 21.10: Multi stage gas turbine

```
rp=7;...........//Pressure ratio
p1=1.01;...............//Pressure of air before entering compressor
ga=1.4;........//Ratio of specific heats for compression
gag=1.333;........//Ratio of specific heats for expansion
cp=1.005;.............//Specific heat at constant pressure in kJ/kgK
cpg=1.15;.............//Specific heat at constant pressure in kJ/kgK in generator
//Calculations
p2=p1*rp;
t2=t1*((p2/p1)^((ga-1)/ga));...............//Ideal temperature of air after compression in K
t21=((t2-t1)/etac)+t1;..............//Actual temperature of air after compression in K
wc=cp*(t21-t1);............//Compressor work in kJ/kg
t41=t3-(wc/cpg);..........//Temperature of gasses
```

```
entering the turbine in K
disp(t41,"Temperature of gasses entering the turbine in K:")
t4=round(t3-((t3-t41)/etathp));.........//Ideal temperature of gases entering the turbine in K
p3=p2;.........//Isobaric processes
p4=p3/((t3/t4)^(1/((gag-1)/gag)));....//Pressure of gasses entering the power turbine in bar
disp(p4,"Pressure of gasses entering the power turbine in bar:")
t5=t41*((((t3/t4)^(1/((gag-1)/gag)))/(rp))^((gag-1)/gag));
t51=t41-(etatlp*(t41-t5));
wlp=cpg*(t41-t51);............//Net power output in kW
disp(wlp,"Net power output in kW:")
wr=wlp/(wlp+wc);............//Work ratio
disp(wr,"Work ratio:")
qs=cpg*(t3-t21);...........//Heat supplied in kJ/kg
etath=wlp/qs;..........//Thermal efficiency
disp(etath*100,"Thermal efficiency of the unit:")
```

Scilab code Exa 21.11 `Power developed and efficiency of power plant`

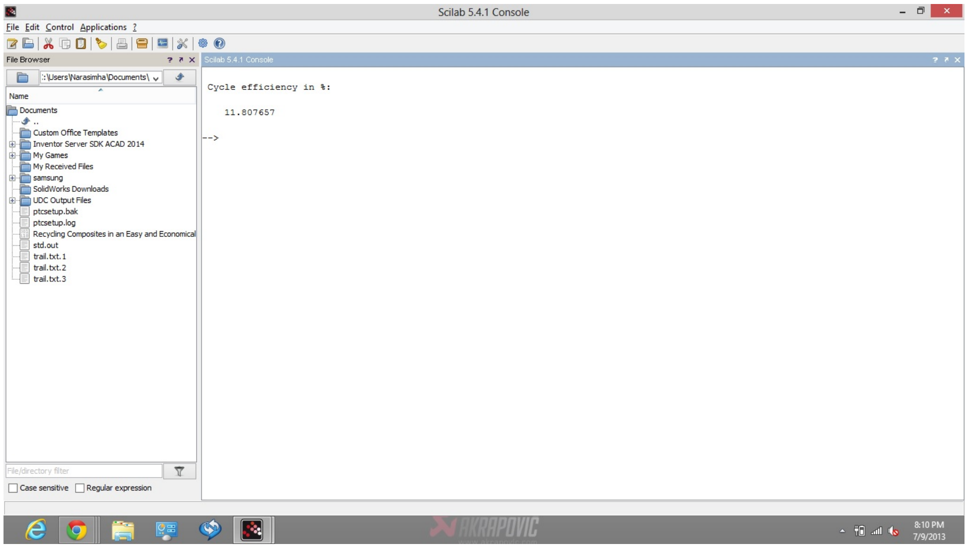
```
clc;funcprot(0);//EXAMPLE 21.11
// Initialisation of Variables
rp=5.6;................//Pressure ratio
t1=303;.............//Temperature of intake air in K
p1=1;............//Pressure of intake air in bar
t5=973;............//Highest temperature of the cycle in K
etac=0.85;..........//Effeciency of compressor
etat=0.9;..........//Efficiency of turbine
```



```
Net work output in kW:

   173.97548

Power plant efficiency in %:

   25.000468

-->
```

Figure 21.11: Power developed and efficiency of power plant

```
ma=1.2;..........//Rate of air flow in kg/s
cp=1.02;...........//Specific heat at constant volume in kJ/kgK
ga=1.41;.............//Ratio of specific heats
//Calculations
t2=t1*((sqrt(rp))^((ga-1)/ga));
t21=((t2-t1)/etac)+t1;
wc=2*ma*cp*(t21-t1);............//Work input for the two stage compressor in kJ/s
t6=t5/(rp^((ga-1)/ga));
t61=t5-etat*(t5-t6);
wt=ma*cp*(t5-t61);..............//Work output from turbine in kJ/s
wnet=wt-wc;....................//Net work available in kJ/s
disp(wnet,"Net work output in kW:")
qs=ma*cp*(t5-t21);................//Heat supplied in kJ/s
etath=wnet/qs;
disp(etath*100,"Power plant efficiency in %:")
```



```
Cycle efficiency in %:

   11.807657

-->
```

Figure 21.12: Efficiency of gas turbine cycle

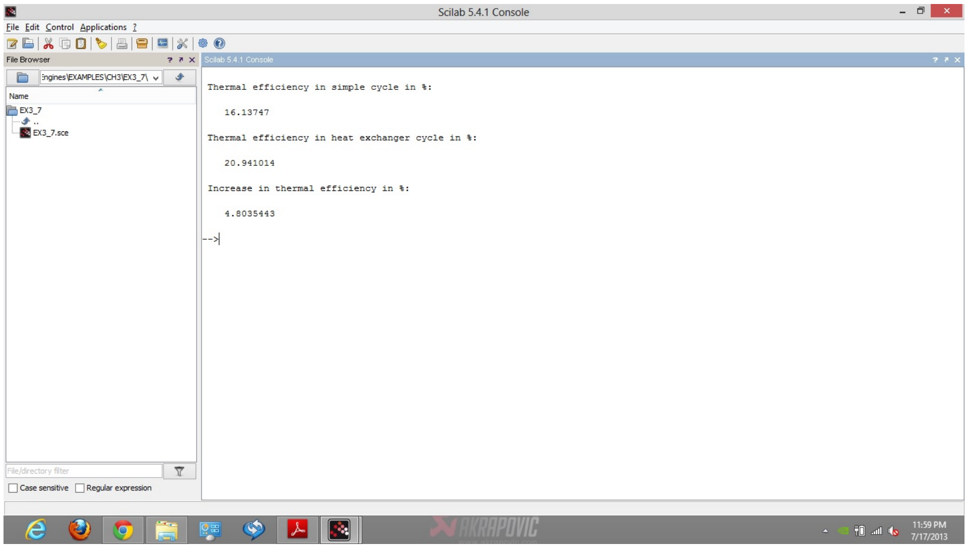
Scilab code Exa 21.13 `Efficiency of gas turbine cycle`

```
clc;funcprot(0);//EXAMPLE 21.13
// Initialisation of Variables
t1=288;.............//Temperature of intake air in K
rp=4;.............//Pressure ratio
etac=0.82;.........//Compressor efficiency
etahe=0.78;...........//Efficiency of heat exchanger
etat=0.7;...........//Turbine efficiency
t3=873;............//Temperature before expansion in
    turbine in K
R=0.287;............//Gas constant for air in kJ/kgK
ga=1.4;..........//Ratio of specific heats
//Calculations
t2=t1*((rp)^((ga-1)/ga));...............//Ideal
```

```
temperature of air after compression in K
t21=((t2-t1)/etac)+t1;...............//Actual temperature of air after compression in K
t4=t3/(rp^((ga-1)/ga));...........//Ideal temperature after expansion in turbine in K
t41=t3-etat*(t3-t4);...........//Actual temperature after expansion in turbine in K
cp=R*(ga/(ga-1));.............//Specific heat at constant pressure in kJ/kgK
wc=cp*(t21-t1);.............//Compressor work in kJ/kg
wt=cp*(t3-t41);..................//Turbine work in kJ/kg
wnet=wt-wc;...................//Net work available in kJ/s
t5=(etahe*(t41-t21))+t21;
qs=cp*(t3-t5);................//Heat supplied in kJ/kg
etac=wnet/qs;..............//Cycle efficiency
disp(etac*100,"Cycle efficiency in %:")
```

Scilab code Exa 21.14 `Heat exchanger in gas turbine`

```
clc;funcprot(0);//EXAMPLE 21.14
// Initialisation of Variables
etahe=0.72;.................//Efficiency of heat exchanger
p1=1.01;.........//Pressure of air while entering the turbine in bar
t1=293;........//Temperature of air entering the turbine in K
p2=4.04;.........//Pressure of air after compression in bar
```



```
Thermal efficiency in simple cycle in %:

   16.13747

Thermal efficiency in heat exchanger cycle in %:

   20.941014

Increase in thermal efficiency in %:

   4.8035443

-->
```

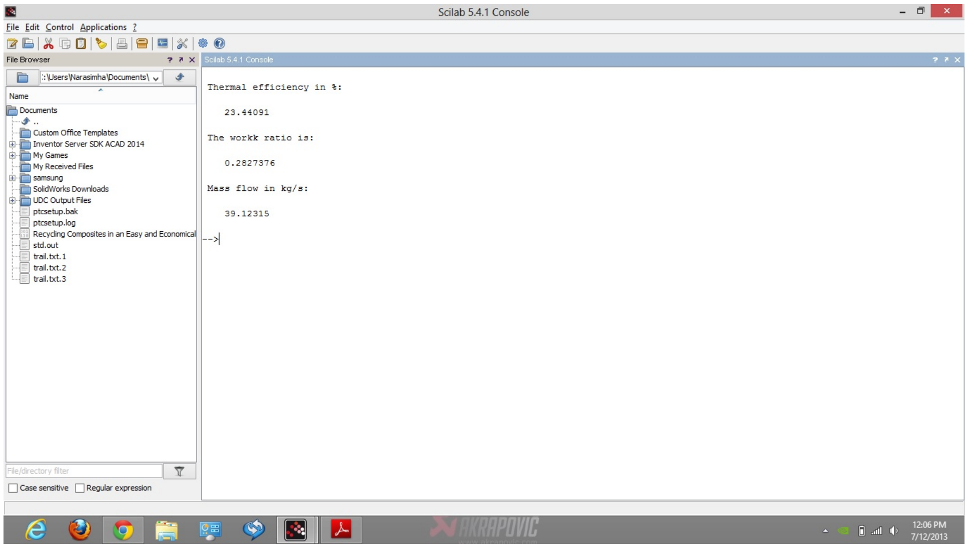
Figure 21.13: Heat exchanger in gas turbine

```
etat=0.85;..........//Turbine efficiency
pdhe=0.05;............//Pressure drop on each side of heat exchanger in bar
pdcc=0.14;...........//Pressure drop in combustion chamber in bar
etac=0.8;...........//Compressor efficiency
ga=1.4;.............//Ratio of specific heats
C=41800;.............//Calorific value of fuel in kJ/kg
cp=1.024;...........//Specific heat at constant pressure in kJ/kgK
afrc=90;..............//Air fuel ratio for simple cycle
//Calculations
t2=(t1*((p2/p1)^((ga-1)/ga)));...............//Ideal temperature of air after compression in K
t21=round(((t2-t1)/etac)+t1);...............//Actual temperature of air after compression in K
t3=((1*C)/(cp*(afrc+1)))+t21;............//Temperature before expansion in turbine in K
```

```
p4=p1;p3=p2-pdcc;t4=round(t3*((p4/p3)^((ga-1)/ga)));............//Ideal temperature after expansion in turbine in K
t41=t3-(etat*(t3-t4));.................//Actual temperature after expansion in turbine in K
etath=(t3-t41-t21+t1)/(t3-t21);...........//Thermal efficiency in simple cycle
disp(etath*100,"Thermal efficiency in simple cycle in %:")
p3he=p2-pdhe-pdcc;..........//Pressure before expansion in turbine in bar in heat exchanger cycle
p4he=p1+pdhe;................//Pressure after expansion in turbine in bar in heat exchanger cycle
t4he=t3*((p4he/p3he)^((ga-1)/ga));............//Ideal temperature after expansion in turbine in K in heat exchanger cycle
t41he=round(t3-(etat*(t3-t4he)));.................//Actual temperature after expansion in turbine in K in heat exchanger cycle
t5=(etahe*(t41he-t21))+t21;
etathhe=(t3-t41he-t21+t1)/(t3-t5);.............//Thermal efficiency for heat exchanger cycle
disp(etathhe*100,"Thermal efficiency in heat exchanger cycle in %:")
inc=etathhe-etath;
disp(inc*100,"Increase in thermal efficiency in %:")
```

Scilab code Exa 21.15 Multi stage gas turbine with intercooler and heat exchanger

```
clc;funcprot(0);//EXAMPLE 21.15
// Initialisation of Variables
```



```
Thermal efficiency in %:

   23.44091

The workk ratio is:

   0.2827376

Mass flow in kg/s:

   39.12315

-->
```

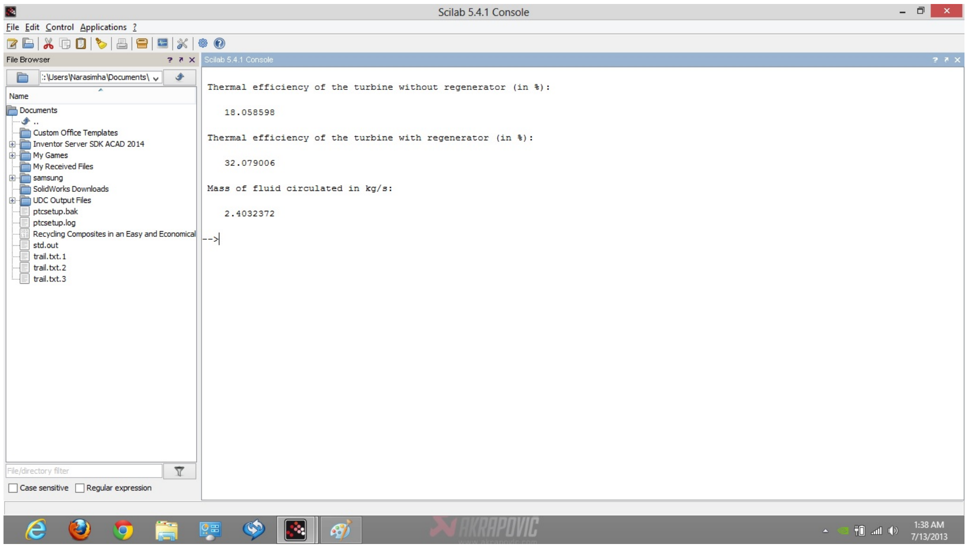
Figure 21.14: Multi stage gas turbine with intercooler and heat exchanger

```
t1=293;........//Temperature of air entering the turbine in K
rp=9;............//Overall pressure ratio
etac=0.8;........//Efficiency of compressor
t6=898;..........//Reheat remperature
t8=t6;etat=0.85;.......//Efficiency of turbine
etamech=0.95;..........//Mechanical efficiency
etahe=0.8;...............//Heat exchanger thermal efficiency
cpg=1.15;.............//Specific heat capacity for gases in heat exchanger in kJ/kgK
cpa=1.005;............//Specific heat capacity for normal air in kJ/kgK
gag=1.333;.............//Ratio of specific heats for gases in heat exchanger
ga=1.4;...............//Ratio of specific heats for normal gases
P=4500;................//Power output of turbine in kW
//Calculations
```

```
t2=t1*((sqrt(rp))^((ga-1)/ga));
t21=((t2-t1)/etac)+t1;
wc=cpa*(t21-t1);............//Work input per compressor stage
whp=(2*wc)/etamech;.........//Work output of HP turbine in kJ/kg
t71=t6-(whp/cpg);t7=round(t6-((t6-t71)/etat));
k=(rp/((t6/t7)^((gag)/(gag-1))))^((gag-1)/gag);
k1=((round((k/2)*100))*2)/100;..............//Rounding off upto 2 decimals
t9=t8/(k1);
t91=t8-((t8-t9)*etat);
wout=cpg*(t8-t91)*etamech;..............//Net work output in kJ/kg
t5=etahe*(t91-t21)+t21;
qs=cpg*(t6-t5)+cpg*(t8-t71);..............//Heat supplied
etath=wout/qs;.................//Thermal efficiency
disp(etath*100,"Thermal efficiency in %:")
wgross=whp+(wout/etamech);.........//Gross work output in kJ/kg
wr=wout/wgross;................//Work ratio
disp(wr,"The workk ratio is:")
m1=P/wout;...............//Mass flow in kg/s
disp(m1,"Mass flow in kg/s:")
```

Scilab code Exa 21.16 Multi stage gas turbine

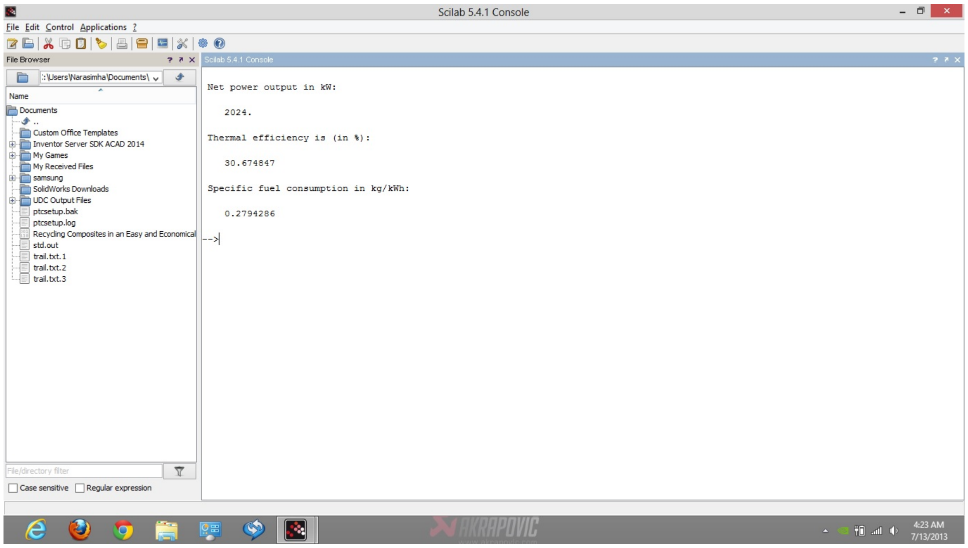
```
clc;funcprot(0);//EXAMPLE 21.16
// Initialisation of Variables
//Conditions of the closed gas turbine
t1=293;.............//Temperature at the inlet of first stage compressor in K
```



```
Thermal efficiency of the turbine without regenerator (in %):

   18.058598

Thermal efficiency of the turbine with regenerator (in %):

   32.079006

Mass of fluid circulated in kg/s:

   2.4032372

-->
```

Figure 21.15: Multi stage gas turbine

```
t5=1023;..................//Maximum temperature in K
p1=1.5;.................//Inlet pressure in bar
p2=6;..................//Pressure in bar
etac=0.82;..............//Compressor efficiency
etat=0.82;..............//Turbine efficiency
etare=0.70;.................//Regenerator efficiency
P=350;...................//Power developed by the plant in kW
ga=1.4;.................//Ratio of specific heats
cp=1.005;..............//Specific heat at constant pressure in kJ/kgK
t3=t1;
//Calculations
t2=t1*((sqrt(p2/p1))^((ga-1)/ga));
t21=((t2-t1)/etac)+t1;t41=t21;
t6=t5/((p2/sqrt(p1*p2))^((ga-1)/ga));
t61=t5-(etat*(t5-t6));t81=t61;
t7=t5;
ta=(etare*(t81-t41))+t41;.......//Temperature of air coming out of regenerator in K
```



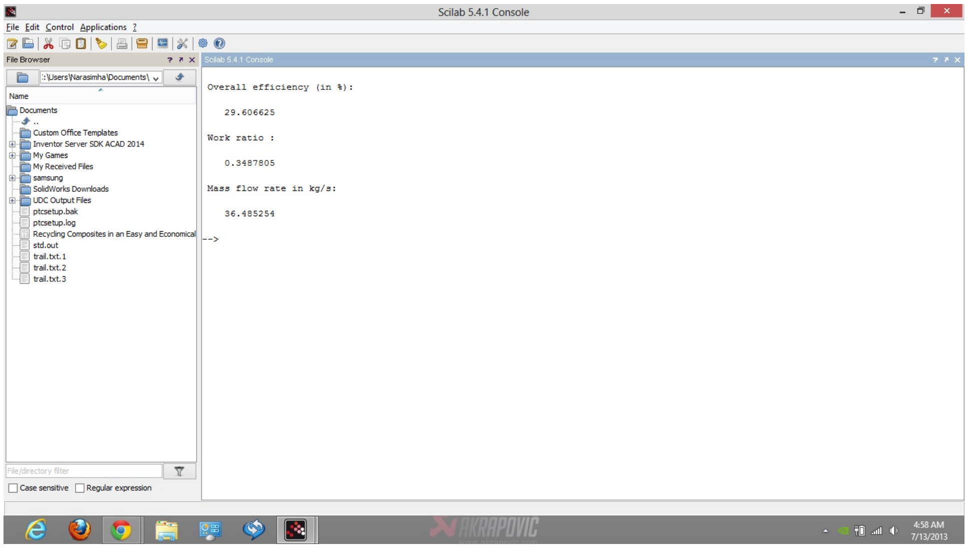
```
Net power output in kW:

   2024.

Thermal efficiency is (in %):

   30.674847

Specific fuel consumption in kg/kWh:

   0.2794286

-->
```

Figure 21.16: gas turbine power plant

```
wnet=2*cp*(t5-t61-t21+t1);........//Net work done in kJ/kg of air
qs=cp*(t5-t41+t7-t61);...........//Heat supplied without regenerator in kJ/kg of air
qsr=cp*(t5-ta+t7-t61);............//Heat supplied with regenerator in kJ/kg of air
etath=wnet/qs;.............//Thermal efficiency (without regenerator)
etathr=wnet/qsr;.........//Thermal efficiency (with regenerator)
mfl=P/wnet;..........//mass of fluid circulated in kg/s
disp(etath*100,"Thermal efficiency of the turbine without regenerator (in %):")
disp(etathr*100,"Thermal efficiency of the turbine with regenerator (in %):")
disp(mfl,"Mass of fluid circulated in kg/s:")
```

Scilab code Exa 21.17 `gas turbine power plant`

```
clc;funcprot(0);//EXAMPLE 21.17
// Initialisation of Variables
t1=293;............//Temperature of inlet air into
   low pressure compressor in K
p1=1.05;.........//Pressure of inlet air into low
   pressure compressor in bar
t3=300;...........//Temperature of air after passing
    it through intercooler in K
t6=1023;..........//temperature of air in combustion
    chamber in K
rp=2;...........//Pressure ratio of each compressor
etac=0.82;........//Compressor efficiency
etat=0.82;..........//Turbine efficiency
etaht=0.72;............//Heat exchanger efficiency
ma=16;...........//Air flow in kg/s
ga=1.4;...........//Ratio of specific heats for air
gag=1.33;..........//Ratio of specific heats for
   gases
cpa=1.0;...........//Specific heat at constant
   pressure in kJ/kgK for air
cpg=1.15;.........//Specific heat at constant
   pressure in kJ/kgK for gases
C=42000;.........//Calorific value of fuel in kJ/kg
//Calculations
t2=round(t1*(rp^((ga-1)/ga)));
t21=round(((t2-t1)/etac)+t1);
t4=t3*(rp^((ga-1)/ga));
t41=round(((t4-t3)/etac)+t3);
t71=round(((cpg*t6)-cpa*(t21-t1+t41-t3))/cpg);
t7=t6-((t6-t71)/etat);
p6=p1*rp*rp;
p7=p6/((t6/t7)^((gag)/(gag-1)));
```



```
Overall efficiency (in %):

   29.606625

Work ratio :

   0.3487805

Mass flow rate in kg/s:

   36.485254

-->
```

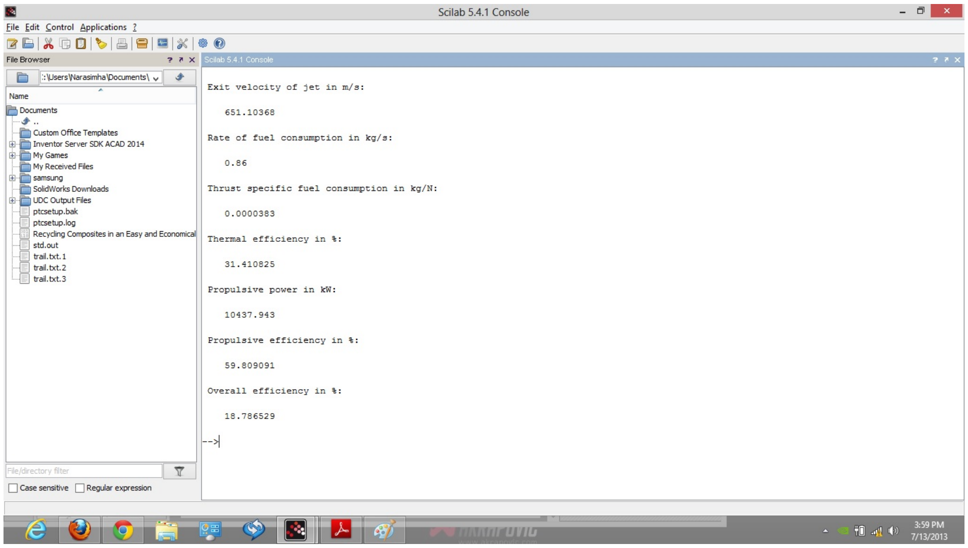
Figure 21.17: Multi stage gas turbine

```
t8=round(t71/((p7/p1)^((gag-1)/gag)));
t81=round(t71-(etat*(t71-t8)));
P=cpg*(t71-t81);...........//Net power output in kJ/kg
disp(P*ma,"Net power output in kW: ")
t5=etaht*(t81-t41)+t41;
qs=ma*cpg*(t6-t5);......//Heat supplied in combustion chamber in kJ/s
etath=P*ma/qs;.........//Thermal efficiency
disp(etath*100,"Thermal efficiency is (in %):")
afr=C/(cpg*(t6-t5));......//Air fuel ratio
mf=ma*3600/afr;..............//Fuel supplied per hour in kg
sfc=mf/(P*ma);...........//Specific fuel consumption in kg/kWh
disp(sfc,"Specific fuel consumption in kg/kWh:")
```

Scilab code Exa 21.18 Multi stage gas turbine

```
clc;funcprot(0);//EXAMPLE 21.18
// Initialisation of Variables
t1=293;............//Temperature of inlet air into low pressure compressor in K
p1=1.1;.........//Pressure of inlet air into low pressure compressor in bar
p2=3.3;..........//Pressure of air in the low pressure compressor in bar
t3=300;.............//Intercooled temperature in K
pli=0.15;..........//Loss in pressure due to intercooling in bar
p3=p2-pli;...........//Pressure after intercooling in bar
p4=9.45;............//Pressure of air after high pressure compressor in bar
p6=p4;t6=973;.........//Temperature of gases supplied to high pressure turbine in K
t8=943;.........//Reheat temperature in K
plr=0.12;...........//Loss of pressure after reheating in bar
p7=3.62;............//Pressure of gases at the end of expansion in high pressure turbine in bar
p8=p7-plr;...........//Pressure of outlet gases in bar
ga=1.4;...........//Ratio of specific heats for air
gag=1.33;..........//Ratio of specific heats for gases
cpa=1.005;...........//Specific heat at constant pressure in kJ/kgK for air
cpg=1.15;.........//Specific heat at constant pressure in kJ/kgK for gases
etac=0.82;........//Compressor efficiency
```

```
etat=0.85;..........//Turbine efficiency
etaht=0.65;.........//Efficiency of heat exchanger
P=6000;...................//Power generated in kW
p9=p1;
//Calculations
t2=round(t1*((p2/p1)^((ga-1)/ga)));
t21=round(((t2-t1)/etac)+t1);
t4=round(t3*((p4/p3)^((ga-1)/ga)));
t41=round(((t4-t3)/etac)+t3);
t7=round(t6/((p6/p7)^((gag-1)/gag)));
t71=round(t6-(etat*(t6-t7)));
t9=round(t8/((p8/p9)^((gag-1)/gag)));
t91=round(t8-(etat*(t8-t9)));
t5=round(etaht*(t91-t41)+t41);
wthp=cpg*(t6-t71);.......//Work done by high pressure turbine in kJ/kg of gas
wtlp=cpg*(t8-t9);.......//Work done by low pressure turbine in kJ/kg of gas
wchp=cpg*(t21-t1);.......//Work done by high pressure compressor in kJ/kg of gas
wclp=cpg*(t41-t3);.......//Work done by low pressure compressor in kJ/kg of gas
qs=cpg*(t6-t5+t8-t71);.........//Heat supplied in kJ/kg of gas
etath=(wthp+wtlp-wchp-wclp)/qs;..//Overall efficiency
disp(etath*100,"Overall efficiency (in %):")
wr=(wthp+wtlp-wchp-wclp)/(wthp+wtlp);......//Work ratio
disp(wr,"Work ratio :")
m=P/(wthp+wtlp-wchp-wclp);.....//Mass flow rate
disp(m,"Mass flow rate in kg/s:")
```

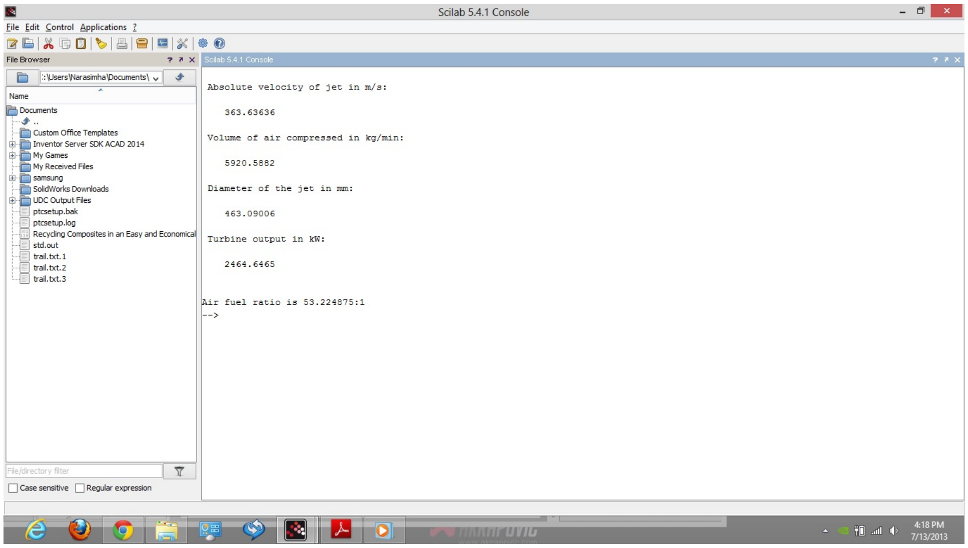


```
Exit velocity of jet in m/s:

   651.10368

Rate of fuel consumption in kg/s:

   0.86

Thrust specific fuel consumption in kg/N:

   0.0000383

Thermal efficiency in %:

   31.410825

Propulsive power in kW:

   10437.943

Propulsive efficiency in %:

   59.809091

Overall efficiency in %:

   18.786529

-->
```

Figure 21.18: Turbo jet engine

Scilab code Exa 21.19 `Turbo jet engine`

```
clc;funcprot(0);//EXAMPLE 21.19
// Initialisation of Variables
ma=60.2;...........//Rate of air consumption in kg/s
delh=230;.......//Enthalpy change for nozzle in kJ/kg
z=0.96;..........//Velocity co efficient
afr=70;............//Air fuel ratio
etaco=0.92;...............//Combustion eficiency
CV=42000;..............//Calorific value of fuel in kJ/kg
v=1000;............//Velocity of aircraft in km/h
Ca=v*(5/18);............//Aircraft velocity in m/s
//Calculations
Cj=z*sqrt(2*delh*v);..........//Exit velocity of jet
disp(Cj,"Exit velocity of jet in m/s:")
mf=ma/afr;.........//Rate of fuel consumption
disp(mf,"Rate of fuel consumption in kg/s:")
```



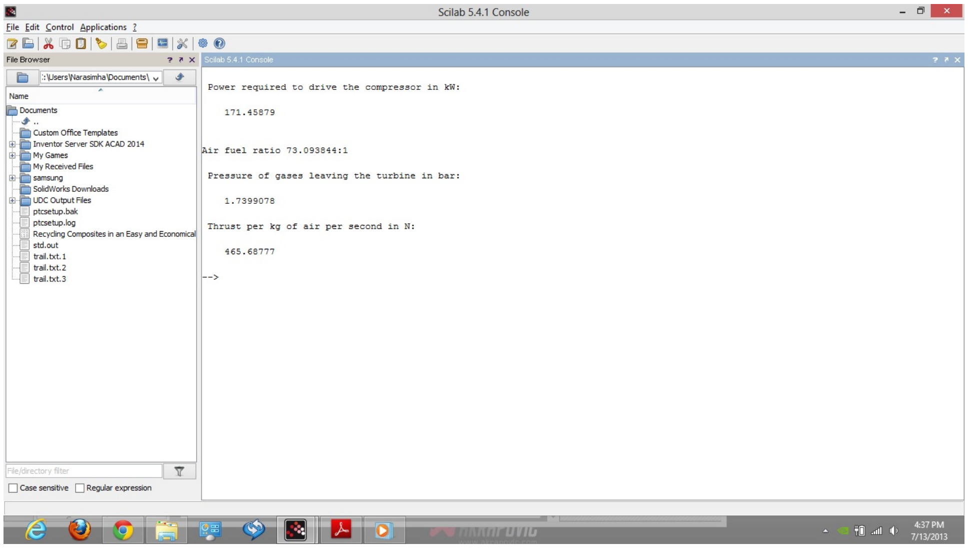
```
Absolute velocity of jet in m/s:

   363.63636

Volume of air compressed in kg/min:

   5920.5882

Diameter of the jet in mm:

   463.09006

Turbine output in kW:

   2464.6465


Air fuel ratio is 53.224875:1
-->
```

Figure 21.19: Turbo jet engine

```
tp=ma*(Cj-Ca);......//Thrust produced in N
tsfc=mf/tp;.........//Thrust specific fuel consumption in kg/N
disp(tsfc,”Thrust specific fuel consumption in kg/N:”)
etath=((Cj^2)-(Ca^2))/(2*(1/afr)*CV*etaco*1000);.........//Thermal efficiency
disp(etath*100,”Thermal efficiency in %:”)
pp=(ma/1000)*((Cj^2)-(Ca^2))/2;................//Propulsive power in kW
disp(pp,”Propulsive power in kW:”)
etapp=(2*Ca)/(Cj+Ca);......................//Propulsive efficiency
disp(etapp*100,”Propulsive efficiency in %:”)
etao=((Cj-Ca)*Ca)/((1/afr)*CV*etaco*1000);............//Overall efficiency
disp(etao*100,”Overall efficiency in %:”)
```

Scilab code Exa 21.20 `Turbo jet engine`

```
clc;funcprot(0);//EXAMPLE 21.20
// Initialisation of Variables
v=800;.............//Speed of the turbojet in km/h
etapp=0.55;......//Propulsive efficiency
etao=0.17;.........//Overall efficiency
al=9500;...............//Altitude in m
rhoa=0.17;............//Density of air at the given altitude in kg/m^3
dr=6100;...........//Drag on the plane in N
CV=46000;.........//Calorific value of fuel in kJ/kg
//Calculations
Ca=v*(1000/3600);.........//Velocity of jet in m/s
Cj=((2*Ca)/etapp)-Ca;........//Velocity of gases at nozzle exit relative to the aircraft in m/s
disp(Cj-Ca,"Absolute velocity of jet in m/s:")
ma=dr/(Cj-Ca);............//Rate of air flow in kg/s
Va=(ma/rhoa)*60;..........//Volume of air compresssed per min in kg
disp(Va,"Volume of air compressed in kg/min:")
d=sqrt((Va*4)/(60*%pi*Cj));..........//Diameter of the jet in m
disp(d*1000,"Diameter of the jet in mm:")
tp=dr*(Ca/1000);...........//Thrust power in kW
wt=tp/etapp;................//Turbine output in kW
disp(wt,"Turbine output in kW:")
mf=wt/(etao*CV);...........//Rate of fuel consumption in kg/s
afr=ma/mf;..........//Air fuel ratio
printf("\n\nAir fuel ratio is %f:1",afr)
```



```
 Power required to drive the compressor in kW:

   171.45879


Air fuel ratio 73.093844:1

 Pressure of gases leaving the turbine in bar:

   1.7399078

 Thrust per kg of air per second in N:

   465.68777

-->
```

Figure 21.20: Jet propulsion

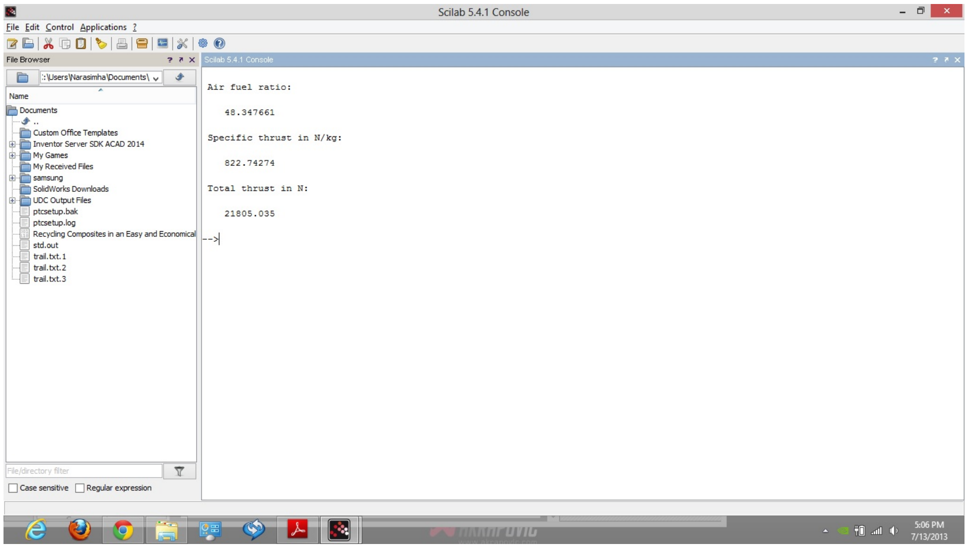
Scilab code Exa 21.21 `Jet propulsion`

```
clc;funcprot(0);//EXAMPLE 21.21
// Initialisation of Variables
t1=288;..........//Temperature of the inlet air into compressor in K
p1=1.01;......//Pressure of the inlet air into compressor in bar
t3=1023;.........//Maximum temperature in K
p2=4.04;.........//Pressure of air at the end of compression in bar
etac=0.82;.......//compressor efficiency
etat=0.78;......//Turbine efficiency
etan=0.88;........//Nozzle efficiency
R=0.287;.........//Gas constant for air in kJ/kgK
ga=1.4;............//Ratio of specific heats
C=42000;..........//Calorific value of fuel in kJ/kg
```

```
//Calculations
t2=t1*((p2/p1)^((ga-1)/ga));........//Ideal temperature at the end of compression in K
t21=((t2-t1)/etac)+t1;..........//Actual temperature at the end of compression in K
cp=R*(ga/(ga-1));.............//Specific heat at constant pressure in kJ/kgK
Pc=cp*(t21-t1);.............//Power required to drive the compressor in kW
disp(Pc,"Power required to drive the compressor in kW:")
afr=((C)/(cp*(t3-t21)))-1;....//Air fuel ratio
printf("\n\nAir fuel ratio %f:1\n",afr)
t41=t1+t3-t21;......//Actual temperatur of gases leaving the turbine in K
t4=t3-((t3-t41)/etat);......//Ideal temperature of gases leaving the turbine in K
p3=p2;p4=p3*((t4/t3)^(ga/(ga-1)));.......//Pressure of gases leaving the turbine in bar
disp(p4,"Pressure of gases leaving the turbine in bar:")
p5=p1;t5=t41/((p4/p5)^((ga-1)/ga));
t51=t41-(etan*(t41-t5));
Cj=sqrt(2*cp*(t41-t51)*1000);.............//Jet velocity in m/s
th=Cj*1;..................//Thrust per kg per second in N
disp(th,"Thrust per kg of air per second in N:")
```

Scilab code Exa 21.22 `Turbo jet with diffuser and nozzle`

```
clc;funcprot(0);//EXAMPLE 21.22
// Initialisation of Variables
```



```
Air fuel ratio:

    48.347661

Specific thrust in N/kg:

    822.74274

Total thrust in N:

    21805.035

-->
```

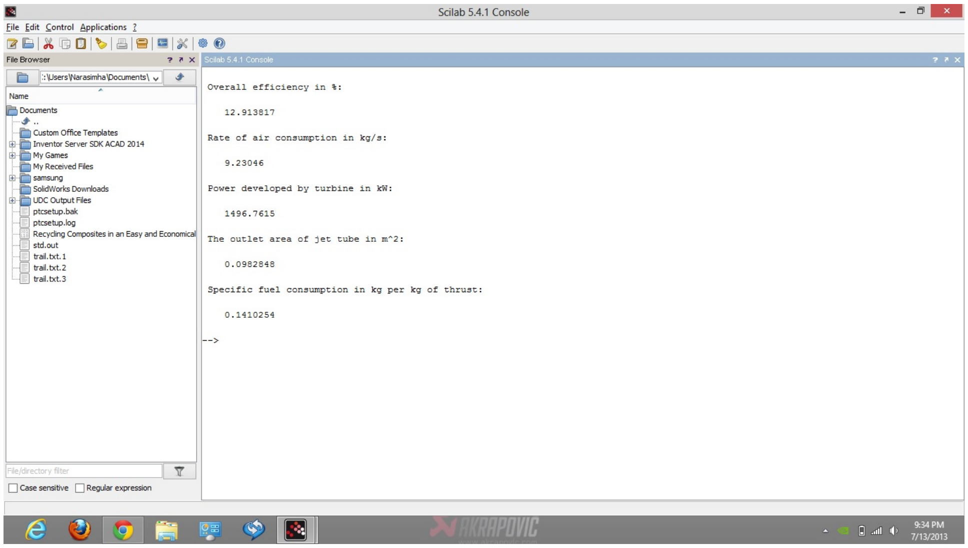
Figure 21.21: Turbo jet with diffuser and nozzle

```
Ca=216;.................//Speed of aircraft in m/s
t1=265.8;...............//Intake air temperature in
   K
p1=0.78;................//Intake air pressure in bar
rp=5.8;.................//Pressure ratio in
   compressor
t4=1383;................//Temperature of gases
   entering the gas turbine in K
pd=0.168;...............//Pressure drop in
   combustion chamber in bar
etad=0.9;..............//Diffuser efficiency
etan=0.9;.............//Nozzle efficiency
etac=0.9;.............//Compressor efficiency
etat=0.8;.............//Turbine efficiency
C=44150;..............//Calorific value of fuel in kJ/
   kg
cp=1.005;.............//Specific heat at constant
   pressure in kJ/kgK
ga=1.4;...............//Ratio of specific heats
cin=0.12;...............//Inlet cross sectio of the
```

```
diffuser in m^3
R=0.287;............//Gas constant in kJ/kgK
//Calculations
t2=t1+((Ca*Ca)/(2*cp*1000));......//For ideal diffuser
t21=t1+((Ca*Ca)/(2*cp*etad*1000));......//For actual diffuser
p2=p1*((t2/t1)^(ga/(ga-1)));
t3=t21*(rp^((ga-1)/ga));t31=t21+((t3-t21)/etac);
afr=(C-(cp*t4))/(cp*(t4-t31));............//Air fuel ratio
disp(afr,"Air fuel ratio:")
p3=p2*rp;p4=p3-pd;...............//Pressure of gases entering the turbine in bar
t51=t4-(t31-t21);t5=round(t4-((t4-t51)/etat));
p5=p4/((t4/t5)^(ga/(ga-1)));p6=p1;
t6=t51/((p5/p6)^((ga-1)/ga));t61=t51-(etac*(t51-t6));
Cj=44.72*sqrt(cp*(t51-t61));........//Velocity at the exit of the nozzle in m/s
st=(1+(1/afr))*Cj;............//Specific thrust in N/kg
disp(st,"Specific thrust in N/kg:")
v1=Ca*cin;...........//Volume of flowing air in m^3/s
ma=(p1*v1*10^5)/(R*t1*1000);.........//Mass flow of air
tt=ma*st;..............//Total thrust in N
disp(tt,"Total thrust in N:")
```

Scilab code Exa 21.23 Jet engine

```
clc;funcprot(0);//EXAMPLE 21.23
```



```
Overall efficiency in %:

   12.913817

Rate of air consumption in kg/s:

   9.23046

Power developed by turbine in kW:

   1496.7615

The outlet area of jet tube in m^2:

   0.0982848

Specific fuel consumption in kg per kg of thrust:

   0.1410254

-->
```

Figure 21.22: Jet engine

```
// Initialisation of Variables
al=9000;..........//Altitude in m
Ca=215;...........//Speed of aircraft in m/s
TP=750;.............//Thrust power developed in kW
p1=0.32;...........//Inlet pressure of air in bar
t1=231;.............//Inlet temperature of air in K
t3=963;.............//Temperature of gases leaving the combustion chamber in K
rpc=5.2;............//Pressure ratio
C=42500;..........//Calorific value of fuel in kJ/kg
C41=195;.........//Velocity in ducts
etac=0.86;..........//Compressor efficiency
ga=1.4;............//Ratio of specific heats for air
gag=1.33;............//Ratio of specific heats for gases
etat=0.86;..........//Turbine efficiency
etajt=0.9;..........//Jet tube efficiency
cp=1.005;............//Specific heat at constant pressure in kJ/kgK for air
cpg=1.087;............//Specific heat at constant
```

```
pressure in kJ/kgK for gases
R=0.29;..................//Gas constant for exhaust gases in kJ/kgK
//Calculations
t2=t1*(rpc^((ga-1)/ga));
t21=t1+((t2-t1)/etac);
mf=(cpg*(t3-t21))/(C-(cpg*(t3-t21)));
afr=1/mf;..........//Air fuel ratio
t41=round(t3-((cp*(t21-t1))/(cpg*(1+mf))));
t4=t3-((t3-t41)/etat);p4=rpc;
rpt=(t3/t4)^(gag/(gag-1));.............//Expansion pressure ratio in turbine
rpj=p4/rpt;....................//Expansion pressure ratio in jet tube
t5=t41/(rpj^((gag-1)/gag));
Cj=sqrt(etajt*2*((cpg*1000*(t41-t5))+((C41*C41)/2)));
etao=((((1+mf)*Cj)-Ca)*Ca)/(1000*mf*C);......//Overall efficiency
disp(etao*100,"Overall efficiency in %:")
ma=(TP*1000)/((((1+mf)*Cj)-Ca)*Ca);........//Rate of air consumption in kg/s
disp(ma,"Rate of air consumption in kg/s:")
P=ma*(1+mf)*cpg*(t3-t41);..............//Power developed by the turbine in kW
disp(P,"Power developed by turbine in kW:")
t51=t41-(((Cj^2)-(C41^2))/(2*1000*cpg));
rhoe=(p1*10^5)/(R*1000*t51);..........//Density of exhaust gases
Ajt=(ma*(1+mf))/(Cj*rhoe);.......//Discharge of jet area in m^2
disp(Ajt,"The outlet area of jet tube in m^2:")
sfc=(mf*ma*3600)/(1000*(TP/Ca));..........//Specific fuel consumption in kg/thrust-hour
disp(sfc,"Specific fuel consumption in kg per kg of thrust:")
```