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SCIENCE & TECHNOLEDGE

Effect of Burn Duration and Injection Timing on Diesel Engine Performance

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Abstract:
Setting ignition timing, so that the spark is initiated before top-dead-center, is necessary because of the time delay before the explosion reaches maximum force. Purpose is to ensure the piston has begun its downward (power) stroke as the expanding gases reaches its maximum pressure, allowing development of peak pressure and extraction of maximum amount of work from the expanding gases. An engine model obtained from literature was used in this study. The original concept was retained and extensive analyses was carried out by varying in turn the ignition timing before top dead center (bTDC) and after top dead center (aTDC) to values (-40^0 to 30^0)and burn duration of charges (-40^0 to 50^0) while keeping other parameters constant and measuring the engine performance, in terms of Indicated Mean Effective Pressure (IMEP), Thermal Efficiency (eta), and Emission rate. By the present study it is concluded that retarded ignition timing was beneficial until 40^0bTDC beyond which it is unfavorable. It is also observed that sufficiently retarded ignition timing goes well with extended combustion duration of 50^0.

***Keywords**: Ignition timing, Combustion duration, Top-Dead-Center, Engine Performance*

1. Introduction

Ignition timing and duration is vital to optimal performance of an internal combustion engine. If ignition is set too far advanced bTDC, the ignition and expansion of the fuel in the cylinder will occur soon and tend to force the piston down while it is still travelling up. This causes engine ping. If the ignition spark is set too far retarded, after TDC, the piston would have already passed TDC and started on its way down when the fuel is ignited. This will cause the piston to be forced down for only a portion of its travel which will result in poor engine performance and lack of power.

In Internal Combustion Engine(ICE), energy is released by burning or oxidizing fuel inside the engine. The fuel air mixture before combustion and the burned products after combustion are the actual working fluids. The Spark-Ignition (Otto engines, gasoline and petrol engine) and the compression ignition (diesel engine) are the common examples of ICEs, (Heywood, 1988).It is well known that injection strategies including the injection timing and pressure play the most important role in determining engine performance, especially in pollutant emissions.

It is very difficult to decide when the End of Combustion (EOC) will be inside a working engine cylinder. Observations from an optical engine showed that even once combustion has completed the flame will remain luminous. However, EOC is very important in engine thermodynamic calculations. Hence, it is necessary to find out when the combustion reaches its end with the aim of attaining higher power output with correct ignition timing. Late ignition timing extends the combustion process longer into expansion process resulting in higher exhaust temperature and hotter exhaust values.

Advancing (late) injection timing is said to create effect of increased thermal efficiency but increases NOx and smoke formation. However extreme advanced injection timing allows extended ignition delay period for even mixing, increases thermal efficiency, reduces NOx and smoke formation. (Sanghoon et al 2007).

It was found byHow (2013)that retarded injection timing caused a reduction in Brake Power, Brake Thermal Efficiency, and NOx emissions with an increase in Bsfc, Brake specific energy consumption, and smoke emissions. This result showed that injection timing has significant effects on variation in peak combustion pressure and heat release rate. Overall result showed that altering the ignition timing resulted in a trade-off between engine performance and emissions. It is already known that diesel engine requires self-ignition of the fuel as it is injected at some degrees before top dead center (BTDC) into the hot compressed cylinder gas. Murari (2009)varied injection timing from 15^0bTDC to TDC in a DI Diesel engine and found that when main combustion takes place very close to TDC there was minimum odorous emissions. Cylinder pressures and temperatures were also found to be gradually decreasing as injection timings are retarded. Pandian et al (2009), conducted experiment on twin cylinder CIDI engine using Bio-diesel blend as fuel. To reduce NOx emission, the fuel injection timing of fuel was altered by retarding to 18^0 CA BTDC and advancing to 30^0 CA BTDC from 24^0 CA BTDC. It was observed that on retarding the injection timing, NOx and brake thermal efficiency reduced, BSFC, CO, HC increased while advancing the injection timing lead to increase in NOx emission and decrease in brake thermal efficiency and reduced BSFC, CO and HC. Nwafor et al (2000) observed that longer delays between injection and ignition leads to unacceptable rates of pressure rise with the result of diesel knock because too much fuel is ready to take part in premixed combustion. Longer delay periods and slower burning rate especially at low load operating conditions hence resulting in late combustion in the expansion stroke. Advanced injection timing was proffered as a solution expected to compensate this effect. With varieties of efforts already made on investigating ignition timing and duration, this study is intended to investigate the impact of a wide range of combination of ignition timing and duration on engine performance. It is intended to determine the most suited combination of ignition time and burn duration angle for a diesel engine

2. Methodology

By making use of an engine model originally written by Ferguson using MATLAB (David, 2002), analysis was carried out by varying in turn the ignition timing before top dead center (bTDC) and after top dead center (aTDC) to values (-40^0 to 30^0)and burn duration of charges (-40^0 to 50^0) while keeping other parameters including cylinder bore, stroke, compression ratio, residual fraction, engine speed, engine surface temperature, initial engine temperature and pressure constant. Design of Experimental (DOE), one tool in the lean engineering and manufacturing toolbox, is a very useful statistical tool used to predict best combination from a number of large factors which has interdependencies between them (factors). By varying the values of all factors simultaneously, a statistically validated estimate of the results for every possible combination of the factors was obtained. Table 1 shows the possible combination of ignition timing and burn duration. The logic is to assign the negative values to bTDC and the positive values to aTDC. The input (predicted possible combination) was analysed using MATLAB program. Graphical plots of pressure, temperature, work, heat transfer, heat leakage, and heatflux for varying crank angle were obtained. These were used to obtain the Indicated Mean Effective Pressure IMEP, Thermal Efficiency and Emission Rate.

ENGINE PARAMETER	MEASURE (ORIGINAL)	VARIED
BORE(m)	0.1	NO
STROKE(m)	0.08	NO
HALF STROKE TO ROD RATIO (s/21)	0.25	NO
COMPRESSION RATIO	10	19
EQIVALENCE RATIO	0.8	NO
START OF BURNING	-35	YES
BURN DURATION ANGLE	60	YES
ENGINE SPEED	1500	NO
ENGINE SURFACE TEMPERATURE	420	NO

Table 1: Engine Parameters

3. Results and Discussion

Fig 1 contains plots of pressure, temperature, work, heat transfer, heat leakage and heat flux throughout the engine cycle at -5^0bTDC and 5^0 burn duration angle. It was observed that there was a reduction in cylinder pressure from peak value of around 6MPa to around 4MPa.The pressure graph exhibited a truncation implying a shorter compression and with a short combustion duration in the cylinder. At -5^0bTDC and -58^0 burn duration angle (Figure 3), the pressure graph was similar to what was observed at -5^0bTDC and 5^0 burn duration angle. A longer combustion line was observed with short compression line at -5^0bTDC and -68.64^0 burn duration angle(Figure 4). At -54.5^0bTDC and 5^0 burn duration angle(Fig.5) a longer compression was observed but no combustion line was visible owing to far retarded ignition timing and short burn duration.At 45.5^0bTDC and 5^0 burn duration angle(Figure 7), cylinder pressure was adversely affected due to retarded ignition timing and there was no combustion line visible owing to retarded ignition timing and/or short burn duration. At 30^0bTDC and $\pm 50^0$ burn duration angle(Figs. 8&9), compression was short with a longer combustion line which may be attributed to the too long burn duration. Appreciable heat transfer was only noticed at the burned zone when the ignition timing and burn duration angle are varied. Temperature, work, heat and heat leakage plots for varying ignition timings and durations presented in Figs. 3-10. showed that with retarded ignition timing a longer compression is experienced as evident by the lines representing compressed unburned gases on temperature graphs of figs 2, 5 and 6 at -40^0bTDC and 50^0 burn duration angle, -54.5^0bTDC and 5^0 burn duration angle and at -40^0bTDC and -40^0 burn duration angle respectively. With advanced ignition timing, shorter compression is experienced as evident on temperature graphs of figs. 2, 4 and 8 at -5^0bTDC and 5^0 burn duration angle, -5^0bTDC and -58^0 burn duration angle and at 45.5^0aTDC and 5^0 burn duration angle respectively. Work delivered by the crankshaft is less than combustion work due to mechanical losses and parasitic loads of the engine such as oil pump, supercharger, a/c compressor, alternator etc. Figure 2 shows compression occurring from 50^0 CA till commencement of combustion at 100^0 CA. This may be attributed to long burn duration and sufficiently advanced ignition timing, unlike what occurs in Figure 1 where compression went dead at 0^0 CA and no combustion line was visible owing to too retarded ignition timing and short burn duration.

4. Conclusion

It is evident that an advanced ignition timing coupled with short burn duration is a worst-case scenario for an engine combustion and performance; also, far retarded ignition timing coupled with short burn duration and a negative burn duration value are abnormal cases. The best result was observed at -40^0bTDC and 50^0 which is close to the values at -35^0bTDC and 60^0 burn duration given in the original model and is thus recommended.

5. References

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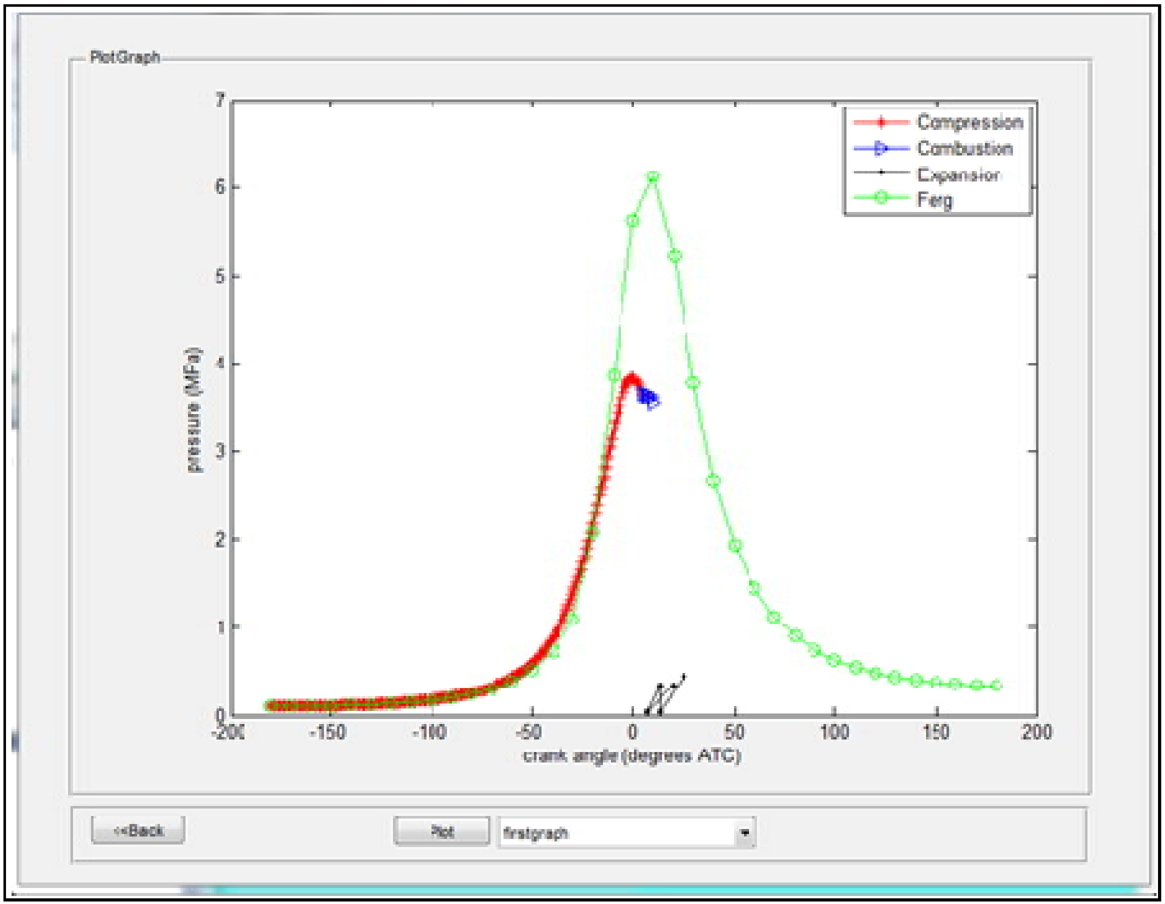
Annexure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crank angle (degrees ATC)
0
1
2
3
4
5
6
7
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-150
-100
-50
0
50
100
150
200
Compression
Combustion
Expansion
Ferg
<<Back
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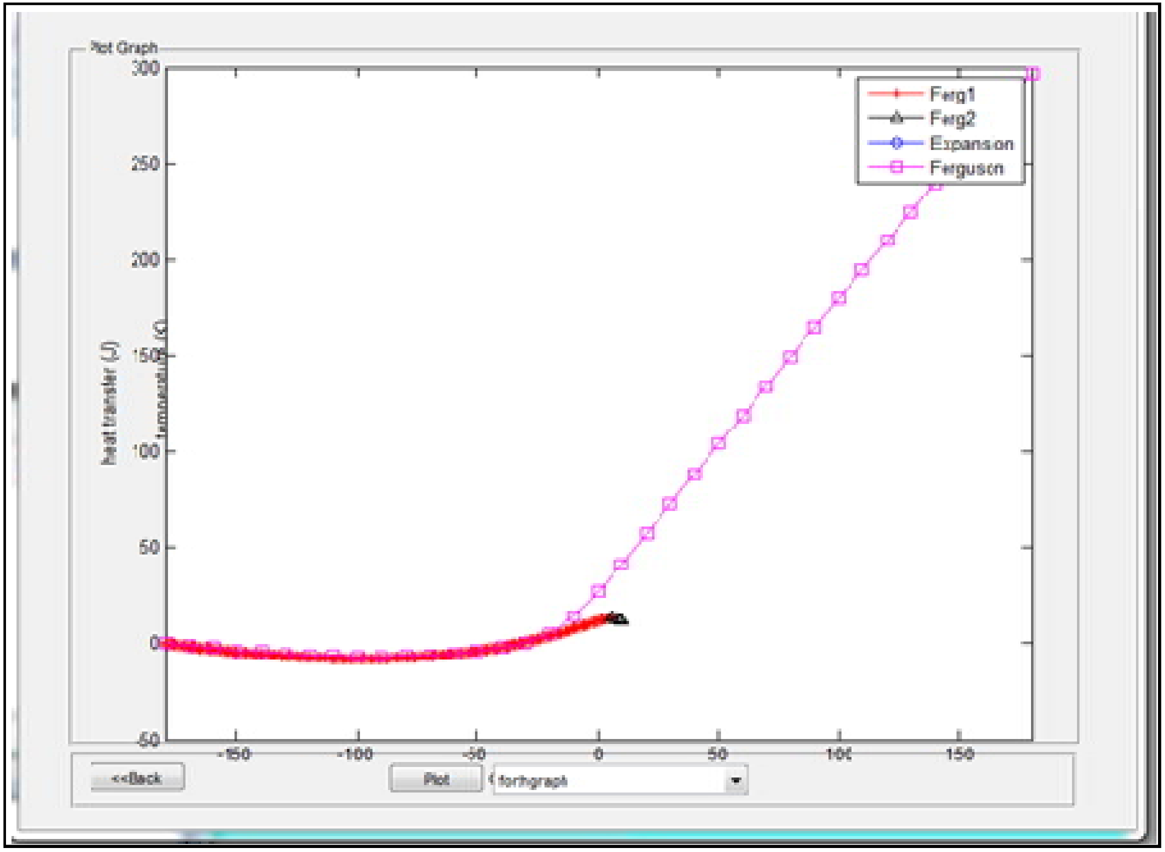
firstgraph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temperature (K)
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50
100
150
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150
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Ferg2
Expansion
Ferguson
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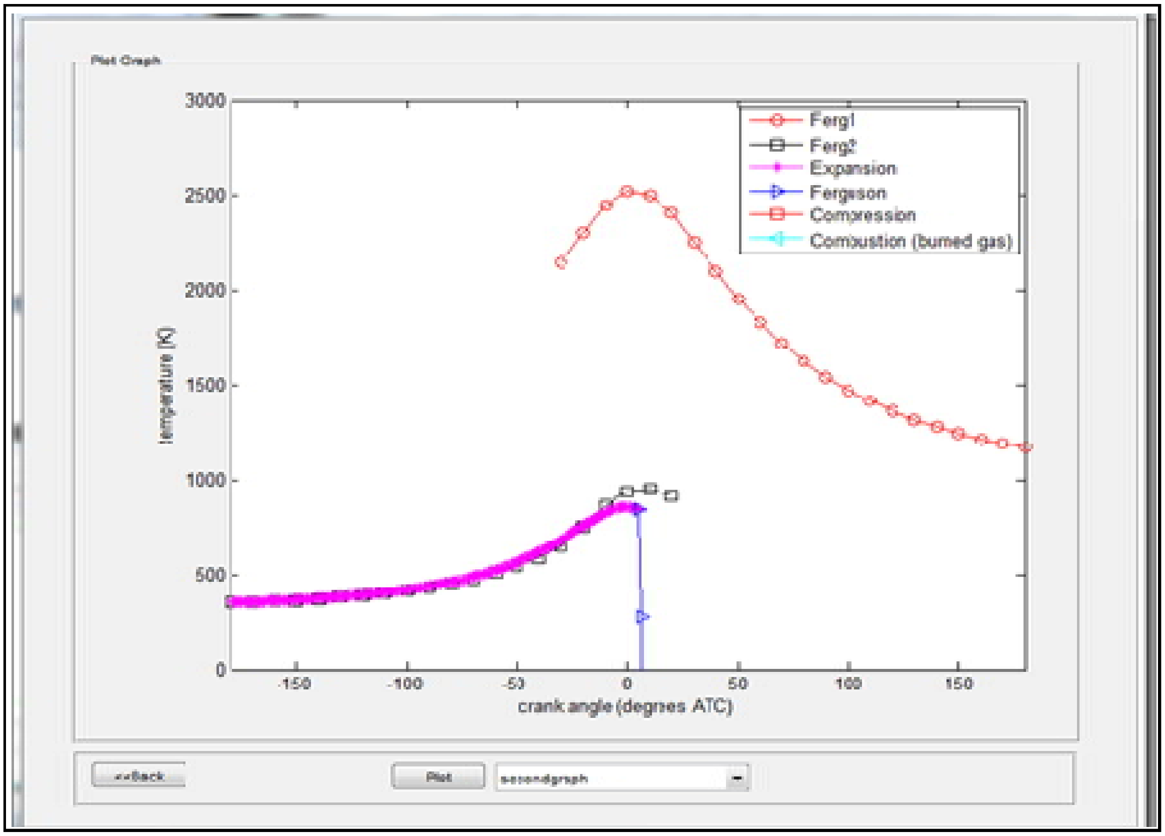
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-50
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Ferg2
Expansion
Ferguson
Compression
Combustion (burned gas)
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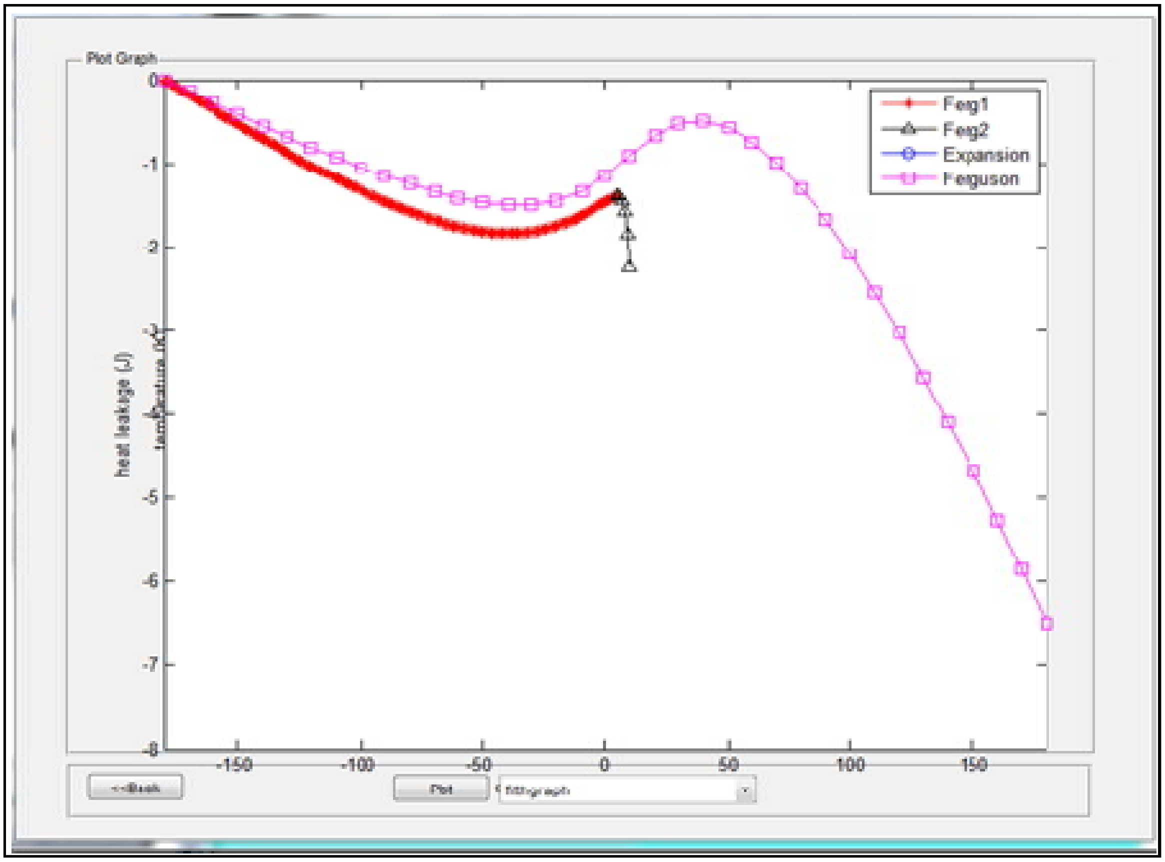
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-8
heat leakage (J)
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50
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150
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Ferg2
Expansion
Ferguson
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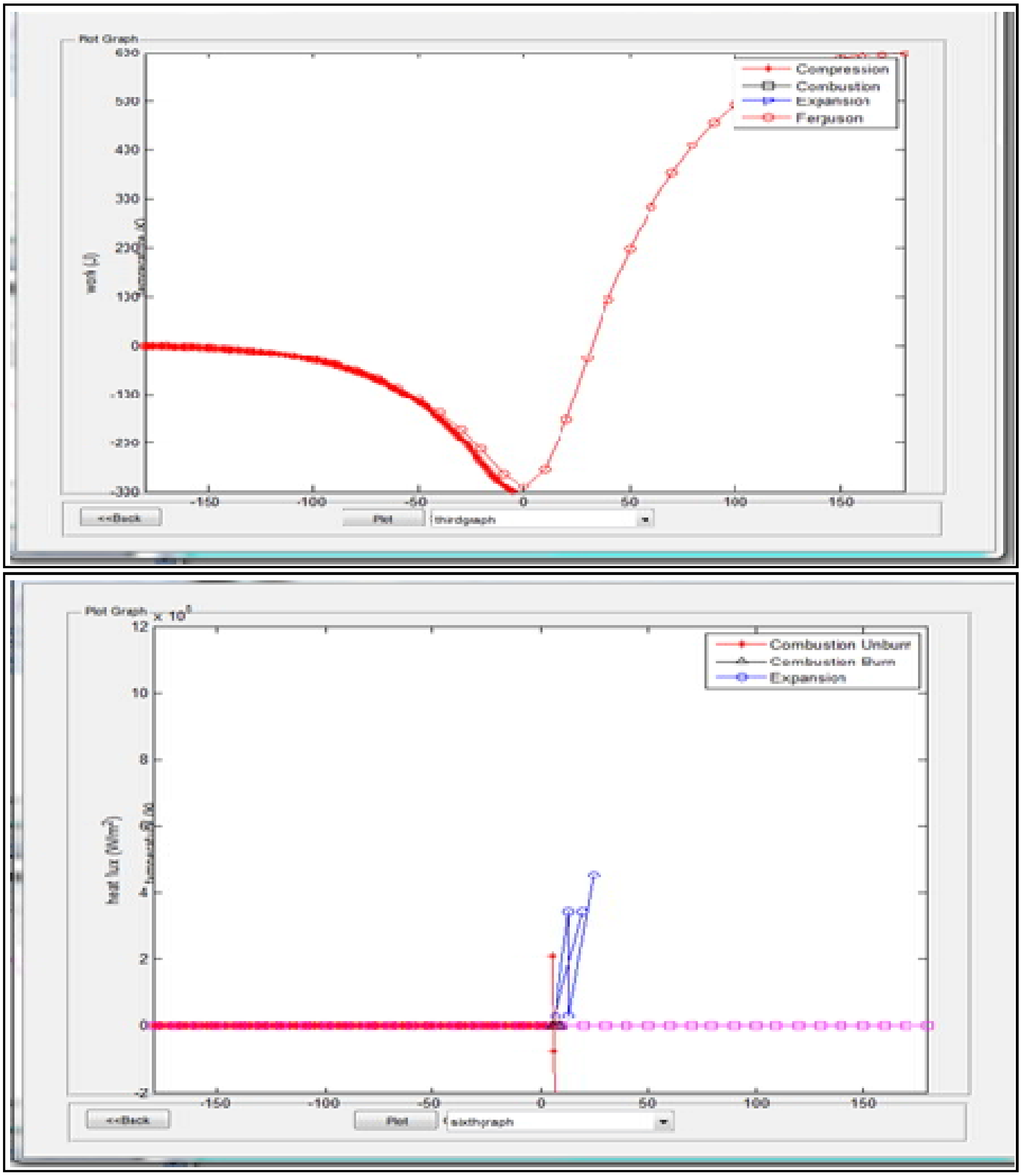
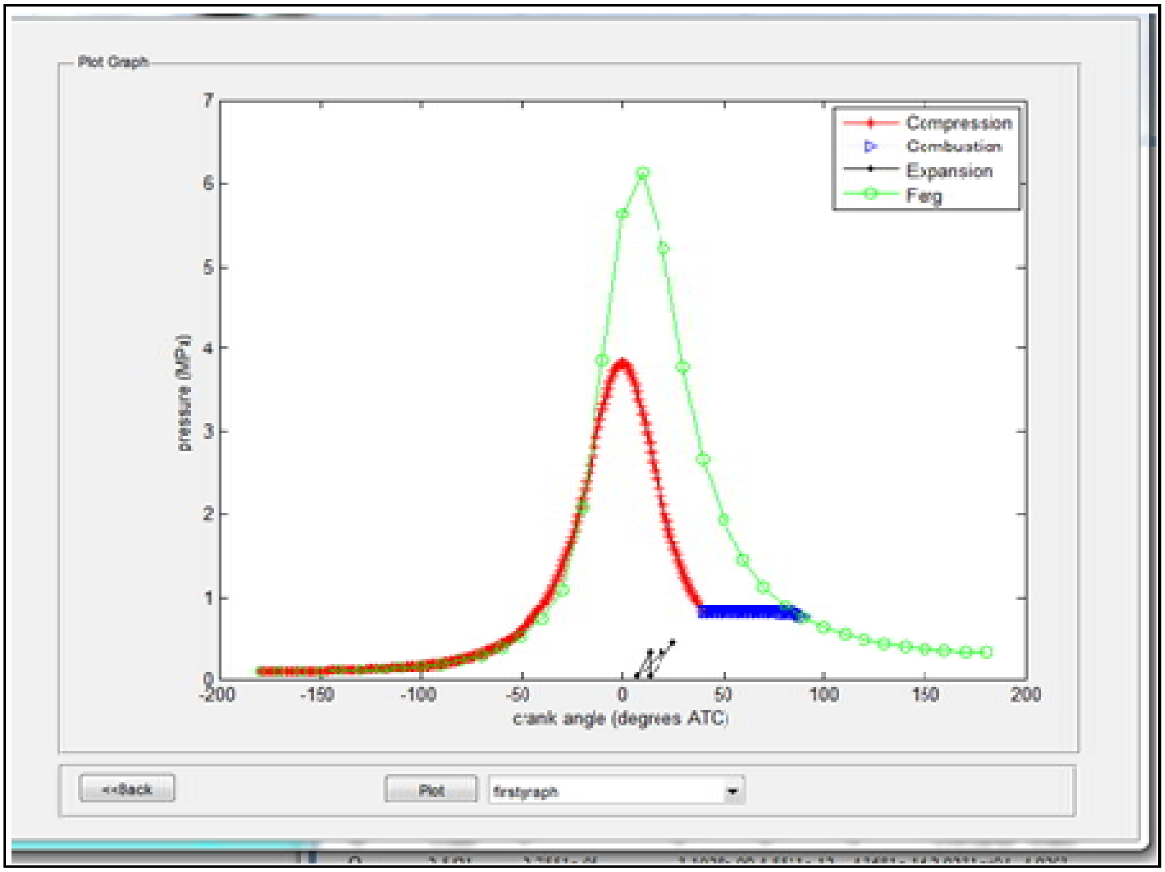


Figure 1 : Plots of Pressure ,Temperature, Heat Leakage, Work Output and Heat Release at -5^{0}bTDC Ignition timing and 5^{0} burn duration angle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5
4
3
2
1
0
pressure (MPa)
-200
-150
-100
-50
0
50
100
150
200
crank angle (degrees ATC)
Compression
Combustion
Expansion
Ferg
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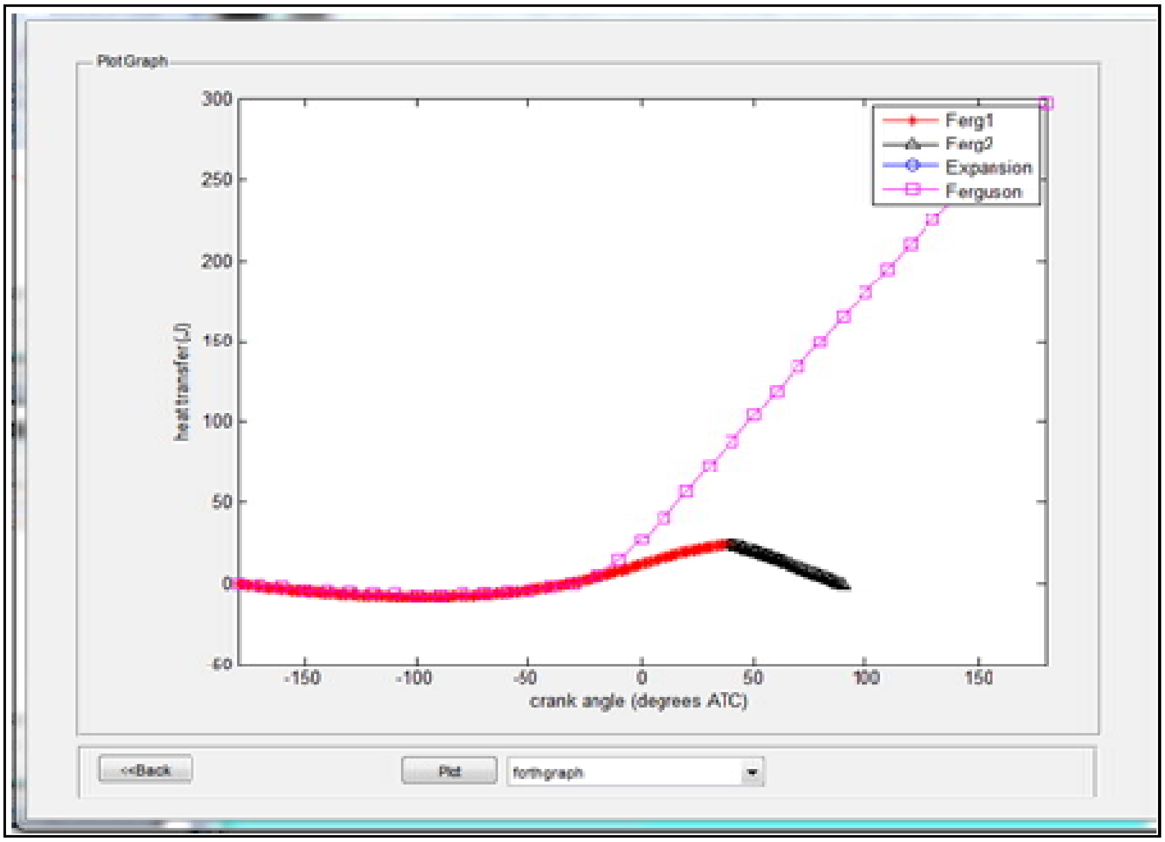
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200
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100
50
0
-50
heat transfer (J)
-150
-100
-50
0
50
100
150
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Ferg1
Ferg2
Expansion
Ferguson
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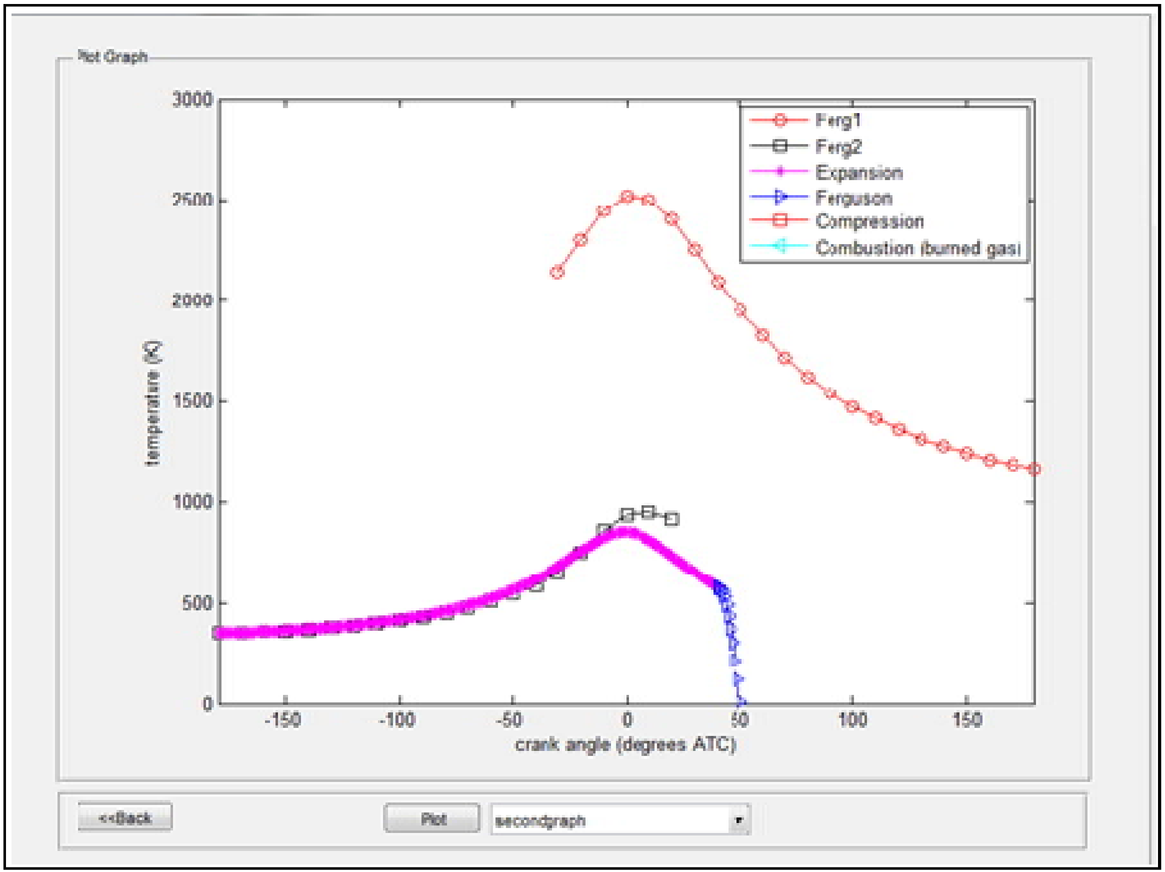
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2000
1500
1000
500
0
temperature (K)
-150
-100
-50
0
50
100
150
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Ferg1
Ferg2
Expansion
Ferguson
Compression
Combustion (burned gas)
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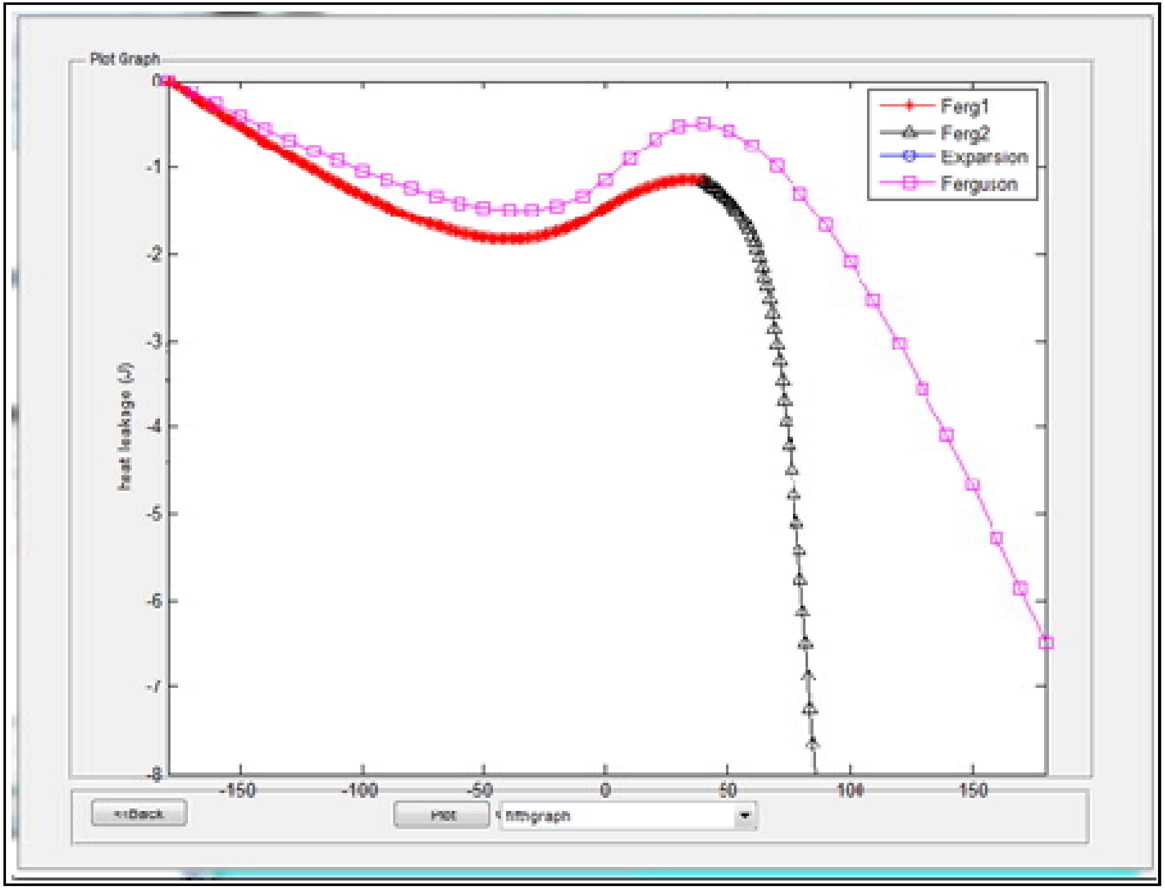
secondgraph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-6
-7
-8
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-100
-50
0
50
100
150
Ferg1
Ferg2
Expansion
Ferguson
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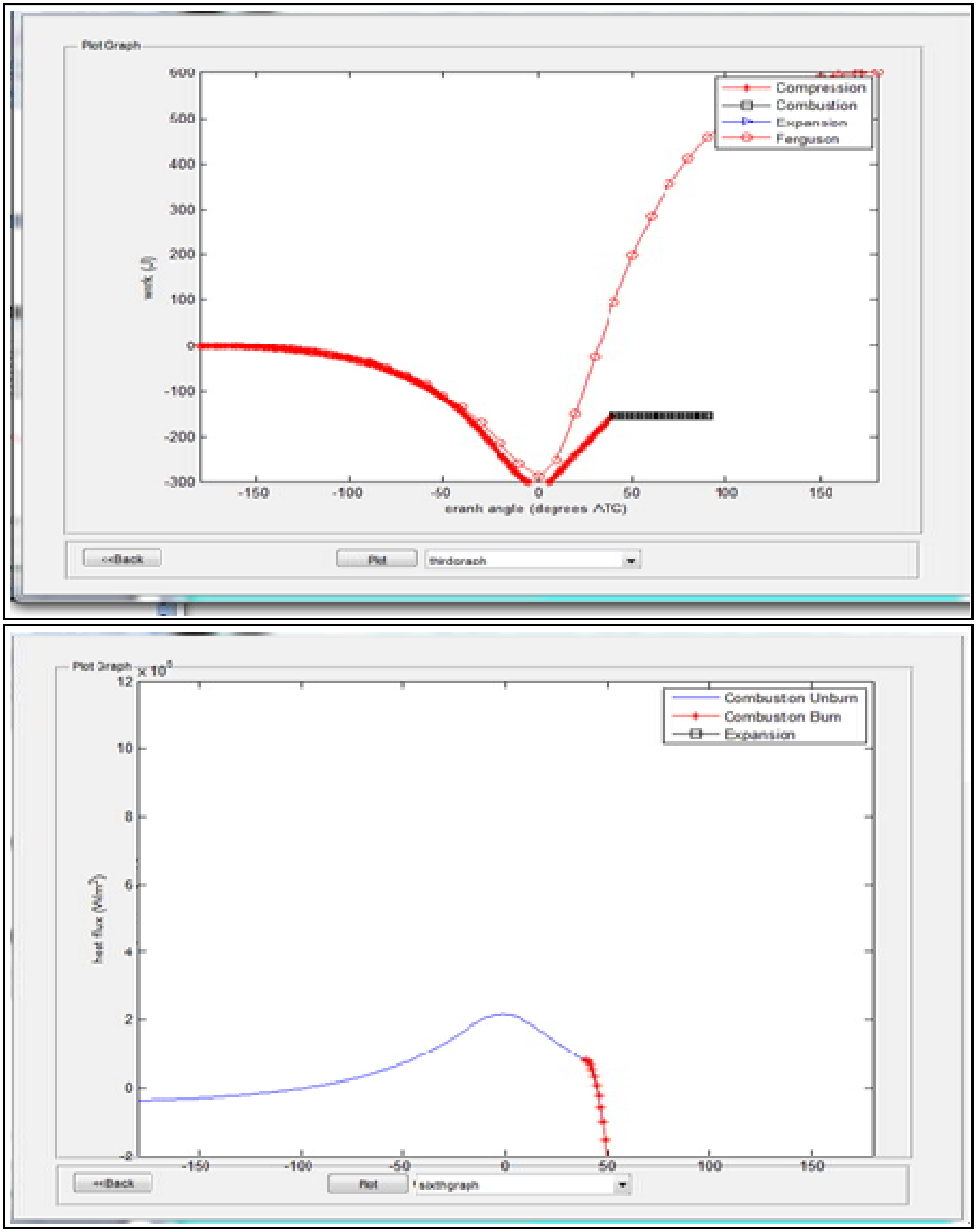
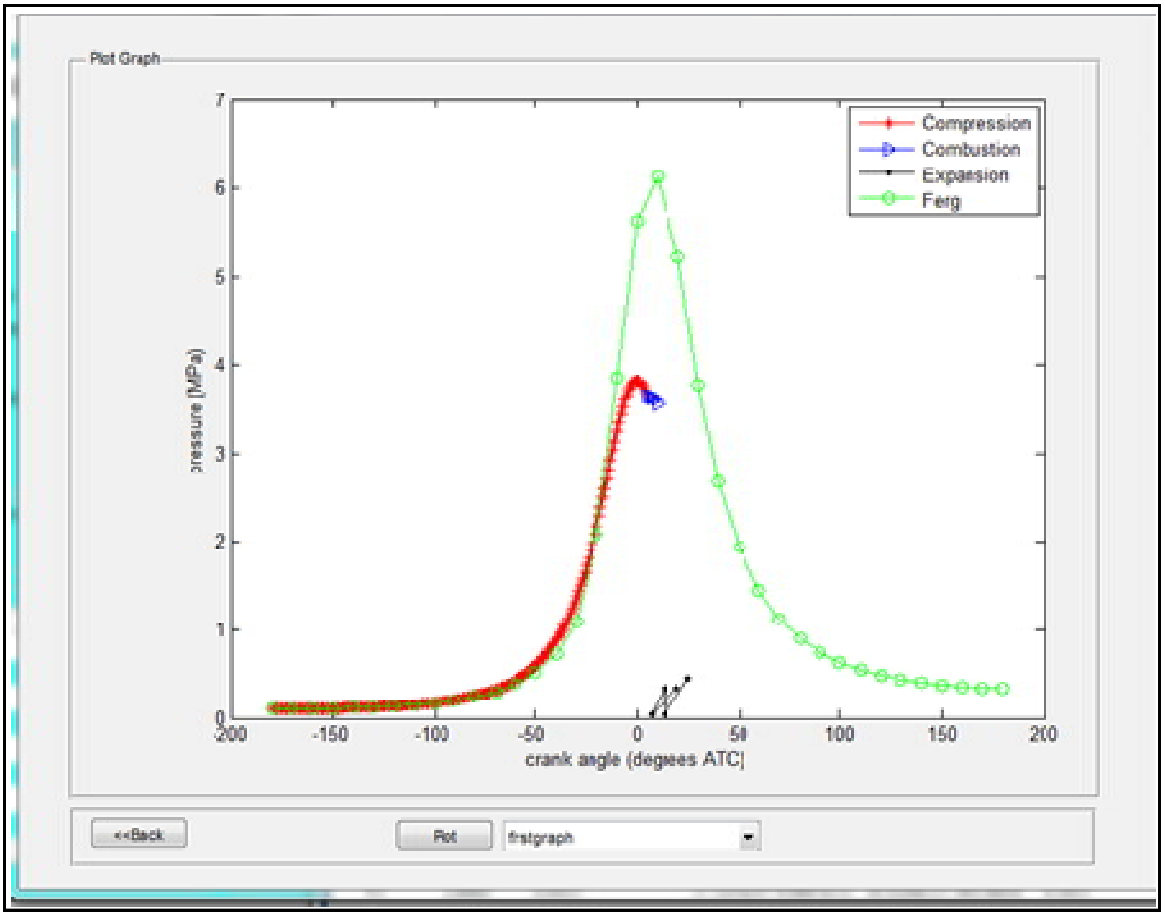


Figure 2: Plots of Pressure, Temperature, Heat Leakage, Work Output and Heat Release at -40^{0}bTDC Ignition timing and 50^0 burn duration angle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Compression
Combustion
Expansion
Ferg
pressure (MPa)
0
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2
3
4
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6
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-100
-50
0
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100
150
200
crank angle (degees ATC)
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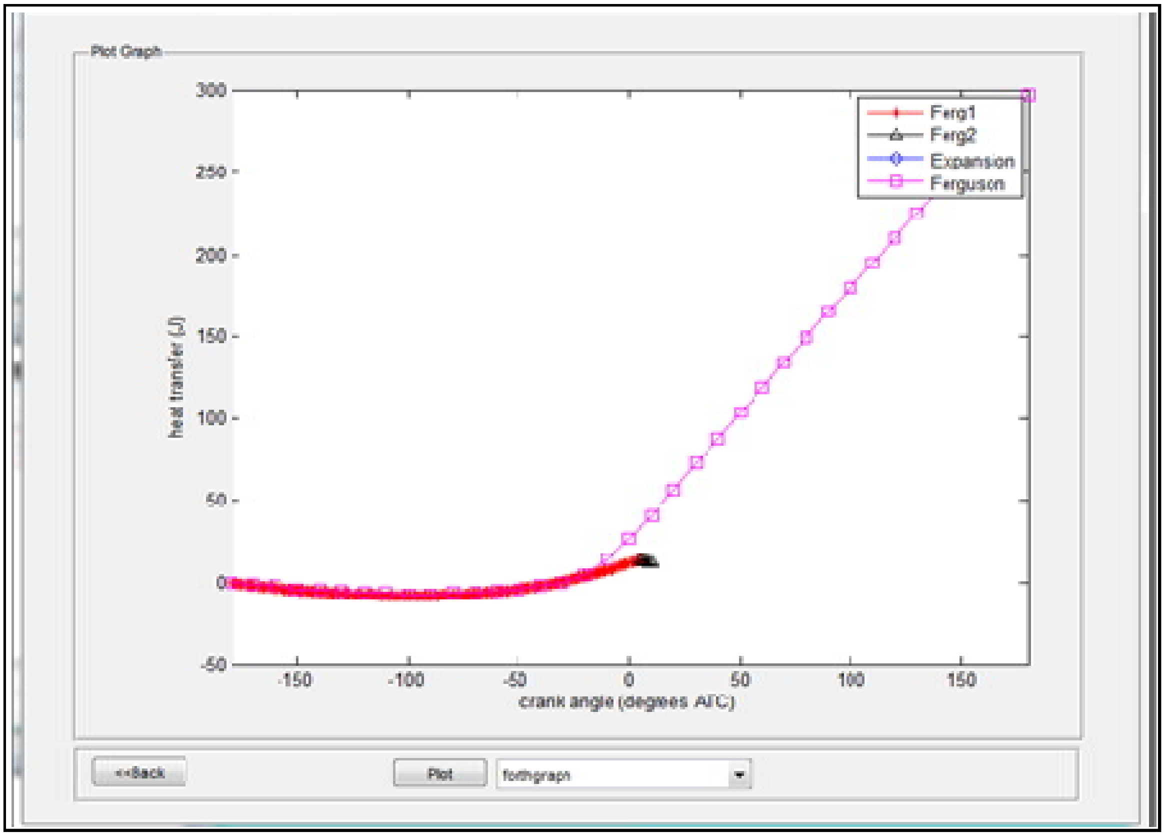
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Ferg1
Ferg2
Expansion
Ferguson
heat transfer (J)
-50
0
50
100
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-150
-100
-50
0
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100
150
crank angle (degees ATC)
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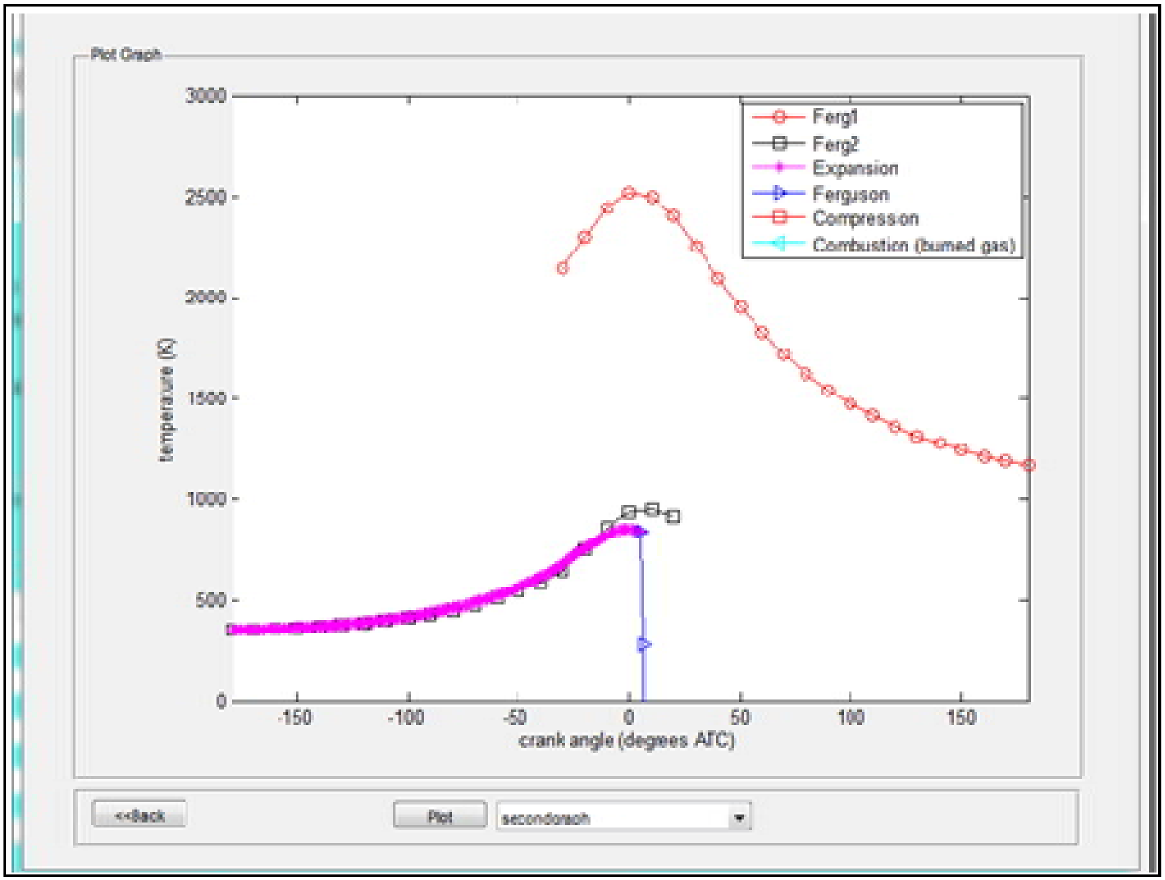
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temperature (K)
-150
-100
-50
0
50
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crank angle (degrees ATC)
Ferg1
Ferg2
Expansion
Ferguson
Compression
Combustion (burned gas)
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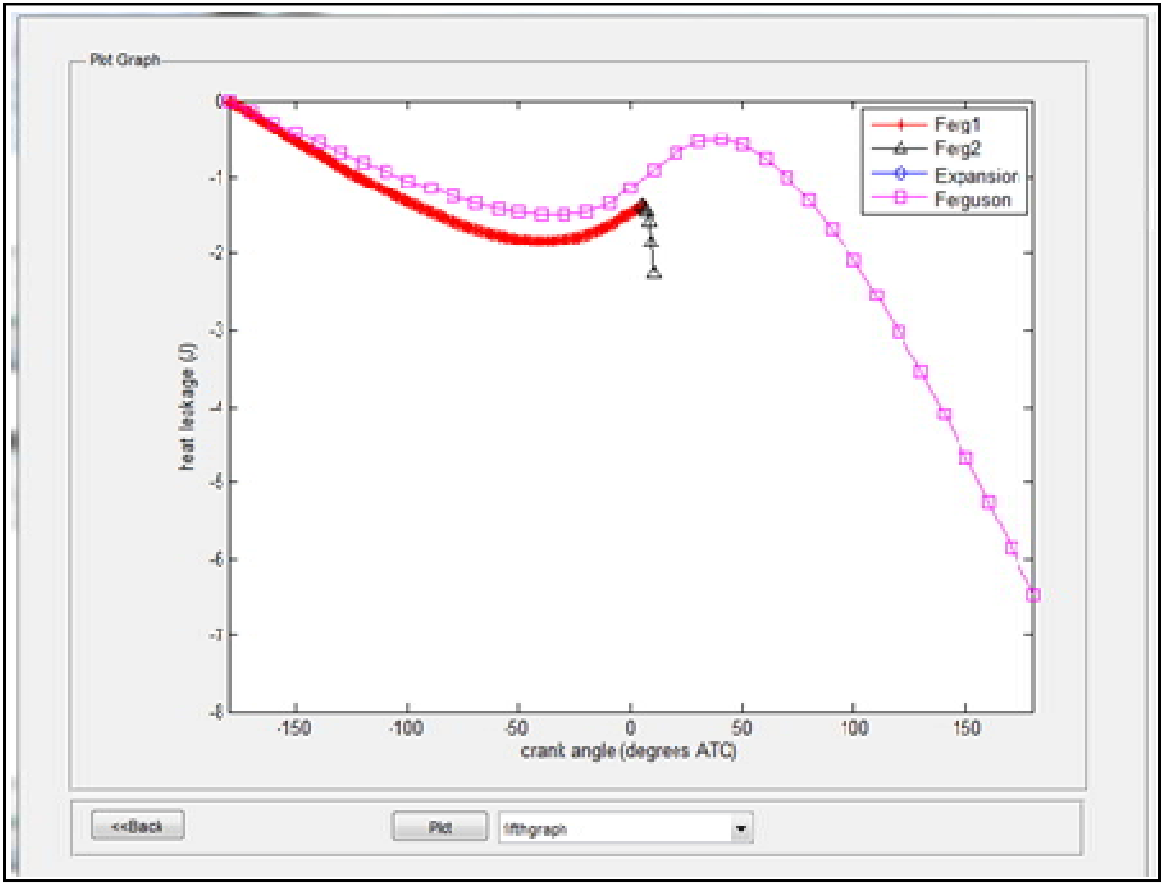
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-8
heat leakage (J)
-150
-100
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50
100
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crank angle (degrees ATC)
Ferg1
Ferg2
Expansion
Ferguson
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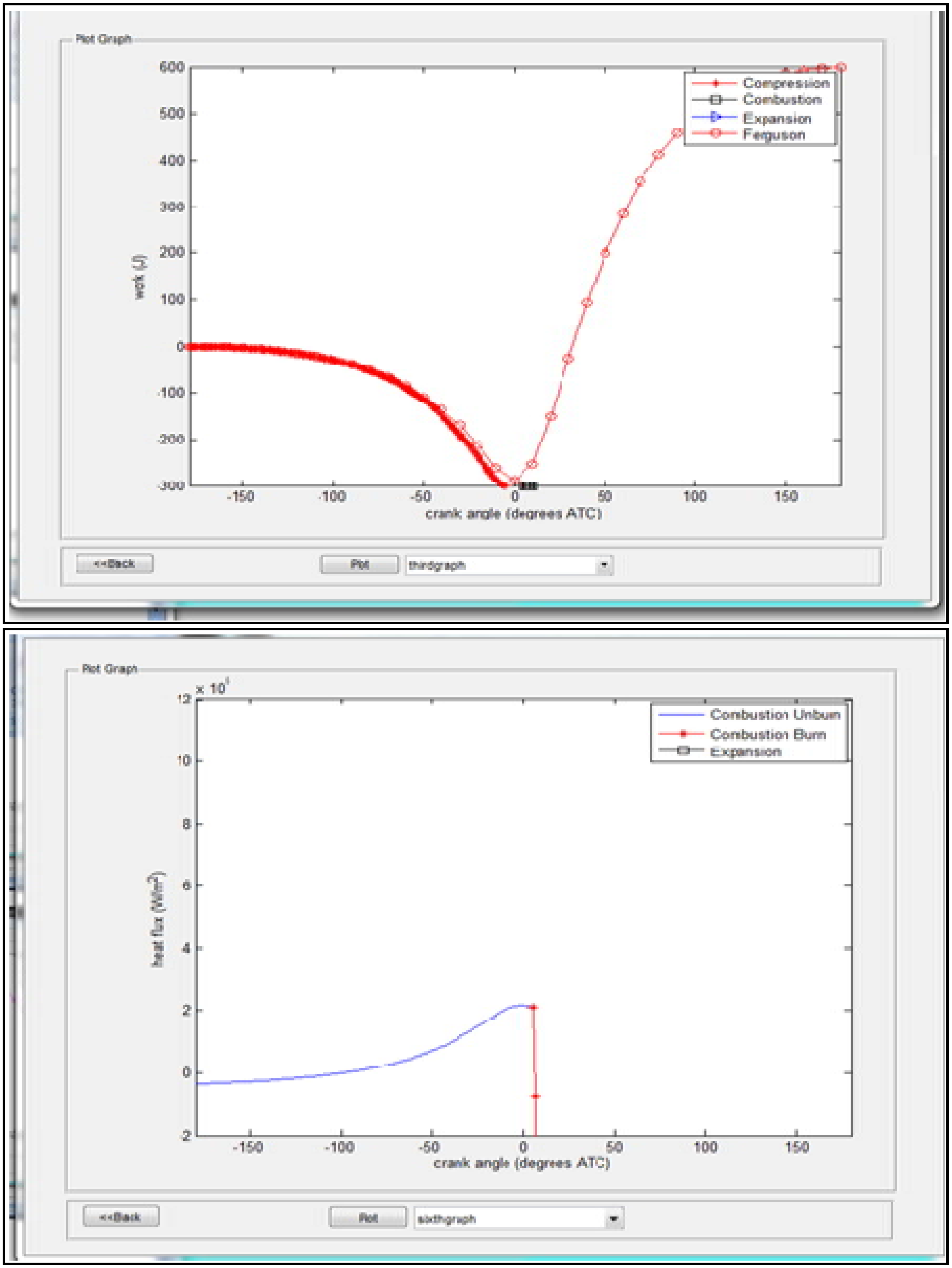
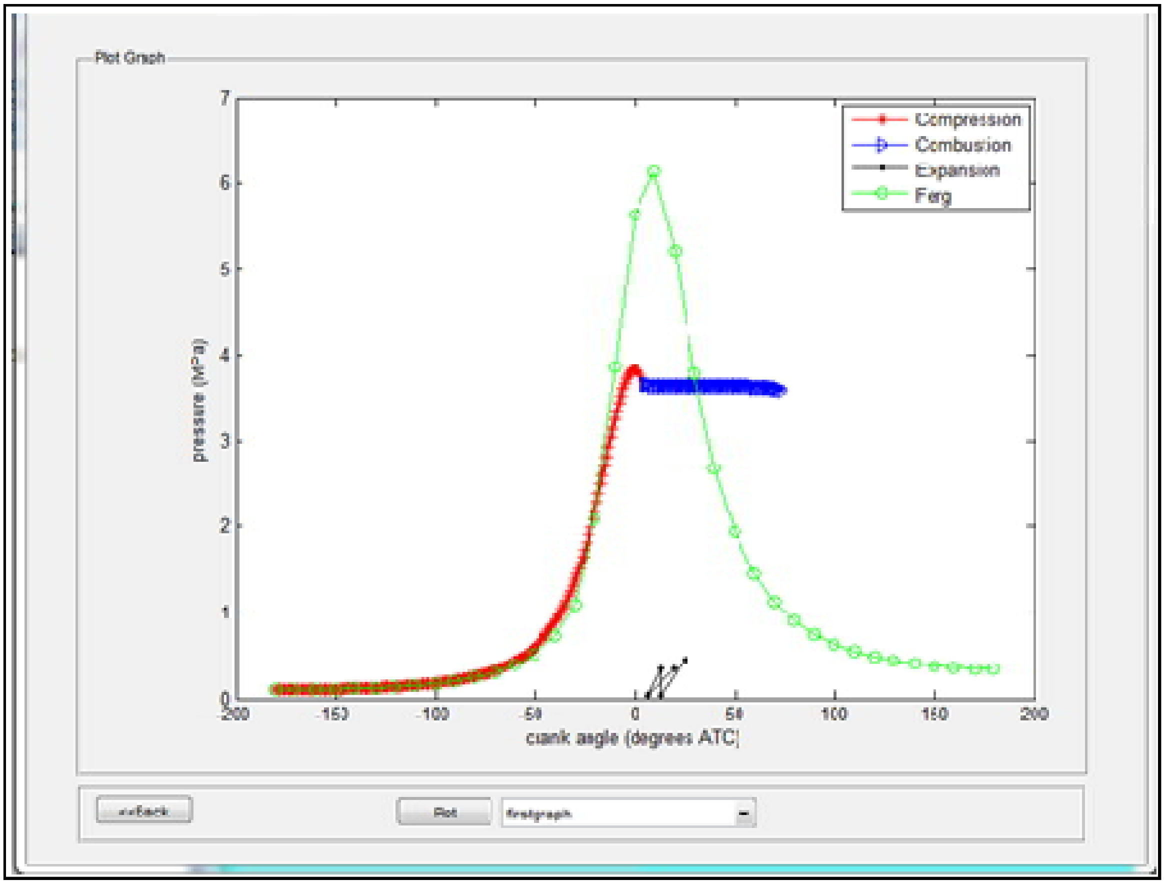


Figure 3: Plots of Pressure, Temperature, Heat Leakage, Work Output and Heat Release at -5^{0}bTDC Ignition timing and --58^{0}burn duration angle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Compression
Combustion
Expansion
Ferg
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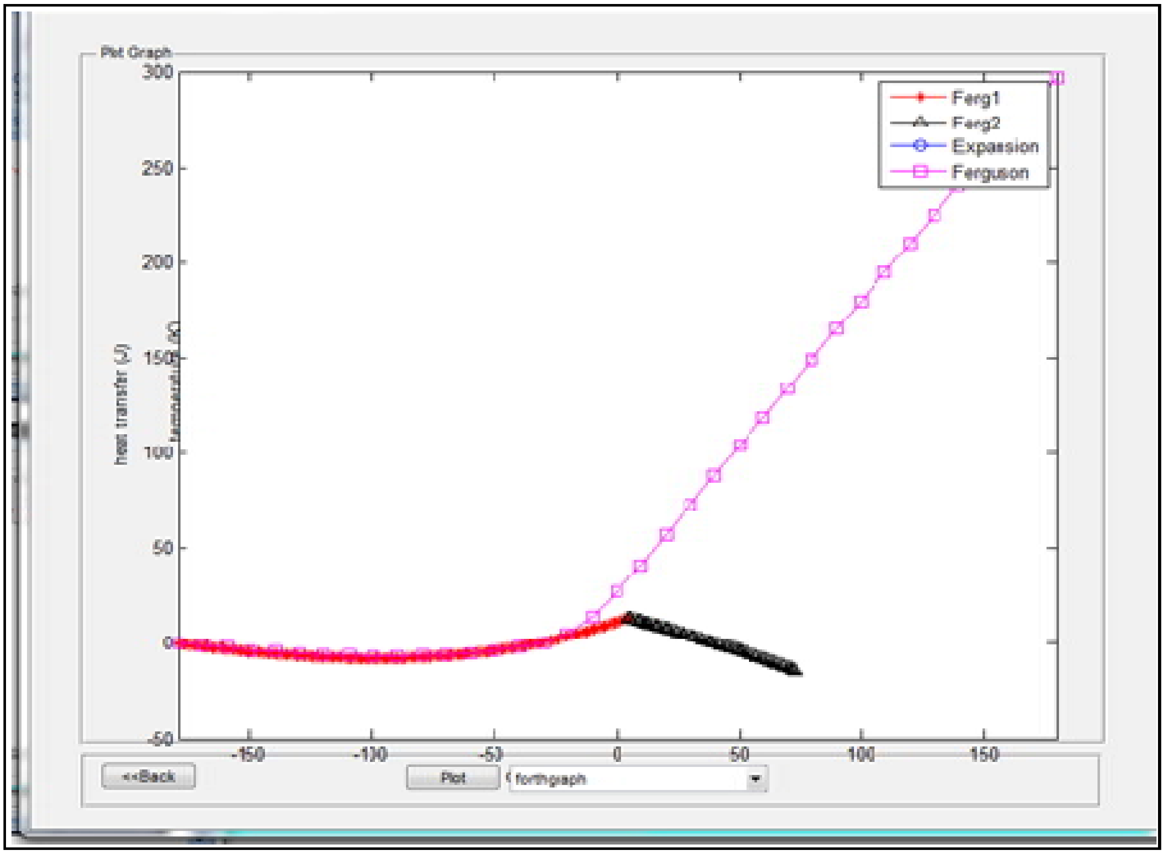
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Ferg1
Ferg2
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Ferguson
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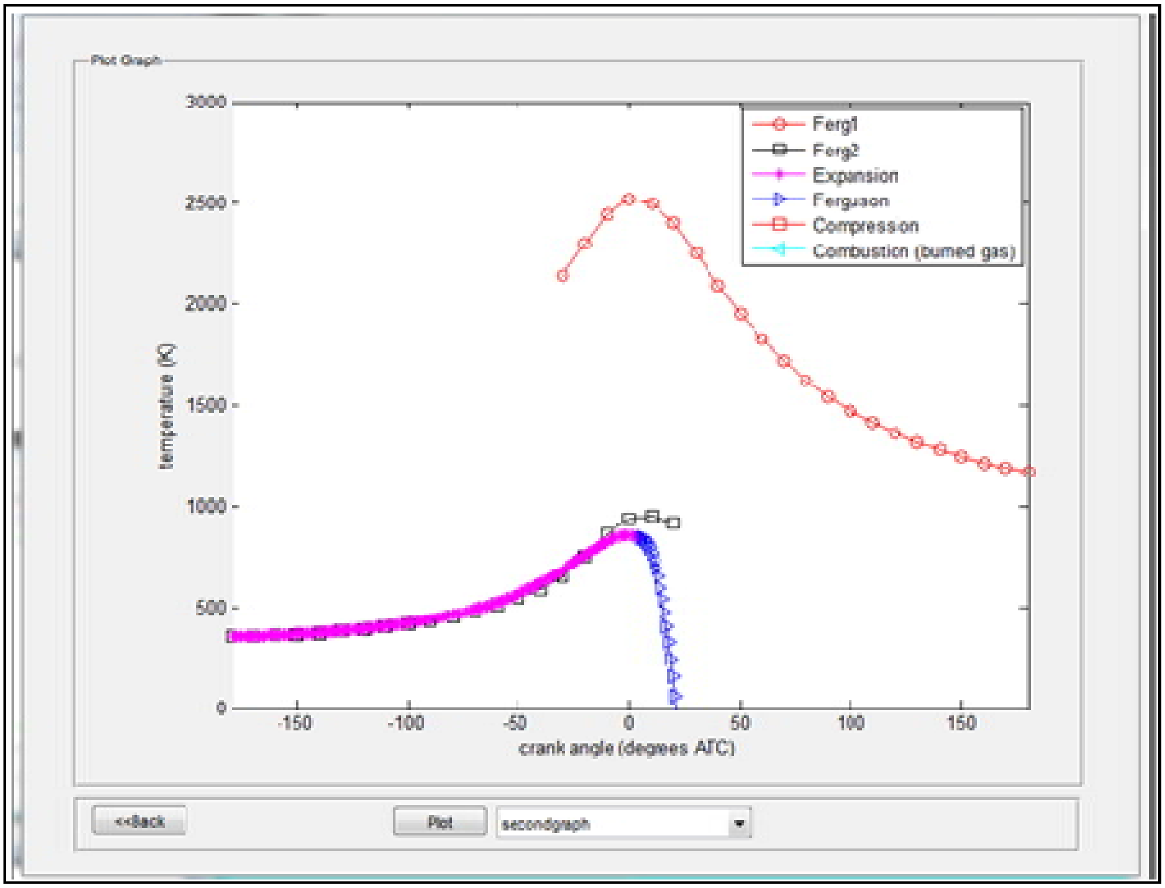
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temperature (K)
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-100
-50
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Ferg1
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Expansion
Ferguson
Compression
Combustion (burned gas)
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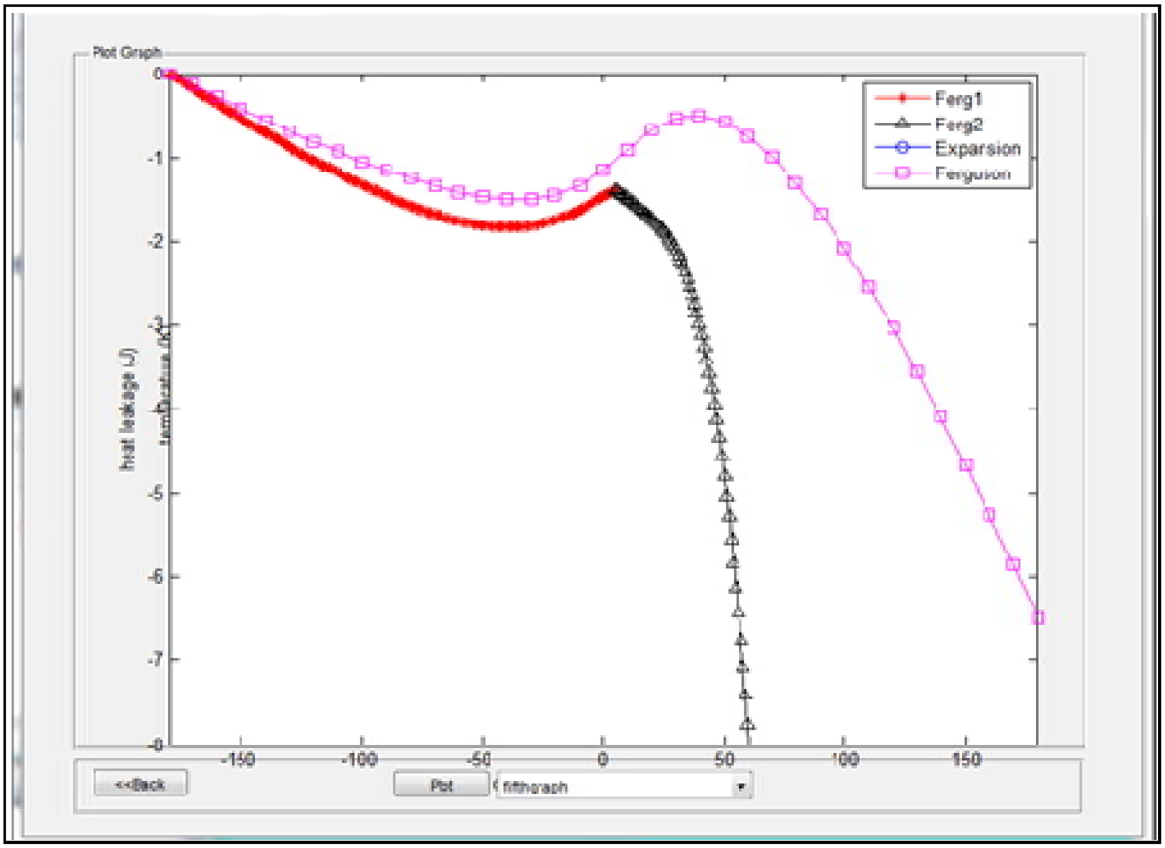
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Ferg1
Ferg2
Expansion
Ferguson
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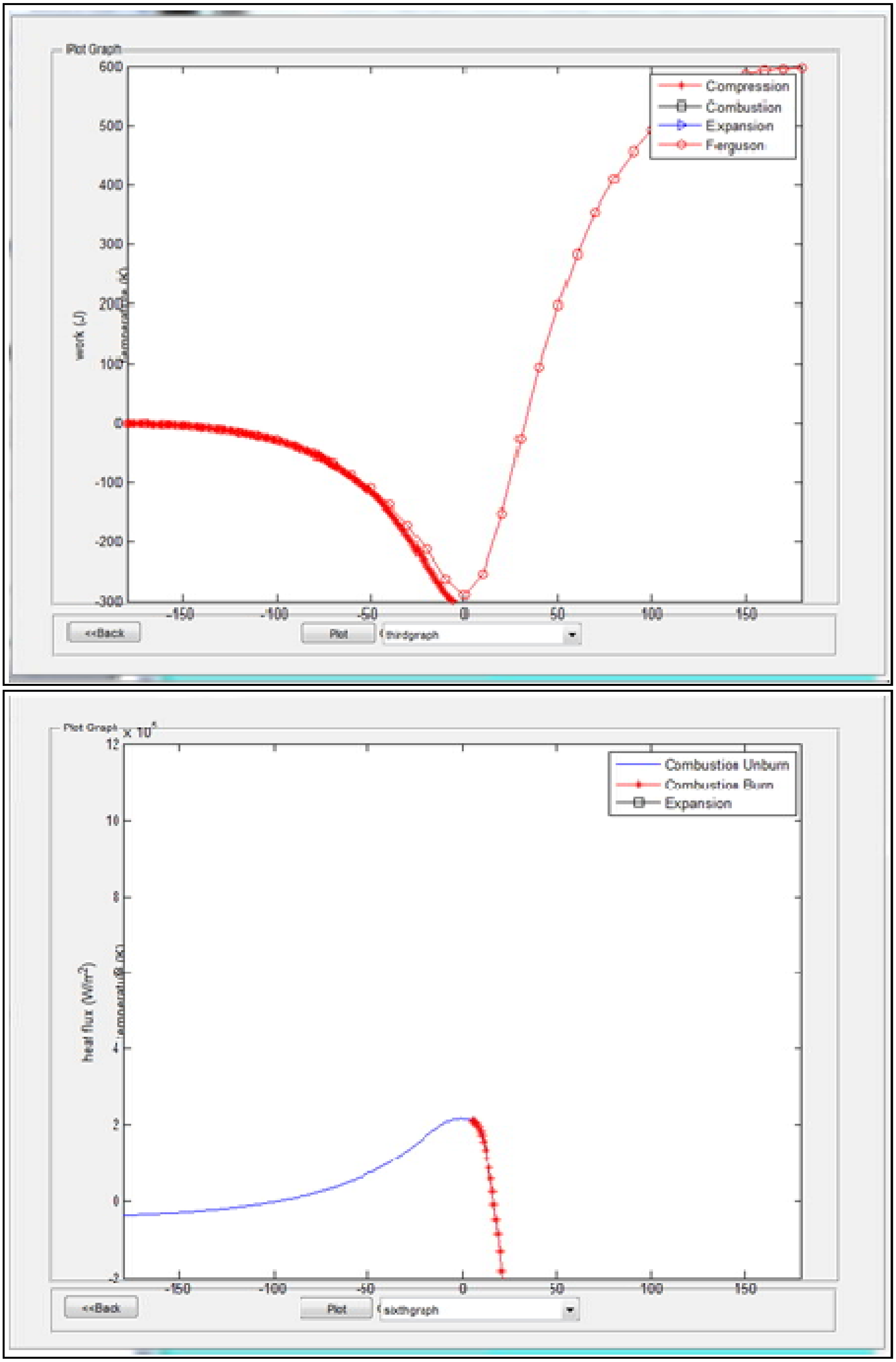
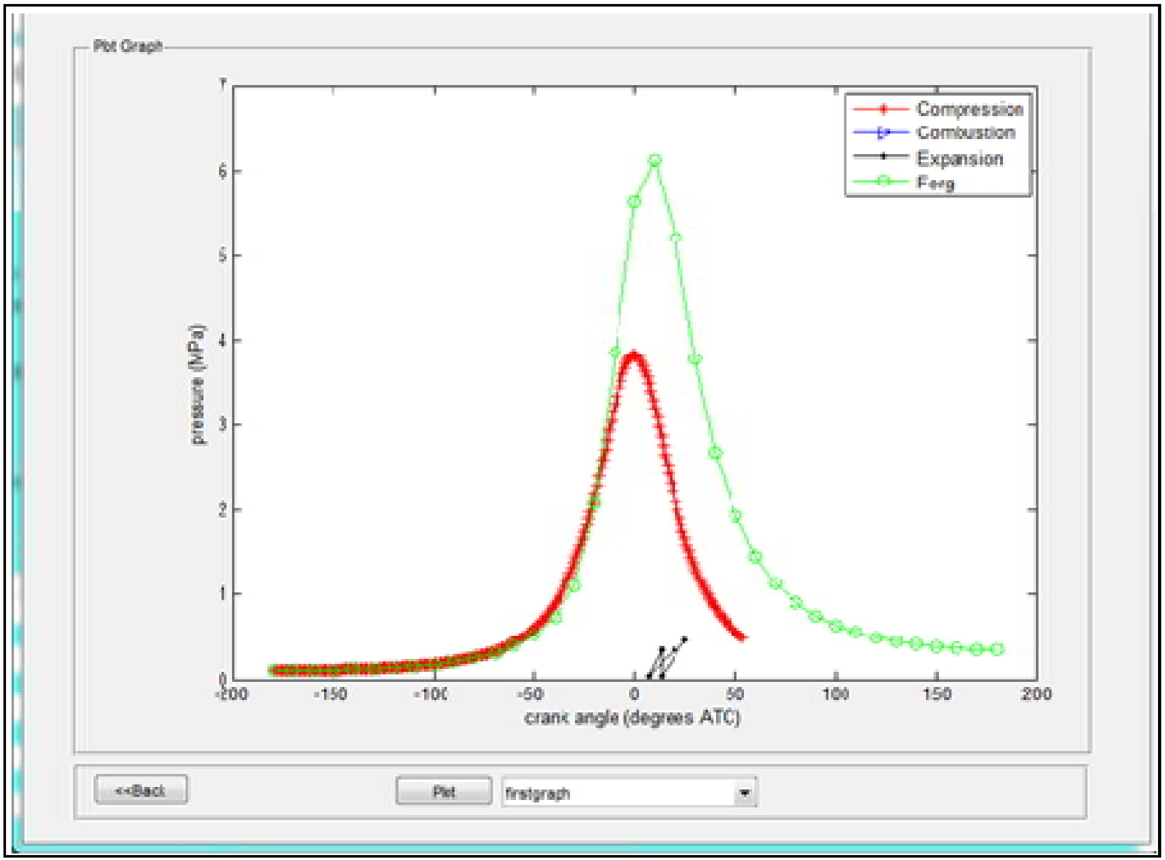


Figure 4: Plots of Pressure, Temperature, Heat Leakage, Work Output and Heat Release at -5^{0}bTDC Ignition timing and 68.64^0 burn duration angle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Compression
Combustion
Expansion
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crank angle (degrees ATC)
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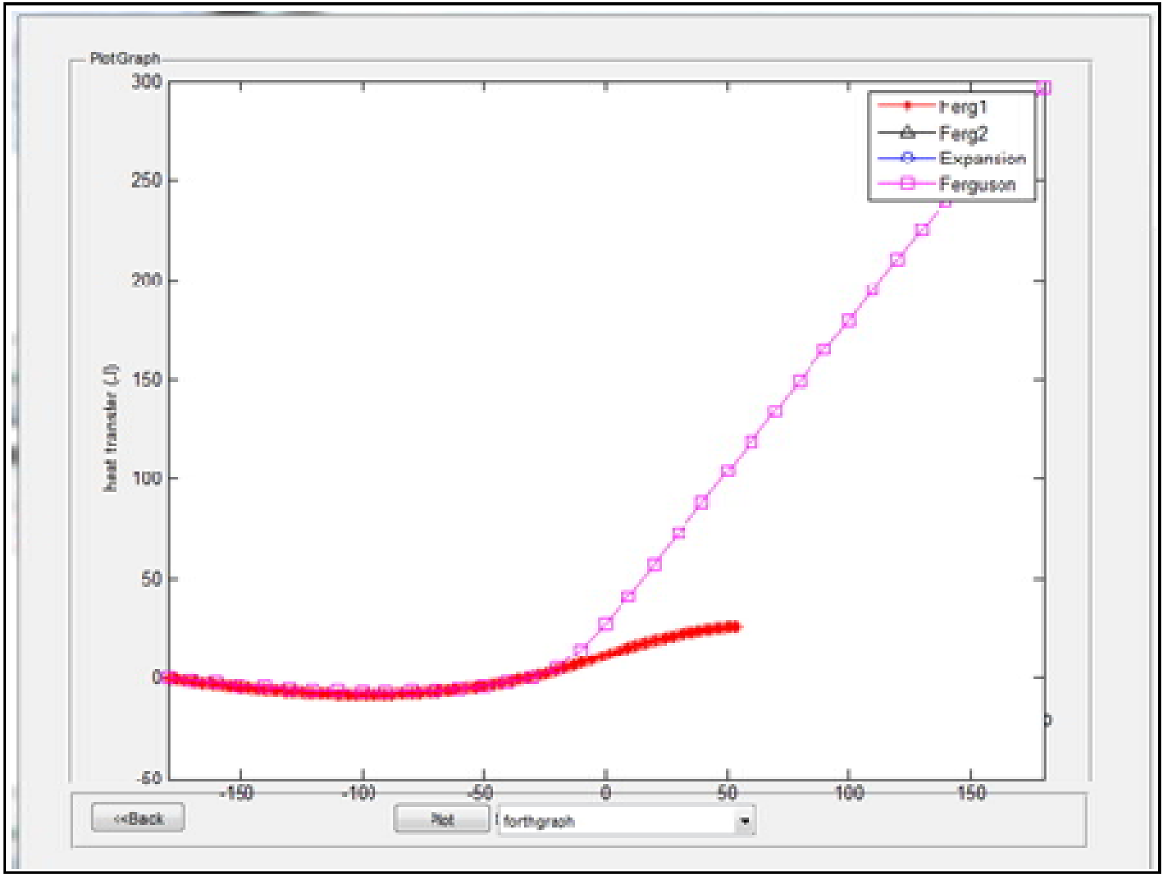
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Ferg2
Expansion
Ferguson
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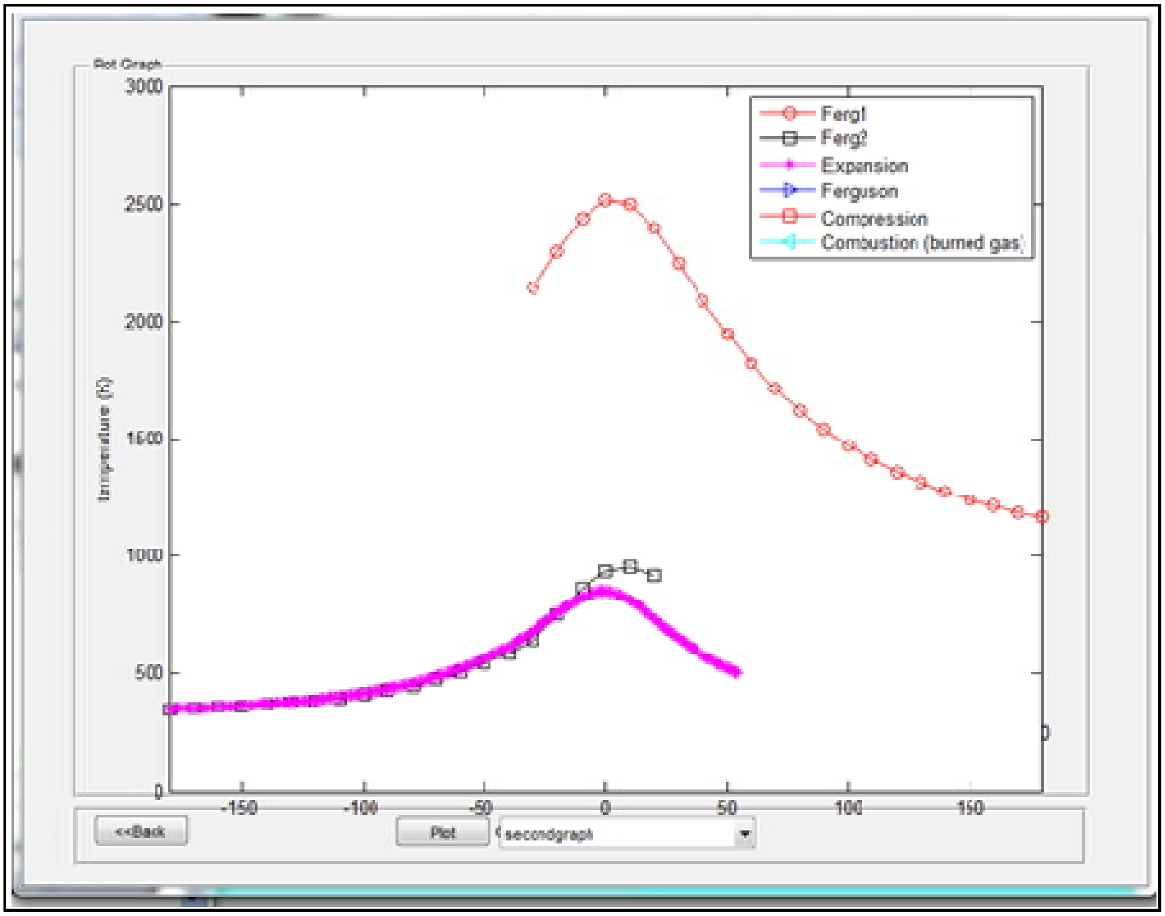
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Ferg2
Expansion
Ferguson
Compression
Combustion (burned gas)
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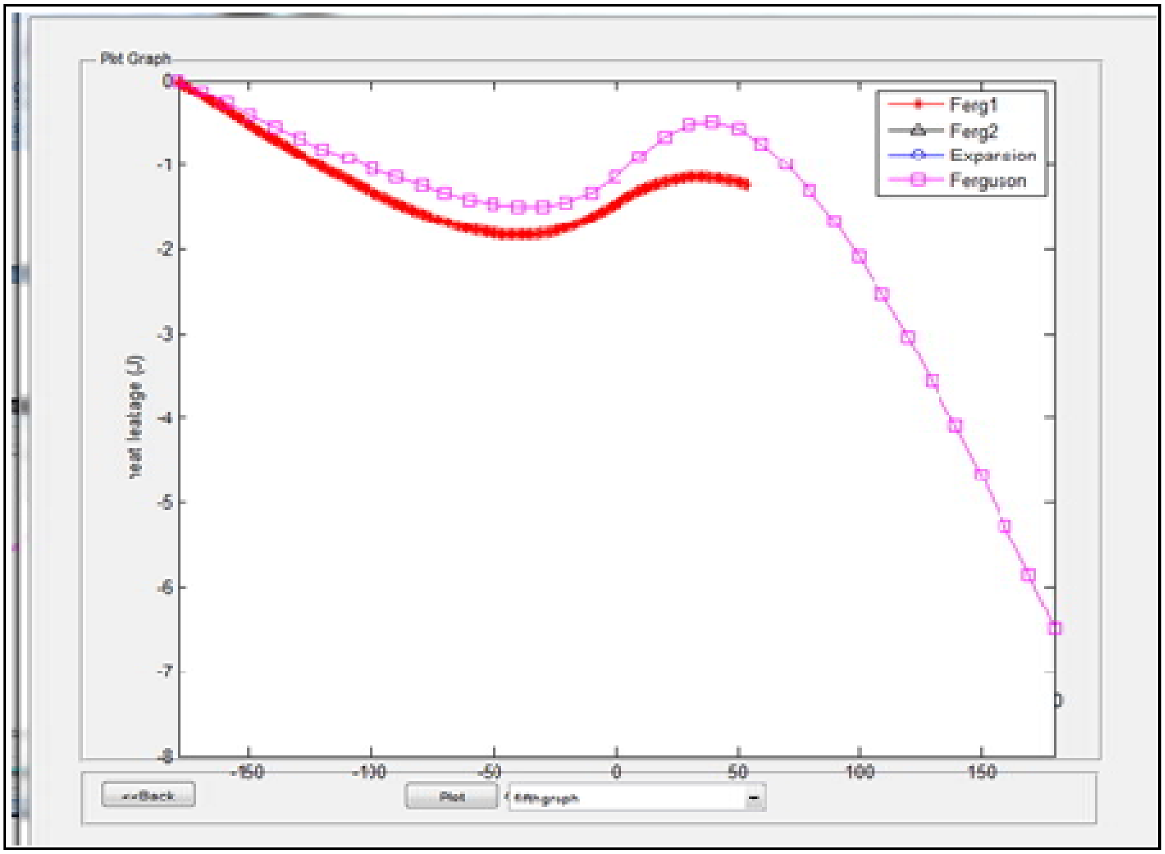
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Ferg1
Ferg2
Expansion
Ferguson
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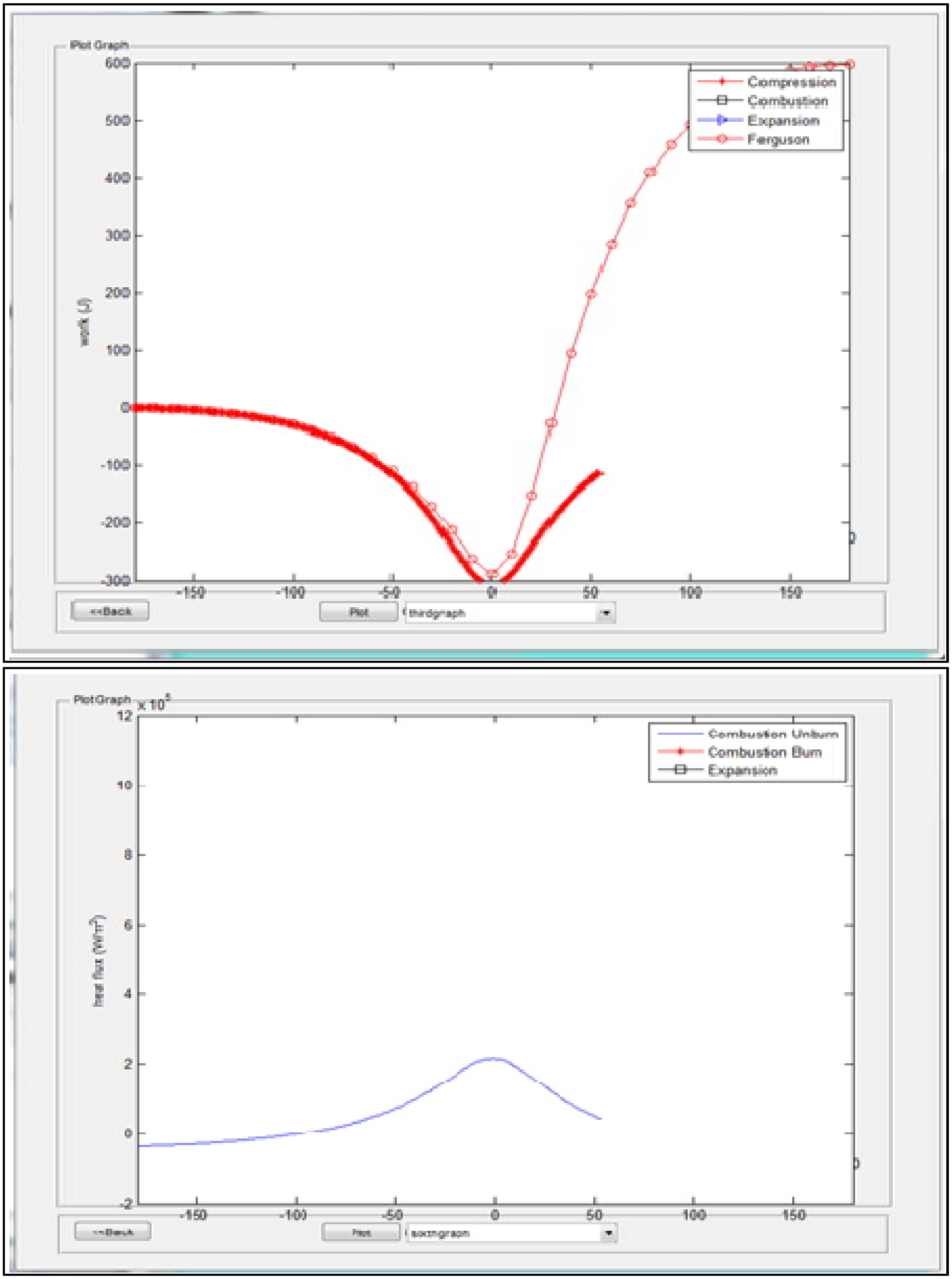
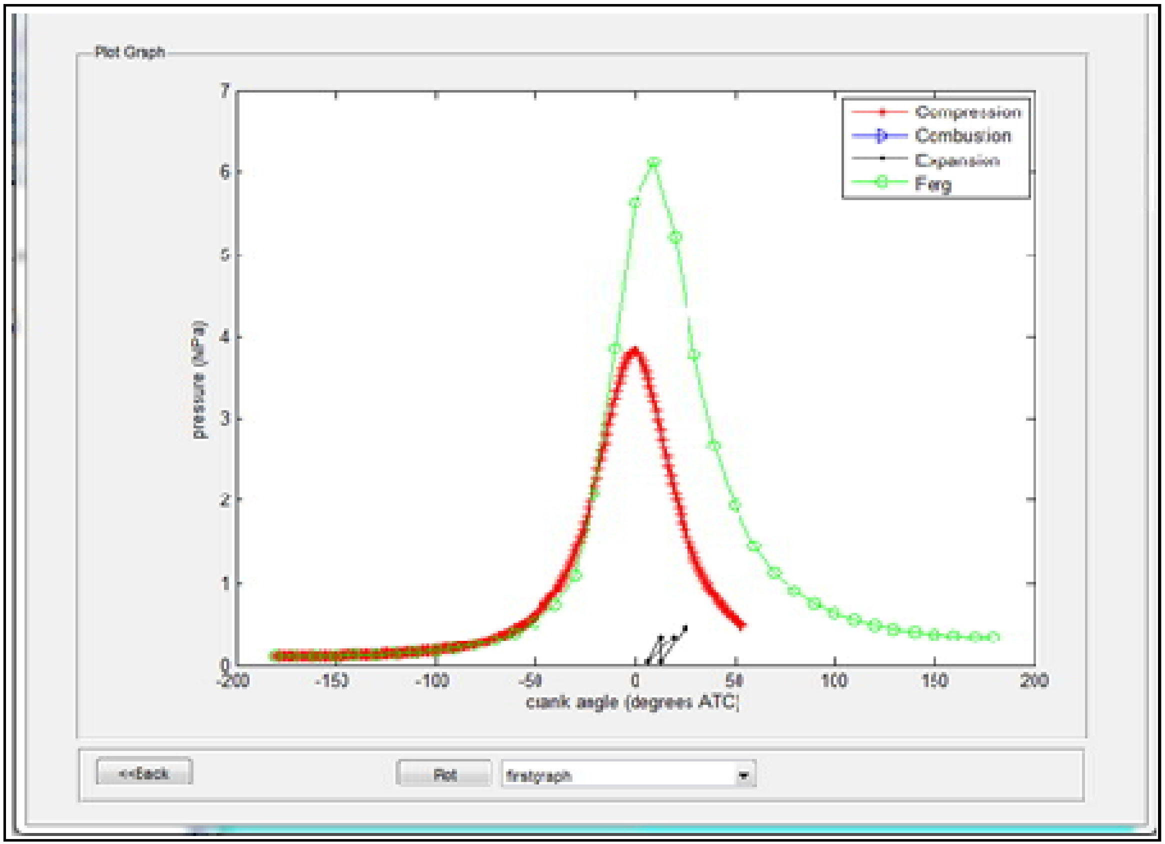


Figure 5: Plots of Pressure, Temperature, Heat Leakage, Work Output and Heat Release at -54.5^{0}bTDC Ignition timing and 5^{0}burn duration angle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pressure (MPa)
-200
-150
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100
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200
crank angle (degrees ATC)
Compression
Combustion
Expansion
Ferg
<<Back
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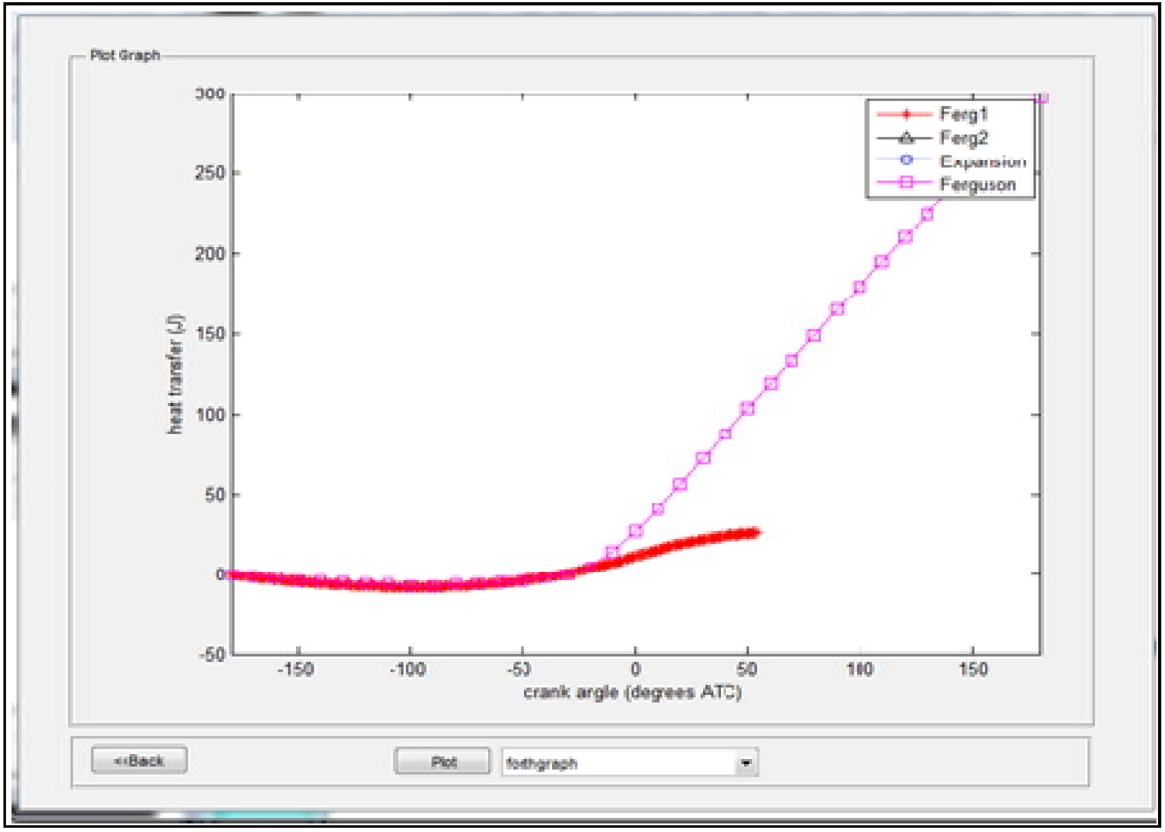
firstgraph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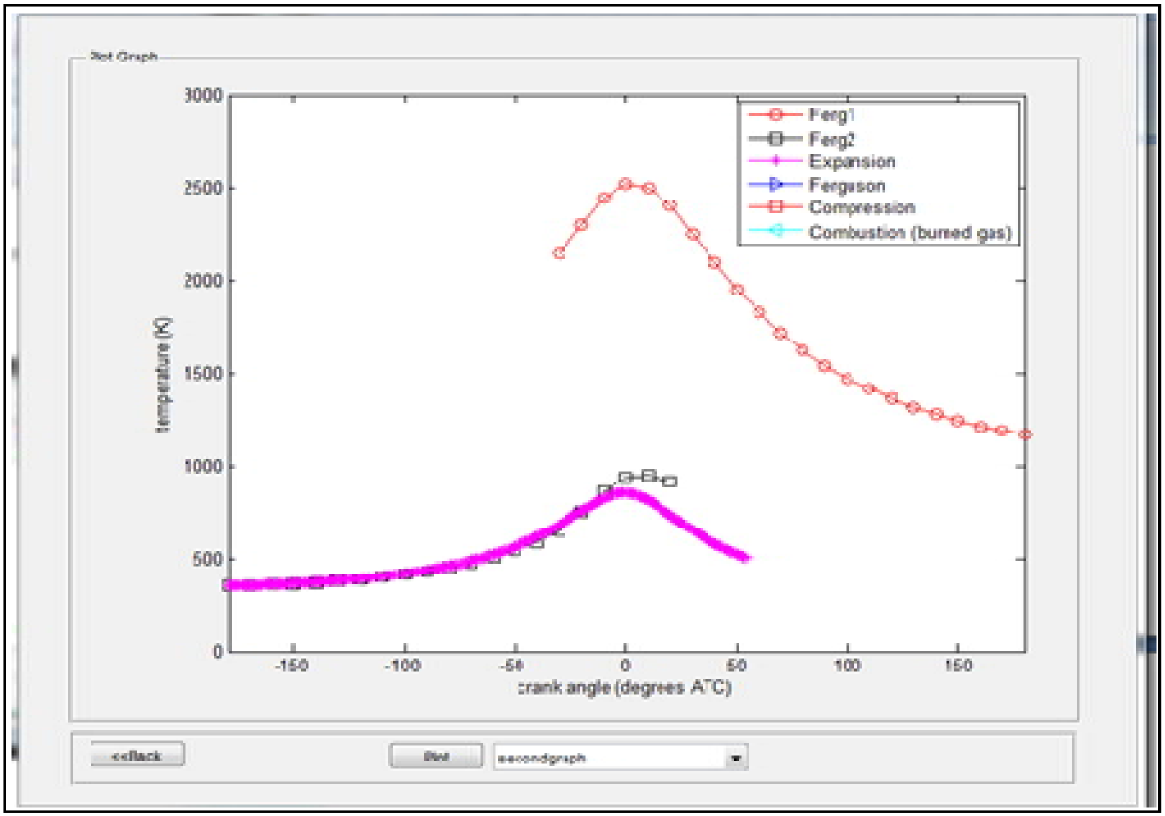
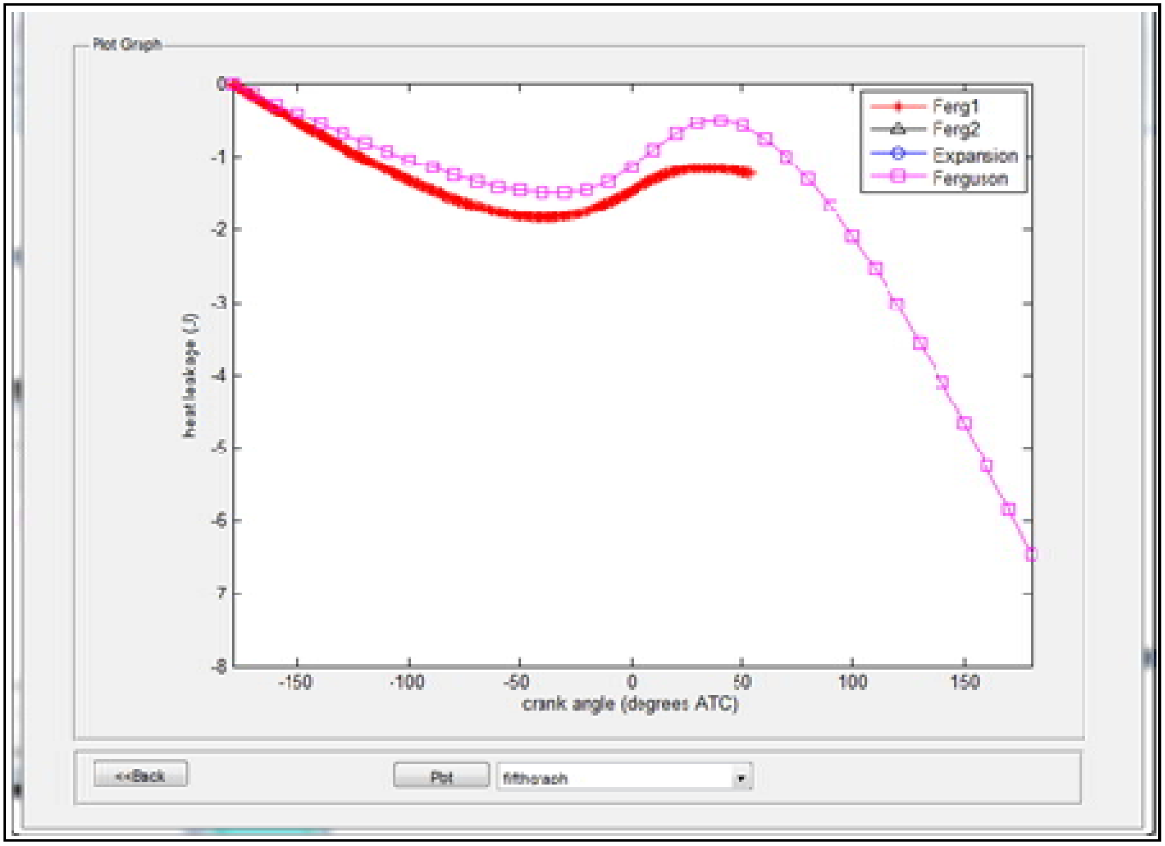
crank angle (degrees ATC)
Ferg1
Ferg2
Expansion
Ferguson
<<Back
Plot
fothgraph


Plot Graph
3000
2500
2000
1500
1000
500
0
temperature (K)
-150
-100
-50
0
50
100
150
crank angle (degrees ATC)
Ferg1
Ferg2
Expansion
Ferguson
Compression
Combustion (burned gas)
<<Back
Plot
secondgraph


Plot Graph
0
-1
-2
-3
-4
-5
-6
-7
-8
heat leakage (J)
-150
-100
-50
0
50
100
150
crank angle (degrees ATC)
Ferg1
Ferg2
Expansion
Ferguson
<<Back
Plot
fifthgraph

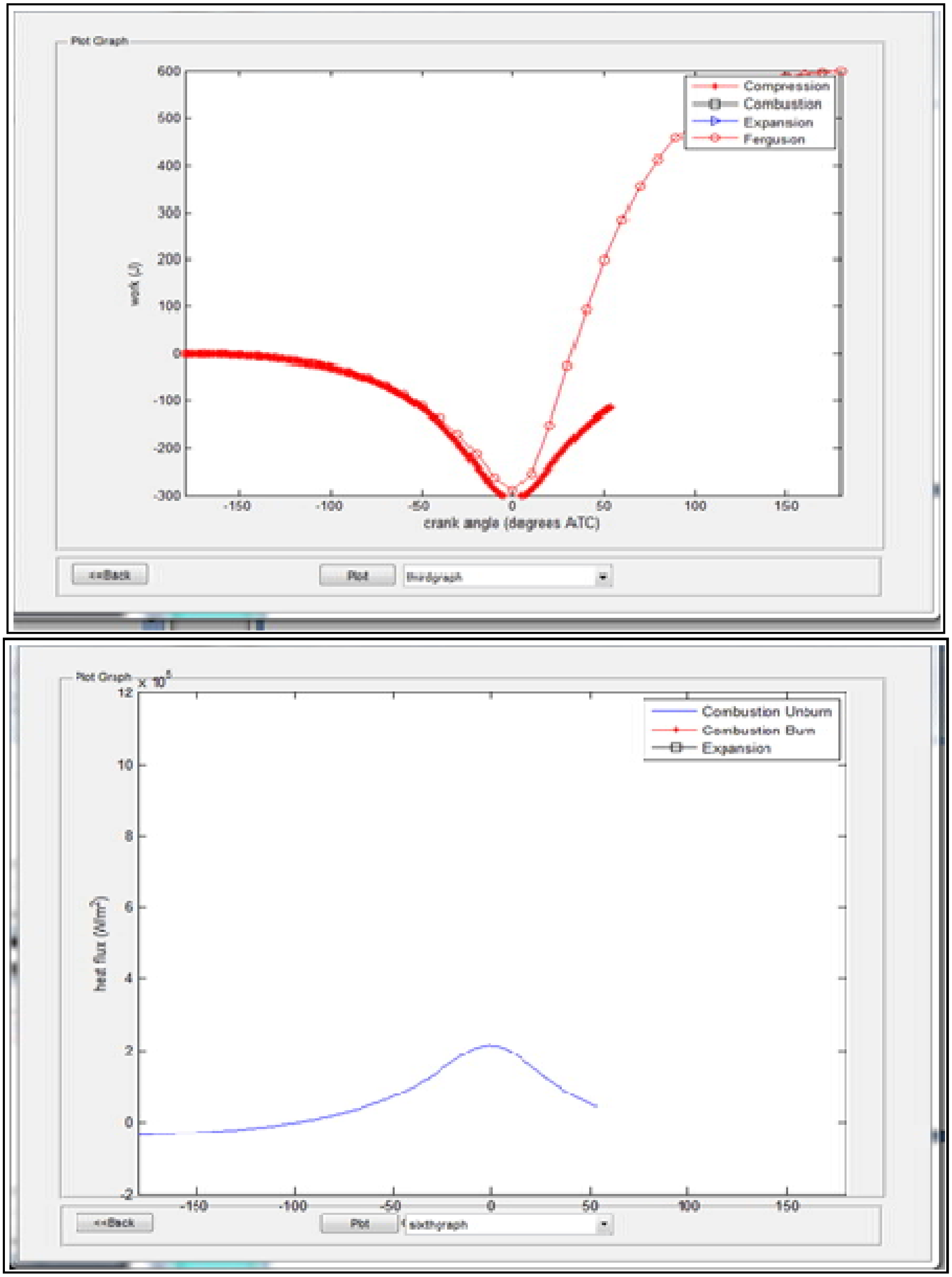
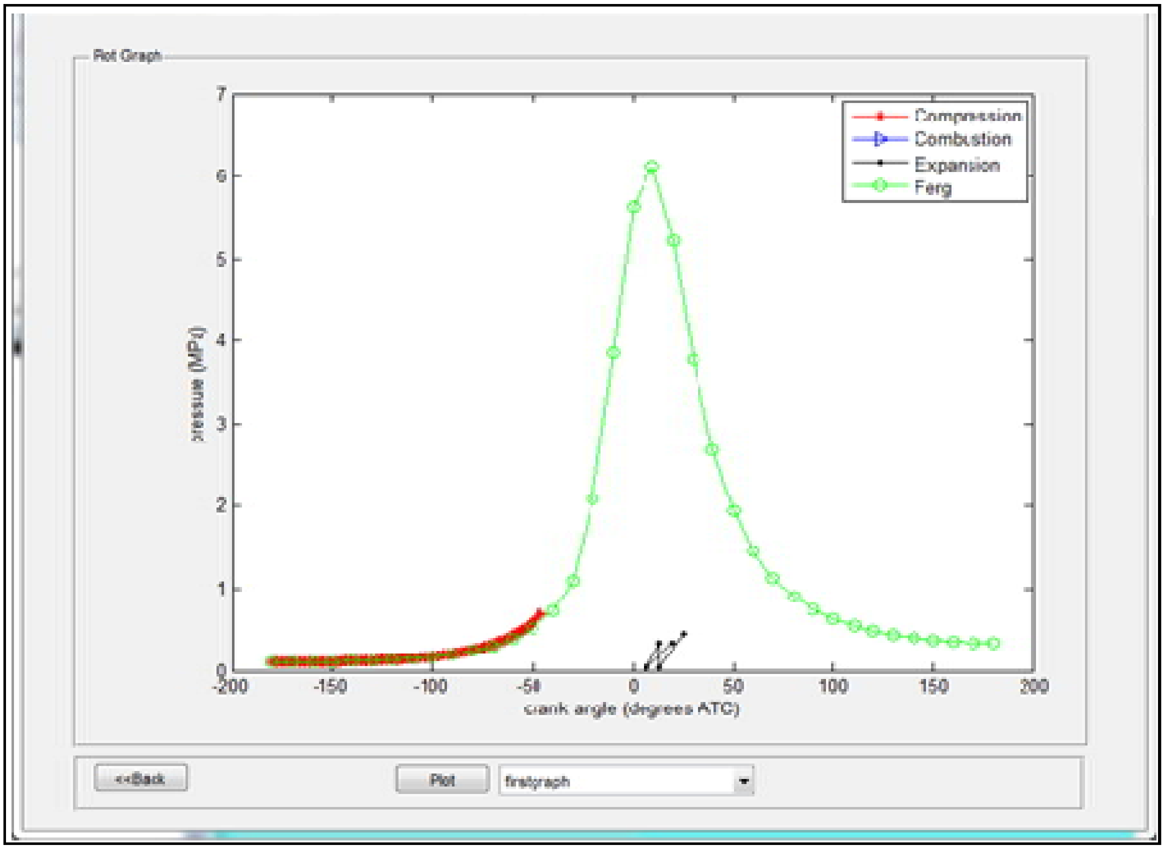
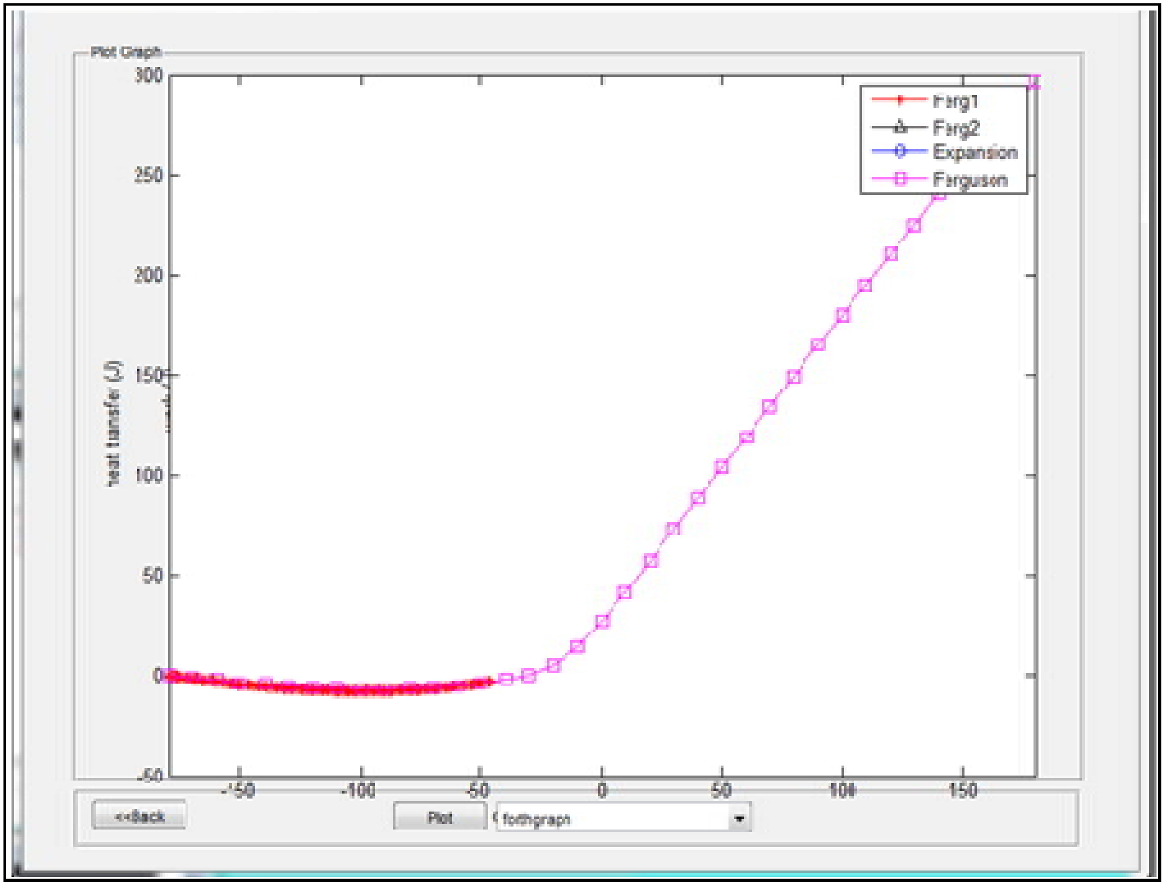
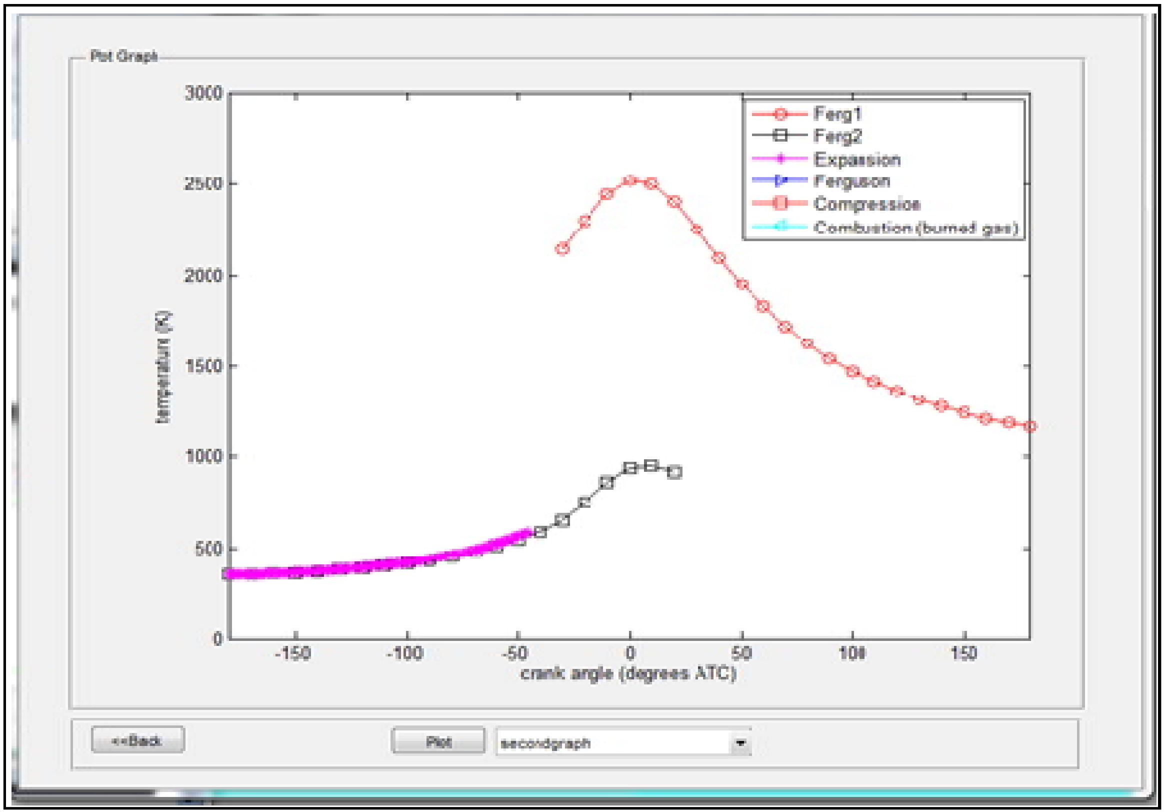
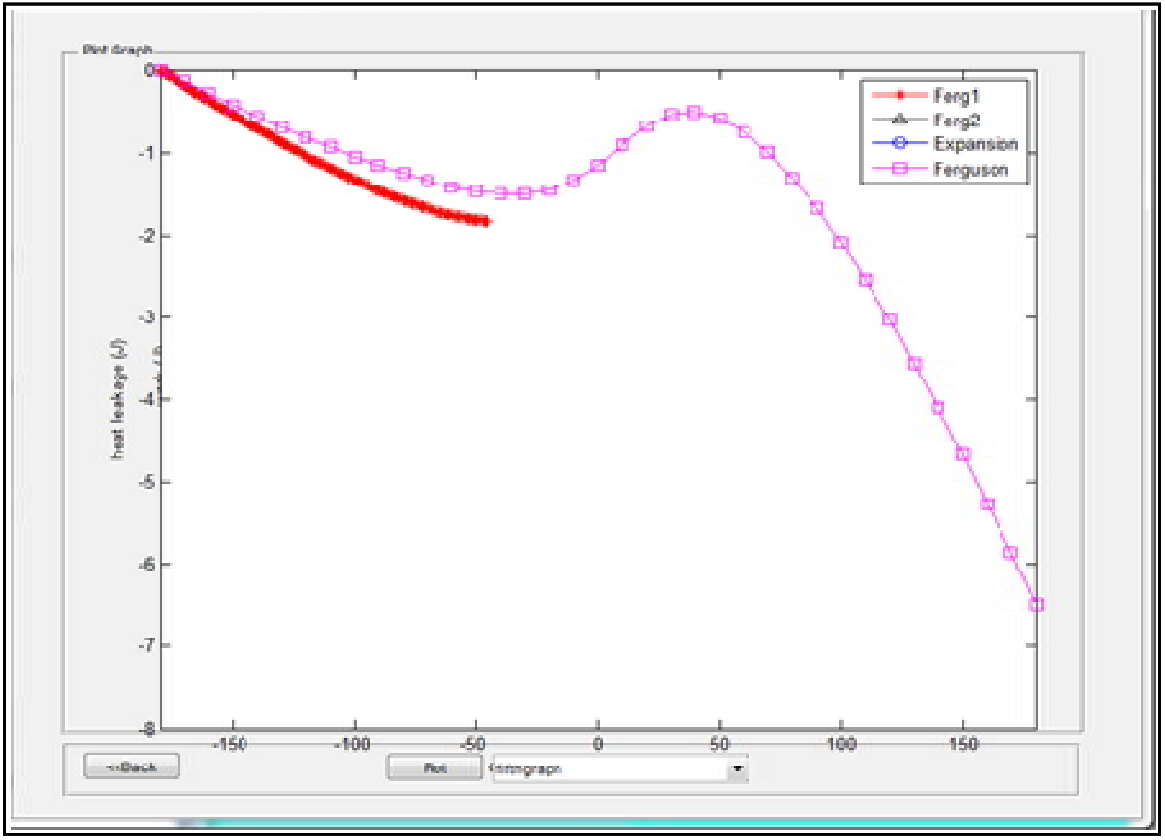


Figure 6: Plots of Pressure, Temperature, Heat Leakage, Work Output and Heat Release at -40^0bTDC Ignition timing and 40^0 burn duration angle


Plot Graph
Compression
Combustion
Expansion
Ferg
pressure (MPa)
crank angle (degrees ATC)
0
1
2
3
4
5
6
7
-200
-150
-100
-50
0
50
100
150
200
<<Back
Plot
firstgraph


Plot Graph
Ferg1
Ferg2
Expansion
Ferguson
heat transfer (J)
-50
0
50
100
150
200
250
300
-150
-100
-50
0
50
100
150
<<Back
Plot
forthgraph


Plot Graph
3000
2500
2000
1500
1000
500
0
temperature (K)
-150
-100
-50
0
50
100
150
crank angle (degrees ATC)
Ferg1
Ferg2
Expansion
Ferguson
Compression
Combustion (burned gas)
<<Back
Plot
secondgraph


Plot Graph
0
-1
-2
-3
-4
-5
-6
-7
-8
heat leakage (J)
-150
-100
-50
0
50
100
150
Ferg1
Ferg2
Expansion
Ferguson
<<Back
Plot
fifthgraph

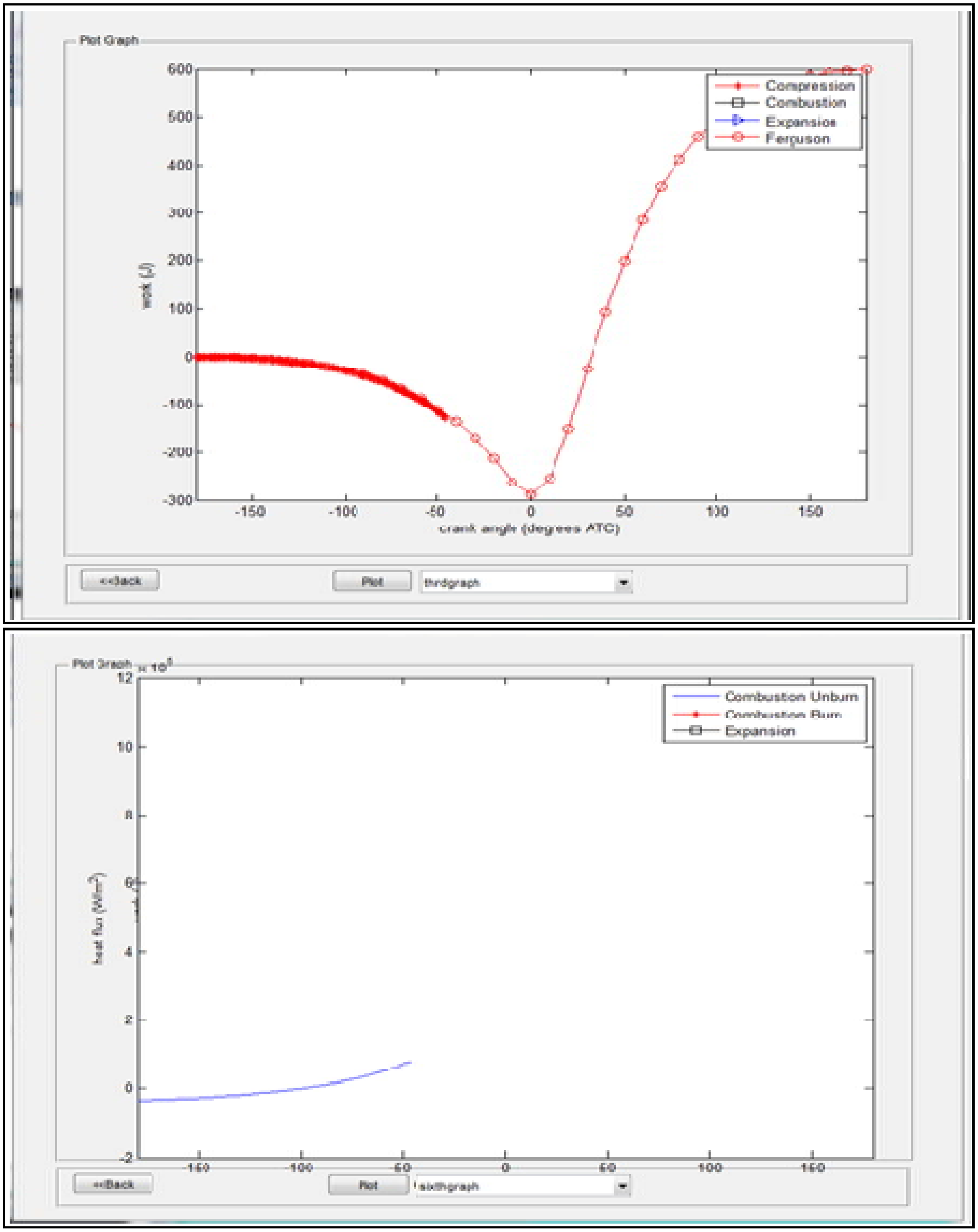
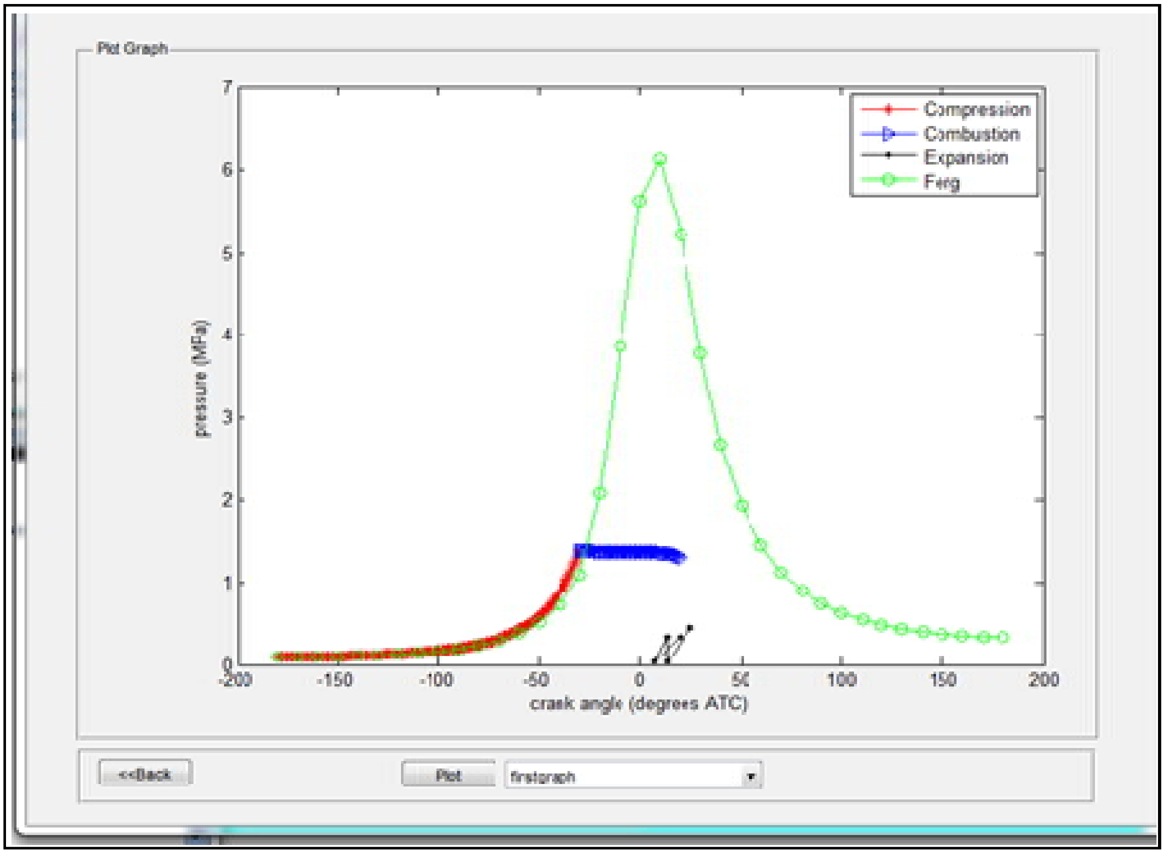
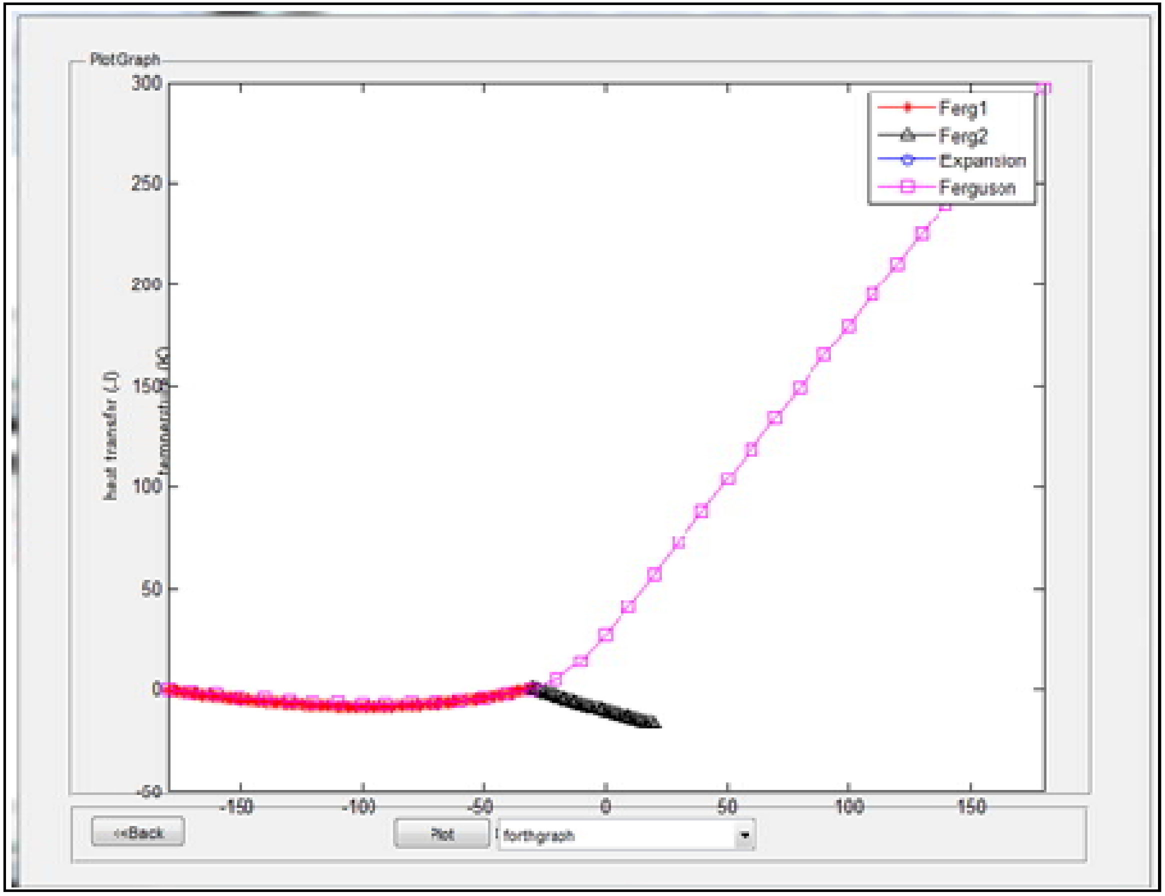
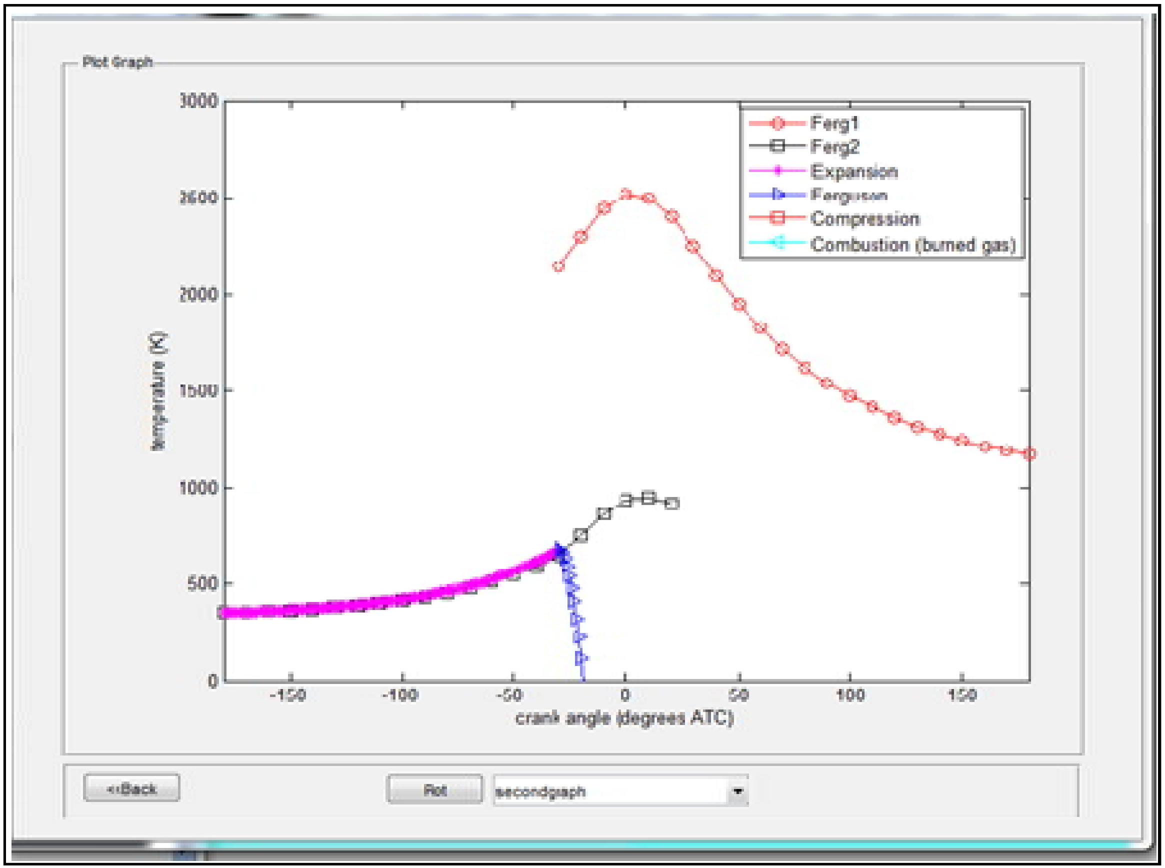
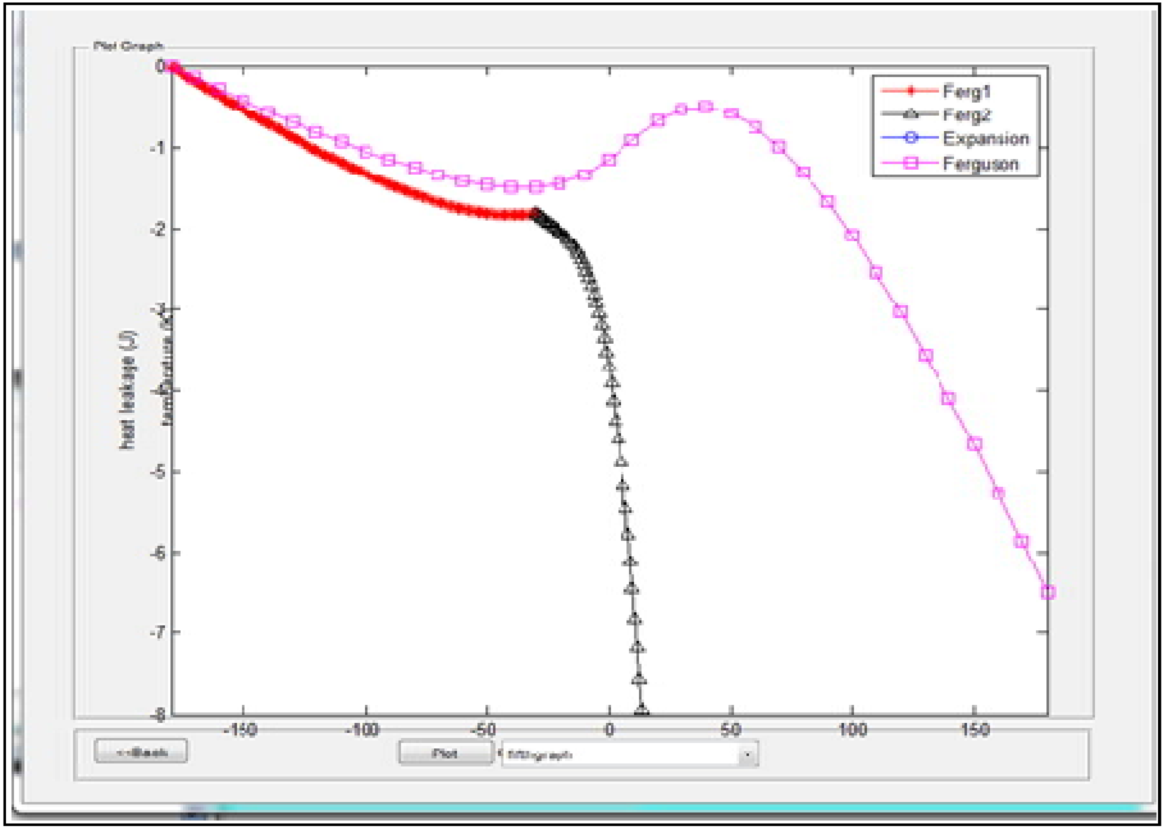


Figure 7: Plots of Pressure, Temperature, Heat Leakage, Work Output and Heat Release at 45.5^0bTDC Ignition timing and 5^0burn duration angle


Plot Graph
Compression
Combustion
Expansion
Ferg
pressure (MPa)
0
1
2
3
4
5
6
7
-200
-150
-100
-50
0
50
100
150
200
crank angle (degrees ATC)
<<Back
Plot
firstgraph


Plot Graph
Ferg1
Ferg2
Expansion
Ferguson
heat transfer (J)
temperature (K)
-50
0
50
100
150
200
250
300
-150
-100
-50
0
50
100
150
<<Back
Plot
forthgraph


Plot Graph
3000
2500
2000
1500
1000
500
0
temperature (K)
-150
-100
-50
0
50
100
150
crank angle (degrees ATC)
Ferg1
Ferg2
Expansion
Ferguson
Compression
Combustion (burned gas)
<<Back
Plot
secondgraph


Plot Graph
0
-1
-2
-5
-6
-7
-8
heat leakage (J)
-150
-100
-50
0
50
100
150
Ferg1
Ferg2
Expansion
Ferguson
<<Back
Plot

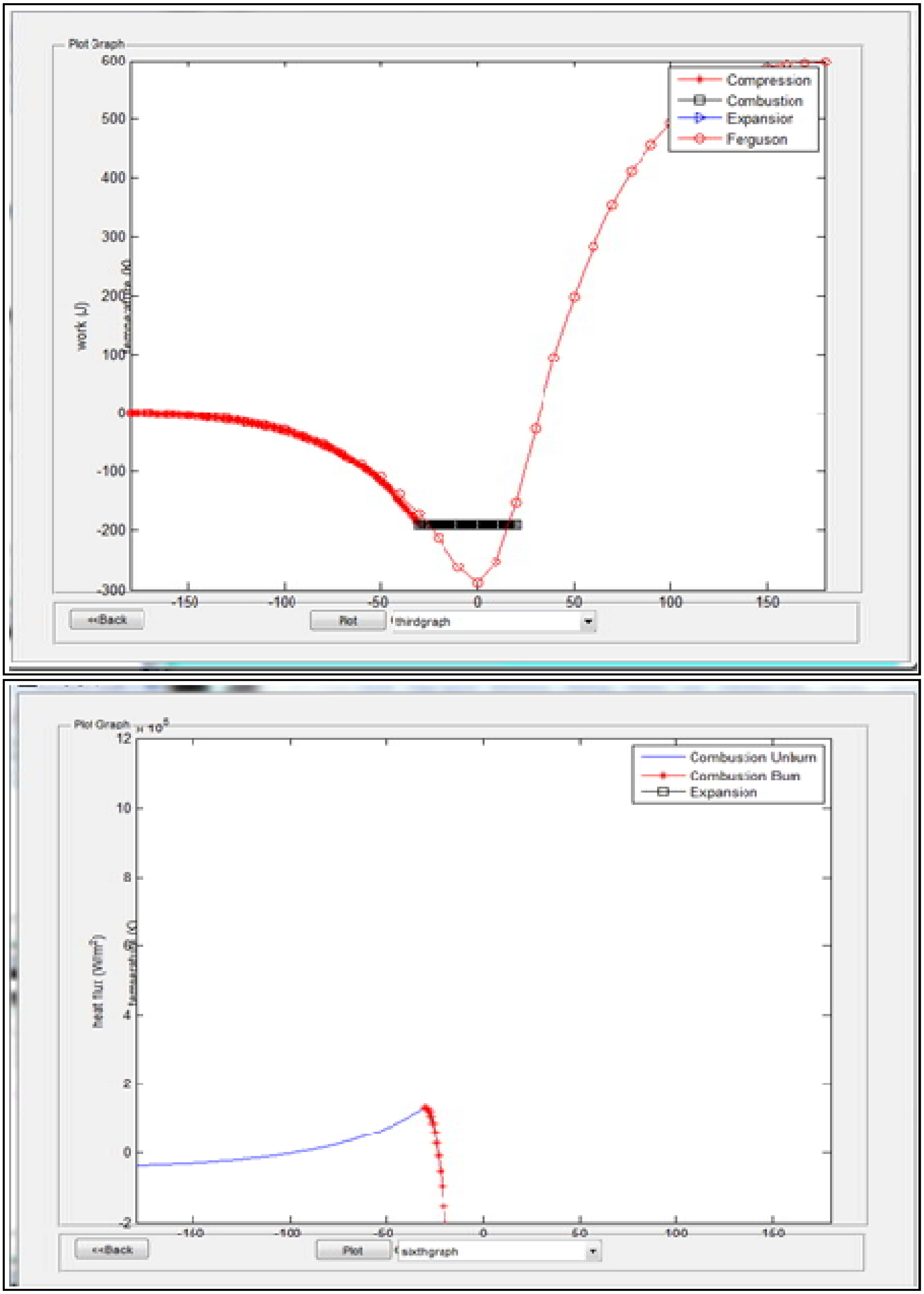
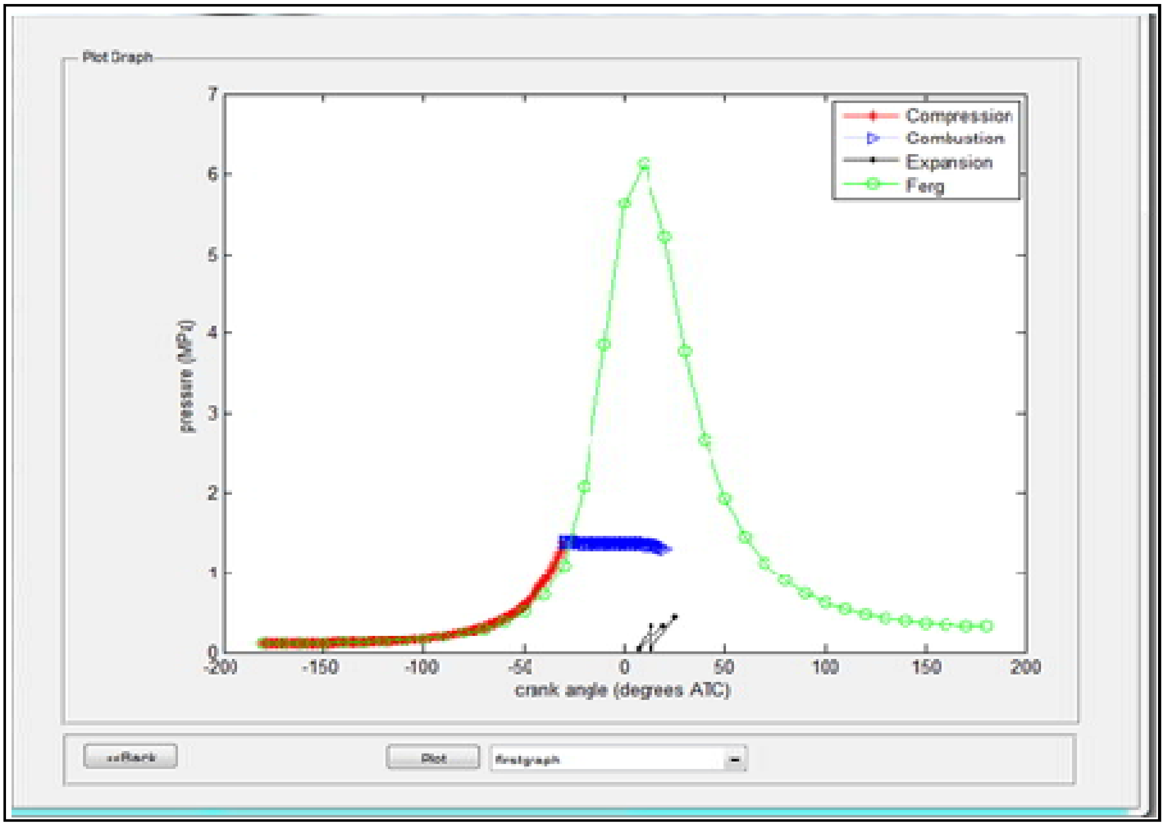
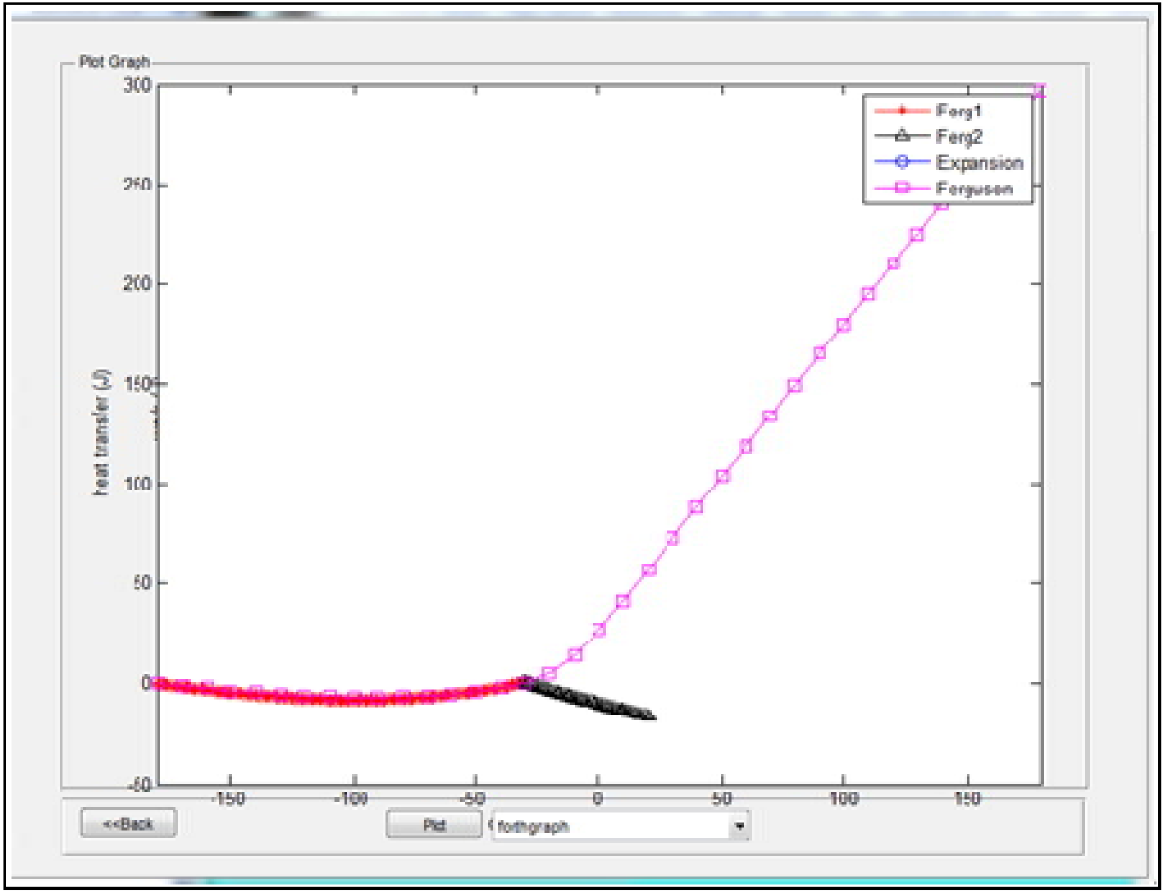
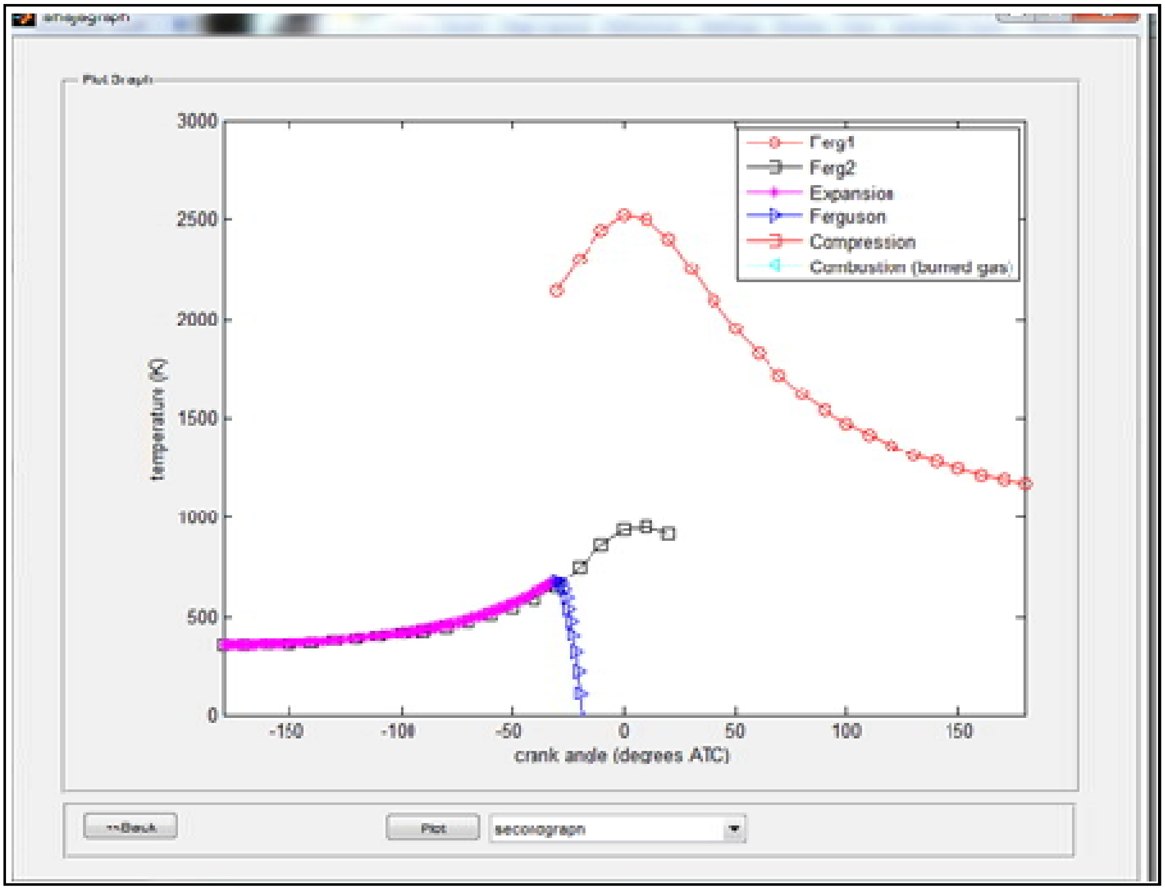
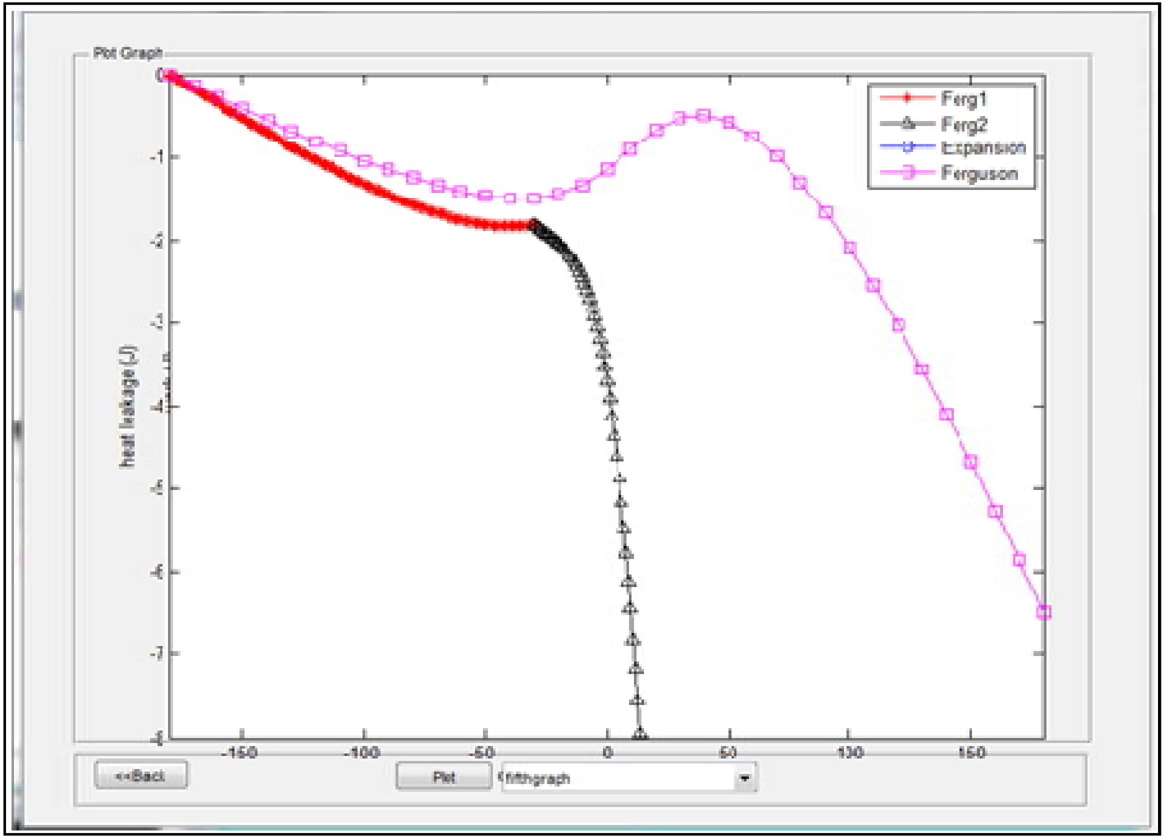


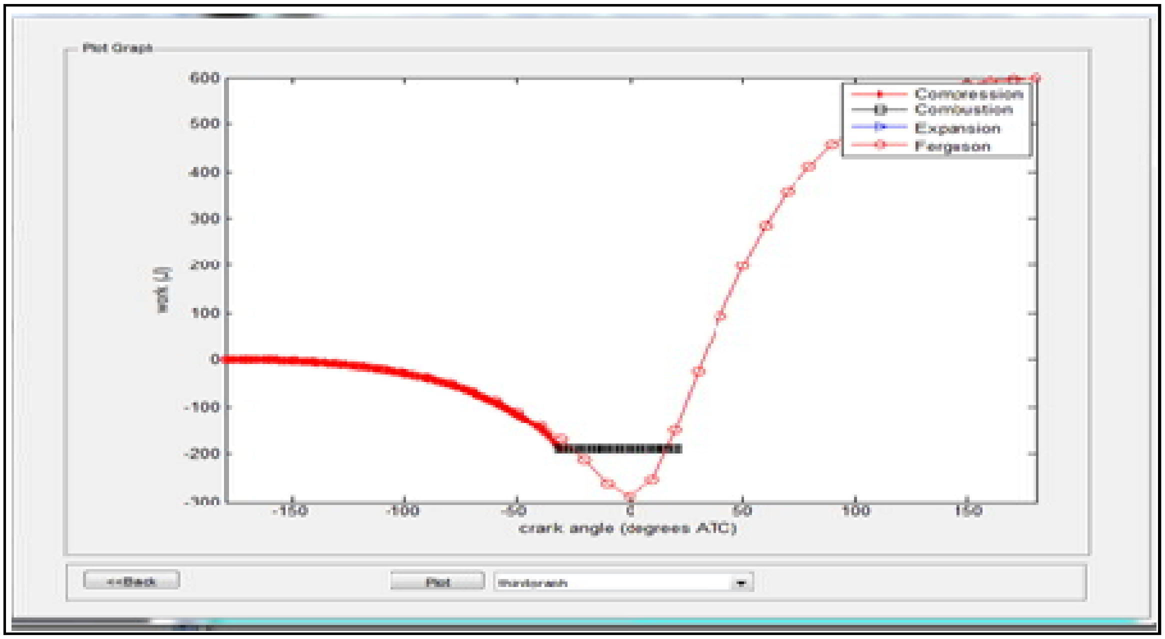
Figure 8: Plots of Pressure, Temperature, Heat Leakage, Work Output and Heat Release at 30^{0}bTDC Ignition timing and 50^0 burn duration angle


Plot Graph
Compression
Combustion
Expansion
Ferg
pressure (MPa)
crank angle (degrees ATC)
0
1
2
3
4
5
6
7
-200
-150
-100
-50
0
50
100
150
200
<<Back
Plot
firstgraph


Plot Graph
Ferg1
Ferg2
Expansion
Ferguson
heat transfer (J)
-50
0
50
100
150
200
250
300
-150
-100
-50
0
50
100
150
<<Back
Plot
forthgraph


Plot Graph
3000
2500
2000
1500
1000
500
0
temperature (K)
-150
-100
-50
0
50
100
150
crank angle (degrees ATC)
Ferg1
Ferg2
Expansion
Ferguson
Compression
Combustion (burned gas)
<<Back
Plot
secondgraph


Plot Graph
0
-1
-2
-3
-4
-5
-6
-7
-8
heat leakage (J)
-150
-100
-50
0
50
100
150
Ferg1
Ferg2
Expansion
Ferguson
<<Back
Plot
fifthgraph



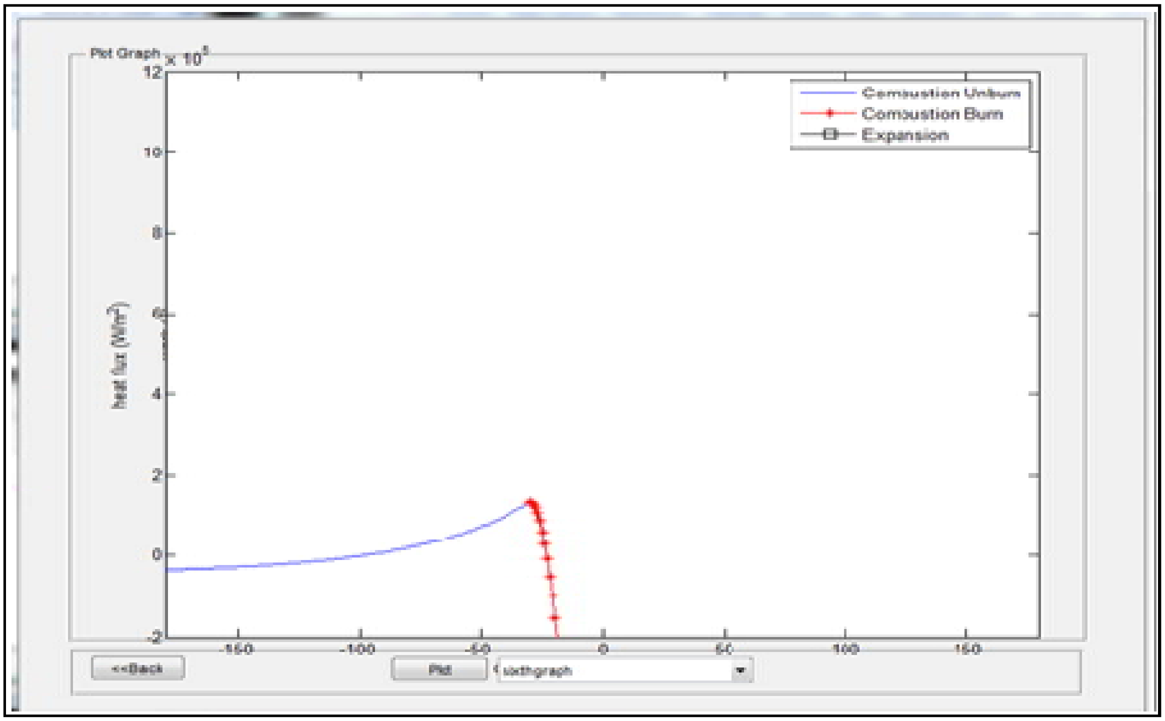


Figure 9: Plots of Pressure, Temperature, Heat Leakage, Work Output and Heat Release at 30^{0}bTDC Ignition timing and -40^0 burn duration angle