NOx Modelling and Combustion Analysis Using Cylinder Pressure Data by Callum Samuels

by Callum Samuels

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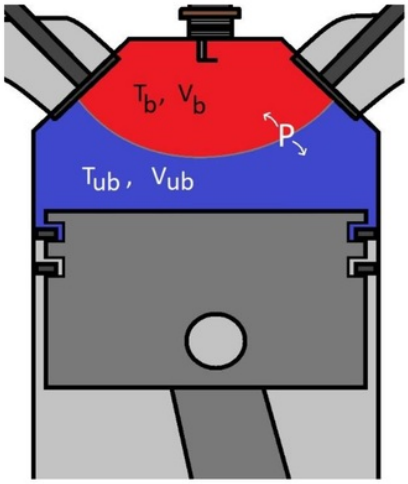
NOx Modelling and Combustion Analysis Using Cylinder Pressure Data

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for the degree of BEng Motorsport Engineering.
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NOx Modelling and Combustion Analysis Using Cylinder Pressure Data

Bachelor of Engineering: Motorsport BEng

Dissertation by Callum Samuels

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: *Date: 30/04/2019*

A B S T R A C T

This paper details a NOx formation model based on thermodynamic combustion principles of spark ignition engines. The cylinder pressure data from a Ford Fox EcoBoost engine is analysed and used to predict the formation of Nitrogen Oxide particles within the exhaust as parts per million (ppm). The thermodynamic relationships for real engine processes are characterized, a polytropic index for compression and expansion is established, the mass fraction burned is defined, and specific heats are found giving a value for gamma, denoting the adiabatic relationship of the burned and unburned zones within the cylinder. An in-dept evaluation of a Two Zone combustion model is produced which calculates temperatures and volumes of the burned and unburned zones using the ideal gas law. A method to calculate the dissociation of product species is included and used with the extended Zeldovich mechanism to plot NOx output throughout the rev range. These results are then compared with real engine test data and the model is analysed for accuracy and sensitivity. The assumptions used are discussed and the limitations of the model are defined.

Keywords: *Thermodynamics, Nitrogen Oxides, Ideal Gas Law, Two Zone Model, Dissociation*

A C K N O W L E D G E M E N T S

I have found this project very challenging and academically difficult. The vast amount of knowledge and background study needed within the realms of thermodynamics, thermochemistry and chemical kinetics seemed to get bigger and bigger as the project progressed. With the support of Malcolm McDonald however, I have stayed on track and focused to a point at which I now feel I have learnt a great deal and know where I can take this in the future. I would like to express my gratitude to Malcolm who really captivated me with this topic of combustion and NOx formation. Appreciation is also due to my family who have always supported me and my ambitions. A special thank you to my partner Alex who has put up with me through this intense time and backed me all the way. This dissertation would not be possible but for the people around me.

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NOMENCLATURE & PHYSICAL CONSTANTS

R	Gas Constant, R = 8.31451 $[\frac{J}{mol.k}]$
C_p	Specific Heat at Constant Pressure
C_v	Specific Heat at Constant Volume
M	Molecular Weight
m	Mass
n	Polytropic Index
P	Cylinder Pressure
ΔP	An increment of pressure due only to combustion
Q	Heat Transfer
Q_R	Chemical Energy Release by the Fuel Burning
Q_{HV}	Lower Heating Value or Calorific Value
T_1	Initial Cylinder Temperature
T_2	Final Cylinder Temperature
T_B	Temperature of Burned Zone
T_{ub}	Temperature of Unburned Zone
V_1	Initial Cylinder Volume
V_2	Final Cylinder Volume
V_B	Volume of Burned Zone
V_{UB}	Volume of Unburned Zone
t	Time

U	Internal Energy
MFB	Mass Fraction Burned
W	Work
γ	Specific Heat Ratio. $\gamma = C_p / C_v$
θ	Crank Angle
ρ	Density
φ	Fuel Air Equivalence Ratio
λ	Lambda, Air Fuel Equivalence Ratio

EOC	End of Combustion
SOC	Start of Combustion
IVO	Inlet Valve Opens
EVO	Exhaust Valve Opens
f	Fuel
C	Constant
TDC	Top Dead Centre
ATDC	After Top Dead Centre
BTDC	Before Top Dead Centre
BDC	Bottom Dead Centre
BMEP	Brake Mean Effective Pressure
IMEP	Indicated Mean Effective Pressure
I.C	Internal Combustion (engine)
MBT	Max Brake Torque (timing)

1 PREFACE

In 1876 Nikolaus Otto developed the spark ignition, internal combustion engine (SI ICE) [1]. Since then the internal combustion engine has changed very much and continues to do so with more and more pressure on automotive companies to find greener and more efficient solutions to the public's needs. Automotive players invest huge sums of money into the industry and into research and development with the goal of reducing fuel economy and more recently reducing the output of harmful emissions [2].

Currently in society the rise of electric cars and hybrid motors is greater than ever before but still very much in the shadow of internal combustion engines. The public are beginning to make a change and put pressure on the big players in response to increased awareness on global warming and air pollution.

This paper focuses on the output of Nitric oxide (NO) and Nitrogen dioxide (NO_2) which together are referred to as NOx. Nitrogen oxides are formed in the cylinder during the combustion process due to the reaction of atomic oxygen and nitrogen. Nitric oxide, NO, is not considered to be hazard to health but Nitrogen dioxide, NO_2, is. NO_2 in the atmosphere can cause irritation to the eyes, nose and throat and when inhaled can cause serious lung problems. The pie chart below, Figure 1, is from an icopal-noxite article [3] which shows that road transport is greatest source of NOx emissions in the EU during 2011.

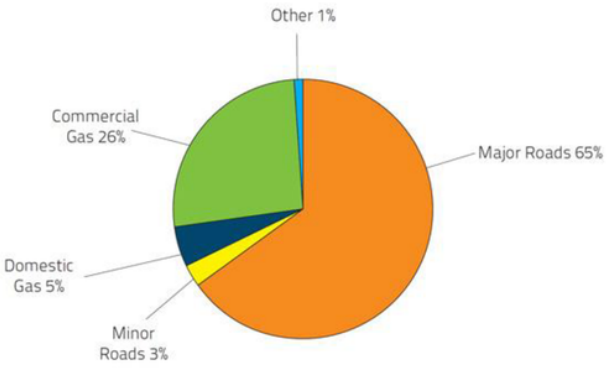


Figure 1 - European Union emission inventory report 2011 of NOx sources.

2 INTRODUCTION

With the goal of reducing NOx emissions having an accurate and useful mathematical model to predict the abundance of NOx in an engines exhaust from cylinder pressure data is desirable to designers. This paper documents, step by step the methodology and science of how to calculate NOx output and why nitrous oxides are formed in the combustion process. This dissertation begins with defining the test engine and data used. The cylinder pressure data is taken from a test that uses piezoelectric pressure transducer sensors in the cylinder. These sensors can accurately take a pressure reading for each degree of crank rotation. Measurements of cylinder pressure can be used to determine the location of peak pressure, instantaneous heat release, burn fraction, and fluid temperatures [4]. A review of various combustion data analysis models can be found in ref [5] by D Foster. The paper continues with a methodology describing how to produce a two-zone model representing the mixture as two zones, a burned and unburned zone. This model assumes the working fluids inside the engine act as ideal gases and obey the ideal gas law. This is used to calculate the relative temperature and volume of each zone. In order to produce a two-zone model, the polytropic indices and combustion timings are evaluated and used to determine a mass fraction burned for the combustion process with the specific heats of reactants and products determined from Heywood [6]. The formation reactions are temperature dependent and increase exponentially with an increase in temperature [5], so a dissociation model is created with the assumption that the working fluids are in chemical equilibrium. This gives values for N_2 and O_2 concentrations which are then used with the burned zone temperatures and the zeldovich/thermal NOx formation theory to yield the mols and ppm of NOx per cycle at each rev range from 1000-6500rpm. These results are compared with the test data results shown in Figure 2.

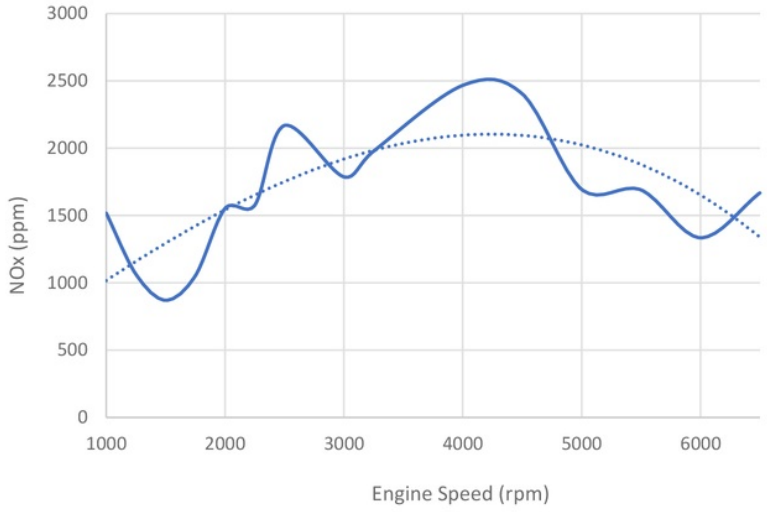


Figure 2 - NOx output at full load, throughout the rev range from engine test data on Ford Fox engine.

This graph shows the actual NOx output at each rpm in a real test. The NOx output is seen to be higher in the middle section of the rev range. This is understandable because at this range the turbo will be forcing more air and therefore fuel into the cylinder. As the revs continue the air to fuel ratio decreases and the mixture is richer, $\lambda<1<\phi$, more Oxygen is needed and used during the combustion and there are less free Oxygen atoms to react with Nitrogen atoms, shown by Jurgen [7] in Figure 3.

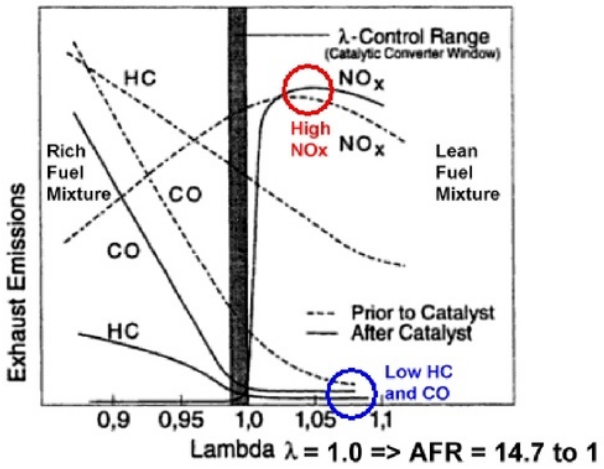


Figure 3 - Emission Curve against λ

3 TIMING PLAN

This project is vast and so good time management is essential. Table 1 shows the timing plan for this project. With guidance from Project Management by Maylor [8], a Gant chart is produced, Figure 4.

Task	Start Date	End Date	Duration
Project Start	18/10/2018	19/10/2018	1
Background reading	19/10/2018	09/05/2019	202
Background writing	19/10/2018	09/05/2019	202
Obtain cylinder pressure data	01/11/2018	02/11/2018	1
Begin Excel spreadsheet calculating engine geometry plotting PV diagrams and pressure vs crank angle graphs for all RPM	05/11/2018	15/11/2018	10
Continue to build on spreadsheet calculating work done and MEP for each RPM's	15/11/2018	22/11/2018	7
Analyse combustion	22/11/2018	29/11/2018	7
Use the polytropic index to calculate the change in pressure due to combustion and using determined combustion times plot the mass fraction burned against crank angle for all rpms	30/11/2018	06/12/2018	6
Create viva presentation	06/12/2018	10/12/2018	4
Interim Viva Presentation	11/12/2018	12/12/2018	1
Christmas and Other Work	12/12/2018	14/01/2019	33
Use the two-zone model to calculate the cylinder conditions at every crank angle degree	14/01/2019	15/02/2019	32
Create dissociation model using Zeldovich mechanism	15/02/2019	28/02/2019	13
Determine rate of formation of NOx for Fox engine	28/02/2019	09/03/2019	9
Research on way to improve methods and accuracy	09/03/2019	31/03/2019	22
Compare calculated results with actual test results	31/03/2019	10/04/2019	10
Evaluate results and findings then Finish writing dissertation	10/04/2019	20/04/2019	10
Start Creating Final Viva Presentation	30/03/2019	04/05/2019	35
Final and Last checks	30/03/2019	25/04/2019	26
Final Report Submission			194
Final Presentation Checks	04/05/2019	06/05/2019	2
Final Viva			1

Table 1 - Project Timings and Gant Chart table.



Figure 4 - Project Gant Chart.

4 TEST & TECHNICAL DATA

The Ford Fox engine, Figure 5, is a 1 litre, 3-cylinder, turbocharged engine found driving many of Ford's hatchback models such as the Ford Fiesta EcoBoost and Focus EcoBoost. The Fox engine has direct fuel injection and variable cam timing technology. The compact engine produces about 125hp at 6000rpm while delivering about 170Nm of torque between 1400-4500rpm. The fox engine is more economical and environmentally friendly than past engine designs for these models and bigger versions on this engine are being use throughout the ford range. The Fox engine averages an mpg of around 35mpg for city driving. An article from 'WardAuto' [9] claims after - 'spanking red line for 10 days' - the value was closer to the official mpg than expected at 36mpg on average. The engine is small, lightweight, and powerful thanks to the collaboration of clever ancillaries and an efficient turbo.



Figure 5 - Ford Fox 1L EcoBoost Engine.

4.1 ENGINE SPECIFICATION

Type	Inline three-cylinder turbo petrol direct fuel injection and Ti-VCT, transverse	
Fuel	Isooctane, C_8H_{18}	
Displacement	999	cm^3
Cylinders	3	
Bore	71.9	mm
Stroke	0.082	mm
Compression Ratio	10:1	
Crank Stroke	0.082	mm
Crank Throw, R	0.041	mm
Length of Con Rod, L	0.183	mm
Valve Gear	DOHC with 4 valves per cylinder, twin independent variable cam timing	
Mass of Piston	0.235	kg
Displacement	0.00099881	mm^3
Cylinder Displacement	0.00033294	mm^3
Head Volume	3.6993E-05	mm^3
Turbocharger	Continental low inertia turbo	
Cylinder Head	Cast Aluminium	
Cylinder Block	Cast Iron	

4.2 ENGINE TEST DATA

The cylinder pressure data used in this project is from a real-life engine test on the Fox engine. The test produces multiple maps of engine parameters which are given in pdf form across the load and rev range.

The engine geometric properties are determined with the below equations;

- $Volume_{Cylinder}$, $V_{cyl} = Clearance\ Volume + (\left(\frac{\pi\ bore^2}{4}\right) x\ Piston\ Travel)$

- $Piston\ Travel,\ S\ =\ (\ R + L\ ) - (R\cos\theta\ ) - (L\cos\phi)$

- $Clearance\ Volume,\quad V_{clearance}\ =\ \frac{Cylinder\ Displacement}{CR\ -1}$

- $Rod\ Angle,\ \phi\ =\ Sin^{-1}\ (\left(\frac{R}{L}\right) * Sin\ \theta)$

Where;
- Bore is in metres and found in the technical data.
- R is the crank throw in metres, or half the stroke found in the technical data.
- L is the length of the connecting rod in metres, given in the technical data.
- θ, is the crank angle in degrees (given).
- ϕ is the con rod angle in degrees.
- CR is the compression ratio found in the technical data.

Figure 6 is from C F Taylor [10] and shows this trigonometric relation.

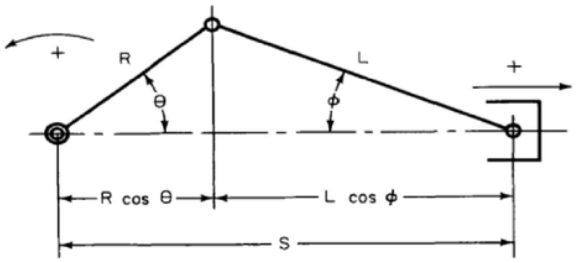


Figure 6 - Piston, Rod and Crank schematics from C F Taylor.

The engine test report contains a vast number of tables on different parameters and conditions during operation throughout the test. Figure 7 and Figure 8 on the next page are the tables used in this model for the mass of air and fuel in the cylinder for each rev range at full load. Although these tables are not exact the error is negligible and these provide an accurate basis for NOx prediction.

The air and fuel mass is converted from kg per hour to kg per cycle with the following step;

$$\frac{Kg}{Hour} \xrightarrow{\div\,(60 \times RPM \times 1.5)} \frac{Kg}{Cycle}$$

From here the mass of the reactants in the cylinder can be used to calculate and the air-fuel ratio, AFR, which in turn gives Lambda, λ, and Fuel Air equivalence ratio, ϕ.

$$Air\ Fuel\ Ratio, \qquad AFR = \frac{Air\ mass}{Fuel\ mass}$$

$$Lambda, \qquad \lambda = \frac{AFR_{Actual}}{AFR_{Stoichimetric}}$$

Stoichiometry is detailed in Appendix 1. For isooctane the stoichiometric air/fuel ratio is 15.05.

$$Fuel\ Air\ Equivalence\ ratio, \qquad \phi = \lambda^{-1}$$

FUELMASS kg/h

	800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
FL		3.24	5.22	7.52	9.39	11.35	12.92	14.34	18.08	18.92	21.54	22.34	25.55	26.61	27.62	25.11
200						11.34	12.96	14.25	17.78	19.47						
190						10.77	12.04	13.39	16.91	18.46						
180					9.11	10.05	11.26	12.52	15.24	17.76	20.61					
170				7.51	8.77	9.38	10.52	11.72	14.06	17.14	18.91	21.41				
160				7.10	8.08	8.74	9.77	10.88	13.05	15.06	17.46	19.80	23.68			
150				6.52	7.46	8.17	9.12	10.19	11.98	14.00	16.18	18.15	20.99	24.47		
140			5.19	6.04	6.84	7.63	8.45	9.44	11.01	12.93	14.87	16.65	18.92	21.63	25.58	
130			4.73	5.46	6.16	6.96	7.73	8.55	10.05	11.89	13.84	15.40	17.30	19.71	22.93	
120			4.35	4.93	5.75	6.39	7.07	7.79	9.15	10.95	12.86	14.24	15.88	18.00	20.45	23.30
110		3.22	3.91	4.52	5.24	5.78	6.43	7.13	8.42	9.97	11.65	13.06	14.58	16.31	18.66	20.90
100		2.97	3.43	4.13	4.66	5.20	5.78	6.48	7.71	9.03	10.53	11.88	13.38	15.00	16.78	19.21
90		2.56	3.00	3.60	4.11	4.55	5.13	5.77	6.90	8.05	9.36	10.70	12.11	13.59	15.15	16.95
80		2.20	2.66	3.15	3.59	4.05	4.55	5.13	6.11	7.13	8.39	9.56	10.95	12.32	13.64	15.25
70		1.89	2.33	2.77	3.21	3.60	4.07	4.56	5.40	6.32	7.45	8.44	9.71	10.92	12.18	13.69
60		1.63	2.02	2.42	2.78	3.12	3.54	4.02	4.75	5.54	6.50	7.39	8.51	9.60	10.76	12.04
50		1.38	1.73	2.08	2.38	2.70	3.03	3.41	4.09	4.80	5.60	6.41	7.31	8.25	9.33	10.42
40	1.04	1.16	1.46	1.76	2.01	2.28	2.57	2.87	3.46	4.10	4.77	5.48	6.27	7.10	7.94	8.92
30	0.89	0.95	1.19	1.42	1.67	1.88	2.13	2.36	2.85	3.41	3.94	4.55	5.21	5.94	6.62	7.51
20	0.61	0.73	0.93	1.10	1.30	1.48	1.65	1.84	2.21	2.67	3.13	3.64	4.18	4.76	5.37	6.08
10	0.44	0.51	0.65	0.78	0.93	1.05	1.16	1.29	1.63	1.92	2.38	2.72	3.18	3.64	4.18	4.79
5	0.36	0.42	0.53	0.63	0.79	0.88	0.98	1.09	1.32	1.60	1.99	2.33	2.73	3.14	3.56	4.08
2	0.32	0.39	0.46	0.56	0.66	0.78	0.86	0.98	1.22	1.44	1.83	2.09				

Figure 8 - Table of Fuel Mass Injected in Cylinder at Different Loads and RPMs.

AIRMASS kg/h

	800	1000	1250	1500	1750	2000	2250	2500	3000	3500	4000	4500	5000	5500	6000	6500
FL		52.6	85.3	121.6	141.1	165.0	186.4	207.8	**	261.1	304.9	312.5	343.7	357.4	362.7	331.9
200						164.9	186.2	206.6	**	282.4						
190						156.2	174.0	194.3	231.1	259.1						
180					136.6	145.9	163.6	181.5	215.2	246.5	291.5					
170				121.5	136.8	136.5	153.2	170.0	204.6	235.8	271.4	299.8				
160				115.2	127.1	127.8	142.4	157.9	190.1	219.1	253.8	278.7	322.5			
150				106.4	118.2	119.9	133.3	147.9	174.5	203.7	235.4	259.4	294.9	335.9		
140			84.2	97.9	108.6	112.0	123.7	137.5	160.6	188.1	216.4	242.4	273.5	303.4	341.8	
130			76.1	88.1	96.7	102.4	113.4	125.3	147.3	172.8	201.3	224.2	252.8	278.5	313.2	
120			69.6	77.4	85.4	94.5	104.0	114.4	134.6	159.1	187.2	208.0	232.1	258.8	283.5	316.6
110		51.7	62.6	70.2	78.0	85.7	94.8	104.8	123.9	145.3	169.9	191.2	213.3	238.5	262.0	290.3
100		44.7	54.2	61.4	69.4	77.2	85.1	95.3	113.5	132.8	154.5	174.6	196.4	220.1	243.1	267.1
90		38.3	46.4	53.6	61.1	67.2	75.6	85.1	101.8	118.6	138.1	158.0	178.5	200.2	222.4	248.2
80		32.7	39.4	46.7	53.2	59.8	67.1	75.7	90.3	105.4	124.0	141.7	161.7	181.6	201.0	224.1
70		28.0	34.5	41.1	47.6	53.3	60.1	67.4	80.0	93.5	110.1	125.0	143.5	161.3	179.6	201.3
60		24.2	29.9	35.9	41.1	46.1	52.4	59.5	70.4	82.0	96.1	109.2	125.9	142.0	158.8	177.1
50		20.6	25.7	31.0	35.4	39.9	44.9	50.5	60.6	71.1	82.9	94.8	108.1	122.1	138.0	153.7
40	15.3	17.3	21.7	26.1	29.8	33.7	38.1	42.5	51.3	60.9	70.7	81.2	92.8	105.1	118.0	132.1
30	13.2	14.2	17.8	21.2	24.8	27.9	31.6	35.0	42.2	50.6	58.4	67.4	77.1	87.8	98.4	111.3
20	9.0	10.7	13.8	16.3	19.3	22.0	24.5	27.4	32.9	39.6	46.4	54.0	61.8	70.4	79.5	89.9
10	6.5	7.5	9.6	11.5	13.8	15.6	17.3	19.2	24.2	28.5	35.2	40.3	46.8	53.6	61.7	70.5
5	5.3	6.2	7.8	9.4	11.6	13.0	14.6	16.2	19.6	23.7	29.5	34.5	40.1	46.1	52.2	59.9
2	4.6	5.7	6.8	8.3	9.7	11.6	12.7	14.6	18.1	21.4	27.0	31.0				

Figure 7 - Table of Air Mass in Cylinder at Different Loads and RPMs.

5 METHODOLOGY & DATA ANALYSIS

This chapter documents the method in which one would go about calculating the parts per million of NOx particles emitted from the Fox engine using cylinder pressure data acquired from engine testing. The method involves modeling the combustion chamber as two zones, an unburned zone, and a burned zone. The following information tells the reader how to construct and calculate properties of these zones such the volumes and temperatures. The temperatures are particularly important as the rate of NOx formation increases exponentially with an increase in temperature. A range of analytical methods are used to make the relevant calculations and evaluations. Several computer programs can be used to aid in the engineer's calculations, those such as MATLAB, SageMath, and Julia can handle vast matrices and produce useful graphs. Studies by A Rohde [11] and J Patterson [12] use MATLAB to simulate combustion. Excel is also well suited to modeling of NOx formation in two zones, this is demonstrated throughout this chapter. For similar studies using this method, the reader is referred to ref [13, 14, 15].

5.1 PRESSURE-CRANK ANGLE DIAGRAM

Pressure vs crank angle graphs are critical in combustion analysis and tell the calibration engineer a lot visually before making any calculations. Cylinder pressure changes with crank angle as a result of cylinder volume change, combustion, heat transfer to the cylinder walls, flow into and out of crevice regions and leakage. The first two of these have the largest effects [6]. Figure 9 shows a p-θ diagram for 3500rpm while Figure 10 highlights the variation across the rev range. Studies on these graphs are found in [16, 17].

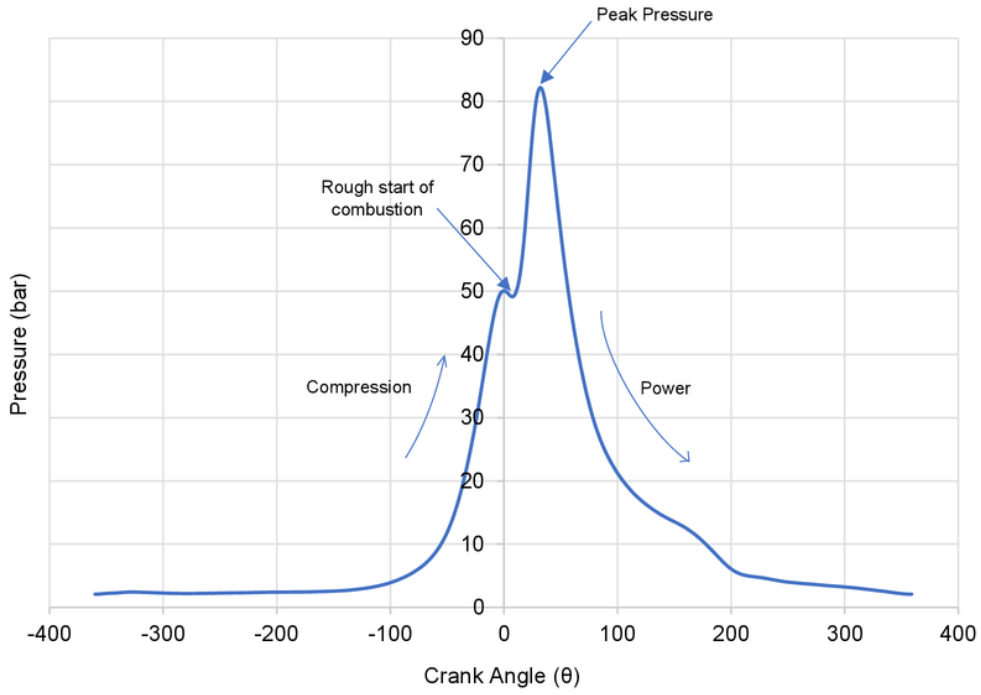


Figure 9 - Pressure vs Crank Angle graph from Ford Fox engine at 3500rpm.

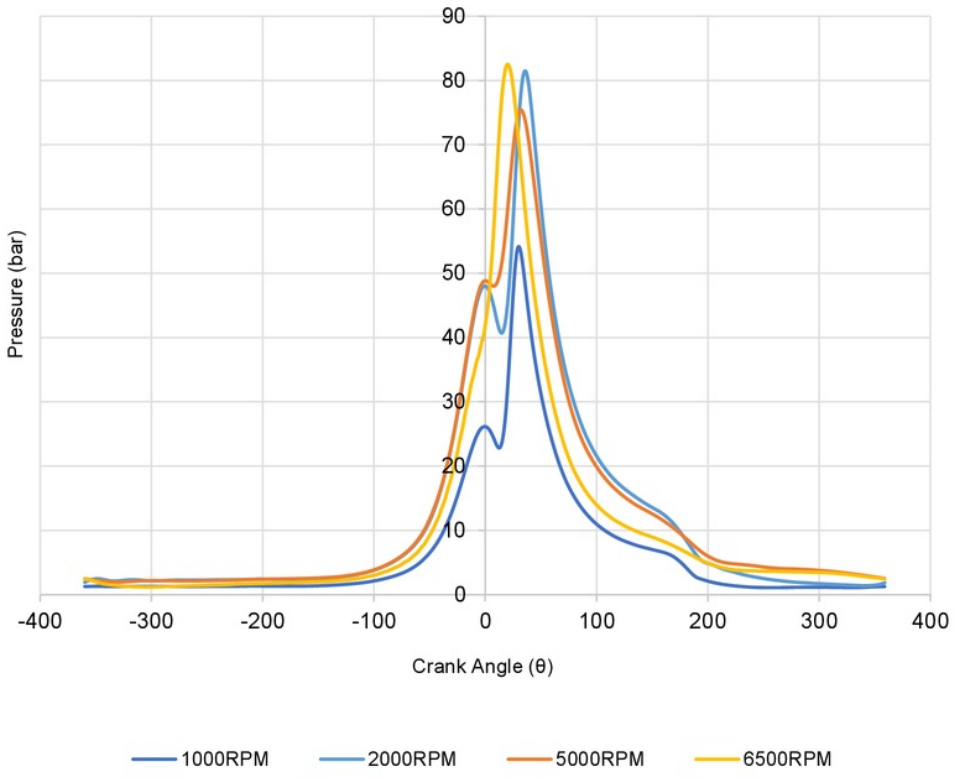


Figure 10 - Pressure vs Crank Angle across the rev range for Ford Fox engine.

5.1 PRESSURE-VOLUME DIAGRAM

Pressure vs volume diagrams are an extremely useful visual aid to what is happening inside the cylinder during a complete four-stroke cycle. The curve follows the variation of pressure and volume inside a cylinder. The graph also indicates the characteristics within the engine.

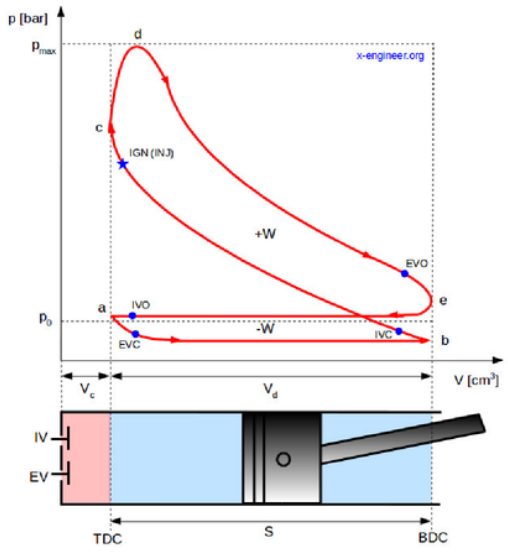


Figure 11 - x-engineer pV Diagram.

Figure 11 is a simple example of a pV diagram, from an automotive engineering article by x-engineering.

- (a-b) Intake Stroke
- (b-c) Compression Stroke
- (c-d) Combustion Process
- (d-e) Expansion Stroke
- (e-a) Exhaust Stroke.

The area bound by the curve between, b-c-d-e-b, +W, equals the amount of work done by the fuel and air combusting.

Because;

$$Work\ Done = Force\ x\ Distance$$

And;

$$Force = Pressure_{cylinder}\ x\ Area_{piston}$$

Then;

$$W = Pressure_{cylinder}\ x\ Area_{piston}\ x\ Distance_{stroke}$$

Therefore, instantaneous work done is;

$$W = Pressure_{cylinder}\ x\ Volume_{cylinder}$$

So the integration of this determines the work for the complete engine cycle;

$$W = \int P\ .\partial V$$

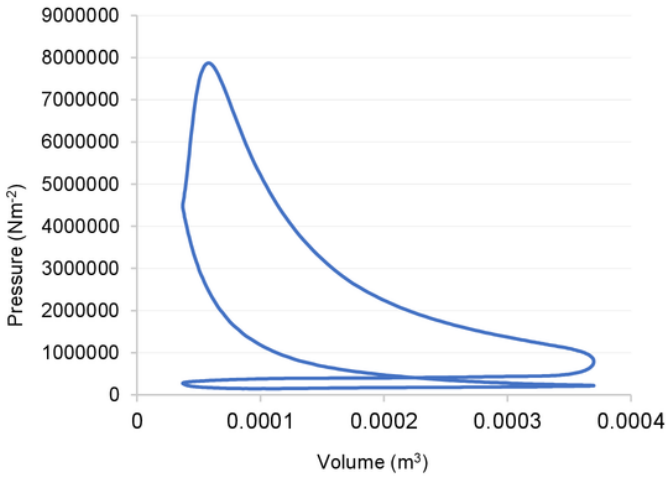


Figure 12 - Pressure vs Volume Graph for Ford Fox engine at 6000rpm.

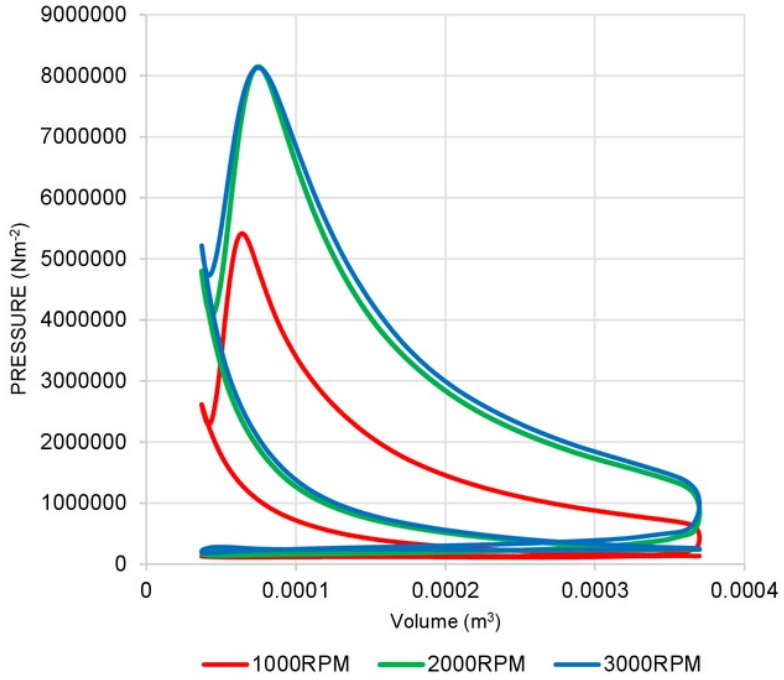


Figure 13 - PV across low rev range for Ford Fox Engine.

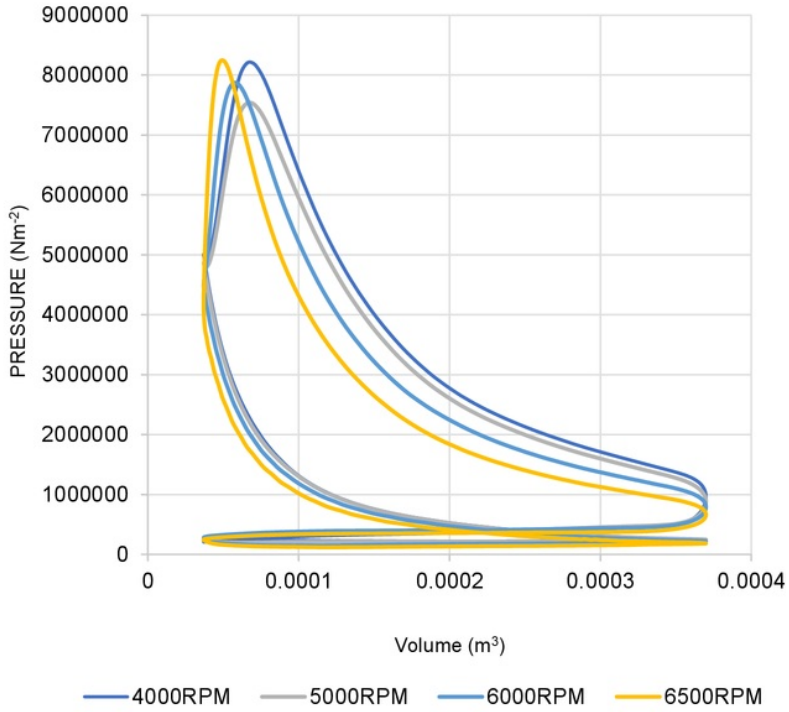


Figure 14 - pV diagram across higher rev range for Ford Fox engine.

5.3 LOG P-LOG V DIAGRAM

Log P vs Log V graphs like the one below in Figure 15 give a great deal of information regarding the quality and timings of the combustion process. The gradient of the straight line gives the polytropic index for the compression and expansion strokes (next section). The point at which the curve begins to depart from the straight line is where combustion starts. The point at which the curve returns to a straight line is where combustion is said to have finished (section 5.5).

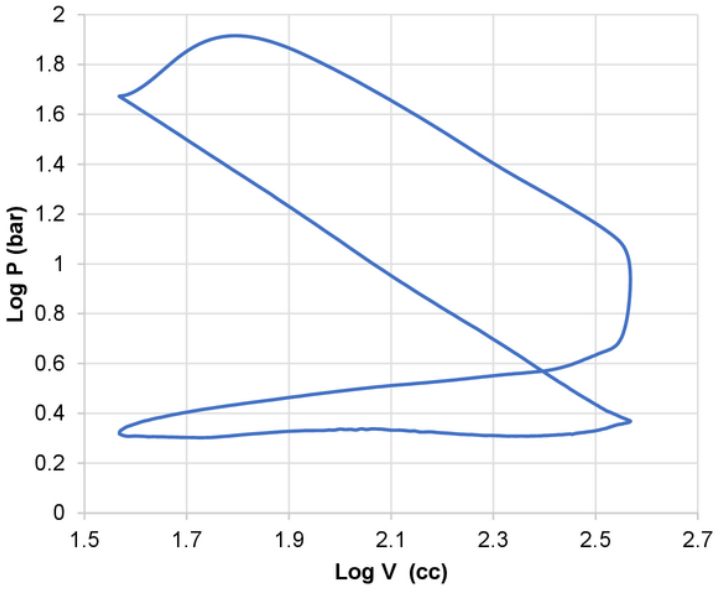


Figure 15 - Log pV diagram from Ford Fox engine at 4500rpm.

5.4 POLYTROPIC INDICES

Heywood [6] states an engine can be analysed best as an open system which releases heat, and exchanges work with the surroundings. During the compression and expansion stroke, the piston does work on the gases inside the cylinder and the pressure and temperature of the gases change. Assuming the air and fuel in the cylinder behaves as an ideal gas, (see Appendix 1), the compression and expansion strokes are not quite adiabatic due to heat loss but can be modeled as polytropic processes according to Lancaster [18] Caris et al [19] where;

Equation 1

$$pV^n = C$$

Where p is pressure, V is volume, n is the polytropic index, and C is a constant [20].

Equation 2

$$K = \frac{\delta Q}{\delta W} = C$$

Where K is the ratio of energy transfer as heat, δQ, to energy transfer as work, δW, is also constant, C [20].

In an ideal cycle, such as the one from Nasa [21] in Figure 16 the compression and expansion strokes can be treated as an isentropic process because they are adiabatic (no heat loss) and reversible. In a real cycle, however, like in Figure 17 taken from the Ford Fox data, the heat loss to cylinder walls and friction are considered. The thermodynamic processes that make up the 4-stroke cycle are defined in more detail in Appendix 1. Taking the logarithm of both sides for Equation 1 allows one to find n;

- log (pV^n) = constant
- log p + log V^n = constant
- log p + n.log V = constant ⟶ log p = n . log V + C (y = mx + c)
  Equation of a straight line.

Equation 3

- n = $\frac{-\Delta \log p}{\Delta \log V}$ = gradient

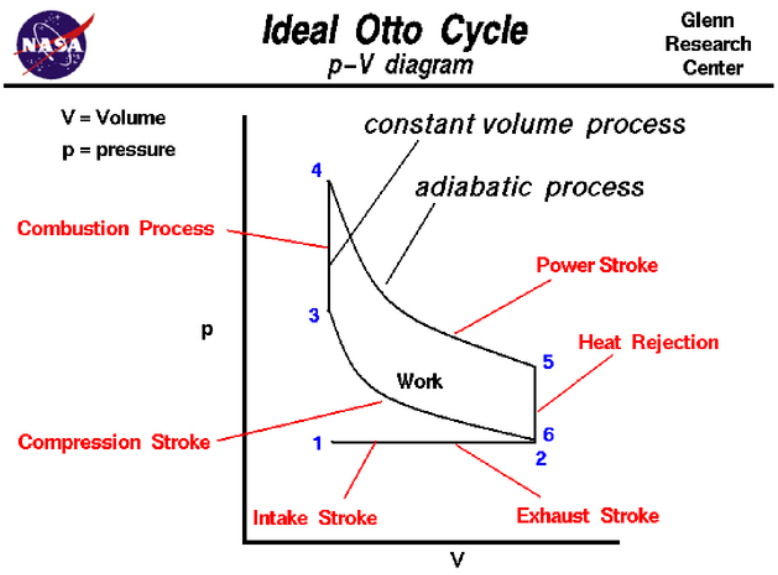


Figure 16 - Ideal Otto Cycle pV diagram from Nasa [21].

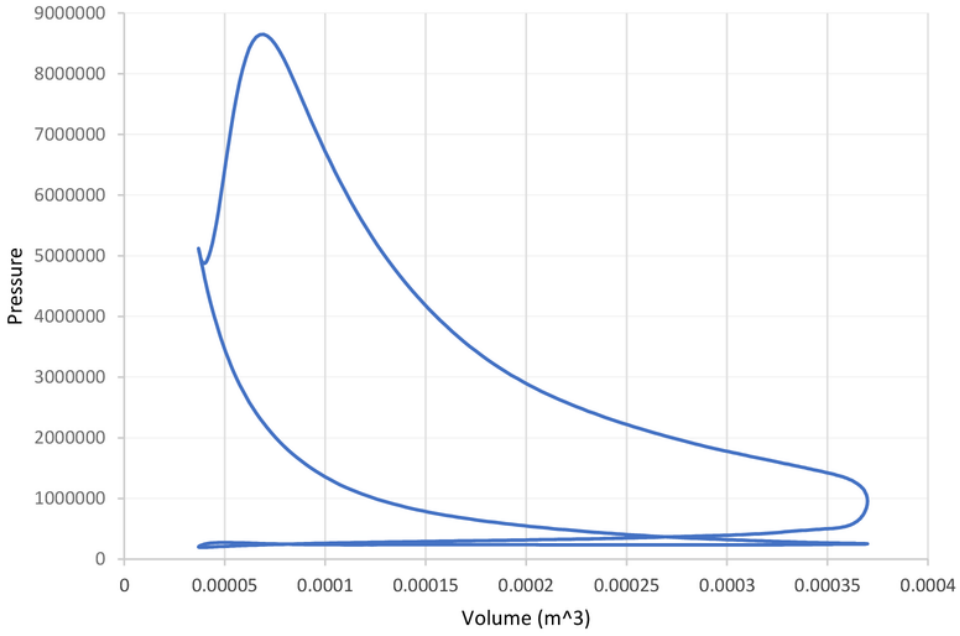


Figure 17 - Real pV diagram from Ford Fox engine at 3500rpm.

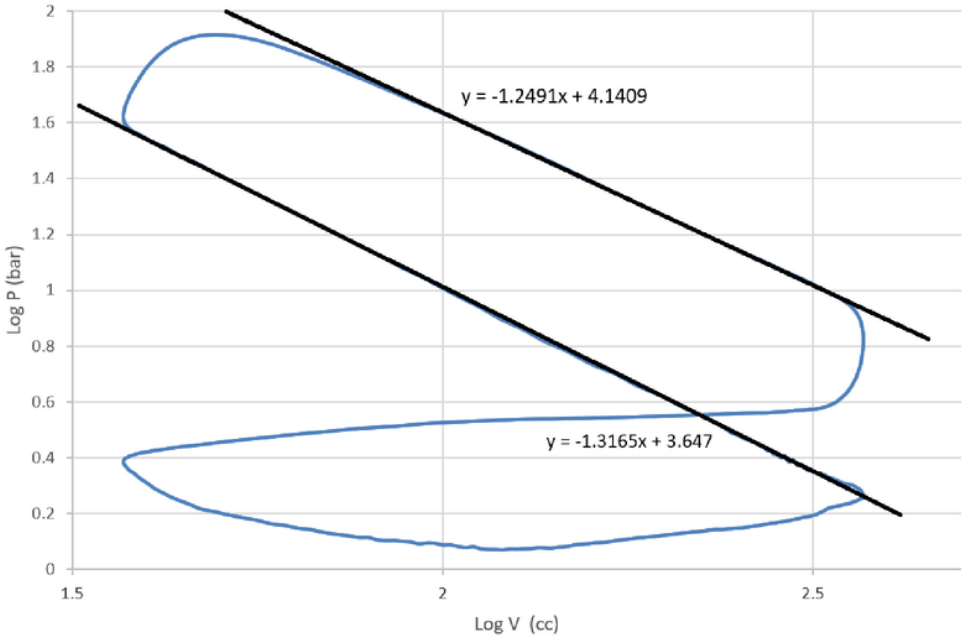


Figure 18 - Log P vs Log V graph for 6500rpm for Ford Fox engine.

Excel has drawn trendlines in for the compression and expansion strokes and displayed an equation on the graph. The coefficient of x is the average gradient of the line and value for n during the respective stroke.

5.5 START AND END OF COMBUSTION

The pressure, volume and crank angle graphs, are great indicators to where the start of combustion (soc) is in relation to the crank angle. The graph in Figure 19 below is from the Ford Fox engine test and shows the pressure vs crank angle at an engine speed of 3000rpm. The orange line represents the motored pressure, i.e. the pressure the engine would be pumping with the absence of combustion. It is visible the measured pressure (blue line) deviates from the motored pressure between the crank angles 10 to 20 and it is around this point the pressure increases purely from the combustion. The limitation of this is the accuracy of which precise degree combustion begins making this only a rough guide.

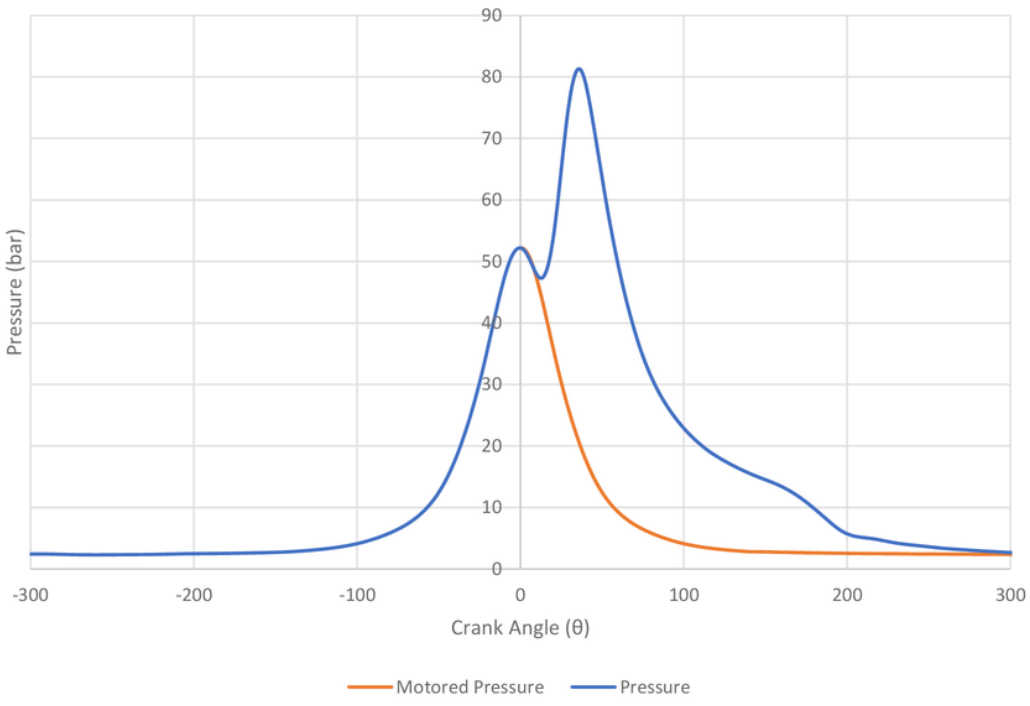


Figure 19 - Pressure/Crank Angle graph for 3000rpm from the Ford Fox data.

A more sophisticated method of finding the start and end of combustion is to evaluate the polytropic index for each degree. According to Heywood the start of combustion can be identified by the departure of the curve from the straight line [6]. Assume the start of combustion is when n changes from its average for compression or expansion. Assume the end of combustion is when it returns to n average for the expansion stroke [6].

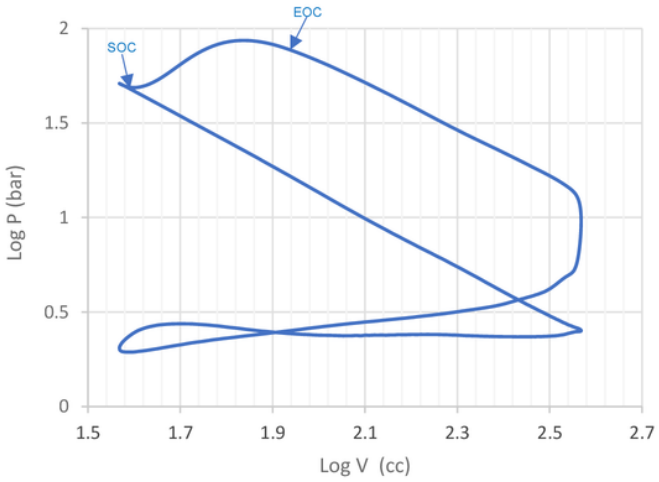


Figure 20 - Log P/Log V graphs from Ford Fox engine at 3500rpm.

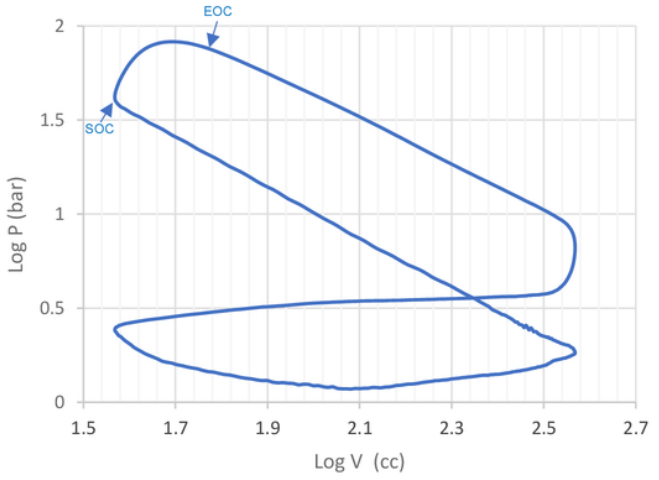


Figure 21 - Log P/Log V graphs from Ford Fox engine at 6500rpm.

Graphs like the ones from Figure 20 and Figure 21 are good indicators of where the start and end of combustion occurs but the graphs vary throughout the rev range, Figure 22, and can give inaccurate predictions.

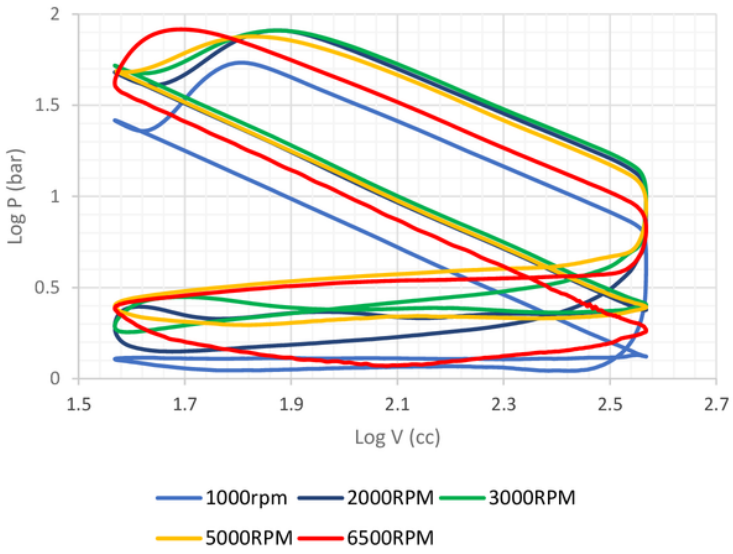


Figure 22 - Log P/LogV diagrams across the rev range for the Ford Fox engine.

It is more accurate looking at spreadsheet data to predict combustion timings. For example, looking at an excel column and assessing the numbers can be much more accurate. Finding the exact degree in which the polytropic index begins to radically deviate from the average can be more precisely found looking at the numbers instead of a graph. As n changes from the norm, it illustrates an extra change in pressure which can only be from combustion starting. As an example, Table 2 and Table 3 show the polytropic indices calculated for each degree, using Equation 3, for 1500rpm and 6000rpm respectively. In Table 2 it is noticeable there is a major deviation from the average n around 9 degrees crank angle, this can be accurately assumed to be where combustion starts as the polytropic index then becomes totally random values as the combustion denies the $pV^n=C$ relation. The same deviation and radical change is found at crank degree 7 in Table 3.

	θ	n	Average $n_{compression}$
	-10	1.33	1.3141
	-9	1.30	
	-8	1.31	
	-7	1.27	
	-6	1.24	
	-5	1.24	
	-4	1.31	
	-3	1.30	
	-2	1.29	
	-1	1.32	
	0	1.34	$n_{expansion}$
	1	1.31	1.2464
Spark	2	1.35	
	3	1.38	
	4	1.34	
	5	1.25	
	6	1.25	
	7	1.28	
	8	1.23	
SOC	9	0.97	
	10	0.71	
	11	0.37	
	12	-0.01	
	13	-0.45	
	14	-0.89	
	15	-1.31	
	16	-1.68	
	17	-2.01	
	18	-2.28	
	19	-2.44	
	20	-2.54	
	21	-2.54	
	22	-2.46	
	23	-2.30	
	24	-2.09	
	25	-1.87	
	26	-1.63	
	27	-1.38	

Table 2 - Polytropic Indices and SOC for Ford Fox engine at 1500rpm.

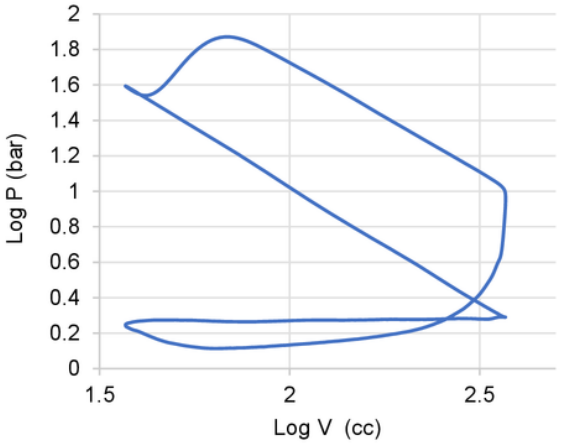


Figure 24 - Log P/Log V diagram for Ford Fox engine at 1500rpm.

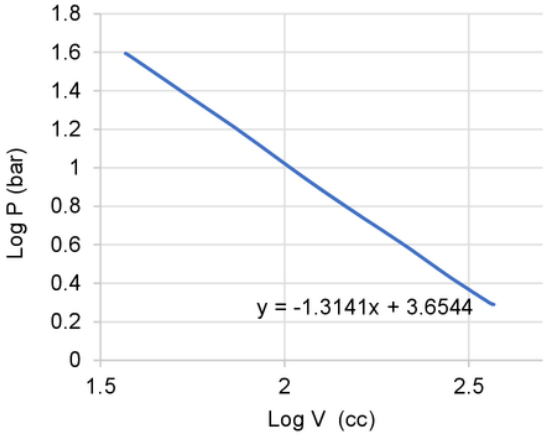


Figure 23 - Compression part of Log P/Log V diagram for Ford Fox engine at 1500rpm.

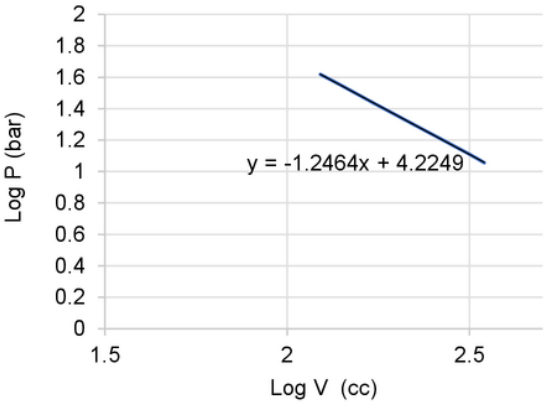


Figure 25 - Expansion stroke Log P/Log V diagram for Ford Fox engine at 1500rpm.

	θ	n	Average $n_{compression}$
	-17	1.31	1.3075
	-16	1.35	
	-15	1.32	
	-14	1.33	
	-13	1.33	
	-12	1.31	
	-11	1.34	
	-10	1.31	
	-9	1.34	
	-8	1.28	
	-7	1.31	
	-6	1.24	
	-5	1.22	
	-4	1.28	
	-3	1.29	
	-2	1.30	
	-1	1.30	
Spark	0	1.28	$n_{expansion}$
	1	1.25	1.2523
	2	1.25	
	3	1.26	
	4	1.29	
	5	1.23	
	6	1.12	
SOC	7	1.01	
	8	0.87	
	9	0.67	
	10	0.49	
	11	0.25	
	12	0.03	
	13	-0.21	
	14	-0.43	
	15	-0.63	
	16	-0.84	
	17	-1.01	
	18	-1.17	
	19	-1.30	
	20	-1.41	

Table 3 - Polytropic Indices and SOC for Ford Fox engine at 6000rpm.

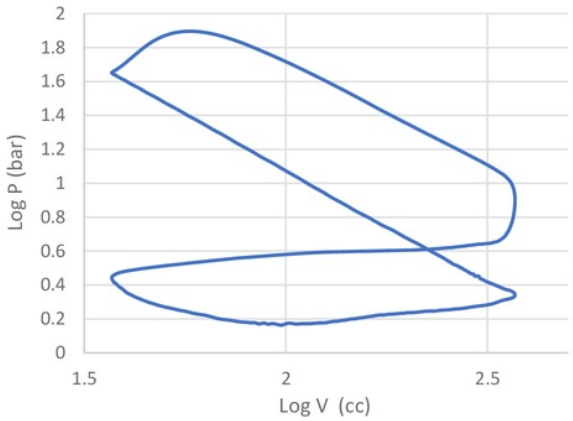


Figure 27 - Figure 6 Log P/Log V diagram for Ford Fox engine at 6000rpm.

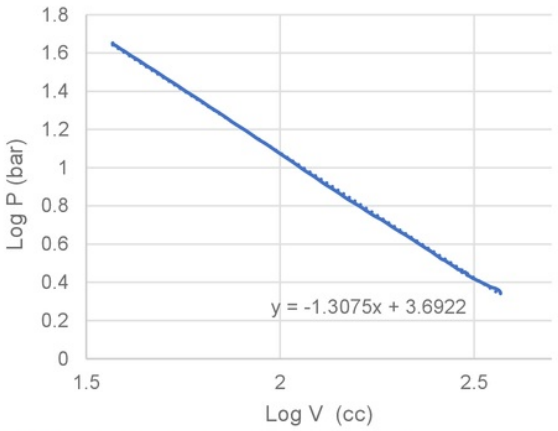


Figure 26 - Compression part of Log P/Log V diagram for Ford Fox engine at 6000rpm.

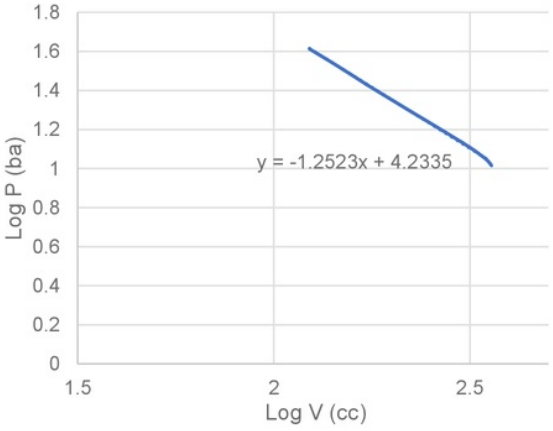


Figure 28 - Expansion stroke Log P/Log V diagram for Ford Fox engine at 6000rpm.

This procedure yields accurate combustion timings. Similar studies by Mohand, Le Corre [22] and J Reyes, E Quiros [23], use these methods when plotting combustion timings.

The end of combustion is found in a similar fashion, evaluating the numbers for n until it returns to the expected n for a polytropic expansion process. The end of combustion can also be assumed to be when ΔP (next section) hits minus. This model uses mixture of those evaluations. Some models use the opening of the exhaust valve as the eoc.

From the engine test data, the spark timing map is given for full loads meaning burn delay can be estimated and Figure 29 can be produced.

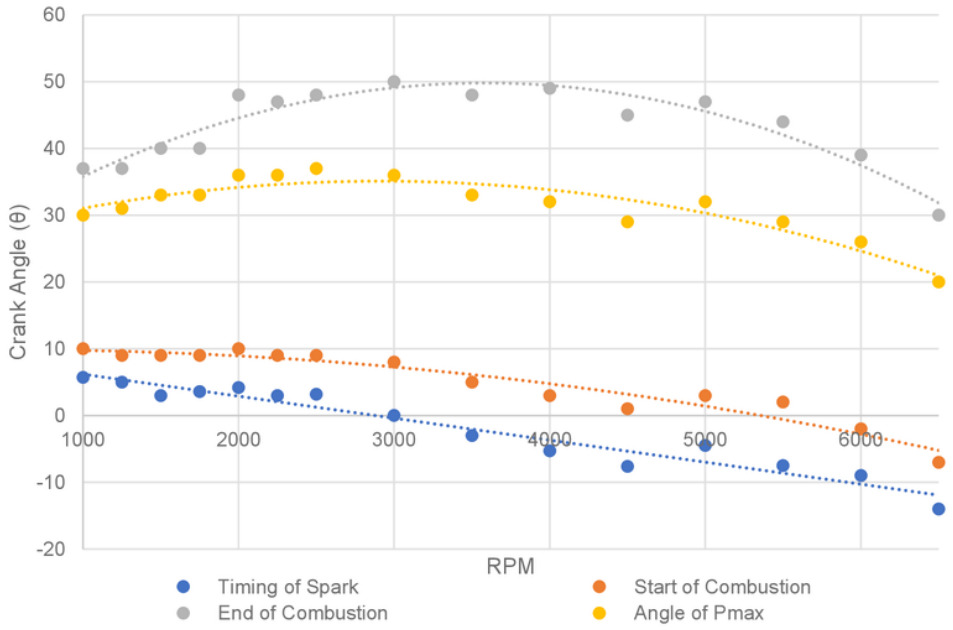


Figure 29 - Combustion timings for the Ford Fox engine.

5.6 EXTRA PRESSURE FROM COMBUSTION

The pressure from the piston compressing the mixture can be calculated using the polytropic relation, $pV^n=C$, where n is the polytropic index found in the previous section. The change in pressure due to combustion is the difference between the pressure, P_2 and the theoretical motored pressure, P_{2n}, Figure 30;

$$P_{2n} = P_1 (\frac{V_1}{V_2})^n$$

$$\Delta P = P_2 - P_{2n}$$

The value for n up to TDC is $n_{compression}$, while $n_{expansion}$ is used from TDC onwards. ΔP provides a basis for finding the mass fraction burned throughout the combustion process. These values can also be used to validate where soc and eoc are located.

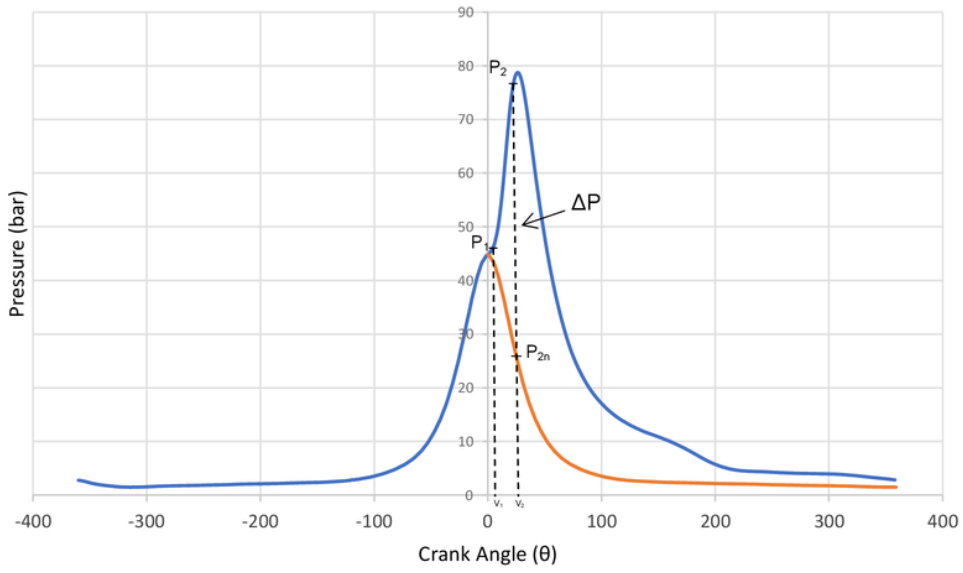


Figure 30 - Graph depicting change in pressure due to combustion for Ford Fox engine at 6000rpm.

5.7 MASS FRACTION BURNED

The mass fraction burned reflects the amount of fuel burned and the rate of burning throughout the combustion process [6]. The mass fraction burned can be calculated by assuming the change in pressure reflects the heat released from the fuel;

$$MFB = \frac{\sum_{soc\to\theta} \Delta Q_R}{\Delta Q_{Fuel\,Total}} = \frac{\sum_{soc\to\theta} \Delta P}{\sum_{soc\to eoc} \Delta P}$$

This approach assumes γ is constant between the two zones such that;

$$\Delta Q = V_2 \Delta \mathrm{P}$$

Where ΔQ_R is the heat released from the first law of thermodynamics (Appendix 1) and the V_2 cancel.

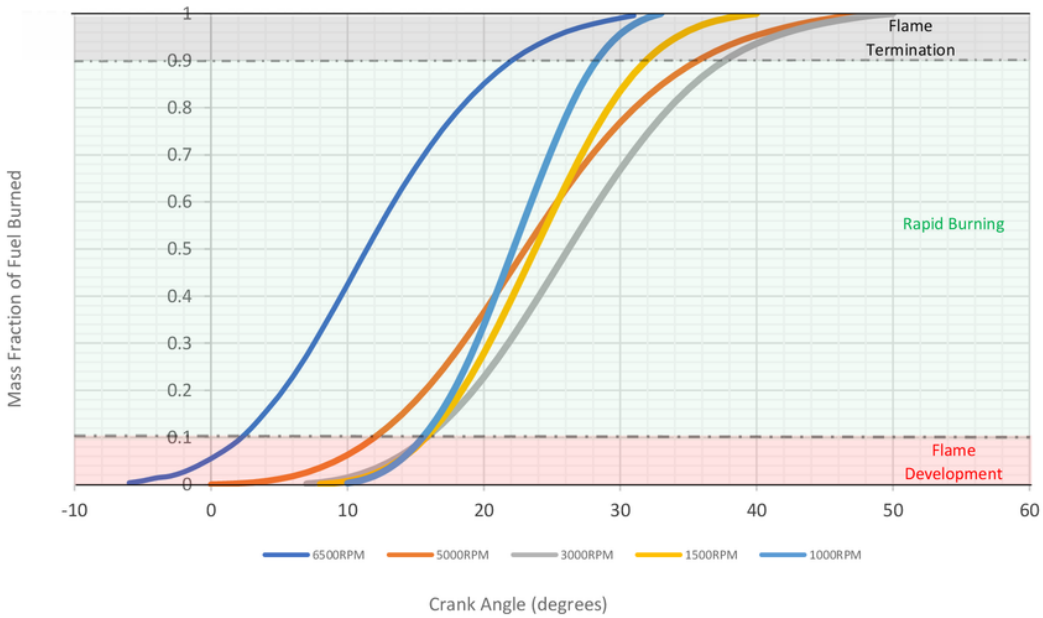


Figure 31 - Mass Fraction Burned vs Crank Angle across the rev range for the Ford Fox engine.

5.8 SPECIFIC HEATS

Heywood says the most complete computer models are based on polynomial curve fits to the thermodynamic data for each species in the mixture [6]. They work on the assumption the reactions in the unburned zone happen so slowly they are negligible and the reactions in the burned zone happen so fast the mixture is in 'chemical equilibrium' [24]. A mixture is said to be in chemical equilibrium when the chemical reactions by which individual species produce and remove each other happens at equal rates. The molar specific heats of O_2 and N_2 are be approximated by Equation 4.39 from Heywood [6];

Equation 4

$$\frac{\tilde{c}_{p,i}}{\tilde{R}} = a_{i1} + a_{21}T + a_{31}T^2 + a_{41}T^3 + a_{51}T^4$$

Where R is the universal gas constant, T is the temperature of the burned zone, and the coefficients for a species thermodynamics properties are sourced from the Nasa equilibrium code [24] and found in table 4.10 from Heywood [6].

The molar specific heat of unburned fuel, C_8H_{18}, can be approximated using Equation 4.42 from Heywood [6];

$$\tilde{c}_{p,f} = A_{f1} + A_{f2}t + A_{f3}t^2 + A_{f4}t^3 + \frac{A_{f5}}{t^2}$$

Where t is the temperature of the unburned fuel divided by 1000, T(K)/1000, and the coefficients come from table 4.11 in Heywood [6]. (values in Heywood are given in cal/gmol, so answer needs to be multiplied by 4184.5 to convert it into J/mol).

The specific heat for the mixture, $C_{p_{mixture}}$, can be approximated by;

$$\tilde{C}_{p_{Mixture}} = \frac{\phi\, \tilde{C}_{p_{fuel}} + 12\frac{1}{2}\,(\tilde{C}_{p_{O_2}} + 3.76\,\tilde{C}_{p_{N_2}})}{(\phi + \ 12\frac{1}{2}\,(1 + 3.76))}$$

Then;

$$\tilde{C}_{V_{mix}} = \ \tilde{C}_{p_{mix}} - 8317$$

And;

$$\gamma = \frac{\tilde{C}_{p_{mix}}}{\tilde{C}_{V_{mix}}}$$

These specific heat values provide a good basis to begin NOx formation predictions. At higher temperatures dissociation has an effect of the specific heats and therefore gamma [6]. This is discussed more in sec 8.

5.9 UNBURNED AND BURNED ZONE PROPERTIES

Using the two-zone model, the chamber is imagined as an unburned zone consisting of fuel and air, and a burned zone consisting of the products of combustion. These zones are separated by the flame front, which is considered a negligible sized third zone. The burned zone originates from the ignition point and travels through the cylinder until it consumes the unburned mixture, Figure 32. As the burned zone pushes through the mixture it compresses the unburned zone against the piston and cylinder walls. This compression, because the process happens too quickly for heat transfer between the two zones and across the flame front, can be thought of as an adiabatic process and obey the adiabatic relation $pV^{\gamma}=C$ [6]. This rule is followed throughout this project however it is proven by Rallis and Garforth [25] the process is closer to a polytropic one and there is some heat transfer between the two zones.

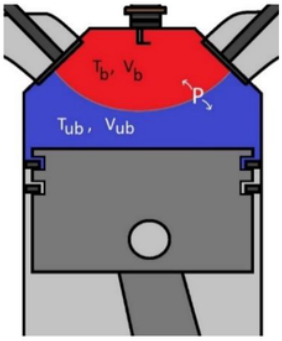


Figure 32 - Two-Zone Model.

Extensive studies by Merker and Hohlbaum [26] have used this process to accurately predict zone temperatures and therefore NOx formation. The following subchapters show the calculations used to find the properties of each zone using adiabatic relations and the ideal gas law such that;

Equation 5

$$p\,V^{\gamma} = C$$

Equation 6

$$p\,V = m\,R\,T$$

5.9.1 UNBURNED ZONE TEMPERATURE

Up to start of combustion (one zone) the ideal gas law applies, so Equation 6 becomes;

$$Temperature_{unburned}, \qquad T_{unburned} = \frac{p\ x\ V}{R\ x\ mass\ of\ air\ and\ fuel}$$

Where T is the temperature in Kelvin, P is pressure is in N/m^2, V is volume in m^3, R is the unburned gas constant (see Appendix 1), and the mass is the total mass of air plus the total mass of fuel found in the engine test data.

After the start of combustion (two zones) the adiabatic relation applies (Equation 5);

$$Temperature_{unburned}, \qquad T_{2unburned} = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{(\gamma-1)}{\gamma}}$$

Where T is the temperature in Kelvin, P is pressure in N/m^2, and γ is gamma (the ratio of specific heats, c_p/c_v).

5.9.2 UNBURNED ZONE VOLUME

Up to the start of combustion, the unburned volume is equal to the cylinder volume. After combustion begins the burned zone takes up some of the cylinder volume so finding the unburned volume requires the use, once again of the ideal gas law, Equation 6 becomes;

$$Volume_{Unburned}, \qquad V_{Ub} = \frac{(1 - MFB)\ x\ Mass\ x\ R_{unburned}\ x\ T_{unburned}}{Pressure}$$

Where MFB is the mass fraction burned, R unburned is the gas constant for the unburned mixture (defined in Appendix 1), and the mass is total mass of air and fuel.

5.9.3 BURNED ZONE VOLUME

After combustion begins the burned zone begins to grow from the spark plug towards the piston and cylinder walls. The burned volume is equal to the total volume subtract the unburned volume already calculated in sec 5.9.2;

$$Volume_{Burned}, \qquad V_B = Volume_{Cylinder} - Volume_{Unburned}$$

When combustion finishes and until the exhaust valve opens the burned volume is equal to the cylinder volume.

5.9.4 BURNED ZONE TEMPERATURE

The burned zone temperature is found, again, by manipulating the ideal gas equation from Equation 6, whereby it becomes;

$$Temperature_{Burned}, \qquad T_b = \frac{Pressure \ x \ Volume_{Burned}}{MFB \ x \ Mass \ x \ R_{Burned}}$$

Where MFB is the mass fraction burned, R burned is the gas constant for the burned mixture (defined in Appendix 1), and the mass is total mass of air and fuel.

6 DISSOCIATION

The hydrogen component in the fuel burns directly to H_2O in the combustion process whereas the carbon firstly goes through the stage of being CO, which is then further oxidized into CO_2. Combustion temperatures often reach temperatures higher that 1800K which is enough for the oxidation products to become agitated thermally and begin to dissociate back to their original H_2, CO and O_2 forms.

The reaction are thus written like below with reversible arrows;

Equation 7

$$H_2 + \frac{1}{2}O_2 \leftrightarrow H_2O$$

Equation 8

$$CO + \frac{1}{2}O_2 \leftrightarrow CO_2$$

Equation 9

$$NO + \frac{1}{2}O_2 \leftrightarrow NO_2$$

The amount of dissociation is very much dependent on the temperature. At a high temperature a condition of dynamic equilibrium exists where the rates of combustion and dissociation are equal meaning the reactant and product materials create and eliminate each other and equal rates. The concentrations of each species can be determined by using Avogadro's principle of 'partial pressure equilibrium constants' for a given temperature.

6.1 EQUILIBRIUM CONSTANTS

The rate of these reactions can be determined experimentally and are found to be proportional to the instantaneous molar concentration of each species raised to a power.

$$A + B \leftrightarrow C$$

$$Forward\ Reaction\ Rate = K_f\ [A]^a\ [B]^b$$

$$Reverse\ Reaction\ Rate = K_R\ [C]^c$$

Since the two rates are in chemical equilibrium

$$K_f [A]^a [B]^b = K_R\ [C]^c$$

Equation 10

$$K' = \frac{K_F}{K_F} = \frac{[C]^C}{[A]^A\ [B]^B}$$

Where;

K = Rate constant for reaction.

[A] = Molar concentration of material 'A'.

[B] = Molar concentration of material 'B'.

In a gases mixture each gas has a partial pressure, which is the pressure of that gas if it alone occupied the entire volume of the original mixture at the same temperature. With Avogadro's Principle [27];

$$\frac{{P_C}^c}{{P_A}^a {P_B}^b} = \frac{mol\ 'x'}{total\ mol}$$

$$Total\ Pressure = \sum Partial\ Pressures$$

Selected values for partial pressure equilibrium constants are found in Transport Fuels Technology table AC2.1 [27].

Giving;

$$K_{pCO2} = \frac{n_1}{n_3(\frac{n_5}{n_T}.p)^{\frac{1}{2}}}$$

And;

$$K_{pH2O} = \frac{n_2}{n_4(\frac{n_5}{n_T}.p)^{\frac{1}{2}}}$$

6.2 N_2 & O_2 CONCENTRATIONS

Calculating the concentrations of N_2 and O_2 inside the cylinder to determine the Nitrous Oxides present is done on Excel. The amount of each species, n, is determined through several steps ultimately balancing the equation. The fluids are assumed to be in chemical equilibrium [6] and the equilibrium equation, Equation 10, from the previous section applies. The first step is to find values for molar concentrations of each species in the burned zone for each degree.

Reactants

Equation 11

$$\phi \,.\, C_8H_{18} + \; 12\frac{1}{2}\,(O_2 + 3.776N_2)$$

Products

Equation 12

$$n_1CO_2 + \; n_2H_2O + n_3CO + \; n_4H_2 + n_5O_2 + \; n_6N_2$$

Equations

$$K_{pCO2} = \frac{n_1}{n_3(\frac{n_5}{n_T}.p)^{\frac{1}{2}}} \quad (1)$$

$$K_{pH2O} = \frac{n_2}{n_4(\frac{n_5}{n_T}.p)^{\frac{1}{2}}} \quad (2)$$

$$Carbon = \quad 8\phi = n_1 + n_3 = n_3.\left(\frac{n_1}{n_3} + 1\right) \quad (3)$$

$$Hydrogen = 18\phi = 2n_2 + 2n_4 \quad (4)$$

$$9\phi = n_2 + n_4 = n_4.\left(\frac{n_2}{n_4} + 1\right)$$

$$Oxygen = \quad 25 = 2n_1 + n_2 + n_3 + 2n_5 \quad (5)$$

$$Nitrogen_2 = \quad 47 = n_6 \quad (6)$$

$$n_T = n_1 + n_2 + n_3 + n_4 + n_5 + n_6 \quad (7)$$

The chemical equilibrium constants are linear interpolated against the temperatures of the burned zone in the combustion process. Equation 13 is used with Table 4 from Transport Fuels Technology [27], derived from the JANAF tables [28], for the constants of the burned zone at each degree throughout the combustion process.

Equation 13

$$K_x = \frac{[(T_2 - T_x)\,.K_1] + [(T_x - T_1).K_2]}{(T_2 - T_1)}$$

Temperature, K	K_{CO2}	K_{H2O}
300	5.75E+44	6.11E+39
500	1.06E+25	7.69E+22
1000	1.66E+10	1.15E+10
1500	2.07E+05	5.31E+05
2000	7.66E+02	3.47E+03
2100	3.46E+02	1.69E+03
2200	1.68E+02	8.75E+02
2300	8.71E+01	4.81E+02
2400	4.78E+01	2.77E+02
2500	2.75E+01	1.67E+02
2700	1.04E+01	6.81E+01
3000	3.05E+00	2.20E+01

Table 4 - Partial Pressure Equilibrium Constants (derived from JANAF tables).

With values for K_p , equation (1) and (2) can be stated as such;

$$\frac{n_1}{n_3} = K_{P_{CO_2}} \cdot \left(\frac{n_5}{n_T}\, P\right)^{\frac{1}{2}} \qquad \text{(1a)}$$

$$\frac{n_2}{n_4} = K_{P_{H_2O}} \cdot \left(\frac{n_5}{n_T}\, P\right)^{\frac{1}{2}} \qquad \text{(2a)}$$

A guessed value is made for $\frac{n_5}{n_T}$ which means equation (1a) and (2a) can be evaluated and equations (3 – 5) can be used to obtain n for each species;

$$n_3 = \frac{8\,\phi}{(\frac{n_1}{n_3}+1)}$$

$$n_1 = 8\,\phi - n_3$$

$$n_4 = \frac{9\,\phi}{(\frac{n_2}{n_4}+1)}$$

$$n_2 = 9\,\phi - n_4$$

$$n_5 = \frac{1}{2}\,(25 - 2n_1 - n_2 - n_3)$$

$$n_T = n_5 / \frac{n_5}{n_T}$$

In order to validate the initial $\frac{n_5}{n_T}$ guess, n_T from the guess needs to match n_T from the calculations which satisfies equations (6) and (7). In excel an error column finds the difference between the two values for n_T. Using excels goal seek function the error cell can be selected and set to value zero by changing the guessed cell. This equals the two n_T values and removes any error between them, now the molar concentrations of each species are correct. Appendix 2 has calculated tables of isooctane product concentrations for generic temperatures and pressures at 3 different ϕ values.

Figure 33, is the visual basic macro code for Excel to bulk goal seek the error column to zero by changing the guest column. Figure 34 shows this method being used in excel for each degree of the combustion process with the interpolated equilibrium constants. Spreadsheets for all other rpms can also be found in Appendix 2.

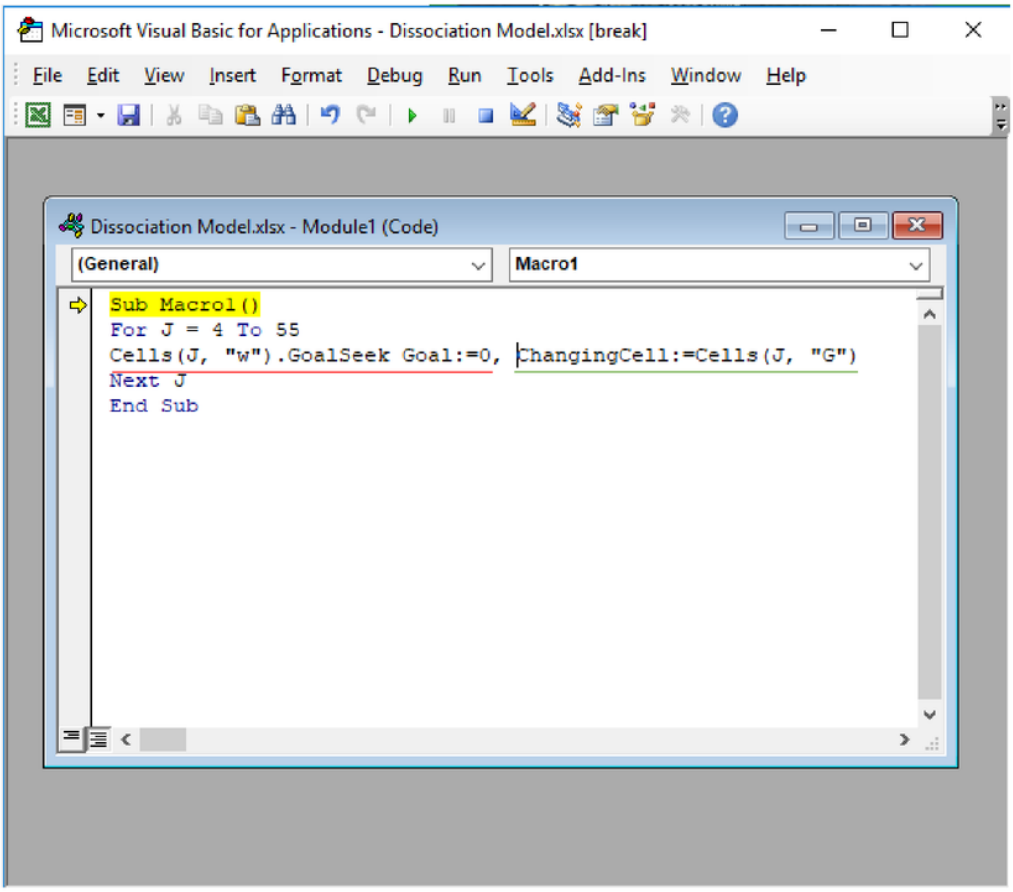


Figure 33 - Code for Macro inside Excel to bulk goal seek data.

	Crank Angle	kCO2	kH2O	Pressure	ϕ	Guessed n5/nt	n5/nt.P ^(1/2)	n1/n3	n3	n1	n2/n4	n4	n2	n5	n6	nt	nt	error
				bar														
SOC	-6	3.16E+24	2.29E+22	37.20666667	1.140882	5.00E-40	1.36E-19	430495.9	2.12E-05	9.127036	3125.718	0.003284	10.26466	-1.75937	47	64.63562	-3.5E+39	############
	-5	1.38E+09	9.55E+08	37.93433333	1.140882	4.25E-19	4.0148E-09	5.527637	1.398218	7.72884	3.834617	2.123837	8.144103	-4.4E-16	47	66.395	-1045.14	-1111.53700
	-4	1.71E+05	4.38E+05	38.651	1.140882	7.64E-12	1.71885E-05	2.935999	2.318867	6.808191	7.533945	1.203188	9.064752	5.08E-10	47	66.395	66.39516	0.00017
	-3	4.52E+04	1.17E+05	39.44466667	1.140882	1.06E-10	6.46945E-05	2.925407	2.325124	6.801934	7.578556	1.196931	9.071009	7.05E-09	47	66.395	66.395	0.00000
	-2	1.17E+05	3.02E+05	39.969	1.140882	1.56E-11	2.49775E-05	2.934255	2.319895	6.807163	7.541241	1.20216	9.06578	1.04E-09	47	66.395	66.39505	0.00005
	-1	1.20E+05	3.10E+05	40.825	1.140882	1.45E-11	2.43639E-05	2.934392	2.319814	6.807244	7.540666	1.202241	9.065699	9.65E-10	47	66.395	66.39495	-0.00004
	0	9.61E+04	2.47E+05	41.94766667	1.140882	2.22E-11	3.05138E-05	2.933017	2.320625	6.806433	7.546432	1.20143	9.06651	1.47E-09	47	66.395	66.39497	-0.00003
	1	7.38E+04	1.90E+05	43.19666667	1.140882	3.65E-11	3.97023E-05	2.930966	2.321836	6.805222	7.555054	1.200219	9.067721	2.42E-09	47	66.395	66.395	0.00001
	2	6.03E+04	1.56E+05	44.53833333	1.140882	5.29E-11	4.85447E-05	2.928996	2.323	6.804058	7.56336	1.199055	9.068885	3.51E-09	47	66.395	66.395	0.00000
	3	5.97E+04	1.54E+05	46.05033333	1.140882	5.23E-11	4.90942E-05	2.928874	2.323072	6.803985	7.563877	1.198983	9.068957	3.48E-09	47	66.395	66.39499	-0.00001
	4	4.58E+04	1.19E+05	48.02266667	1.140882	8.50E-11	6.38778E-05	2.925588	2.325016	6.802041	7.577787	1.197038	9.070901	5.64E-09	47	66.395	66.395	0.00001
	5	2.42E+04	6.34E+04	50.30433333	1.140882	2.88E-10	0.000120296	2.913143	2.332411	6.794646	7.631105	1.189644	9.078296	1.91E-08	47	66.395	66.395	0.00000
	6	1.15E+04	3.08E+04	52.65966667	1.140882	1.21E-09	0.000251904	2.884674	2.349504	6.777553	7.756926	1.172551	9.095389	8E-08	47	66.395	66.395	0.00000
	7	7.22E+02	3.28E+03	55.30533333	1.140882	2.04E-07	0.003354828	2.422045	2.667136	6.459922	11.01004	0.854946	9.412993	1.35E-05	47	66.39501	66.39502	0.00000
	8	5.78E+02	2.67E+03	58.17433333	1.140882	2.99E-07	0.004171748	2.410378	2.67626	6.450798	11.13941	0.845835	9.422105	1.99E-05	47	66.39502	66.39502	0.00000
	9	3.81E+02	1.84E+03	61.29933333	1.140882	6.37253E-07	0.006250052	2.381739	2.698924	6.428133	11.47297	0.823215	9.444724	4.23E-05	47	66.39504	66.39504	0.00000
	10	2.88E+02	1.42E+03	64.37633333	1.140882	1.04924E-06	0.008218662	2.365095	2.712274	6.414784	11.67771	0.809921	9.458019	6.97E-05	47	66.39507	66.39507	0.00000
	11	2.20E+02	1.11E+03	67.41633333	1.140882	1.69048E-06	0.010675476	2.350037	2.724465	6.402593	11.87009	0.797814	9.470125	0.000112	47	66.39511	66.39511	0.00000
	12	1.59E+02	8.28E+02	70.40533333	1.140882	3.06147E-06	0.014681411	2.328558	2.742046	6.385012	12.15702	0.780415	9.487524	0.000203	47	66.3952	66.3952	0.00000
	13	1.28E+02	6.79E+02	73.15366667	1.140882	4.48725E-06	0.018117914	2.317878	2.750872	6.376185	12.30426	0.771778	9.496161	0.000298	47	66.3953	66.3953	0.00000
	14	9.85E+01	5.36E+02	75.623	1.140882	7.22282E-06	0.023371168	2.301912	2.764173	6.362884	12.53109	0.758841	9.509099	0.00048	47	66.39548	66.39548	0.00000
	15	7.94E+01	4.41E+02	77.727	1.140882	1.07075E-05	0.028848955	2.289169	2.774882	6.352175	12.71629	0.748595	9.519345	0.000711	47	66.39571	66.39571	0.00000
	16	6.84E+01	3.84E+02	79.409	1.140882	1.40101E-05	0.033354624	2.282155	2.780812	6.346245	12.81765	0.743103	9.524837	0.00093	47	66.39593	66.39593	0.00000
	17	5.83E+01	3.32E+02	80.75466667	1.140882	1.88489E-05	0.039014555	2.273395	2.788254	6.338804	12.94525	0.736304	9.531636	0.001251	47	66.39625	66.39625	0.00000
	18	4.85E+01	2.81E+02	81.74066667	1.140882	2.66165E-05	0.046643901	2.26167	2.798278	6.32878	13.11766	0.727312	9.540628	0.001767	47	66.39676	66.39676	0.00000
	19	4.40E+01	2.57E+02	82.297	1.140882	3.19897E-05	0.051309405	2.256914	2.802364	6.324694	13.18343	0.723939	9.544001	0.002124	47	66.39712	66.39712	0.00000
	20	4.06E+01	2.38E+02	82.483	1.140882	3.73756E-05	0.055523413	2.25296	2.80577	6.321288	13.23634	0.721248	9.546691	0.002482	47	66.39748	66.39748	0.00000
	21	3.76E+01	2.22E+02	82.355	1.140882	4.34932E-05	0.059848811	2.248859	2.809311	6.317746	13.29042	0.718519	9.549421	0.002888	47	66.39789	66.39789	0.00000
	22	3.52E+01	2.09E+02	81.91733333	1.140882	4.96068E-05	0.063746826	2.245116	2.812552	6.314505	13.33889	0.71609	9.55185	0.003294	47	66.39829	66.39829	0.00000
	23	3.29E+01	1.97E+02	81.22633333	1.140882	5.70788E-05	0.068090372	2.240892	2.816218	6.31084	13.39262	0.713417	9.554523	0.00379	47	66.39879	66.39879	0.00000
	24	3.14E+01	1.89E+02	80.214	1.140882	6.31248E-05	0.071158249	2.237835	2.818877	6.308181	13.43016	0.711561	9.556379	0.004191	47	66.39919	66.39919	0.00000
	25	3.07E+01	1.85E+02	78.959	1.140882	6.7173E-05	0.072827972	2.236088	2.820399	6.306659	13.45015	0.710577	9.557363	0.00446	47	66.39946	66.39946	0.00000
	26	3.04E+01	1.83E+02	77.53666667	1.140882	6.99074E-05	0.073623254	2.235163	2.821205	6.305853	13.45916	0.710134	9.557806	0.004642	47	66.39964	66.39964	0.00000
	27	3.01E+01	1.82E+02	75.97333333	1.140882	7.2364E-05	0.074146701	2.234479	2.821802	6.305256	13.46468	0.709863	9.558077	0.004805	47	66.3998	66.3998	0.00000
	28	3.07E+01	1.85E+02	74.22733333	1.140882	7.14105E-05	0.072805278	2.235611	2.820814	6.306244	13.44715	0.710724	9.557216	0.004742	47	66.39974	66.39974	0.00000
	29	3.18E+01	1.91E+02	72.383	1.140882	6.82591E-05	0.070290811	2.2379	2.81882	6.308237	13.4152	0.712299	9.55564	0.004532	47	66.39953	66.39953	0.00000
EOC	30	3.33E+01	1.99E+02	70.507	1.140882	6.43731E-05	0.067370289	2.240595	2.816475	6.310582	13.37829	0.714128	9.553812	0.004274	47	66.39927	66.39927	0.00000

Figure 34 - Excel extract balancing combustion equation and calculating molar mass of each species.

The concentrations for the oxygen and nitrogen species are calculated with Equation 14 and Equation 15 below.

Equation 14

$$[O_2] = \alpha \frac{n_5 . MFB}{V_B}$$

Equation 15

$$[N_2] = \alpha \frac{n_6 . MFB}{V_B}$$

Where MFB is the mass fraction burned, V_B is the burned volume and alpha, α, is a multiplier defined by;

$$\alpha = \frac{mass\ of\ fuel}{(molar\ mass\ of\ fuel)\ x\ \phi}$$

Now all the variables for the Zeldovich mechanism are known it can be applied to calculate the NOx output in kmol per degree. The next section touches on the Zeldovich theory and applies it to the calculated Fox data.

6.3 NO_x FORMATION & ZELDOVICH MECHANISM

NO and NO_2 usually stick together but NO is the predominant oxide of nitrogen produced in the engine. The nitrogen comes from the atmospheric air in the cylinder. The most prominent mechanism for NO_x formation is the Zeldovich mechanism [4] described by Zeldovich in 1946 [29]. It states NO is formed under high temperatures due to dissociating atomic oxygen atoms from gases burned by the flame front. The three reversible reaction equations, that govern the formation and destruction of NO from molecular nitrogen, below form what is known as the extended Zeldovich Mechanism;

Equation 16

$$O + N_2 \leftrightarrow NO + N$$

Equation 17

$$N + O_2 \leftrightarrow NO + O$$

Equation 18

$$N + OH \leftrightarrow NO + H$$

The reaction rates of these equations are experimentally determined.

Equation 19 tells the probability or proportion of molecule with energy enough to cause a reaction.

Equation 19

$$\frac{\partial[C]}{\partial t} \propto [A][B] \exp\left(\frac{-EA}{R_u T}\right))$$

Equation 20 is for the rate of NO formation which is applied to each degree of crank angle for the combustion process. Using the calculated N_2 and O_2 concentrations and burned zone temperature.

Equation 20

$$\frac{\partial[NO]}{\partial t} = 4.7x10^{13}\,[N_2][O_2]^{\frac{1}{2}}\,exp\,(\frac{-67837}{T})$$

This equation represents a crude way of calculating NO formation rate, as it predicts an excessively high NO concentration. [30]

The following steps are taken to go from the rate of formation per unit time to kmol per degree.

1. $\frac{\partial[NO]}{\partial t} \xrightarrow{\div\,(6 \times RPM)} \frac{\partial[NO]}{\partial \theta}$

2. $\frac{\partial[NO]}{\partial \theta} \xrightarrow{\times\,V_B} \frac{kmol}{\theta}$

From here the kmols produced per degree from the start of combustion to the end of combustion is totaled in order to calculate the parts per million, ppm. PPM is a generic reading of the NOx emission and a way of expressing dilute concentrations of substances in a greater substance. 1% is 1 out of 100, 1 ppm is 1 out of a million [31]

$$PPM = \frac{total\ kmol\ in\ combustion\ process}{(\alpha\ x\ n_T)} \text{x } 1000000$$

7 RESULTS

The NOx ppm for each rpm is calculated and tabulated below with the results from the real-life engine test, Table 5.

RPM	*NOx PPM (tested)*	*NOx PPM (calculated)*
1000	1518	73.99
1250	1064	31.41
1500	871	26.34
1750	1053	87.28
2000	1553	548.18
2250	1577	682.65
2500	2169	1424.88
3000	1787	885.64
3251	1979	621.52
4000	2467	1106.43
4500	2404	1040.78
5000	1695	573.92
5500	1690	608.91
6000	1335	287.50
6500	1668	573.76

Table 5 - Table of calculated results vs tested results.

The initial set of results are a lot lower than the tested values by almost 3 times. There is however an encouraging pattern shown on the graph in Figure 35, with similar curve trends shown between the two results. While the trends show signs the model works mathematically, there is clearly limitations and assumptions made within the process that hinders the accuracy. The next section explores different approaches to some of the steps in the method, in particularly looking at MFB, specific heats, and reasons the results are low.

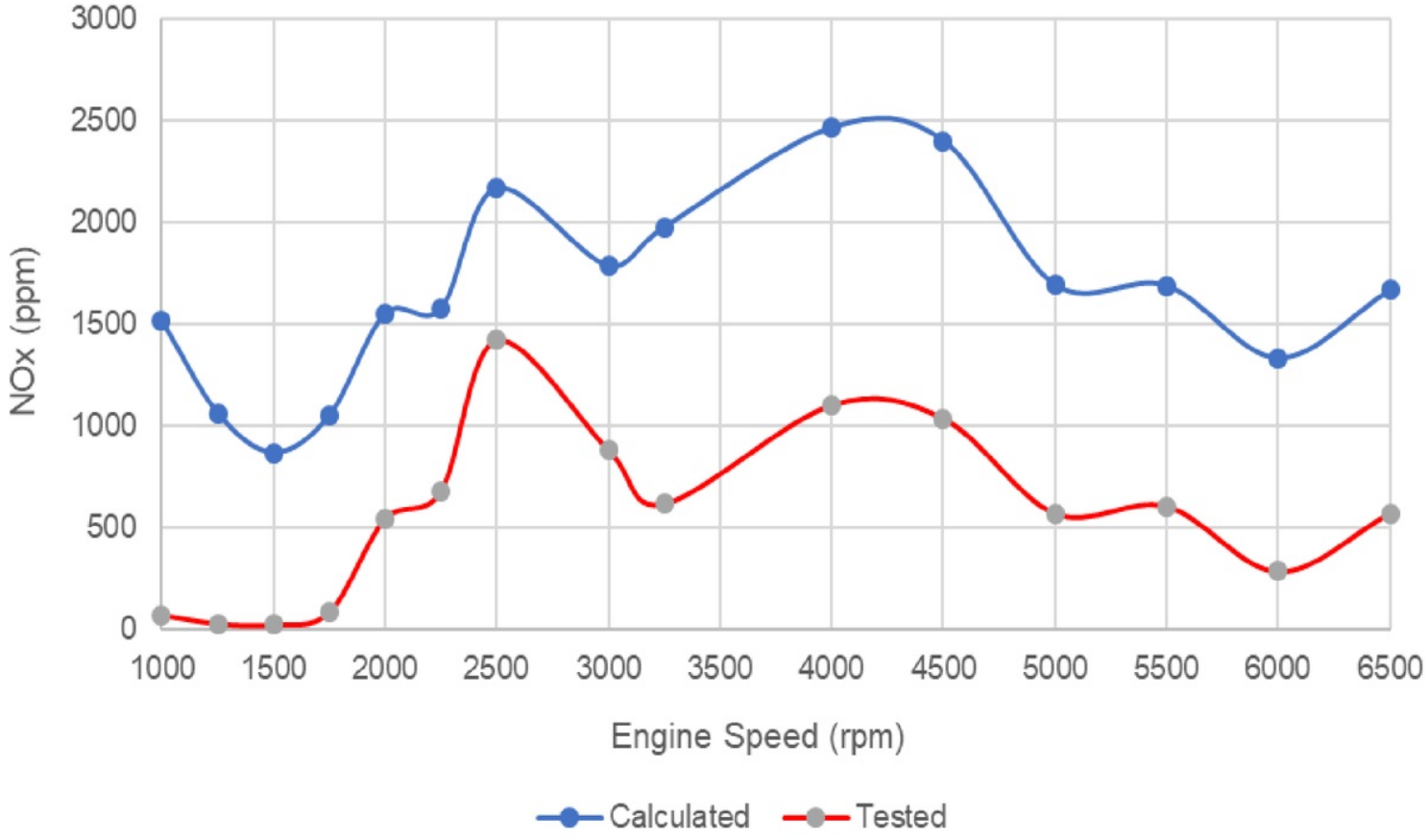


Figure 35 - Graph of calculated results vs tested results.

8 LIMITATIONS OF MODEL

A study by Westerberg [32], presents a NOx model on a direct injection gasoline engine with ppm results 1.5 times lower than real life comparative data. In the article the author touches on the effects of the direct injectors which are at the disadvantage of injecting fuel near the end of the compression stroke meaning the fuel injector has less time to mix with air and create a homogeneous mixture. Direct injectors hinder the accuracy by creating lean and rich patches in the cylinder with relative hotter and cooler patches. It should be noted that the turbo and high piston speed towards the higher rpm range increases turbulence and homogeny of the mixture and explains the slightly better accuracy in the upper rev range.

Another study by Benoit [33], has also fallen short of target while using similar maths to this model. It was discussed in the report the effects of dissociation on the specific heats of the reactants and products affects gamma. While the specific heats were assumed to remain constant across the zones, the dissociated gamma can have a real impact on accuracy.

9 DISCUSSION & CONCLUSION

There are limiting assumptions made in this model that could be explored in more depth. Fundamental assumptions like in the list below can be altered into the model and with more research more analytically determined;

- Equilibrium Constants
- Gasoline ($C_{8.26}H_{15.5}$), used instead of Isooctane (C_8H_{18})
- Dissociated Gamma
- More Accurate SOC and EOC
- More sophisticated MFB
- Effects of EGR

This model serves a brilliant basis for the start of a more complex and thorough NOx formation model for a GDi engine.

10 RECOMMENDED FURTHER WORK

There is clearly a lot of extra work to do on this model to refine its accuracy. While this model provides a decent basis for NOx prediction a more accurate model will be required that can account for the rich and lean patches in the mixture. The effects of dissociation on the gamma values of reactants and product can be introduced and incorporated into the model. With more sophisticated sensors the cylinders pressure can be measured and analysed every tenth of a degree. While the mathematical model is enough for designers and developers to get a rough idea of NOx formation and definitely the trend of output, a more complete approach is needed with the aid of computer software. These software packages can process multi-zone models, handle extra calculations involving crevice regions, heat transfer to cylinder walls, heat transfer between the two zones, across the flame front and so on reducing the number of assumptions and otherwise negligible aspects of the calculations. Changing the fuel used from isooctane to gasoline and manipulating that aspect is easy enough the model could also be adapted for a variety of alternative fuels in the future with an always changing market.

11 APPENDIX 1 - THERMODYNAMICS

A1.1 FIRST LAW OF THERMODYNAMICS

The first law of thermodynamics regards the conservation of energy. Energy cannot be created nor destroyed only manipulated. In a combustion process, fuel and oxidizer react to produce products of different composition. The first law can be used to relate changes in internal energy to heat and work defining the states of mixtures undergoing a combustion process. [6]

Equation 21

$$\Delta U = Q - W$$

The change in energy of a system is heat added to the system and the work done by the system. Q and W are path dependent while U is a function of the state of the system not the path it took to get there. [34]

A1.2 IDEAL GAS LAW

An internal combustion engine is classed as an open thermodynamic system. The working fluids are said to be ideal gasses and obey the ideal gas law;

Equation 22

$$pV = mRT$$

Where p and V is the absolute pressure and volume, T is temperature in Kelvin, R is the particular gas constant, a physical constant, and m is the mass of the gas.

The ideal gas law was first stated by Emile Clapeyron in 1834 as a combinations of other gas laws from Boyle, Charles and Avogadro. It says that the state of a thermally perfect gas is determined by its pressure, volume and temperature [35].

The gas constant is equal to the universal gas constant divided by the molecular weight of the gas [6].

$$R_{Gas} = \frac{R_{Universal}}{Molecular\ weight}$$

$R_{universal}$ is equal to 8314.472 j/kmol.k

For the model in this text a Gas constant for both zones is needed. Below is the equation calculating the molecular weight of the unburned zone;

$$Molecular\ Weight = \frac{\left(\phi\ x\ mol\ wt_{fuel}\right) + 12\frac{1}{2}\ (32 + (3.76x28))}{\phi + \ 12\frac{1}{2}\ (1 + 3.76)}$$

And the equation for the burned zone;

$$Molecular\ Weight_{Lean} = \frac{(n_1 x\ 44) + (n_3 x\ 32) + (n_4\ x\ 18) + (n_5\ x\ 28)}{(n_1 + n_3 + n_4 + n_5)}$$

$$Molecular\ Weight_{Rich} = \frac{(n_1 x\ 44) + (n_2 x\ 32) + (n_4\ x\ 18) + (n_5\ x\ 28)}{(n_1 + n_2 + n_4 + n_5)}$$

The molar concentrations, n_i, is found by evaluating and balancing the equation with the fuel equivalence ratio. The following is for a rich mixture;

$$\phi\ .\ C_8H_{18} + 12\frac{1}{2}\ (O_2 + 3.776N_2) \rightarrow n_1CO_2 + n_2CO + n_3H_2O + n_4N_2$$

- $C = 8\,\phi = n_1 + n_2$ (1)

- $H = 18\,\phi = 2\,n_3$

  $\underline{n_3 = 9\,\phi}$

- $O = 25\,\phi = 2\,n_1 + n_2 + n_3$

  $O = 16\,\phi = 2\,n_1 + n_2$ (2)

- $\underline{n_1 = 25 - (17\,\phi)}$

- $\underline{n_2 = (8\,\phi) - n_1}$

- $\underline{n_4 = 47}$

The next steps are for balancing a lean mixture;

$$\phi \, . C_8H_{18} + \; 12\frac{1}{2} \, (O_2 + 3.776N_2) \; \rightarrow \; n_1CO_2 + \; n_2O_2 + \; n_3H_2O + \; n_4N_2$$

- $\underline{C \; = \; 8 \, \phi = \; n_1}$ (1)

- $H = 18 \, \phi = 2 \, n_3$

  $\underline{n_3 = 9 \, \phi}$

- $O \; = \; 25 \, \phi \; = 2 \, n_1 + \; 2n_2 + \; n_3$

  $O \; = \; 16 \, \phi \; = 2 \, n_1 + \; 2n_2$

- $\underline{n_2 \; = \left(\frac{25}{2}\right) x \, (1 - \; \phi \,)}$
- $\underline{n_4 \; = 47}$

Engine Speed	Total Mass	Fuel Air Equiv	Molecular wt o	R unburned						Mol Wt Burned	R burned
RPM	Kg				CO2	CO	O2	H2O	N2		
1000	0.00062044	0.928882129	30.149	275.760	7.43		0.8890	8.3599	47	28.610	290.596
1250	0.00080462	0.922832356	30.141	275.837	7.38		0.9646	8.3055	47	28.612	290.582
1500	0.00095644	0.932578947	30.154	275.713	7.46		0.8428	8.3932	47	28.609	290.605
1750	0.00095549	1.003552091	30.253	274.817	7.94	0.089		9.0320	47	28.573	290.973
2000	0.00097972	1.037321212	30.300	274.393	7.37	0.933		9.3359	47	28.379	292.964
2250	0.0009843	1.045244635	30.311	274.294	7.23	1.131		9.4072	47	28.334	293.430
2500	0.00098729	1.040650626	30.304	274.352	7.31	1.016		9.3659	47	28.360	293.160
3000	0.00092289	1.17977672	30.496	272.625	4.94	4.494		10.6180	47	27.596	301.274
3251	0.00095704	1.092736882	30.376	273.702	6.42	2.318		9.8346	47	28.068	296.214
4000	0.00090678	1.065343391	30.338	274.043	6.89	1.634		9.5881	47	28.220	294.610
4500	0.00082677	1.07803904	30.356	273.885	6.67	1.951		9.7024	47	28.149	295.354
5000	0.00082056	1.12101833	30.415	273.351	5.94	3.025		10.0892	47	27.912	297.864
5500	0.00077578	1.122772244	30.418	273.329	5.91	3.069		10.1050	47	27.902	297.966
6000	0.00072281	1.148358423	30.453	273.013	5.48	3.709		10.3352	47	27.764	299.454
6500	0.00061027	1.140882193	30.443	273.105	5.61	3.522		10.2679	47	27.804	299.019

Figure 36 - Molecular weight balance and burned/unburned gas constants from Excel for Ford Fox engine.

A1.3 STOICHIOMETRY

The complete combustion of the blended mixture of isooctane is expressed by the following statement;

$$C_8H_{18} + x(O_2 + 3.76N_2) \Rightarrow n_1CO_2 + n_2H_2O + n_3N_2$$

The number of air molecules, x, represents the number needed for complete combustion. The following process balances the equation.

- Carbons atoms on the left-hand side: 8
- Hydrogen atoms on the left-hand side: 18
- This means there are 8 CO_2 molecules, and 9 H_2O molecules on the right-hand side. (n_1=9, n_2=11)
- Now, the total number of oxygen atoms on the right is known, and the number of air molecules needed for complete burn can be determined. On the right hand-side there are 8 CO_2 molecules which require 16 Oxygen atoms (8 x O_2), and 9H_2O molecules meaning an extra 9 Oxygen atoms. This means in total there are 25 Oxygen atoms needed to balance the equation.
- Therefore $x = \left(\frac{29}{2}\right) = 12.5$ Air molecules.
- 12.5 air molecules are needed to balance the complete combustion equation, this means the stoichiometric air to fuel ratio for best combustion is 12.5:1.

$$Air\ Fuel\ Mass\ Ratio = \frac{Stoichiometric\ Mass\ Ratio\ x\ Molecular\ Mass\ of\ Air}{Molecular\ Mass\ of\ Fuel}$$

$$Air\ Fuel\ Mass\ Ratio = \frac{12.5\ x\ 137.28}{114} = \ 15.05$$

A1.4 THERMODYNAMIC PROCESSES

A1.4.1 ADIABATIC PROCESS

An adiabatic process has energy transfer as work without the transfer or loss of heat in the system.

$$Q = 0$$

$$\Delta U = - W$$

$$pV^{\gamma}=C$$

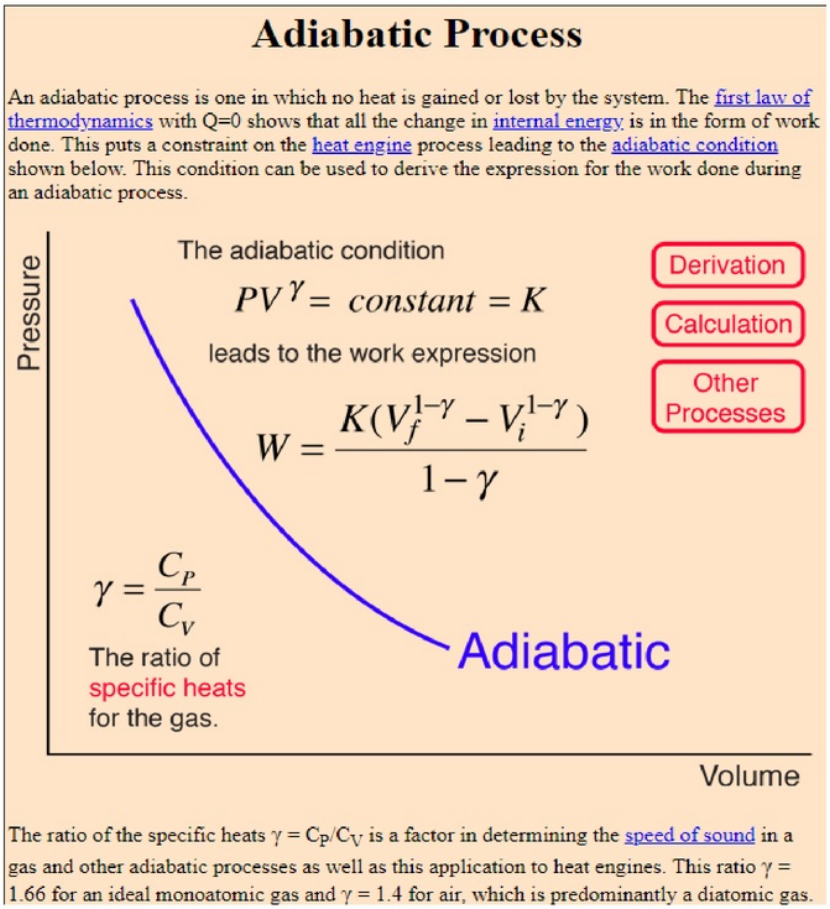


Figure 37 - Adiabatic Process from [#]

A1.4.2 POLYTROPIC PROCESS

A polytropic process is the thermodynamic process that obeys the relation;

$$pV^n=C$$

Where the process has some heat loss and therefore is not totally adiabatic.

A polytropic process is a thermodynamic process that contains heat transfer and obeys the equation [38];

$$PV^n = C$$

Where P is the pressure, V is the volume, n which is known as the polytropic index, and C which is constant.

n = 0 = Isobaric Process (constant pressure)

n = 1 = Isothermic Process (constant temperature)

n = ∞ = Isochoric Process (constant volume)

n = γ = Adiabatic (no heat transfer)

13 APPENDIX 2 - DISSOCIATION DATA

The below tables are dissociation models for generic gas properties for isooctane, C_8H_{18}.

Fuel Equivalence Ratio: 1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	100	8	9	4.833E-07	7.841E-07	6.337E-07	47
1500	2.07E+05	5.31E+05	100	7.9989	8.9995	1.099E-03	4.823E-04	7.908E-04	47
2000	765.600	3467.000	100	7.9520	8.9880	0.04800	0.01198	0.02999	47
2100	345.940	1686.600	100	7.9183	8.9810	0.08166	0.01900	0.05033	47
2200	168.270	874.980	100	7.8680	8.9711	0.13196	0.02894	0.08045	47
2300	87.097	480.840	100	7.7959	8.9575	0.20412	0.04248	0.12330	47
2400	47.753	277.430	100	7.6971	8.9394	0.30291	0.06055	0.18173	47
2500	27.543	167.490	100	7.5669	8.9161	0.43313	0.08393	0.25853	47
2700	10.351	68.077	100	7.1935	8.8491	0.80655	0.15086	0.47870	47
3000	3.0549	22.029	100	6.3268	8.6816	1.67319	0.31839	0.99579	47

Fuel Equivalence Ratio: 1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	90	8	9	5.006E-07	8.1212E-07	6.5636E-07	47
1500	2.07E+05	5.31E+05	90	7.9989	8.9995	0.0011386	0.00049951	0.00081904	47
2000	765.600	3467.000	90	7.9503	8.9876	0.0497034	0.01240777	0.03105557	47
2100	345.940	1686.600	90	7.9154	8.9803	0.0845546	0.01967625	0.0521154	47
2200	168.270	874.980	90	7.8634	8.9700	0.1366258	0.02997272	0.08329928	47
2300	87.097	480.840	90	7.7887	8.9560	0.2112824	0.0440062	0.12764432	47
2400	47.753	277.430	90	7.6866	8.9373	0.3134428	0.06273046	0.18808661	47
2500	27.543	167.490	90	7.5520	8.9131	0.4480039	0.08694983	0.26747686	47
2700	10.351	68.077	90	7.1668	8.8437	0.8332421	0.15633727	0.49478967	47
3000	3.0549	22.029	90	6.2765	8.6699	1.7234696	0.33014011	1.02680487	47

Fuel Equivalence Ratio: 1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	80	8	9	5.206E-07	8.4464E-07	6.8264E-07	47
1500	2.07E+05	5.31E+05	80	7.9988	8.9995	0.0011841	0.00051951	0.00085183	47
2000	765.600	3467.000	80	7.9483	8.9871	0.0516848	0.01290491	0.03229485	47
2100	345.940	1686.600	80	7.9121	8.9795	0.0879146	0.02046503	0.05418981	47
2200	168.270	874.980	80	7.8580	8.9688	0.1420292	0.03117536	0.08660229	47
2300	87.097	480.840	80	7.7804	8.9542	0.2195818	0.04577454	0.13267816	47
2400	47.753	277.430	80	7.6744	8.9347	0.3256375	0.06525616	0.19544685	47
2500	27.543	167.490	80	7.5348	8.9095	0.4652123	0.09046025	0.27783626	47
2700	10.351	68.077	80	7.1360	8.8373	0.8640415	0.16269862	0.51337007	47
3000	3.0549	22.029	80	6.2189	8.6562	1.7810876	0.34379578	1.06244167	47

Fuel Equivalence Ratio: 1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	70	8	9	5.443E-07	8.8309E-07	7.1372E-07	47
1500	2.07E+05	5.31E+05	70	7.9988	8.9995	0.001238	0.00054315	0.0008906	47
2000	765.600	3467.000	70	7.9460	8.9865	0.0540261	0.0134926	0.03375935	47
2100	345.940	1686.600	70	7.9081	8.9786	0.0918841	0.02139759	0.05664085	47
2200	168.270	874.980	70	7.8516	8.9674	0.1484113	0.03259753	0.09050442	47
2300	87.097	480.840	70	7.7706	8.9521	0.2293767	0.0478655	0.13862108	47
2400	47.753	277.430	70	7.6600	8.9318	0.3400199	0.06824342	0.20413164	47
2500	27.543	167.490	70	7.5145	8.9054	0.485486	0.09461303	0.29004949	47
2700	10.351	68.077	70	7.0998	8.8298	0.9002139	0.17022833	0.53522112	47
3000	3.0549	22.029	70	6.1518	8.6400	1.8482256	0.35997456	1.10410006	47
Fuel Equivalence Ratio: 1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	60	8	9	5.730E-07	9.296E-07	7.513E-07	47
1500	2.07E+05	5.31E+05	60	7.9987	8.9994	1.303E-03	5.718E-04	9.376E-04	47
2000	765.600	3467.000	60	7.9431	8.9858	0.05686	0.01420	0.03553	47
2100	345.940	1686.600	60	7.9033	8.9775	0.09669	0.02253	0.05961	47
2200	168.270	874.980	60	7.8439	8.9657	0.15613	0.03432	0.09523	47
2300	87.097	480.840	60	7.7588	8.9496	0.24122	0.05040	0.14581	47
2400	47.753	277.430	60	7.6426	8.9281	0.35739	0.07186	0.21463	47
2500	27.543	167.490	60	7.4901	8.9004	0.50994	0.09965	0.30479	47
2700	10.351	68.077	60	7.0563	8.8206	0.94368	0.17936	0.56152	47
3000	3.0549	22.029	60	6.0719	8.6204	1.92814	0.37962	1.15388	47
Fuel Equivalence Ratio: 1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	50	8	9	6.089E-07	9.879E-07	7.9842E-07	47
1500	2.07E+05	5.31E+05	50	7.9986	8.9994	0.001385	0.00060762	0.00099629	47
2000	765.600	3467.000	50	7.9396	8.9849	0.0604048	0.01509506	0.03774993	47
2100	345.940	1686.600	50	7.8973	8.9761	0.1026928	0.02394061	0.06331668	47
2200	168.270	874.980	50	7.8342	8.9635	0.1657719	0.03647556	0.10112372	47
2300	87.097	480.840	50	7.7440	8.9464	0.2559949	0.05356957	0.15478226	47
2400	47.753	277.430	50	7.6210	8.9236	0.3790413	0.07639493	0.22771814	47
2500	27.543	167.490	50	7.4596	8.8941	0.5403747	0.10594974	0.32316221	47
2700	10.351	68.077	50	7.0025	8.8092	0.9975299	0.19080631	0.59416812	47
3000	3.0549	22.029	50	5.9740	8.5957	2.0260174	0.40426349	1.21514044	47

Fuel Equivalence Ratio: 1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	40	8	9	6.56E-07	1.0642E-06	8.6008E-07	47
1500	2.07E+05	5.31E+05	40	7.9985	8.9993	0.0014919	0.00065454	0.00107322	47
2000	765.600	3467.000	40	7.9350	8.9837	0.0650429	0.01626151	0.04065223	47
2100	345.940	1686.600	40	7.8895	8.9742	0.1105462	0.02579181	0.06816901	47
2200	168.270	874.980	40	7.8216	8.9607	0.1783742	0.03929936	0.10883676	47
2300	87.097	480.840	40	7.7247	8.9423	0.2752896	0.05772424	0.1665069	47
2400	47.753	277.430	40	7.5927	8.9177	0.4072677	0.0823342	0.24480093	47
2500	27.543	167.490	40	7.4200	8.8858	0.5799711	0.11421389	0.34709247	47
2700	10.351	68.077	40	6.9328	8.7942	1.0671791	0.20582787	0.63650347	47
3000	3.0549	22.029	40	5.8492	8.5633	2.1507552	0.43665346	1.29370431	47

Fuel Equivalence Ratio: 1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	30	8	9	7.22E-07	1.1713E-06	9.4664E-07	47
1500	2.07E+05	5.31E+05	30	7.9984	8.9993	0.001642	0.00072041	0.00118122	47
2000	765.600	3467.000	30	7.9285	8.9821	0.0715485	0.01789938	0.04472394	47
2100	345.940	1686.600	30	7.8784	8.9716	0.1215545	0.02839157	0.07497302	47
2200	168.270	874.980	30	7.8040	8.9567	0.1960204	0.04326567	0.11964305	47
2300	87.097	480.840	30	7.6977	8.9364	0.3022644	0.06356105	0.18291271	47
2400	47.753	277.430	30	7.5533	8.9093	0.4466529	0.09068228	0.2686676	47
2500	27.543	167.490	30	7.3649	8.8742	0.6350718	0.12583578	0.3804538	47
2700	10.351	68.077	30	6.8367	8.7730	1.1633223	0.22697916	0.69515071	47
3000	3.0549	22.029	30	5.6804	8.5177	2.3195602	0.48233255	1.40094635	47

Fuel Equivalence Ratio: 1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	20	8	9	8.265E-07	1.3408E-06	1.0836E-06	47
1500	2.07E+05	5.31E+05	20	7.9981	8.9992	0.0018796	0.00082466	0.00135213	47
2000	765.600	3467.000	20	7.9182	8.9795	0.0818286	0.02049184	0.05116023	47
2100	345.940	1686.600	20	7.8611	8.9675	0.1389329	0.03250747	0.08572017	47
2200	168.270	874.980	20	7.7762	8.9505	0.2238352	0.04954689	0.13669103	47
2300	87.097	480.840	20	7.6553	8.9272	0.3446902	0.07280876	0.2087495	47
2400	47.753	277.430	20	7.4916	8.8961	0.5084055	0.10391592	0.3061607	47
2500	27.543	167.490	20	7.2789	8.8557	0.7211118	0.1442727	0.43269227	47
2700	10.351	68.077	20	6.6883	8.7394	1.3116538	0.26059394	0.78612389	47
3000	3.0549	22.029	20	5.4276	8.4449	2.5724273	0.55505557	1.56374143	47

Fuel Equivalence Ratio: 1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	10	8	9	1.041E-06	1.6893E-06	1.3653E-06	47
1500	2.07E+05	5.31E+05	10	7.9976	8.9990	0.0023681	0.001039	0.00170353	47
2000	765.600	3467.000	10	7.8971	8.9742	0.1029074	0.02582391	0.06436565	47
2100	345.940	1686.600	10	7.8255	8.9590	0.1744965	0.04097547	0.107736	47
2200	168.270	874.980	10	7.7194	8.9375	0.2805921	0.06247657	0.17153434	47
2300	87.097	480.840	10	7.5691	8.9081	0.4309024	0.09185959	0.26138101	47
2400	47.753	277.430	10	7.3668	8.8688	0.6331739	0.13120621	0.38219007	47
2500	27.543	167.490	10	7.1064	8.8177	0.8936319	0.18234195	0.53798693	47
2700	10.351	68.077	10	6.3975	8.6698	1.6025208	0.33020639	0.96636362	47
3000	3.0549	22.029	10	4.9575	8.2941	3.0424518	0.70587763	1.87416472	47
Fuel Equivalence Ratio: 1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	1	8.0000	9.0000	2.243E-06	3.6395E-06	2.9414E-06	47
1500	2.07E+05	5.31E+05	1	7.9949	8.9978	0.0051006	0.0022384	0.0036695	47
2000	765.600	3467.000	1	7.7806	8.9443	0.2194352	0.05570439	0.13756979	47
2100	345.940	1686.600	1	7.6306	8.9115	0.3694343	0.08849529	0.22896477	47
2200	168.270	874.980	1	7.4122	8.8648	0.5877762	0.13518906	0.36148265	47
2300	87.097	480.840	1	7.1109	8.8007	0.889121	0.19932248	0.54422172	47
2400	47.753	277.430	1	6.7199	8.7143	1.2800843	0.28572818	0.78290621	47
2500	27.543	167.490	1	6.2405	8.6012	1.7594987	0.39879626	1.0791475	47
2700	10.351	68.077	1	5.0658	8.2715	2.9342333	0.72847853	1.83135591	47
3000	3.0549	22.029	1	3.1941	7.4463	4.805886	1.55369598	3.17979101	47

Fuel Equivalence Ratio: 1.1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	100	8.8	9.9	4.25335E-24	6.90022E-24	-1.25	47
1500	2.07E+05	5.31E+05	100	7.129049	9.070951	1.67095134	0.829048661	2.79074E-10	47
2000	765.600	3467.000	100	6.876068	9.323903	1.923931941	0.576096693	1.43174E-05	47
2100	345.940	1686.600	100	6.847036	9.352829	1.952963764	0.547171198	6.74811E-05	47
2200	168.270	874.980	100	6.82224	9.377208	1.977760337	0.522791858	0.000276098	47
2300	87.097	480.840	100	6.799041	9.398959	2.000959257	0.501040671	0.000999964	47
2400	47.753	277.430	100	6.777268	9.416263	2.022732003	0.48373721	0.003234606	47
2500	27.543	167.490	100	6.751629	9.42955	2.048371035	0.47044991	0.009410472	47
2700	10.351	68.077	100	6.647483	9.435449	2.15251681	0.464551383	0.058534097	47
3000	3.0549	22.029	100	6.124039	9.334374	2.675961498	0.565625996	0.370793747	47

Fuel Equivalence Ratio: 1.1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	90	8.8	9.9	4.03504E-18	6.54606E-18	-1.25	47
1500	2.07E+05	5.31E+05	90	7.129049	9.070951	1.67095134	0.829048661	3.10081E-10	47
2000	765.600	3467.000	90	6.876066	9.323902	1.923934279	0.576097537	1.59081E-05	47
2100	345.940	1686.600	90	6.847025	9.352825	1.952974952	0.547175004	7.49779E-05	47
2200	168.270	874.980	90	6.822193	9.377193	1.977806684	0.522806827	0.000306755	47
2300	87.097	480.840	90	6.798871	9.398907	2.001128815	0.501092843	0.001110829	47
2400	47.753	277.430	90	6.776717	9.4161	2.023282967	0.483899949	0.003591458	47
2500	27.543	167.490	90	6.750035	9.429095	2.049965261	0.470904548	0.010434905	47
2700	10.351	68.077	90	6.638388	9.432969	2.161611991	0.467030699	0.064321345	47
3000	3.0549	22.029	90	6.085601	9.32331	2.714399101	0.576690194	0.395544648	47

Fuel Equivalence Ratio: 1.1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	80	8.8	9.9	1.18013E-16	1.91453E-16	-1.25	47
1500	2.07E+05	5.31E+05	80	7.129049	9.070951	1.67095134	0.829048661	3.48842E-10	47
2000	765.600	3467.000	80	6.876063	9.323901	1.923937201	0.576098592	1.78966E-05	47
2100	345.940	1686.600	80	6.847011	9.35282	1.952988936	0.547179761	8.43485E-05	47
2200	168.270	874.980	80	6.822135	9.377174	1.977864612	0.522825536	0.000345074	47
2300	87.097	480.840	80	6.798659	9.398842	2.001340681	0.501158037	0.001249359	47
2400	47.753	277.430	80	6.776029	9.415897	2.023970614	0.484103091	0.004036853	47
2500	27.543	167.490	80	6.748051	9.428529	2.051949253	0.471470578	0.011709916	47
2700	10.351	68.077	80	6.627282	9.429934	2.172717681	0.470065525	0.071391603	47
3000	3.0549	22.029	80	6.040747	9.310255	2.759252774	0.589745445	0.424499109	47

Fuel Equivalence Ratio: 1.1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	70	8.8	9.9	1.26161E-16	2.04671E-16	-1.25	47
1500	2.07E+05	5.31E+05	70	7.129049	9.070951	1.67095134	0.829048661	3.98675E-10	47
2000	765.600	3467.000	70	6.876059	9.3239	1.923940959	0.576099948	2.04532E-05	47
2100	345.940	1686.600	70	6.846993	9.352814	1.953006916	0.547185878	9.63967E-05	47
2200	168.270	874.980	70	6.822061	9.37715	1.977939079	0.522849586	0.000394332	47
2300	87.097	480.840	70	6.798387	9.398758	2.001612853	0.501241791	0.001427322	47
2400	47.753	277.430	70	6.775147	9.415636	2.024852942	0.484363792	0.004608367	47
2500	27.543	167.490	70	6.745514	9.427805	2.054485525	0.472194559	0.013340042	47
2700	10.351	68.077	70	6.613405	9.426131	2.186594824	0.473869267	0.080232046	47
3000	3.0549	22.029	70	5.987487	9.294547	2.812513321	0.605453047	0.458983184	47

Fuel Equivalence Ratio: 1.1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	60	8.8	9.9	1.363E-16	2.211E-16	-1.250E+00	47
1500	2.07E+05	5.31E+05	60	7.1290	9.0710	1.671E+00	8.290E-01	4.651E-10	47
2000	765.600	3467.000	60	6.87605	9.32390	1.92395	0.57610	0.00002	47
2100	345.940	1686.600	60	6.84697	9.35281	1.95303	0.54719	0.00011	47
2200	168.270	874.980	60	6.82196	9.37712	1.97804	0.52288	0.00046	47
2300	87.097	480.840	60	6.79802	9.39865	2.00198	0.50135	0.00166	47
2400	47.753	277.430	60	6.77397	9.41529	2.02603	0.48471	0.00537	47
2500	27.543	167.490	60	6.74216	9.42685	2.05784	0.47315	0.01550	47
2700	10.351	68.077	60	6.59555	9.42122	2.20445	0.47878	0.09161	47
3000	3.0549	22.029	60	5.92282	9.27517	2.87718	0.62483	0.50101	47

Fuel Equivalence Ratio: 1.1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	50	8.8	9.9	1.49273E-16	2.42167E-16	-1.25	47
1500	2.07E+05	5.31E+05	50	7.129049	9.070951	1.67095134	0.829048661	5.58147E-10	47
2000	765.600	3467.000	50	6.876047	9.323896	1.923952981	0.576104287	2.86339E-05	47
2100	345.940	1686.600	50	6.846936	9.352795	1.953064441	0.547205447	0.000134944	47
2200	168.270	874.980	50	6.821823	9.377073	1.978177271	0.522926518	0.000551895	47
2300	87.097	480.840	50	6.797517	9.398491	2.002482598	0.50150947	0.001996034	47
2400	47.753	277.430	50	6.772337	9.414806	2.027662951	0.485194419	0.006428685	47
2500	27.543	167.490	50	6.737506	9.425517	2.062494084	0.474483453	0.018488768	47
2700	10.351	68.077	50	6.571696	9.41462	2.228304303	0.485379863	0.106842083	47
3000	3.0549	22.029	50	5.841951	9.25045	2.958048561	0.649549784	0.553799173	47

Fuel Equivalence Ratio: 1.1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	40	8.8	9.9	1.66891E-16	2.70748E-16	-1.25	47
1500	2.07E+05	5.31E+05	40	7.129049	9.070951	1.67095134	0.829048661	6.97683E-10	47
2000	765.600	3467.000	40	6.876036	9.323892	1.923963501	0.576108084	3.57923E-05	47
2100	345.940	1686.600	40	6.846885	9.352777	1.953114769	0.547222569	0.000168669	47
2200	168.270	874.980	40	6.821614	9.377006	1.97838557	0.522993798	0.000689684	47
2300	87.097	480.840	40	6.796758	9.398257	2.003241972	0.501743224	0.002492598	47
2400	47.753	277.430	40	6.769895	9.414083	2.030105139	0.485916761	0.00801095	47
2500	27.543	167.490	40	6.730628	9.423547	2.069371948	0.476452646	0.022912297	47
2700	10.351	68.077	40	6.538079	9.405257	2.261920514	0.494743056	0.128331785	47
3000	3.0549	22.029	40	5.736569	9.2174	3.063431111	0.682600397	0.623015754	47

Fuel Equivalence Ratio: 1.1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	30	8.8	9.9	1.92706E-16	3.12628E-16	-1.25	47
1500	2.07E+05	5.31E+05	30	7.129049	9.070951	1.670951341	0.829048661	9.30245E-10	47
2000	765.600	3467.000	30	6.876019	9.323886	1.923981032	0.576114411	4.77214E-05	47
2100	345.940	1686.600	30	6.846801	9.352749	1.953198635	0.5472511	0.000224868	47
2200	168.270	874.980	30	6.821268	9.376894	1.978732473	0.523105854	0.000919164	47
2300	87.097	480.840	30	6.795496	9.397868	2.004504319	0.502131896	0.003318107	47
2400	47.753	277.430	30	6.765858	9.412888	2.034141717	0.487111585	0.010626651	47
2500	27.543	167.490	30	6.71942	9.420332	2.080579937	0.479668459	0.030124198	47
2700	10.351	68.077	30	6.486868	9.390843	2.313132026	0.509157137	0.161144582	47
3000	3.0549	22.029	30	5.590486	9.16994	3.209514444	0.730059938	0.719787191	47

Fuel Equivalence Ratio: 1.1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	20	8.8	9.9	2.36011E-16	3.8288E-16	-1.25	47
1500	2.07E+05	5.31E+05	20	7.129049	9.070951	1.670951341	0.829048662	1.39537E-09	47
2000	765.600	3467.000	20	6.875984	9.323873	1.924016092	0.576127065	7.15788E-05	47
2100	345.940	1686.600	20	6.846634	9.352692	1.95336631	0.547308145	0.000337227	47
2200	168.270	874.980	20	6.820575	9.37667	1.979425333	0.523329687	0.00137751	47
2300	87.097	480.840	20	6.792983	9.397094	2.007016544	0.502905733	0.004961139	47
2400	47.753	277.430	20	6.757908	9.410532	2.042092303	0.489468239	0.015780271	47
2500	27.543	167.490	20	6.697888	9.414129	2.102112374	0.485870572	0.043991473	47
2700	10.351	68.077	20	6.398061	9.365408	2.401938563	0.534591575	0.218265069	47
3000	3.0549	22.029	20	5.365732	9.09293	3.434268041	0.807070126	0.870669083	47

Fuel Equivalence Ratio: 1.1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	10	8.8	9.9	3.33751E-16	5.41445E-16	-1.25	47
1500	2.07E+05	5.31E+05	10	7.129049	9.070951	1.670951343	0.829048663	2.79073E-09	47
2000	765.600	3467.000	10	6.875879	9.323835	1.924121254	0.576165021	0.000143138	47
2100	345.940	1686.600	10	6.846131	9.352521	1.953868888	0.547479139	0.000674014	47
2200	168.270	874.980	10	6.818504	9.376001	1.981496355	0.52399895	0.002747653	47
2300	87.097	480.840	10	6.785543	9.3948	2.014456655	0.505200114	0.009828385	47
2400	47.753	277.430	10	6.73497	9.403708	2.065030053	0.496291797	0.030660925	47
2500	27.543	167.490	10	6.639207	9.397065	2.160792884	0.50293462	0.081863752	47
2700	10.351	68.077	10	6.196287	9.30546	2.603713485	0.594540474	0.349126979	47
3000	3.0549	22.029	10	4.934604	8.929953	3.8653957	0.97004748	1.16772159	47

Fuel Equivalence Ratio: 1.1									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	1	8.8	9.9	1.05499E-15	1.7115E-15	-1.25	47
1500	2.07E+05	5.31E+05	1	7.129049	9.070951	1.670951375	0.829048681	2.79073E-08	47
2000	765.600	3467.000	1	6.873991	9.323153	1.926009089	0.576846543	0.001427816	47
2100	345.940	1686.600	1	6.837198	9.349478	1.962802408	0.550521786	0.006662097	47
2200	168.270	874.980	1	6.783012	9.364483	2.016987688	0.535516713	0.0262522	47
2300	87.097	480.840	1	6.670826	9.358922	2.129173577	0.541077985	0.085125781	47
2400	47.753	277.430	1	6.449283	9.315553	2.3507168	0.584446505	0.217581653	47
2500	27.543	167.490	1	6.09196	9.225604	2.708040265	0.674396399	0.441218332	47
2700	10.351	68.077	1	5.047751	8.894677	3.752248758	1.005323293	1.128786025	47
3000	3.0549	22.029	1	3.240183	7.997066	5.559816817	1.902934316	2.481375566	47

Fuel Equivalence Ratio: 0.9									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	100	7.199863	8.099778	0.000136876	0.00022205	1.250179464	47
1500	2.07E+05	5.31E+05	100	2.848556	5.076247	4.351444149	3.0237533	4.937598725	47
2000	765.600	3467.000	100	0.017389	0.087842	7.182610614	8.01215777	8.847384194	47
2100	345.940	1686.600	100	0.007868	0.042972	7.192132107	8.05702786	8.874579985	47
2200	168.270	874.980	100	0.003829	0.02235	7.196170799	8.07764971	8.886910255	47
2300	87.097	480.840	100	0.001983	0.012298	7.198017487	8.08770225	8.892859867	47
2400	47.753	277.430	100	0.001087	0.0071	7.198912905	8.09290001	8.895906459	47
2500	27.543	167.490	100	0.000627	0.004288	7.199372945	8.09571211	8.897542526	47
2700	10.351	68.077	100	0.000236	0.001743	7.199764332	8.09825662	8.899010476	47
3000	3.0549	22.029	100	6.96E-05	0.000564	7.199930445	8.09943578	8.899683112	47

Fuel Equivalence Ratio: 0.9									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	90	7.199856	8.099766	0.00014428	0.00023406	1.250189172	47
1500	2.07E+05	5.31E+05	90	2.75838	4.975771	4.441620451	3.12422859	5.032924518	47
2000	765.600	3467.000	90	0.016499	0.083381	7.183500935	8.01661914	8.85006004	47
2100	345.940	1686.600	90	0.007465	0.040778	7.192535443	8.05922195	8.875878696	47
2200	168.270	874.980	90	0.003633	0.021206	7.196367202	8.07879365	8.887580427	47
2300	87.097	480.840	90	0.001881	0.011668	7.198119196	8.08833242	8.893225807	47
2400	47.753	277.430	90	0.001031	0.006736	7.198968683	8.09326406	8.89611637	47
2500	27.543	167.490	90	0.000595	0.004068	7.19940512	8.09593204	8.897668579	47
2700	10.351	68.077	90	0.000224	0.001654	7.199776425	8.09834607	8.899061246	47
3000	3.0549	22.029	90	6.6E-05	0.000535	7.199934015	8.09946473	8.899699373	47

Fuel Equivalence Ratio: 0.9									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	80	7.199847	8.099752	0.000153032	0.00024826	1.250200647	47
1500	2.07E+05	5.31E+05	80	2.658882	4.862015	4.541117838	3.23798547	5.139551652	47
2000	765.600	3467.000	80	0.015558	0.078659	7.184442493	8.02134147	8.85289198	47
2100	345.940	1686.600	80	0.007038	0.038457	7.192961931	8.06154301	8.877252471	47
2200	168.270	874.980	80	0.003425	0.019997	7.196574866	8.08000347	8.888289167	47
2300	87.097	480.840	80	0.001773	0.011001	7.198226735	8.08899879	8.893612764	47
2400	47.753	277.430	80	0.000972	0.006351	7.199027657	8.09364899	8.896338324	47
2500	27.543	167.490	80	0.000561	0.003835	7.199439139	8.09616458	8.897801859	47
2700	10.351	68.077	80	0.000211	0.001559	7.199789211	8.09844064	8.899114925	47
3000	3.0549	22.029	80	6.22E-05	0.000505	7.199937788	8.09949534	8.899716565	47

Fuel Equivalence Ratio: 0.9									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	70	7.199836	8.099735	0.000163598	0.0002654	1.2502145	47
1500	2.07E+05	5.31E+05	70	2.547927	4.731423	4.652073434	3.36857661	5.260325021	47
2000	765.600	3467.000	70	0.014555	0.073624	7.185445254	8.0263755	8.855910379	47
2100	345.940	1686.600	70	0.006584	0.035984	7.193416073	8.06401575	8.878715911	47
2200	168.270	874.980	70	0.003204	0.018708	7.196795982	8.08129197	8.889043979	47
2300	87.097	480.840	70	0.001659	0.010292	7.198341236	8.08970841	8.894024823	47
2400	47.753	277.430	70	0.00091	0.005941	7.199090448	8.09405887	8.896574661	47
2500	27.543	167.490	70	0.000525	0.003588	7.19947536	8.09641218	8.897943771	47
2700	10.351	68.077	70	0.000197	0.001459	7.199802825	8.09854133	8.899172079	47
3000	3.0549	22.029	70	5.82E-05	0.000472	7.199941806	8.09952793	8.89973487	47

Fuel Equivalence Ratio: 0.9									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	60	7.1998	8.0997	1.767E-04	2.867E-04	1.250E+00	47
1500	2.07E+05	5.31E+05	60	2.4225	4.5789	4.777E+00	3.521E+00	5.399E+00	47
2000	765.600	3467.000	60	0.01348	0.06821	7.18652	8.03179	8.85916	47
2100	345.940	1686.600	60	0.00610	0.03333	7.19390	8.06667	8.88029	47
2200	168.270	874.980	60	0.00297	0.01732	7.19703	8.08268	8.88986	47
2300	87.097	480.840	60	0.00154	0.00953	7.19846	8.09047	8.89447	47
2400	47.753	277.430	60	0.00084	0.00550	7.19916	8.09450	8.89683	47
2500	27.543	167.490	60	0.00049	0.00332	7.19951	8.09668	8.89810	47
2700	10.351	68.077	60	0.00018	0.00135	7.19982	8.09865	8.89923	47
3000	3.0549	22.029	60	0.00005	0.00044	7.19995	8.09956	8.89975	47

Fuel Equivalence Ratio: 0.9									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	50	7.199806	8.099686	0.00019357	0.00031403	1.250253798	47
1500	2.07E+05	5.31E+05	50	2.27823	4.396438	4.921769728	3.70356185	5.562665788	47
2000	765.600	3467.000	50	0.012305	0.062312	7.187695143	8.03768824	8.862691693	47
2100	345.940	1686.600	50	0.005565	0.030433	7.194434778	8.06956682	8.8820008	47
2200	168.270	874.980	50	0.002708	0.015817	7.197291924	8.08418318	8.89073755	47
2300	87.097	480.840	50	0.001402	0.0087	7.198598038	8.09130031	8.894949173	47
2400	47.753	277.430	50	0.000769	0.005022	7.199231274	8.09497826	8.897104767	47
2500	27.543	167.490	50	0.000443	0.003032	7.199556594	8.09696753	8.898262063	47
2700	10.351	68.077	50	0.000167	0.001233	7.199833356	8.09876717	8.899300261	47
3000	3.0549	22.029	50	4.92E-05	0.000399	7.199950817	8.09960103	8.899775922	47

Fuel Equivalence Ratio: 0.9									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	40	7.199784	8.099649	0.000216418	0.00035109	1.250283754	47
1500	2.07E+05	5.31E+05	40	2.108134	4.171318	5.091865744	3.92868229	5.760274018	47
2000	765.600	3467.000	40	0.011008	0.055779	7.188992215	8.04422137	8.866606792	47
2100	345.940	1686.600	40	0.004978	0.027231	7.195021908	8.07276894	8.883895422	47
2200	168.270	874.980	40	0.002422	0.01415	7.197577727	8.08585009	8.891713906	47
2300	87.097	480.840	40	0.001254	0.007782	7.198746022	8.09221788	8.895481949	47
2400	47.753	277.430	40	0.000688	0.004492	7.199312422	8.09550813	8.897410274	47
2500	27.543	167.490	40	0.000397	0.002712	7.199603403	8.09728757	8.898445487	47
2700	10.351	68.077	40	0.000149	0.001103	7.199850949	8.0988973	8.899374126	47
3000	3.0549	22.029	40	4.4E-05	0.000357	7.19995601	8.09964315	8.899799578	47

Fuel Equivalence Ratio: 0.9									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	30	7.19975	8.099595	0.000249896	0.0004054	1.250327649	47
1500	2.07E+05	5.31E+05	30	1.900239	3.880176	5.299760966	4.21982444	6.009792706	47
2000	765.600	3467.000	30	0.009535	0.04835	7.190465026	8.05164968	8.871057354	47
2100	345.940	1686.600	30	0.004312	0.023593	7.195688447	8.07640658	8.886047513	47
2200	168.270	874.980	30	0.002098	0.012257	7.197902156	8.08774295	8.892822551	47
2300	87.097	480.840	30	0.001086	0.00674	7.198913998	8.09325962	8.896086806	47
2400	47.753	277.430	30	0.000595	0.00389	7.199404533	8.09610963	8.897757084	47
2500	27.543	167.490	30	0.000343	0.002349	7.199656534	8.09765086	8.898653698	47
2700	10.351	68.077	30	0.000129	0.000955	7.199870917	8.09904502	8.899457968	47
3000	3.0549	22.029	30	3.81E-05	0.000309	7.199961903	8.09969095	8.899826428	47

Fuel Equivalence Ratio: 0.9									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	20	7.199694	8.099503	0.000306057	0.00049651	1.250401282	47
1500	2.07E+05	5.31E+05	20	1.630505	3.473485	5.569494981	4.62651542	6.348005198	47
2000	765.600	3467.000	20	0.007787	0.039521	7.192212834	8.06047884	8.876345837	47
2100	345.940	1686.600	20	0.003521	0.019274	7.196479245	8.08072575	8.888602498	47
2200	168.270	874.980	20	0.001713	0.010011	7.198287026	8.08998938	8.894138202	47
2300	87.097	480.840	20	0.000887	0.005504	7.199113258	8.09449566	8.896804458	47
2400	47.753	277.430	20	0.000486	0.003177	7.199513796	8.09682325	8.898168523	47
2500	27.543	167.490	20	0.00028	0.001918	7.199719559	8.09808183	8.898900697	47
2700	10.351	68.077	20	0.000105	0.00078	7.199894604	8.09922024	8.899557424	47
3000	3.0549	22.029	20	3.11E-05	0.000252	7.199968894	8.09974766	8.899858278	47

Fuel Equivalence Ratio: 0.9									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	10	7.199567	8.099298	0.000432822	0.00070215	1.250567486	47
1500	2.07E+05	5.31E+05	10	1.234846	2.808926	5.965153561	5.29107441	6.878113988	47
2000	765.600	3467.000	10	0.005508	0.027986	7.194491897	8.07201433	8.883253112	47
2100	345.940	1686.600	10	0.00249	0.013638	7.197510093	8.08636154	8.891935818	47
2200	168.270	874.980	10	0.001211	0.007081	7.19878866	8.09291886	8.895853759	47
2300	87.097	480.840	10	0.000627	0.003893	7.199372956	8.09610707	8.897740012	47
2400	47.753	277.430	10	0.000344	0.002247	7.199656195	8.09775344	8.898704818	47
2500	27.543	167.490	10	0.000198	0.001356	7.199801696	8.09864356	8.899222627	47
2700	10.351	68.077	10	7.45E-05	0.000551	7.199925474	8.09944861	8.899687044	47
3000	3.0549	22.029	10	2.2E-05	0.000178	7.199978005	8.09982157	8.899899787	47

Fuel Equivalence Ratio: 0.9									
Temp	kCO2	kH2O	Pressure	n_1CO_2	n_2H_2O	n_3CO	n_4H_2	n_5O_2	n_6N_2
1000	1.66E+10	1.15E+10	1	7.198631	8.09778	0.001368527	0.00221998	1.251794252	47
1500	2.07E+05	5.31E+05	1	0.44237	1.16435	6.757629935	6.93565003	8.096639984	47
2000	765.600	3467.000	1	0.001743	0.008871	7.198257273	8.0911292	8.894693235	47
2100	345.940	1686.600	1	0.000788	0.004318	7.199212436	8.09568217	8.897447303	47
2200	168.270	874.980	1	0.000383	0.002241	7.199616897	8.09775941	8.898688152	47
2300	87.097	480.840	1	0.000198	0.001231	7.1998017	8.09876854	8.899285121	47
2400	47.753	277.430	1	0.000109	0.000711	7.199891276	8.09928944	8.899590358	47
2500	27.543	167.490	1	6.27E-05	0.000429	7.19993729	8.09957101	8.899754148	47
2700	10.351	68.077	1	2.36E-05	0.000174	7.199976433	8.09982563	8.89990103	47
3000	3.0549	22.029	1	6.96E-06	5.64E-05	7.199993044	8.09994357	8.899968309	47

The following screenshots are from the Ford Fox excel workbook that has calculated the molar amounts and concentration each species during the combustion process at each degree. In the early stage of combustion, the temperature are too low and the constants are extremely small so the NOx output is negligible.

	Crank Angle	kCO2	kH2O	Pressure	ϕ	Guessed n5/n	n5/nt.P ^(1/2)	n1/n3	n3	n1	n2/n4	n4	n2	n5	n6	nt	nt	error
				bar														
SOC	10				0.928882	9.04E-20	0.00E+00	0	7.431057	0	0	8.359939	0	8.784471	47	71.57547	9.72E+19	############
	11	1.56E+10	1.08E+10	23.35	0.928882	3.19702E-06	0.008640045	1.35E+08	5.51E-08	7.431057	93604592	8.93E-08	8.359939	0.888973	47	63.67997	278063.3	277999.59491
	12	1.40E+10	9.70E+09	23.04066667	0.928882	3.19702E-06	0.008582624	1.2E+08	6.19E-08	7.431057	83229507	1E-07	8.359939	0.888973	47	63.67997	278063.3	277999.59773
	13	1.23E+10	8.52E+09	22.856	0.928882	3.19702E-06	0.008548161	1.05E+08	7.08E-08	7.431057	72803087	1.15E-07	8.359939	0.888973	47	63.67997	278063.3	277999.60136
	14	1.06E+10	7.32E+09	22.872	0.928882	3.19702E-06	0.008551152	90258565	8.23E-08	7.431057	62591841	1.34E-07	8.359939	0.888973	47	63.67997	278063.3	277999.60610
	15	8.77E+09	6.08E+09	23.151	0.928882	3.19702E-06	0.008603149	75472000	9.85E-08	7.431057	52338326	1.6E-07	8.359939	0.888974	47	63.67997	278063.3	277999.61271
	16	6.93E+09	4.81E+09	23.74266667	0.928882	6.39E+14	123165384	8.54E+17	8.7E-18	7.431057	5.92E+17	1.41E-17	8.359939	0.888973	47	63.67997	1.39E-15	-63.67997
	17	5.20E+09	3.61E+09	24.673	0.928882	6.39E+14	125558999.4	6.53E+17	1.14E-17	7.431057	4.53E+17	1.84E-17	8.359939	0.888973	47	63.67997	1.39E-15	-63.67997
	18	3.57E+09	2.48E+09	25.94133333	0.928882	9.18E-15	4.88116E-07	1744.463	0.004257	7.4268	1209.862	0.006904	8.353035	0.894554	47	63.68555	9.74E+13	############
	19	1.85E+09	1.28E+09	27.57066667	0.928882	1.40E-02	0.620392545	1.15E+09	6.48E-09	7.431057	7.96E+08	1.05E-08	8.359939	0.888973	47	63.67997	63.67998	0.00001
	20	3.60E+07	2.53E+07	29.60833333	0.928882	1.40E-02	0.642907178	23134235	3.21E-07	7.431057	16291127	5.13E-07	8.359939	0.888974	47	63.67997	63.68049	0.00052
	21	1.82E+05	4.67E+05	32.049	0.928882	1.40E-02	0.668899253	121873.5	6.1E-05	7.430996	312667.3	2.67E-05	8.359912	0.889017	47	63.68001	63.68003	0.00001
	22	1.56E+05	4.01E+05	34.86166667	0.928882	1.40E-02	0.697635867	108873.6	6.83E-05	7.430989	279466.9	2.99E-05	8.359909	0.889022	47	63.68002	63.68003	0.00001
	23	1.31E+05	3.37E+05	37.88133333	0.928882	1.40E-02	0.727225371	95393.52	7.79E-05	7.430979	245040.1	3.41E-05	8.359905	0.889029	47	63.68003	63.68004	0.00002
	24	1.08E+05	2.78E+05	40.928	0.928882	1.40E-02	0.755907936	81721.47	9.09E-05	7.430966	210120.9	3.98E-05	8.359899	0.889039	47	63.68003	63.68005	0.00002
	25	8.64E+04	2.22E+05	43.885	0.928882	1.40E-02	0.782744397	67613.91	0.00011	7.430947	174085.2	4.8E-05	8.359891	0.889052	47	63.68005	63.68007	0.00002
	26	6.61E+04	1.70E+05	46.67033333	0.928882	1.40E-02	0.80721168	53331.11	0.000139	7.430918	137597.8	6.08E-05	8.359878	0.889073	47	63.68007	63.68009	0.00002
	27	4.66E+04	1.21E+05	49.178	0.928882	1.40E-02	0.828631636	38653.48	0.000192	7.430865	100096.2	8.35E-05	8.359856	0.889111	47	63.68011	63.68013	0.00002
	28	2.91E+04	7.59E+04	51.30433333	0.928882	1.40E-02	0.846392533	24633.84	0.000302	7.430755	64271.61	0.00013	8.359809	0.889189	47	63.68019	63.68023	0.00004
	29	1.46E+04	3.89E+04	52.893	0.928882	0.013966495	0.859493933	12581.67	0.000591	7.430466	33471.28	0.00025	8.359689	0.889394	47	63.68039	63.68051	0.00012
	30	3.70E+03	1.10E+04	53.84366667	0.928882	0.013984381	0.867738642	3209.923	0.002314	7.428743	9518.072	0.000878	8.359061	0.89057	47	63.68157	63.68317	0.00160
	31	7.21E+02	3.28E+03	54.15833333	0.928882	0.014073819	0.87304902	629.2011	0.011792	7.419265	2860.533	0.002921	8.357018	0.89633	47	63.68733	63.68775	0.00043
	32	6.80E+02	3.10E+03	53.90466667	0.928882	0.014080733	0.871215944	592.6166	0.012518	7.418539	2704.923	0.003089	8.35685	0.896777	47	63.68777	63.68825	0.00048
	33	6.67E+02	3.05E+03	53.19066667	0.928882	0.014083913	0.865524521	577.2144	0.012852	7.418205	2638.333	0.003167	8.356772	0.896983	47	63.68798	63.68848	0.00050
	34	6.78E+02	3.10E+03	52.142	0.928882	0.014083093	0.856925106	581.2112	0.012764	7.418294	2653.407	0.003149	8.35679	0.89693	47	63.68793	63.68841	0.00049
	35	7.08E+02	3.22E+03	50.85933333	0.928882	0.014079551	0.846213089	598.8306	0.012389	7.418668	2725.811	0.003066	8.356873	0.896701	47	63.6877	63.68815	0.00045
	36	7.43E+02	3.37E+03	49.45133333	0.928882	0.014075537	0.834298548	620.0988	0.011964	7.419093	2813.432	0.00297	8.356969	0.896441	47	63.68744	63.68786	0.00042
EOC	37	2.70E+03	8.41E+03	48.00633333	0.928882	0.01399474	0.819656132	2210.823	0.00336	7.427697	6890.585	0.001213	8.358726	0.89126	47	63.68226	63.68534	0.00308

Figure 38 - Excel extract balancing combustion equation and calculation dissociated molar masses for each species at 1000rpm.

	Crank Angle	kCO2	kH2O	Pressure	ϕ	Guessed n5/nt	n5/nt.P ^(1/2)	n1/n3	n3	n1	n2/n4	n4	n2	n5	n6	nt	nt	error
				bar														
SOC	9			30.19566667	0.922832	9.18E-15	#REF!	#REF!	#REF!	#REF!	#REF!	#REF!	#REF!	#REF!	47	#REF!	#REF!	#REF!
	10	6.11E+23	4.44E+21	29.74966667	0.922832	9.18E-15	5.26622E-07	3.22E+17	2.29E-17	7.382659	2.34E+15	3.55E-15	8.305491	0.964596	47	63.65275	1.05E+14	###########
	11	1.55E+10	1.07E+10	29.41133333	0.922832	9.18E-15	5.22718E-07	8084.753	0.000913	7.381746	5606.461	0.001481	8.30401	0.965793	47	63.65394	1.05E+14	###########
	12	1.38E+10	9.57E+09	29.246	0.922832	9.18E-15	5.19738E-07	7169.626	0.00103	7.381629	4971.877	0.00167	8.303821	0.965945	47	63.6541	1.05E+14	###########
	13	1.22E+10	8.49E+09	29.325	0.922832	9.18E-15	5.18275E-07	6343.845	0.001164	7.381495	4399.251	0.001888	8.303604	0.966121	47	63.65427	1.05E+14	###########
	14	1.07E+10	7.41E+09	29.713	0.922832	9.18E-15	5.18974E-07	5544.788	0.001331	7.381328	3845.156	0.002159	8.303332	0.966341	47	63.65449	1.05E+14	###########
	15	9.07E+09	6.29E+09	30.457	0.922832	9.18E-15	5.22396E-07	4737.202	0.001558	7.381101	3285.148	0.002527	8.302964	0.966638	47	63.65479	1.05E+14	###########
	16	7.45E+09	5.16E+09	31.57466667	0.922832	9.18E-15	5.28896E-07	3938.165	0.001874	7.380785	2731.07	0.00304	8.302451	0.967053	47	63.6552	1.05E+14	###########
	17	5.88E+09	4.08E+09	33.07066667	0.922832	9.18E-15	5.38513E-07	3167.514	0.00233	7.380329	2196.676	0.003779	8.301712	0.96765	47	63.6558	1.05E+14	###########
	18	4.34E+09	3.01E+09	34.963	0.922832	1.52E-02	0.707921866	3.07E+09	2.41E-09	7.382659	2.13E+09	3.9E-09	8.305491	0.964596	47	63.65275	63.65281	0.00006
	19	2.72E+09	1.89E+09	37.26733333	0.922832	1.52E-02	0.727894092	1.98E+09	3.73E-09	7.382659	1.37E+09	6.05E-09	8.305491	0.964596	47	63.65275	63.65281	0.00006
	20	1.08E+09	7.47E+08	39.95666667	0.922832	1.52E-02	0.751498292	8.09E+08	9.12E-09	7.382659	5.62E+08	1.48E-08	8.305491	0.964596	47	63.65275	63.65281	0.00006
	21	1.98E+05	5.08E+05	43.00633333	0.922832	1.52E-02	0.778155089	154244.6	4.79E-05	7.382611	395612.3	2.1E-05	8.30547	0.96463	47	63.65278	63.65282	0.00004
	22	1.75E+05	4.50E+05	46.27433333	0.922832	1.52E-02	0.807306413	141586.7	5.21E-05	7.382607	363287.1	2.29E-05	8.305468	0.964633	47	63.65278	63.65283	0.00005
	23	1.53E+05	3.93E+05	49.6	0.922832	1.52E-02	0.837419593	128166.3	5.76E-05	7.382601	329013.6	2.52E-05	8.305466	0.964637	47	63.65279	63.65285	0.00006
	24	1.32E+05	3.39E+05	52.849	0.922832	1.52E-02	0.866991691	114415.1	6.45E-05	7.382594	293893.3	2.83E-05	8.305463	0.964642	47	63.65279	63.65286	0.00007
	25	1.13E+05	2.89E+05	55.926	0.922832	1.52E-02	0.894939832	100697.5	7.33E-05	7.382586	258856.7	3.21E-05	8.305459	0.964648	47	63.6528	63.65288	0.00008
	26	9.43E+04	2.43E+05	58.77666667	0.922832	1.52E-02	0.920627914	86822.72	8.5E-05	7.382574	223414.5	3.72E-05	8.305454	0.964657	47	63.65281	63.65291	0.00010
	27	7.69E+04	1.98E+05	61.32966667	0.922832	1.52E-02	0.943805094	72575.44	0.000102	7.382557	187016	4.44E-05	8.305447	0.964669	47	63.65282	63.65294	0.00012
	28	6.05E+04	1.56E+05	63.47033333	0.922832	1.52E-02	0.964093091	58363.79	0.000126	7.382532	150704.3	5.51E-05	8.305436	0.964686	47	63.65284	63.65299	0.00015
	29	4.55E+04	1.18E+05	65.08933333	0.922832	1.52E-02	0.980787905	44627.17	0.000165	7.382493	115601.8	7.18E-05	8.305419	0.964714	47	63.65286	63.65305	0.00019
	30	3.28E+04	8.55E+04	66.087	0.922832	1.52E-02	0.993239797	32617.87	0.000226	7.382433	84910.17	9.78E-05	8.305393	0.964758	47	63.65291	63.65314	0.00023
	31	2.25E+04	5.92E+04	66.46666667	0.922832	1.52E-02	1.000859114	22568.43	0.000327	7.382332	59223	0.00014	8.305351	0.964829	47	63.65298	63.65325	0.00027
	32	1.51E+04	4.00E+04	66.24833333	0.922832	1.52E-02	1.003787896	15124.35	0.000488	7.382171	40191.25	0.000207	8.305285	0.964943	47	63.65309	63.6534	0.00031
	33	1.02E+04	2.77E+04	65.51566667	0.922832	1.52E-02	1.002220842	10247.63	0.00072	7.381938	27718.03	0.0003	8.305192	0.965106	47	63.65326	63.65359	0.00033
	34	8.07E+03	2.22E+04	64.361	0.922832	1.52E-02	0.996732834	8048.057	0.000917	7.381742	22084.94	0.000376	8.305115	0.965242	47	63.65339	63.65374	0.00035
	35	8.56E+03	2.34E+04	62.90966667	0.922832	1.52E-02	0.987895152	8454.151	0.000873	7.381786	23110.07	0.000359	8.305132	0.965212	47	63.65336	63.65371	0.00035
	36	1.00E+04	2.72E+04	61.32366667	0.922832	1.52E-02	0.976651933	9795.452	0.000754	7.381905	26523.11	0.000313	8.305178	0.965129	47	63.65328	63.65362	0.00034
EOC	37	1.25E+04	3.34E+04	59.63533333	0.922832	1.52E-02	0.964214148	12040.33	0.000613	7.382046	32244.99	0.000258	8.305234	0.965031	47	63.65318	63.65351	0.00032

Figure 39 - Excel extract balancing combustion equation and calculation dissociated molar masses for each species at 1250rpm.

	Crank Angle	kCO2	kH2O	Pressure	ϕ	Guessed n5/nt	n5/nt.P ^(1/2)	n1/n3	n3	n1	n2/n4	n4	n2	n5	n6	nt	nt	error
				bar														
SOC	9				0.932579	9.04E-20	0.00E+00	0	7.460632	0	0	8.393211	0	8.769684	47	71.62353	9.7E+19	############
	10	1.53E+10	1.06E+10	35.86133333	0.932579	3.19702E-06	0.010707444	1.64E+08	4.55E-08	7.460632	1.14E+08	7.39E-08	8.39321	0.842763	47	63.69661	263609.1	263545.41186
	11	1.41E+10	9.78E+09	35.35466667	0.932579	3.19702E-06	0.010631535	1.5E+08	4.98E-08	7.460632	1.04E+08	8.07E-08	8.39321	0.842763	47	63.69661	263609.1	263545.41359
	12	1.28E+10	8.88E+09	34.95733333	0.932579	3.19702E-06	0.010571624	1.35E+08	5.51E-08	7.460632	93895149	8.94E-08	8.39321	0.842763	47	63.69661	263609.1	263545.41577
	13	1.16E+10	8.05E+09	34.73466667	0.932579	3.19702E-06	0.010537902	1.22E+08	6.1E-08	7.460632	84862106	9.89E-08	8.39321	0.842763	47	63.69661	263609.1	263545.41818
	14	1.04E+10	7.18E+09	34.74366667	0.932579	3.19702E-06	0.010539267	1.09E+08	6.84E-08	7.460632	75661614	1.11E-07	8.39321	0.842763	47	63.69661	263609.1	263545.42122
	15	9.04E+09	6.27E+09	35.047	0.932579	6.39E+14	149640565.9	1.35E+18	5.52E-18	7.460632	9.38E+17	8.95E-18	8.393211	0.842763	47	63.69661	1.32E-15	-63.69661
	16	7.70E+09	5.34E+09	35.68833333	0.932579	6.39E+14	151008015.4	1.16E+18	6.42E-18	7.460632	8.06E+17	1.04E-17	8.393211	0.842763	47	63.69661	1.32E-15	-63.69661
	17	6.34E+09	4.40E+09	36.69533333	0.932579	9.18E-15	5.8054E-07	3680.564	0.002026	7.458605	2552.46	0.003287	8.389924	0.84542	47	63.69926	9.2E+13	############
	18	4.94E+09	3.43E+09	38.08733333	0.932579	9.18E-11	5.91449E-05	292436.4	2.55E-05	7.460606	202808.8	4.14E-05	8.393169	0.842797	47	63.69664	9.18E+09	############
	19	3.45E+09	2.39E+09	39.88033333	0.932579	1.08E-10	6.568E-05	226510.3	3.29E-05	7.460599	157095.8	5.34E-05	8.393157	0.842806	47	63.69665	7.79E+09	############
	20	1.95E+09	1.35E+09	42.077	0.932579	1.32E-02	0.74613418	1.45E+09	5.13E-09	7.460632	1.01E+09	8.33E-09	8.393211	0.842763	47	63.69661	63.69663	0.00002
	21	3.73E+08	2.59E+08	44.63166667	0.932579	1.32E-02	0.768446342	2.86E+08	2.61E-08	7.460632	1.99E+08	4.22E-08	8.39321	0.842763	47	63.69661	63.69738	0.00077
	22	1.92E+05	4.91E+05	47.52433333	0.932579	1.32E-02	0.792977661	151928.2	4.91E-05	7.460582	389711	2.15E-05	8.393189	0.842798	47	63.69664	63.69684	0.00020
	23	1.71E+05	4.40E+05	50.67033333	0.932579	1.32E-02	0.818800212	140347.3	5.32E-05	7.460578	360135.2	2.33E-05	8.393187	0.842801	47	63.69664	63.69761	0.00096
	24	1.52E+05	3.89E+05	53.96433333	0.932579	1.32E-02	0.845003816	128152.4	5.82E-05	7.460573	328989.6	2.55E-05	8.393185	0.842805	47	63.69665	63.69665	0.00000
	25	1.33E+05	3.41E+05	57.28366667	0.932579	1.32E-02	0.870604497	115715.2	6.45E-05	7.460567	297223.4	2.82E-05	8.393182	0.84281	47	63.69665	63.69692	0.00027
	26	1.15E+05	2.96E+05	60.519	0.932579	1.32E-02	0.894854191	102947.6	7.25E-05	7.460559	264610.5	3.17E-05	8.393179	0.842815	47	63.69666	63.69709	0.00043
	27	9.81E+04	2.52E+05	63.598	0.932579	1.32E-02	0.917342438	89963.79	8.29E-05	7.460549	231441.9	3.63E-05	8.393174	0.842823	47	63.69666	63.69667	0.00001
	28	8.20E+04	2.11E+05	66.43933333	0.932579	0.013231971	0.937615753	76916.1	9.7E-05	7.460535	198106.7	4.24E-05	8.393168	0.842833	47	63.69667	63.6967	0.00002
	29	6.69E+04	1.73E+05	68.96	0.932579	0.013232192	0.955244437	63929.6	0.000117	7.460515	164923.9	5.09E-05	8.39316	0.842847	47	63.69669	63.6967	0.00001
	30	5.35E+04	1.38E+05	71.07466667	0.932579	0.013232463	0.969790145	51919.57	0.000144	7.460488	134233.5	6.25E-05	8.393148	0.842866	47	63.69671	63.69685	0.00014
	31	4.17E+04	1.08E+05	72.68466667	0.932579	0.01323285	0.980726904	40864.64	0.000183	7.460449	105980.1	7.92E-05	8.393131	0.842894	47	63.69674	63.69709	0.00036
	32	3.18E+04	8.28E+04	73.773	0.932579	0.013233461	0.988064825	31427.31	0.000237	7.460394	81857.83	0.000103	8.393108	0.842933	47	63.69678	63.6971	0.00033
	33	2.39E+04	6.25E+04	74.30866667	0.932579	0.013234324	0.991677847	23668.63	0.000315	7.460316	62022.6	0.000135	8.393075	0.842988	47	63.69683	63.69713	0.00030
	34	1.81E+04	4.77E+04	74.323	0.932579	0.013235477	0.991816709	17929.98	0.000416	7.460216	47347.8	0.000177	8.393033	0.84306	47	63.6969	63.69697	0.00007
	35	1.44E+04	3.84E+04	73.85266667	0.932579	0.013236624	0.98871633	14248.7	0.000524	7.460108	37929.26	0.000221	8.392989	0.843136	47	63.69698	63.69718	0.00020
	36	1.22E+04	3.27E+04	72.97733333	0.932579	0.013237701	0.982879494	12002.11	0.000622	7.46001	32175.44	0.000261	8.39295	0.843204	47	63.69705	63.69719	0.00015
	37	1.13E+04	3.04E+04	71.80066667	0.932579	0.013238284	0.974944917	11008.22	0.000678	7.459954	29621.86	0.000283	8.392927	0.843244	47	63.69709	63.69736	0.00027
	38	1.21E+04	3.25E+04	70.37333333	0.932579	0.013237884	0.965191179	11682.69	0.000639	7.459993	31331.9	0.000268	8.392943	0.843216	47	63.69706	63.69722	0.00016
	39	1.40E+04	3.73E+04	68.72966667	0.932579	0.013237034	0.953822273	13335.35	0.000559	7.460072	35540.96	0.000236	8.392974	0.843161	47	63.697	63.69712	0.00012
EOC	40	1.67E+04	4.42E+04	66.96933333	0.932579	0.013236114	0.941495464	15728.65	0.000474	7.460157	41642.57	0.000202	8.393009	0.843101	47	63.69694	63.69703	0.00008

Figure 40 - Excel extract balancing combustion equation and calculation dissociated molar masses for each species at 1500rpm.

	Crank Angle	kCO2	kH2O	Pressure	ϕ	Guessed n5/nt	n5/nt.P ^(1/2)	n1/n3	n3	n1	n2/n4	n4	n2	n5	n6	nt	nt	error
				bar														
SOC	9	#DIV/0!	#DIV/0!	39.60633333	1.003552	9.04E-20	1.89E-09	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	47	#DIV/0!	#DIV/0!	#DIV/0!
	10	1.15E+10	7.95E+09	39.07266667	1.003552	9.04E-20	1.87953E-09	21.54887	0.356045	7.672372	14.94349	0.566499	8.46547	0.416871	47	64.47726	4.61E+18	############
	11	9.94E+09	6.89E+09	38.65866667	1.003552	9.04E-20	1.86954E-09	18.5788	0.410057	7.61836	12.88393	0.650534	8.381435	0.485894	47	64.54628	5.37E+18	############
	12	8.73E+09	6.05E+09	38.41333333	1.003552	9.04E-20	1.8636E-09	16.26658	0.464968	7.563448	11.28055	0.735469	8.2965	0.555818	47	64.6162	6.15E+18	############
	13	7.49E+09	5.19E+09	38.402	1.003552	9.04E-20	1.86333E-09	13.9515	0.536964	7.491453	9.67519	0.846071	8.185898	0.647116	47	64.7075	7.16E+18	############
	14	6.16E+09	4.27E+09	38.678	1.003552	9.04E-20	1.87001E-09	11.52558	0.640962	7.387455	7.992974	1.004336	8.027633	0.778248	47	64.83863	8.61E+18	############
	15	4.84E+09	3.35E+09	39.276	1.003552	9.04E-20	1.88441E-09	9.112527	0.793908	7.234509	6.319683	1.233929	7.79804	0.969517	47	65.0299	1.07E+19	############
	16	3.47E+09	2.40E+09	40.22733333	1.003552	9.04E-20	1.9071E-09	6.610613	1.054897	6.973519	4.584775	1.617248	7.41472	1.291672	47	65.35206	1.43E+19	############
	17	2.09E+09	1.45E+09	41.547	1.003552	3.07E-16	1.12926E-07	235.7691	0.033908	7.994509	163.5345	0.054894	8.977075	1.98E-14	47	64.06039	64.55383	0.49344
	18	6.84E+08	4.75E+08	43.25133333	1.003552	2.75E-15	3.44569E-07	235.6892	0.03392	7.994497	163.5688	0.054883	8.977086	1.76E-13	47	64.06039	64.08128	0.02090
	19	1.97E+05	5.05E+05	45.35066667	1.003552	9.49E-09	0.000656092	129.247	0.06164	7.966777	331.5035	0.027164	9.004805	6.08E-07	47	64.06039	64.06039	0.00000
	20	1.78E+05	4.58E+05	47.817	1.003552	1.10E-08	0.000724691	129.2343	0.061646	7.966771	331.5746	0.027158	9.004811	7.04E-07	47	64.06039	64.06041	0.00002
	21	1.58E+05	4.07E+05	50.64266667	1.003552	1.31E-08	0.000815343	129.2175	0.061654	7.966763	331.6685	0.02715	9.004819	8.41E-07	47	64.06039	64.06132	0.00093
	22	1.38E+05	3.54E+05	53.75166667	1.003552	1.64E-08	0.000937706	129.1948	0.061665	7.966752	331.7952	0.02714	9.004829	1.05E-06	47	64.06039	64.06039	0.00000
	23	1.17E+05	3.00E+05	57.038	1.003552	2.15E-08	0.001106959	129.1633	0.06168	7.966737	331.9701	0.027125	9.004843	1.38E-06	47	64.06039	64.06111	0.00072
	24	9.60E+04	2.47E+05	60.378	1.003552	3.00E-08	0.00134554	129.1188	0.061701	7.966716	332.2162	0.027105	9.004863	1.92E-06	47	64.06039	64.06041	0.00002
	25	7.60E+04	1.96E+05	63.66833333	1.003552	4.52E-08	0.001697067	129.0527	0.061732	7.966685	332.5778	0.027076	9.004893	2.9E-06	47	64.06039	64.06039	0.00000
	26	5.73E+04	1.48E+05	66.82733333	1.003552	7.58E-08	0.002251091	128.9477	0.061782	7.966635	333.1453	0.02703	9.004939	4.86E-06	47	64.06039	64.06039	0.00000
	27	3.92E+04	1.02E+05	69.80666667	1.003552	1.54E-07	0.003282793	128.7489	0.061877	7.96654	334.1941	0.026945	9.005023	9.89E-06	47	64.0604	64.06065	0.00026
	28	2.20E+04	5.77E+04	72.52133333	1.003552	4.70E-07	0.005839203	128.2389	0.062121	7.966296	336.7479	0.026742	9.005227	3.01E-05	47	64.06042	64.06042	0.00000
	29	5.50E+03	1.56E+04	74.88633333	1.003552	6.81E-06	0.022586073	124.2835	0.064082	7.964335	351.9073	0.025593	9.006376	0.000436	47	64.06082	64.06082	0.00000
	30	6.62E+02	3.03E+03	76.802	1.003552	2.15E-04	0.128563048	85.10899	0.093236	7.935181	389.223	0.023146	9.008823	0.013789	47	64.07418	64.07483	0.00066
	31	5.22E+02	2.43E+03	78.23866667	1.003552	2.88E-04	0.150159407	78.41393	0.101096	7.927321	365.548	0.024641	9.007328	0.018467	47	64.07885	64.07886	0.00001
	32	4.03E+02	1.93E+03	79.12833333	1.003552	3.88E-04	0.17531981	70.69987	0.111973	7.916444	338.3302	0.026617	9.005352	0.024894	47	64.08528	64.08536	0.00009
	33	3.28E+02	1.60E+03	79.49866667	1.003552	4.87E-04	0.196669553	64.47174	0.122624	7.905793	315.4215	0.028544	9.003425	0.031183	47	64.09157	64.09194	0.00037
	34	2.94E+02	1.45E+03	79.37166667	1.003552	5.46E-04	0.208120277	61.26132	0.128947	7.89947	301.9731	0.029811	9.002158	0.034978	47	64.09536	64.09607	0.00070
	35	2.70E+02	1.34E+03	78.80866667	1.003552	5.99E-04	0.217322882	58.61036	0.134682	7.893735	290.8414	0.030948	9.001021	0.038414	47	64.0988	64.0988	0.00000
	36	2.52E+02	1.26E+03	77.88966667	1.003552	6.46E-04	0.224387032	56.45564	0.139732	7.888684	281.7492	0.031943	9.000025	0.041437	47	64.10182	64.10182	0.00000
	37	2.40E+02	1.20E+03	76.652	1.003552	6.82E-04	0.228713351	54.91211	0.14359	7.884827	275.1581	0.032706	8.999263	0.043747	47	64.10413	64.10414	0.00000
	38	2.37E+02	1.19E+03	75.13633333	1.003552	6.99E-04	0.229151416	54.24015	0.145337	7.88308	272.1351	0.033068	8.998901	0.044801	47	64.10519	64.10519	0.00000
	39	2.39E+02	1.20E+03	73.43666667	1.003552	6.99E-04	0.226549292	54.24955	0.145312	7.883105	271.9014	0.033096	8.998873	0.044803	47	64.10519	64.10519	0.00000
EOC	40	2.47E+02	1.23E+03	71.62266667	1.003552	6.87E-04	0.221862864	54.74154	0.144029	7.884387	273.6507	0.032885	8.999084	0.044056	47	64.10444	64.10444	0.00000

Figure 41 - Excel extract balancing combustion equation and calculation dissociated molar masses for each species at 1750rpm.

	Crank Angle	kCO2	kH2O	Pressure	ϕ	Guessed n5/nt	n5/nt.P ^(1/2)	n1/n3	n3	n1	n2/n4	n4	n2	n5	n6	nt	nt	error
				bar														
SOC	10				1.037321	9.04E-20	0.00E+00	0	8.29857	0	0	9.335891	0	8.350715	47	72.98518	9.24E+19	############
	11	1.08E+10	7.48E+09	42.956	1.037321	3.19702E-06	0.011718837	1.26E+08	6.56E-08	8.29857	87666340	1.06E-07	9.335891	-0.46652	47	64.16795	-145922	-145986.08043
	12	8.58E+09	5.95E+09	42.21566667	1.037321	3.19702E-06	0.011617412	99700158	8.32E-08	8.29857	69140168	1.35E-07	9.335891	-0.46652	47	64.16795	-145922	-145986.07322
	13	6.96E+09	4.83E+09	41.569	1.037321	6.96728E+13	53816637.5	3.74E+17	2.22E-17	8.29857	2.6E+17	3.6E-17	9.335891	-0.46652	47	64.16795	-6.7E-15	-64.16795
	14	5.52E+09	3.83E+09	41.06566667	1.037321	-2.33783E+19	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	47	#NUM!	#NUM!	#NUM!
	15	4.18E+09	2.90E+09	40.76133333	1.037321	-2.33783E+19	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	47	#NUM!	#NUM!	#NUM!
	16	2.71E+09	1.88E+09	40.70833333	1.037321	1.62E-18	8.12268E-09	22.0495	0.360032	7.938537	15.29306	0.572998	8.762893	2.22E-16	47	64.63446	137.0014	72.36692
	17	1.29E+09	8.92E+08	40.95533333	1.037321	7.18E-18	1.71449E-08	22.04643	0.36008	7.938489	15.29443	0.57295	8.762941	7.77E-16	47	64.63446	108.2806	43.64619
	18	-1.67E+08	-1.15E+08	41.51833333	1.037321	-3.16E-07	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	47	#NUM!	#NUM!	#NUM!
	19	1.87E+05	4.79E+05	42.41766667	1.037321	9.72E-11	6.42016E-05	11.98701	0.63899	7.65958	30.75036	0.29404	9.04185	6.28E-09	47	64.63446	64.63446	0.00000
	20	1.69E+05	4.33E+05	43.657	1.037321	1.15E-10	7.096E-05	11.98572	0.639054	7.659516	30.75725	0.293977	9.041914	7.45E-09	47	64.63446	64.63447	0.00001
	21	1.51E+05	3.87E+05	45.23366667	1.037321	1.39E-10	7.94084E-05	11.9841	0.639133	7.659436	30.76586	0.293897	9.041994	9.01E-09	47	64.63446	64.63446	0.00000
	22	1.32E+05	3.40E+05	47.16566667	1.037321	1.74E-10	9.06371E-05	11.98195	0.639239	7.659331	30.77731	0.293791	9.0421	1.13E-08	47	64.63446	64.63446	0.00000
	23	1.12E+05	2.89E+05	49.46233333	1.037321	2.30E-10	0.000106621	11.97889	0.63939	7.65918	30.79361	0.293641	9.04225	1.49E-08	47	64.63446	64.63446	0.00000
	24	9.13E+04	2.35E+05	52.11	1.037321	3.30E-10	0.000131162	11.9742	0.639621	7.658949	30.81865	0.293409	9.042482	2.13E-08	47	64.63446	64.63446	0.00000
	25	6.99E+04	1.80E+05	55.05566667	1.037321	5.33E-10	0.000171233	11.96656	0.639998	7.658572	30.85958	0.293032	9.042858	3.44E-08	47	64.63446	64.63446	0.00000
	26	4.84E+04	1.25E+05	58.20033333	1.037321	1.05E-09	0.000247059	11.95215	0.64071	7.65786	30.93717	0.292321	9.04357	6.78E-08	47	64.63446	64.63446	0.00000
	27	2.74E+04	7.15E+04	61.45233333	1.037321	3.09E-09	0.000435569	11.91662	0.642472	7.656098	31.13083	0.290559	9.045332	2E-07	47	64.63446	64.63446	0.00000
	28	6.97E+03	1.93E+04	64.70566667	1.037321	4.35E-08	0.001677177	11.69298	0.653792	7.644778	32.43274	0.279244	9.056647	2.81E-06	47	64.63446	64.63446	0.00000
	29	6.24E+02	2.87E+03	67.874	1.037321	3.95956E-06	0.016393624	10.22952	0.738996	7.559574	46.98803	0.194546	9.141345	0.000256	47	64.63472	64.63472	0.00000
	30	4.41E+02	2.09E+03	70.871	1.037321	7.47431E-06	0.02301547	10.15491	0.743939	7.554631	48.12138	0.190058	9.145833	0.000483	47	64.63494	64.63494	0.00000
	31	3.11E+02	1.53E+03	73.55866667	1.037321	1.42846E-05	0.03241534	10.06801	0.74978	7.54879	49.43777	0.185097	9.150794	0.000923	47	64.63538	64.63538	0.00000
	32	2.41E+02	1.21E+03	75.96833333	1.037321	2.26543E-05	0.041485096	10.01399	0.753457	7.545112	50.15511	0.182502	9.153389	0.001464	47	64.63592	64.63592	0.00000
	33	1.77E+02	9.17E+02	77.982	1.037321	4.01386E-05	0.05594719	9.924176	0.759652	7.538918	51.28216	0.178567	9.157323	0.002594	47	64.63706	64.63705	0.00000
	34	1.46E+02	7.67E+02	79.57566667	1.037321	5.73054E-05	0.067528633	9.866447	0.763687	7.534882	51.8194	0.176751	9.15914	0.003704	47	64.63816	64.63906	0.00089
	35	1.23E+02	6.57E+02	80.69333333	1.037321	7.82885E-05	0.079484756	9.808681	0.767769	7.530801	52.2316	0.175383	9.160508	0.005061	47	64.63952	64.64027	0.00075
	36	1.04E+02	5.64E+02	81.32633333	1.037321	0.000107251	0.093393228	9.735698	0.772988	7.525581	52.68302	0.173908	9.161983	0.006933	47	64.64139	64.64201	0.00062
	37	8.90E+01	4.90E+02	81.47066667	1.037321	0.000144181	0.108381483	9.64991	0.779215	7.519355	53.13483	0.172456	9.163435	0.00932	47	64.64378	64.64429	0.00051
	38	7.79E+01	4.36E+02	81.14966667	1.037321	0.000185752	0.122774929	9.560026	0.785847	7.512722	53.53228	0.171199	9.164692	0.012008	47	64.64647	64.6469	0.00043
	39	7.90E+01	4.39E+02	80.41033333	1.037321	0.000182669	0.121195935	9.578526	0.784473	7.514097	53.22329	0.172175	9.163716	0.011809	47	64.64627	64.64653	0.00026
	40	7.72E+01	4.30E+02	79.31833333	1.037321	0.000193296	0.123822262	9.560564	0.785807	7.512762	53.21066	0.172215	9.163676	0.012496	47	64.64696	64.64721	0.00025
	41	7.70E+01	4.29E+02	77.941	1.037321	0.000197337	0.124018737	9.554605	0.786251	7.512319	53.18585	0.172294	9.163597	0.012757	47	64.64722	64.64747	0.00025
	42	7.79E+01	4.33E+02	76.35833333	1.037321	0.00019723	0.12271982	9.556146	0.786136	7.512433	53.15414	0.172395	9.163496	0.01275	47	64.64721	64.64746	0.00025
	43	7.93E+01	4.40E+02	74.665	1.037321	0.000194958	0.120650358	9.561593	0.785731	7.512839	53.11909	0.172506	9.163384	0.012603	47	64.64706	64.64731	0.00025
	44	7.53E+01	4.24E+02	72.911	1.037321	0.000218361	0.126178254	9.506318	0.789865	7.508705	53.46868	0.171399	9.164492	0.014117	47	64.64858	64.64895	0.00037
	45	8.09E+01	4.51E+02	71.10666667	1.037321	0.000196357	0.118162071	9.554147	0.786285	7.512284	53.23649	0.172133	9.163758	0.012694	47	64.64715	64.64755	0.00040
	46	8.70E+01	4.81E+02	69.29033333	1.037321	0.000175591	0.110303067	9.600287	0.782863	7.515707	53.00521	0.17287	9.163021	0.011351	47	64.64581	64.64624	0.00042
	47	9.37E+01	5.13E+02	67.488	1.037321	0.000156992	0.102932234	9.642655	0.779746	7.518823	52.78389	0.173582	9.162309	0.010149	47	64.64461	64.64506	0.00045
EOC	48	1.01E+02	5.47E+02	65.713	1.037321	0.000140788	0.096185336	9.680537	0.776981	7.521589	52.57695	0.174252	9.161639	0.009101	47	64.64356	64.64404	0.00048

Figure 42 - Excel extract balancing combustion equation and calculation dissociated molar masses for each species at 2000rpm.

	Crank Angle	kCO2	kH2O	Pressure	ϕ	Guessed n5/nt	n5/nt.P ^(1/2)	n1/n3	n3	n1	n2/n4	n4	n2	n5	n6	nt	nt	error
				bar														
SOC	9			44.92233333	1.045245	1.14E-01	2.26E+00	0	8.361957	0	0	9.407202	0	8.319021	47	73.08818	73.08836	0.00018
	10	1.13E+10	7.86E+09	44.18033333	1.045245	5.15E+04	1508.057193	1.71E+13	4.89E-13	8.361957	1.19E+13	7.93E-13	9.407202	-0.56556	47	64.2036	-1.1E-05	-64.20361
	11	8.69E+09	6.02E+09	43.49533333	1.045245	5.41E+04	1534.152097	1.33E+13	6.27E-13	8.361957	9.24E+12	1.02E-12	9.407202	-0.56556	47	64.2036	-1E-05	-64.20361
	12	7.04E+09	4.88E+09	42.91333333	1.045245	5.71E+04	1565.318565	1.1E+13	7.59E-13	8.361957	7.64E+12	1.23E-12	9.407202	-0.56556	47	64.2036	-9.9E-06	-64.20361
	13	5.55E+09	3.85E+09	42.49133333	1.045245	6.19E+04	1622.352426	9E+12	9.29E-13	8.361957	6.24E+12	1.51E-12	9.407202	-0.56556	47	64.2036	-9.1E-06	-64.20361
	14	4.07E+09	2.83E+09	42.27833333	1.045245	6.98E+04	1717.983152	7E+12	1.19E-12	8.361957	4.85E+12	1.94E-12	9.407202	-0.56556	47	64.2036	-8.1E-06	-64.20361
	15	2.76E+09	1.92E+09	42.30866667	1.045245	5.27E-11	4.71998E-05	130439.1	6.41E-05	8.361893	90469.44	0.000104	9.407098	-0.56547	47	64.20368	-1.1E+10	############
	16	1.33E+09	9.19E+08	42.628	1.045245	5.27E-11	4.73776E-05	62775.99	0.000133	8.361824	43549.48	0.000216	9.406986	-0.56538	47	64.20378	-1.1E+10	############
	17	2.06E+05	5.28E+05	43.239	1.045245	5.27E-11	4.77159E-05	9.829226	0.772166	7.589791	25.20754	0.35895	9.048252	3.41E-09	47	64.76916	64.76916	0.00000
	18	1.89E+05	4.85E+05	44.15266667	1.045245	6.13E-11	5.20363E-05	9.828387	0.772226	7.589732	25.21191	0.35889	9.048311	3.97E-09	47	64.76916	64.76915	-0.00001
	19	1.71E+05	4.39E+05	45.37966667	1.045245	7.27E-11	5.74329E-05	9.827338	0.7723	7.589657	25.21738	0.358816	9.048386	4.71E-09	47	64.76916	64.76915	-0.00001
	20	1.54E+05	3.96E+05	46.90466667	1.045245	8.65E-11	6.36884E-05	9.826123	0.772387	7.58957	25.22371	0.358729	9.048473	5.6E-09	47	64.76916	64.76915	-0.00001
	21	1.37E+05	3.52E+05	48.76133333	1.045245	1.05E-10	7.16927E-05	9.824569	0.772498	7.589459	25.23182	0.358618	9.048584	6.83E-09	47	64.76916	64.76932	0.00016
	22	1.19E+05	3.06E+05	50.955	1.045245	1.33E-10	8.24649E-05	9.82248	0.772647	7.58931	25.24273	0.358469	9.048733	8.64E-09	47	64.76916	64.76916	0.00000
	23	9.98E+04	2.57E+05	53.47733333	1.045245	1.81E-10	9.84241E-05	9.819387	0.772868	7.589089	25.25891	0.358248	9.048954	1.17E-08	47	64.76916	64.76915	-0.00001
	24	7.94E+04	2.05E+05	56.263	1.045245	2.71E-10	0.000123574	9.814522	0.773216	7.588741	25.28442	0.3579	9.049301	1.76E-08	47	64.76916	64.76916	0.00000
	25	5.87E+04	1.52E+05	59.22633333	1.045245	4.72E-10	0.000167143	9.806114	0.773817	7.58814	25.32867	0.357299	9.049903	3.06E-08	47	64.76916	64.76916	0.00000
	26	3.79E+04	9.84E+04	62.27933333	1.045245	1.07E-09	0.000258379	9.788598	0.775074	7.586884	25.42157	0.356042	9.051159	6.94E-08	47	64.76916	64.76916	0.00000
	27	1.75E+04	4.62E+04	65.33066667	1.045245	4.74E-09	0.00055654	9.732195	0.779147	7.58281	25.72732	0.35197	9.055232	3.07E-07	47	64.76916	64.76916	0.00000
	28	7.36E+02	3.34E+03	68.29933333	1.045245	1.90E-06	0.011399637	8.388406	0.890668	7.471289	38.08368	0.240694	9.166508	0.000123	47	64.76928	64.76928	0.00000
	29	5.39E+02	2.51E+03	71.12466667	1.045245	3.36E-06	0.015464835	8.342334	0.895061	7.466896	38.77832	0.236491	9.170711	0.000218	47	64.76938	64.76938	0.00001
	30	3.58E+02	1.74E+03	73.701	1.045245	7.22E-06	0.023065487	8.259105	0.903106	7.458851	40.08943	0.228945	9.178257	0.000468	47	64.76963	64.76963	0.00000
	31	2.77E+02	1.37E+03	76.018	1.045245	1.16E-05	0.029670659	8.219116	0.907024	7.454933	40.70001	0.225592	9.181609	0.00075	47	64.76991	64.76991	0.00000
	32	2.09E+02	1.06E+03	77.99366667	1.045245	1.96E-05	0.03907758	8.167589	0.912122	7.449835	41.46459	0.22153	9.185671	0.001268	47	64.77043	64.77043	0.00000
	33	1.58E+02	8.24E+02	79.616	1.045245	3.32E-05	0.051408775	8.105545	0.918337	7.44362	42.33533	0.217079	9.190122	0.00215	47	64.77131	64.77131	0.00000
	34	1.31E+02	6.93E+02	80.83	1.045245	4.71E-05	0.061687058	8.06763	0.922177	7.43978	42.74671	0.215038	9.192164	0.003049	47	64.77221	64.77279	0.00058
	35	1.07E+02	5.77E+02	81.59466667	1.045245	6.90E-05	0.075035181	8.015221	0.927538	7.434419	43.26556	0.212517	9.194684	0.00447	47	64.77363	64.77372	0.00009
	36	8.69E+01	4.80E+02	81.894	1.045245	1.02E-04	0.091464398	7.945971	0.934718	7.427239	43.87477	0.209632	9.197569	0.006617	47	64.77578	64.77579	0.00001
	37	7.87E+01	4.37E+02	81.76266667	1.045245	1.24E-04	0.100593553	7.914182	0.938051	7.423906	43.98927	0.209099	9.198103	0.008017	47	64.77718	64.77747	0.00029
	38	7.24E+01	4.05E+02	81.216	1.045245	1.46E-04	0.108856204	7.883008	0.941343	7.420614	44.08048	0.208676	9.198526	0.009451	47	64.77861	64.77861	0.00000
	39	6.78E+01	3.81E+02	80.31766667	1.045245	1.67E-04	0.115786117	7.854581	0.944365	7.417592	44.14519	0.208377	9.198825	0.010813	47	64.77997	64.77998	0.00001
	40	6.50E+01	3.67E+02	79.117	1.045245	1.83E-04	0.120440117	7.833285	0.946642	7.415315	44.17724	0.208229	9.198973	0.011877	47	64.78104	64.78108	0.00004
	41	6.37E+01	3.60E+02	77.69	1.045245	1.94E-04	0.12280453	7.820105	0.948056	7.413901	44.18133	0.20821	9.198992	0.012575	47	64.78173	64.78184	0.00011
	42	6.39E+01	3.61E+02	76.09433333	1.045245	1.97E-04	0.122299875	7.818233	0.948258	7.413699	44.15624	0.208326	9.198876	0.012734	47	64.78189	64.78202	0.00013
	43	6.47E+01	3.65E+02	74.433	1.045245	1.97E-04	0.120940347	7.819748	0.948095	7.413862	44.12254	0.208481	9.19872	0.01273	47	64.78189	64.78201	0.00013
	44	6.61E+01	3.72E+02	72.70933333	1.045245	1.93E-04	0.118388949	7.826182	0.947404	7.414553	44.07787	0.208688	9.198514	0.012488	47	64.78165	64.78174	0.00010
	45	6.82E+01	3.83E+02	70.952	1.045245	1.86E-04	0.114924201	7.83646	0.946302	7.415655	44.02518	0.208932	9.19827	0.012059	47	64.78122	64.78127	0.00006
	46	7.07E+01	3.96E+02	69.19133333	1.045245	1.78E-04	0.111014036	7.848645	0.944999	7.416958	43.96874	0.209194	9.198007	0.011539	47	64.7807	64.78073	0.00003
EOC	47	7.35E+01	4.10E+02	67.44666667	1.045245	1.70E-04	0.106974314	7.861417	0.943637	7.41832	43.91137	0.209461	9.19774	0.010991	47	64.78015	64.78016	0.00001

Figure 43 - Excel extract balancing combustion equation and calculation dissociated molar masses for each species at 2250rpm.

	Crank Angle	kCO2	kH2O	Pressure	ϕ	Guessed n5/nt	n5/nt.P ^(1/2)	n1/n3	n3	n1	n2/n4	n4	n2	n5	n6	nt	nt	error
				bar														
SOC	10	2.12E+25	1.54E+23	46.29466667	1.040651	1.95E+02	9.50E+01	2.01E+27	4.14E-27	8.325205	1.46E+25	6.41E-25	9.365856	-0.50813	47	64.18	-0.00261	-64.19
	11	5.24E+09	3.64E+09	45.596	1.040651	3.03E-19	3.7192E-09	19.5026	0.406056	7.919149	13.52525	0.644798	8.721057	0.017294	47	64.71	5.7E+16	##################
	12	4.01E+09	2.78E+09	44.99933333	1.040651	5.25E-19	4.86151E-09	19.48494	0.406406	7.918799	13.51344	0.645323	8.720533	0.017732	47	64.71	3.38E+16	##################
	13	3.04E+09	2.11E+09	44.544	1.040651	9.24E-19	6.41433E-09	19.47844	0.406535	7.91867	13.50954	0.645497	8.720359	0.017883	47	64.71	1.94E+16	##################
	14	1.92E+09	1.34E+09	44.28066667	1.040651	2.49E-18	1.04988E-08	20.20731	0.392563	7.932642	14.01654	0.623703	8.742153	7.49E-16	47	64.69	301.0562	236.37
	15	8.37E+08	5.80E+08	44.24066667	1.040651	1.32E-17	2.4151E-08	20.20273	0.392648	7.932557	14.01865	0.623615	8.742241	-1.4E-06	47	64.69	-1E+11	-103995738452.16
	16	2.02E+05	5.18E+05	44.459	1.040651	6.65E-11	5.44E-05	10.97819	0.69503	7.630175	28.15573	0.321236	9.04462	4.3E-09	47	64.69	64.69107	0.00
	17	1.87E+05	4.81E+05	44.93666667	1.040651	7.64E-11	5.86031E-05	10.97737	0.695078	7.630127	28.16004	0.321188	9.044668	4.94E-09	47	64.69	64.69106	0.00
	18	1.72E+05	4.41E+05	45.69833333	1.040651	8.94E-11	6.39315E-05	10.97635	0.695137	7.630068	28.16546	0.321128	9.044727	5.79E-09	47	64.69	64.69106	0.00
	19	1.56E+05	4.00E+05	46.73733333	1.040651	1.06E-10	7.05149E-05	10.97508	0.695211	7.629994	28.17215	0.321055	9.044801	6.88E-09	47	64.69	64.69106	0.00
	20	1.40E+05	3.59E+05	48.04733333	1.040651	1.28E-10	7.84912E-05	10.97354	0.6953	7.629905	28.18025	0.320966	9.04489	8.3E-09	47	64.69	64.69106	0.00
	21	1.24E+05	3.18E+05	49.64	1.040651	1.59E-10	8.8782E-05	10.97156	0.695415	7.62979	28.19072	0.32085	9.045005	1.03E-08	47	64.69	64.69106	0.00
	22	1.07E+05	2.75E+05	51.514	1.040651	2.04E-10	0.000102582	10.96891	0.695569	7.629636	28.20476	0.320696	9.045159	1.32E-08	47	64.69	64.69106	0.00
	23	8.92E+04	2.30E+05	53.666	1.040651	2.82E-10	0.00012294	10.96499	0.695797	7.629408	28.22548	0.320469	9.045387	1.82E-08	47	64.69	64.69106	0.00
	24	7.07E+04	1.82E+05	56.05233333	1.040651	4.29E-10	0.000155104	10.95883	0.696156	7.629049	28.25825	0.32011	9.045746	2.78E-08	47	64.69	64.69106	0.00
	25	5.18E+04	1.34E+05	58.618	1.040651	7.63E-10	0.000211435	10.94805	0.696783	7.628422	28.31572	0.319482	9.046373	4.93E-08	47	64.69	64.69106	0.00
	26	3.25E+04	8.47E+04	61.312	1.040651	1.84E-09	0.00033578	10.92442	0.698164	7.627041	28.44295	0.318102	9.047754	1.19E-07	47	64.69	64.69106	0.00
	27	1.31E+04	3.50E+04	64.062	1.040651	1.07E-08	0.000828321	10.83279	0.703571	7.621634	28.95195	0.312696	9.05316	6.93E-07	47	64.69	64.69045	0.00
	28	6.98E+02	3.18E+03	66.78133333	1.040651	2.70E-06	0.013430447	9.375689	0.802376	7.522829	42.71686	0.214239	9.151617	0.000175	47	64.69	64.69123	0.00
	29	5.06E+02	2.37E+03	69.41933333	1.040651	4.89E-06	0.0184157	9.319349	0.806757	7.518448	43.5694	0.210141	9.155715	0.000316	47	64.69	64.69138	0.00
	30	3.37E+02	1.65E+03	71.87866667	1.040651	1.04E-05	2.74E-02	9.224682	0.814226	7.510979	45.04922	0.203388	9.162468	0.000674	47	64.69	64.69173	0.00
	31	2.64E+02	1.31E+03	74.13333333	1.040651	1.64E-05	0.034821007	9.182432	0.817605	7.5076	45.64805	0.200777	9.165079	0.001058	47	64.69	64.69212	0.00
	32	1.95E+02	9.96E+02	76.13933333	1.040651	2.88E-05	0.046805071	9.112717	0.823241	7.501964	46.60349	0.196747	9.169108	0.001861	47	64.69	64.69292	0.00
	33	1.50E+02	7.87E+02	77.87266667	1.040651	4.66E-05	0.06021318	9.04483	0.828805	7.4964	47.40616	0.193485	9.172371	0.003012	47	64.69	64.69407	0.00
	34	1.22E+02	6.50E+02	79.28033333	1.040651	6.86E-05	0.073735396	8.986623	0.833636	7.491569	47.90696	0.191504	9.174352	0.004437	47	64.70	64.69639	0.00
	35	9.56E+01	5.22E+02	80.31766667	1.040651	1.08E-04	0.093065811	8.895304	0.841329	7.483876	48.58347	0.188891	9.176965	0.006977	47	64.70	64.69872	0.00
	36	8.01E+01	4.44E+02	80.94133333	1.040651	1.50E-04	0.110122642	8.816043	0.848122	7.477083	48.94299	0.187531	9.178325	0.009694	47	64.70	64.70108	0.00
	37	7.03E+01	3.94E+02	81.16933333	1.040651	1.91E-04	0.124503969	8.75049	0.853824	7.471381	49.04336	0.187155	9.178701	0.012357	47	64.70	64.70371	0.00
	38	6.23E+01	3.53E+02	81.00233333	1.040651	2.40E-04	0.139289412	8.676381	0.860364	7.464841	49.11184	0.186899	9.178957	0.015498	47	64.71	64.70681	0.00
	39	5.56E+01	3.18E+02	80.49066667	1.040651	2.96E-04	0.154421529	8.593155	0.867828	7.457377	49.14377	0.18678	9.179076	0.019171	47	64.71	64.71045	0.00
	40	5.08E+01	2.93E+02	79.646	1.040651	3.52E-04	0.16754501	8.513787	0.875067	7.450138	49.1343	0.186815	9.17904	0.022809	47	64.71	64.71407	0.00
	41	4.76E+01	2.77E+02	78.53633333	1.040651	4.01E-04	0.177506701	8.447505	0.881207	7.443998	49.08808	0.186988	9.178868	0.025964	47	64.72	64.71714	0.00
	42	4.67E+01	2.72E+02	77.207	1.040651	4.21E-04	0.180341751	8.423061	0.883493	7.441712	49.00517	0.187298	9.178558	0.027262	47	64.72	64.71843	0.00
	43	4.63E+01	2.70E+02	75.74466667	1.040651	4.35E-04	0.181457025	8.407168	0.884985	7.44022	48.93841	0.187548	9.178307	0.028134	47	64.72	64.7193	0.00
	44	4.64E+01	2.70E+02	74.18766667	1.040651	4.43E-04	0.181192787	8.398473	0.885804	7.439401	48.88644	0.187744	9.178112	0.028641	47	64.72	64.7198	0.00
	45	4.68E+01	2.72E+02	72.55833333	1.040651	4.44E-04	0.179487537	8.397813	0.885866	7.439339	48.85274	0.18787	9.177985	0.028736	47	64.72	64.7199	0.00
	46	4.75E+01	2.76E+02	70.891	1.040651	4.41E-04	0.176854666	8.402492	0.885425	7.43978	48.8317	0.18795	9.177906	0.028555	47	64.72	64.71972	0.00
	47	4.94E+01	2.86E+02	69.20233333	1.040651	4.21E-04	0.170762941	8.430948	0.882754	7.442451	48.80431	0.188053	9.177803	0.027271	47	64.72	64.7185	0.00
EOC	48	5.16E+01	2.97E+02	67.53333333	1.040651	3.99E-04	0.16412143	8.463592	0.879709	7.445496	48.77021	0.188182	9.177674	0.025813	47	64.72	64.71705	0.00

Figure 44 - Excel extract balancing combustion equation and calculation dissociated molar masses for each species at 2500rpm.

	Crank Angle	kCO2	kH2O	Pressure bar	Φ	Guessed n5/nt	n5/nt.P ^(1/2)	n1/n3	n3	n1	n2/n4	n4	n2	n5	n6	nt	nt	error
SOC	9			48.929	1.179777	1.70E-18	9.12E-09	0	9.438214	0	0	10.61799	0	7.780893	47	74.84	4.58E+18	###################
	10	6.63E+24	4.81E+22	48.36333333	1.179777	1.29E-08	0.000790618	5.24E+21	1.8E-21	9.438214	3.81E+19	2.79E-19	10.61799	-2.24721	47	64.81	-1.7E+08	-173870729.40
	11	6.56E+24	4.76E+22	47.88833333	1.179777	5.04E-12	1.55332E-05	1.02E+20	9.26E-20	9.438214	7.4E+17	1.44E-17	10.61799	-2.24721	47	64.81	-4.5E+11	-446017639456.81
	12	6.44E+24	4.67E+22	47.518	1.179777	5.96E-12	1.68273E-05	1.08E+20	8.71E-20	9.438214	7.87E+17	1.35E-17	10.61799	-2.24721	47	64.81	-3.8E+11	-377112538105.92
	13	6.25E+24	4.54E+22	47.31766667	1.179777	3.70E-13	4.1821E-06	2.61E+19	3.61E-19	9.438214	1.9E+17	5.6E-17	10.61799	-2.24721	47	64.81	-6.1E+12	-6079651865187.19
	14	1.64E+10	1.13E+10	47.28866667	1.179777	3.02E+02	119.5970361	1.96E+12	4.83E-12	9.438214	1.36E+12	7.83E-12	10.61799	-2.24721	47	64.81	-0.00743	-64.82
	15	9.77E+09	6.78E+09	47.483	1.179777	3.30E+02	1.25E+02	1.22E+12	7.71E-12	9.438214	8.48E+11	1.25E-11	10.61799	-2.24721	47	64.81	-0.00681	-64.82
	16	5.13E+09	3.56E+09	47.90166667	1.179777	4.07E+02	139.6847094	7.17E+11	1.32E-11	9.438214	4.97E+11	2.14E-11	10.61799	-2.24721	47	64.81	-0.00552	-64.81
	17	1.66E+09	1.15E+09	48.55266667	1.179777	1.34E-19	2.55538E-09	4.241102	1.800807	7.637407	2.941922	2.693607	7.924383	-2E-06	47	67.06	-1.5E+13	-14564054573000.80
	18	1.92E+05	4.93E+05	49.45833333	1.179777	2.73E-12	1.16207E-05	2.235091	2.917449	6.520765	5.733165	1.576969	9.041022	1.83E-10	47	67.06	67.05633	0.00
	19	1.63E+05	4.17E+05	50.61466667	1.179777	3.73E-12	1.37457E-05	2.234591	2.917901	6.520313	5.735092	1.576517	9.041473	2.5E-10	47	67.06	67.05639	0.00
	20	1.36E+05	3.48E+05	52.032	1.179777	5.22E-12	1.64815E-05	2.233947	2.918481	6.519732	5.737575	1.575937	9.042054	3.5E-10	47	67.06	67.05633	0.00
	21	1.11E+05	2.86E+05	53.68666667	1.179777	7.50E-12	2.0071E-05	2.233103	2.919243	6.51897	5.740834	1.575175	9.042816	5.03E-10	47	67.06	67.05623	0.00
	22	8.79E+04	2.26E+05	55.592	1.179777	1.16E-11	2.53766E-05	2.231857	2.920369	6.517845	5.745654	1.574049	9.043941	7.77E-10	47	67.06	67.05624	0.00
	23	6.53E+04	1.68E+05	57.71833333	1.179777	2.02E-11	3.41655E-05	2.229796	2.922232	6.515982	5.753649	1.572186	9.045805	1.36E-09	47	67.06	67.05619	0.00
	24	4.30E+04	1.11E+05	60.024	1.179777	4.46E-11	5.1768E-05	2.225682	2.925959	6.512255	5.769695	1.568459	9.049531	2.99E-09	47	67.06	67.05642	0.00
	25	2.10E+04	5.51E+04	62.45333333	1.179777	1.78E-10	0.000105526	2.213231	2.937297	6.500917	5.818987	1.557121	9.060869	1.2E-08	47	67.06	67.05621	0.00
	26	7.56E+02	3.43E+03	64.93066667	1.179777	8.93E-08	0.002407633	1.820311	3.346515	6.091699	8.249804	1.147915	9.470075	5.99E-06	47	67.06	67.05621	0.00
	27	5.45E+02	2.53E+03	67.41466667	1.179777	1.63E-07	0.003316785	1.806083	3.363483	6.07473	8.388504	1.130957	9.487034	1.09E-05	47	67.06	67.05622	0.00
	28	3.44E+02	1.68E+03	69.826	1.179777	3.83E-07	0.005171248	1.778483	3.396895	6.041319	8.67405	1.097575	9.520416	2.57E-05	47	67.06	67.05623	0.00
	29	2.62E+02	1.30E+03	72.10966667	1.179777	6.33E-07	6.76E-03	1.76761	3.410239	6.027974	8.792814	1.084263	9.533727	4.24E-05	47	67.06	67.05625	0.00
	30	1.82E+02	9.36E+02	74.218	1.179777	1.25E-06	0.00962452	1.748531	3.433912	6.004302	9.010612	1.060673	9.557317	8.37E-05	47	67.06	67.05629	0.00
	31	1.41E+02	7.44E+02	76.067	1.179777	1.99E-06	0.01229798	1.737087	3.448269	5.989944	9.147015	1.046415	9.571575	0.000133	47	67.06	67.05634	0.00
	32	1.10E+02	5.90E+02	77.67833333	1.179777	3.20E-06	0.015756715	1.725411	3.463043	5.975171	9.290704	1.031804	9.586186	0.000214	47	67.06	67.05642	0.00
	33	8.40E+01	4.65E+02	78.99633333	1.179777	5.25E-06	0.020363947	1.711371	3.480975	5.957239	9.469873	1.014147	9.603843	0.000352	47	67.06	67.05656	0.00
	34	7.08E+01	3.96E+02	80.045	1.179777	7.25E-06	0.024093603	1.705082	3.489068	5.949146	9.55128	1.006322	9.611668	0.000486	47	67.06	67.05669	0.00
	35	5.89E+01	3.35E+02	80.773	1.179777	1.03E-05	0.028817509	1.697205	3.499257	5.938957	9.654853	0.99654	9.62145	0.000689	47	67.06	67.05689	0.00
	36	4.79E+01	2.78E+02	81.201	1.179777	1.53E-05	0.035241157	1.686651	3.513003	5.925211	9.796498	0.983466	9.634524	0.001026	47	67.06	67.05723	0.00
	37	4.30E+01	2.52E+02	81.294	1.179777	1.88E-05	0.039141077	1.682871	3.517952	5.920261	9.845827	0.978993	9.638997	0.001264	47	67.06	67.05744	0.00
	38	3.86E+01	2.28E+02	81.10333333	1.179777	2.33E-05	0.043450166	1.678748	3.523367	5.914847	9.899493	0.974173	9.643818	0.001561	47	67.06	67.05777	0.00
	39	3.51E+01	2.09E+02	80.60433333	1.179777	2.83E-05	0.047727797	1.674647	3.52877	5.909444	9.952723	0.969438	9.648552	0.001895	47	67.06	67.0581	0.00
	40	3.22E+01	1.93E+02	79.84133333	1.179777	3.36E-05	0.051806733	1.670724	3.533954	5.90426	10.00341	0.964973	9.653018	0.002254	47	67.06	67.05845	0.00
	41	3.00E+01	1.81E+02	78.85033333	1.179777	3.92E-05	0.055573699	1.667083	3.538778	5.899436	10.05013	0.960893	9.657097	0.002627	47	67.06	67.05882	0.00
	42	2.85E+01	1.73E+02	77.646	1.179777	4.38E-05	0.05833841	1.664383	3.542363	5.895851	10.08427	0.957934	9.660057	0.002939	47	67.06	67.05914	0.00
	43	2.77E+01	1.68E+02	76.291	1.179777	4.72E-05	0.060004342	1.662723	3.544573	5.893641	10.10465	0.956175	9.661815	0.003165	47	67.06	67.05914	0.00
	44	2.74E+01	1.67E+02	74.84333333	1.179777	4.91E-05	0.060614752	1.662186	3.545287	5.892926	10.11	0.955715	9.662276	0.003292	47	67.06	67.05952	0.00
	45	2.74E+01	1.67E+02	73.31833333	1.179777	5.02E-05	0.060657275	1.662089	3.545416	5.892798	10.10979	0.955733	9.662258	0.003365	47	67.06	67.05957	0.00
	46	2.75E+01	1.67E+02	71.742	1.179777	5.09E-05	0.060408175	1.662136	3.545354	5.89286	10.10801	0.955886	9.662105	0.003411	47	67.06	67.05966	0.00
	47	2.81E+01	1.70E+02	70.12933333	1.179777	5.01E-05	0.059268783	1.663129	3.544032	5.894182	10.09387	0.957104	9.660886	0.003359	47	67.06	67.0596	0.00
EOC	48	2.90E+01	1.75E+02	68.5	1.179777	4.83E-05	0.057503055	1.664762	3.54186	5.896353	10.07157	0.959032	9.658959	0.003237	47	67.06	67.05944	0.00
	49	2.99E+01	1.81E+02	66.88233333	1.179777	4.63E-05	0.055659133	1.666426	3.53965	5.898564	10.04806	0.961073	9.656918	0.003152	48	68.06	68.05936	0.00
	50	3.10E+01	1.86E+02	65.27066667	1.179777	4.44E-05	0.053809143	1.668106	3.537421	5.900793	10.02453	0.963124	9.654867	0.003063	49	69.06	69.05927	0.00
	51	3.24E+01	1.94E+02	63.64166667	1.179777	4.17E-05	0.051507791	1.670241	3.534593	5.903621	9.995506	0.965666	9.652324	0.002921	50	70.06	70.05912	0.00
	52	3.41E+01	2.03E+02	62.022	1.179777	3.88E-05	0.049042768	1.672552	3.531536	5.906677	9.964547	0.968393	9.649597	0.002756	51	71.06	71.05896	0.00
	53	3.60E+01	2.13E+02	60.43133333	1.179777	3.58E-05	0.046539349	1.674917	3.528414	5.9098	9.933203	0.971169	9.646821	0.002583	52	72.06	72.05879	0.00
	54	3.78E+01	2.23E+02	58.89866667	1.179777	3.35E-05	0.044417817	1.676918	3.525777	5.912437	9.906623	0.973536	9.644454	0.002447	53	73.06	73.05865	0.00
	55	3.97E+01	2.33E+02	57.398	1.179777	3.12E-05	0.042316208	1.678911	3.523153	5.915061	9.880356	0.975886	9.642104	0.00231	54	74.06	74.05855	0.00
	56	4.16E+01	2.44E+02	55.94833333	1.179777	2.92E-05	0.040435804	1.680696	3.520807	5.917407	9.856859	0.977998	9.639992	0.002194	55	75.06	75.05789	0.00
	57	4.34E+01	2.54E+02	54.542	1.179777	2.76E-05	0.038770739	1.682276	3.518734	5.91948	9.836047	0.979877	9.638114	0.002096	56	76.06	76.05818	0.00
	58	4.54E+01	2.65E+02	53.15333333	1.179777	2.58E-05	0.03705668	1.683913	3.516587	5.921627	9.814683	0.981812	9.636178	0.001991	57	77.06	77.05833	0.00
	59	4.76E+01	2.77E+02	51.79966667	1.179777	2.42E-05	0.035413911	1.685487	3.514526	5.923688	9.794237	0.983672	9.634318	0.00189	58	78.06	78.05808	0.00
	60	5.17E+01	2.98E+02	50.48966667	1.179777	2.12E-05	0.03269711	1.689923	3.508731	5.929483	9.735703	0.989035	9.628955	0.001674	59	79.06	79.05788	0.00
	61	5.59E+01	3.20E+02	49.22633333	1.179777	1.86E-05	0.030297202	1.693936	3.503503	5.934711	9.683149	0.993901	9.62409	0.001493	60	80.06	80.0577	0.00
	62	6.01E+01	3.41E+02	48.011	1.179777	1.66E-05	0.028254392	1.697371	3.499042	5.939172	9.638507	0.998072	9.619919	0.001348	61	81.06	81.05758	0.00
	63	6.41E+01	3.62E+02	46.84366667	1.179777	1.50E-05	0.026540372	1.700264	3.495293	5.94292	9.601109	1.001592	9.616398	0.001234	62	82.06	82.05721	0.00

Figure 45 - Excel extract balancing combustion equation and calculation dissociated molar masses for each species at 3000rpm.

	Crank Angle	MFB	Volume Burned	Temperature Bu	kCO2	kH2O	Pressure	ϕ	Guessed n5/nt	n5/nt.P ^(1/2)	n1/n3	n3	n1	n2/n4	n4	n2	n5	n6	nt	nt	error
				K			bar														
SOC	11	0	7.65635E-07	#DIV/0!	#DIV/0!	#DIV/0!	48.93466667	1.092737	1.06E-25	2.28E-12	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	47	#DIV/0!	#DIV/0!	#DIV/0!
	12	0.032462565	3.02318E-06	1621.20	1.57E+05	4.03E+05	49.35033333	1.092737	1.76E-11	2.95E-05	4.624414	1.554277	7.187618	11.87011	0.764145	9.070487	1.15E-09	47	65.58	65.57718	0.00
	13	0.053702567	5.01692E-06	1647.89	1.46E+05	3.75E+05	50.006	1.092737	2.01E-11	3.17E-05	4.623949	1.554405	7.18749	11.87227	0.764017	9.070615	1.32E-09	47	65.58	65.57659	0.00
	14	0.078692367	7.33199E-06	1673.56	1.35E+05	3.48E+05	50.92	1.092737	2.29E-11	3.41E-05	4.623432	1.554548	7.187347	11.87468	0.763874	9.070758	1.5E-09	47	65.58	65.57654	0.00
	15	0.107481339	9.95581E-06	1703.08	1.23E+05	3.17E+05	52.12266667	1.092737	2.70E-11	3.75E-05	4.622728	1.554743	7.187152	11.87796	0.763679	9.070952	1.77E-09	47	65.58	65.57627	0.00
	16	0.140317818	1.28604E-05	1733.35	1.11E+05	2.85E+05	53.614	1.092737	3.25E-11	4.17E-05	4.621846	1.554986	7.186909	11.88207	0.763436	9.071196	2.13E-09	47	65.58	65.57654	0.00
	17	0.177127351	1.6011E-05	1766.89	9.69E+04	2.49E+05	55.413	1.092737	4.10E-11	4.77E-05	4.620605	1.55533	7.186565	11.88787	0.763092	9.07154	2.69E-09	47	65.58	65.57654	0.00
	18	0.217893693	1.93588E-05	1802.23	8.23E+04	2.12E+05	57.50566667	1.092737	5.47E-11	5.61E-05	4.618849	1.555816	7.186079	11.89608	0.762606	9.072026	3.59E-09	47	65.58	65.57652	0.00
	19	0.2620352	2.2842E-05	1841.40	6.62E+04	1.71E+05	59.88366667	1.092737	8.12E-11	6.97E-05	4.616007	1.556603	7.185292	11.90941	0.761819	9.072813	5.33E-09	47	65.58	65.57648	0.00
	20	0.308851767	2.63857E-05	1882.97	4.90E+04	1.27E+05	62.48266667	1.092737	1.41E-10	9.40E-05	4.610964	1.558002	7.183893	11.93316	0.76042	9.074212	9.28E-09	47	65.58	65.57653	0.00
	21	0.3579205	2.99388E-05	1924.64	3.19E+04	8.30E+04	65.22833333	1.092737	3.20E-10	1.44E-04	4.60055	1.560899	7.180996	11.98262	0.757523	9.077109	2.1E-08	47	65.58	65.57653	0.00
	22	0.408047803	3.34486E-05	1968.46	1.38E+04	3.67E+04	68.076	1.092737	1.61E-09	3.31E-04	4.562646	1.571535	7.17036	12.1675	0.746887	9.087745	1.06E-07	47	65.58	65.57653	0.00
	23	0.458616678	3.6878E-05	2011.26	7.18E+02	3.27E+03	70.90633333	1.092737	4.12E-07	5.40E-03	3.880821	1.791071	6.950824	17.6472	0.527405	9.307227	2.7E-05	47	65.58	65.5765	0.00
	24	0.508819247	4.02097E-05	2053.38	5.42E+02	2.52E+03	73.661	1.092737	6.89E-07	7.13E-03	3.859151	1.799058	6.942837	17.93262	0.519454	9.315178	4.52E-05	47	65.58	65.57656	0.00
	25	0.558025332	4.34349E-05	2093.99	3.71E+02	1.79E+03	76.265	1.092737	1.39E-06	1.03E-02	3.82089	1.813336	6.928559	18.46419	0.505268	9.329364	9.11E-05	47	65.58	65.57661	0.00
	26	0.605718314	4.6555E-05	2132.73	2.88E+02	1.42E+03	78.66366667	1.092737	2.22E-06	1.32E-02	3.800312	1.82111	6.920785	18.76401	0.497603	9.337029	0.000145	47	65.58	65.57667	0.00
	27	0.651001056	4.95635E-05	2170.40	2.21E+02	1.12E+03	80.81566667	1.092737	3.62E-06	1.71E-02	3.779121	1.829185	6.91271	19.08246	0.489713	9.344919	0.000238	47	65.58	65.57675	0.00
	28	0.693828691	5.24736E-05	2204.77	1.64E+02	8.56E+02	82.64366667	1.092737	6.30E-06	2.28E-02	3.750375	1.840254	6.901642	19.53183	0.478994	9.355638	0.000413	47	65.58	65.57692	0.00
	29	0.733265019	5.52813E-05	2238.07	1.37E+02	7.25E+02	84.15733333	1.092737	8.80E-06	2.72E-02	3.737956	1.845077	6.896818	19.72636	0.474499	9.360133	0.000577	47	65.58	65.5771	0.00
	30	0.769439801	5.80015E-05	2267.60	1.13E+02	6.09E+02	85.278	1.092737	1.26E-05	3.28E-02	3.722254	1.851213	6.890683	19.97533	0.468867	9.365765	0.000829	47	65.58	65.57657	0.00
	31	0.802203506	6.06464E-05	2294.36	9.17E+01	5.03E+02	86.035	1.092737	1.89E-05	4.04E-02	3.701379	1.859432	6.882463	20.31131	0.461475	9.373157	0.001242	47	65.58	65.57776	0.00
	32	0.831641227	6.32291E-05	2317.95	8.00E+01	4.44E+02	86.429	1.092737	2.46E-05	4.61E-02	3.690045	1.863925	6.87797	20.48601	0.457723	9.376909	0.001613	47	65.58	65.57871	0.00
	33	0.857814775	6.57598E-05	2338.65	7.19E+01	4.02E+02	86.48366667	1.092737	3.03E-05	5.12E-02	3.682046	1.86711	6.874785	20.60078	0.455291	9.379341	0.001989	47	65.58	65.57852	0.00
	34	0.880451965	6.82377E-05	2357.15	6.46E+01	3.65E+02	86.21933333	1.092737	3.75E-05	5.69E-02	3.673101	1.870684	6.871211	20.72658	0.452654	9.381977	0.002458	47	65.58	65.57899	0.00
	35	0.900550626	7.06917E-05	2370.89	5.92E+01	3.37E+02	85.62233333	1.092737	4.48E-05	6.19E-02	3.66493	1.873961	6.867934	20.83866	0.450331	9.384301	0.002935	47	65.58	65.57949	0.00
	36	0.917652613	7.31146E-05	2383.48	5.43E+01	3.11E+02	84.80466667	1.092737	5.35E-05	6.74E-02	3.655911	1.877591	6.864304	20.95947	0.447854	9.386778	0.003511	47	65.58	65.57986	0.00
	37	0.932208685	7.55177E-05	2392.67	5.06E+01	2.92E+02	83.73033333	1.092737	6.20E-05	7.20E-02	3.648054	1.880765	6.86113	21.06122	0.445788	9.388844	0.004065	47	65.58	65.58059	0.00
	38	0.944526243	7.79097E-05	2399.13	4.81E+01	2.79E+02	82.454	1.092737	6.95E-05	7.57E-02	3.641675	1.883349	6.858546	21.14044	0.444193	9.390439	0.00456	47	65.58	65.58175	0.00
	39	0.954510815	8.02872E-05	2403.76	4.70E+01	2.73E+02	81.014	1.092737	7.40E-05	7.74E-02	3.63908	1.884403	6.857492	21.16366	0.443728	9.390904	0.004854	47	65.58	65.58139	0.00
	40	0.963172903	8.26759E-05	2404.36	4.69E+01	2.73E+02	79.40733333	1.092737	7.59E-05	7.76E-02	3.638474	1.884649	6.857246	21.16371	0.443727	9.390905	0.004977	47	65.58	65.58167	0.00
	41	0.970073513	8.50629E-05	2404.61	4.68E+01	2.72E+02	77.74	1.092737	7.77E-05	7.77E-02	3.637973	1.884852	6.857043	21.16227	0.443756	9.390876	0.005093	47	65.58	65.58162	0.00
	42	0.976536579	8.74828E-05	2400.75	4.76E+01	2.77E+02	75.971	1.092737	7.69E-05	7.64E-02	3.639019	1.884427	6.857468	21.14585	0.444085	9.390547	0.005045	47	65.58	65.58157	0.00
	43	0.981995721	8.99191E-05	2397.81	4.86E+01	2.82E+02	74.23466667	1.092737	7.56E-05	7.49E-02	3.641116	1.883576	6.858319	21.11238	0.444757	9.389875	0.004955	47	65.58	65.5815	0.00
	44	0.986545951	9.2372E-05	2393.70	5.02E+01	2.90E+02	72.474	1.092737	7.26E-05	7.26E-02	3.644689	1.882127	6.859768	21.05949	0.445823	9.388809	0.004764	47	65.58	65.58143	0.00
	45	0.990657965	9.48535E-05	2387.85	5.25E+01	3.02E+02	70.699	1.092737	6.83E-05	6.95E-02	3.649565	1.880153	6.861742	20.99045	0.447223	9.387409	0.004477	47	65.58	65.5815	0.00
	46	0.994079854	9.73545E-05	2382.18	5.48E+01	3.14E+02	68.95633333	1.092737	6.46E-05	6.67E-02	3.65389	1.878406	6.863489	20.92867	0.448483	9.386149	0.004233	47	65.58	65.58076	0.00
	47	0.997280913	9.98876E-05	2374.95	5.76E+01	3.28E+02	67.21966667	1.092737	6.00E-05	6.35E-02	3.658998	1.876347	6.865548	20.85729	0.449947	9.384684	0.003936	47	65.58	65.58046	0.00
EOC	48	1	0.000102443	2368.21	6.03E+01	3.42E+02	65.53466667	1.092737	5.64E-05	6.08E-02	3.663311	1.874611	6.867284	20.79628	0.451207	9.383425	0.003698	47	65.58	65.58023	0.00

Figure 46 - Excel extract balancing combustion equation and calculation dissociated molar masses for each species at 3500rpm.

	Crank Angle	kCO2	kH2O	Pressure	ϕ	Guessed n5/nt	n5/nt.P ^(1/2)	n1/n3	n3	n1	n2/n4	n4	n2	n5	n6	nt	nt	error
				bar														
SOC	6	#DIV/0!	#DIV/0!	49.226	1.065343	1.12E-01	2.351397517	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	47	#DIV/0!	#DIV/0!	#DIV/0!
	7	1.90E+05	4.87E+05	49.13266667	1.065343	1.36E+22	8.1681E+11	1.55E+17	5.5E-17	8.522747	3.98E+17	2.41E-17	9.588091	-0.81679	47	64.29	-6E-23	-64.29
	8	1.83E+05	4.68E+05	49.141	1.065343	1.36E+22	8.16871E+11	1.49E+17	5.71E-17	8.522747	3.83E+17	2.51E-17	9.588091	-0.81679	47	64.29	-6E-23	-64.29
	9	1.72E+05	4.41E+05	49.28033333	1.065343	4.92E+17	4924686514	8.46E+14	1.01E-14	8.522747	2.17E+15	4.42E-15	9.588091	-0.81679	47	64.29	-1.7E-18	-64.29
	10	1.62E+05	4.16E+05	49.55966667	1.065343	3.45E-11	4.1352E-05	6.700942	1.106715	7.416032	17.19821	0.52687	9.061221	2.25E-09	47	65.11	65.11084	0.00
	11	1.51E+05	3.87E+05	50.01	1.065343	3.95E-11	4.44E-05	6.700325	1.106804	7.415944	17.20128	0.526781	9.061309	2.57E-09	47	65.11	65.11081	0.00
	12	1.39E+05	3.57E+05	50.63366667	1.065343	4.59E-11	4.82132E-05	6.699566	1.106913	7.415834	17.20505	0.526672	9.061418	2.99E-09	47	65.11	65.11085	0.00
	13	1.29E+05	3.31E+05	51.431	1.065343	5.25E-11	5.19874E-05	6.698809	1.107022	7.415726	17.20881	0.526563	9.061527	3.42E-09	47	65.11	65.11092	0.00
	14	1.16E+05	2.99E+05	52.45533333	1.065343	6.30E-11	5.75009E-05	6.697704	1.10718	7.415567	17.21431	0.526404	9.061686	4.1E-09	47	65.11	65.11083	0.00
	15	1.04E+05	2.68E+05	53.67733333	1.065343	7.67E-11	6.41652E-05	6.69637	1.107372	7.415375	17.22095	0.526212	9.061878	4.99E-09	47	65.11	65.11084	0.00
	16	9.19E+04	2.37E+05	55.12066667	1.065343	9.63E-11	7.28398E-05	6.694634	1.107622	7.415125	17.2296	0.525963	9.062128	6.27E-09	47	65.11	65.11083	0.00
	17	7.83E+04	2.02E+05	56.80066667	1.065343	1.28E-10	8.54266E-05	6.692118	1.107984	7.414763	17.24217	0.5256	9.06249	8.37E-09	47	65.11	65.11174	0.00
	18	6.40E+04	1.65E+05	58.69933333	1.065343	1.86E-10	0.000104433	6.688326	1.108531	7.414216	17.26115	0.525054	9.063037	1.21E-08	47	65.11	65.11085	0.00
	19	4.83E+04	1.25E+05	60.80166667	1.065343	3.15E-10	0.000138296	6.681589	1.109503	7.413244	17.29503	0.524082	9.064009	2.05E-08	47	65.11	65.11094	0.00
	20	3.24E+04	8.45E+04	63.03533333	1.065343	6.70E-10	0.000205584	6.668274	1.11143	7.411317	17.36253	0.522155	9.065935	4.37E-08	47	65.11	65.11084	0.00
	21	1.63E+04	4.31E+04	65.373	1.065343	2.54E-09	0.000407667	6.628857	1.117172	7.405575	17.56671	0.516413	9.071678	1.66E-07	47	65.11	65.11086	0.00
	22	7.52E+02	3.41E+03	67.77033333	1.065343	8.42E-07	0.007555214	5.682334	1.275415	7.247332	25.76146	0.35828	9.229811	5.48E-05	47	65.11	65.1109	0.00
	23	5.81E+02	2.68E+03	70.13866667	1.065343	1.35E-06	0.009732858	5.656638	1.280338	7.242409	26.12925	0.353423	9.234668	8.79E-05	47	65.11	65.11093	0.00
	24	4.15E+02	1.98E+03	72.411	1.065343	2.52E-06	0.01351232	5.613489	1.288692	7.234056	26.77373	0.345222	9.242869	0.000164	47	65.11	65.11106	0.00
	25	3.07E+02	1.51E+03	74.54833333	1.065343	4.44E-06	1.82E-02	5.573718	1.296488	7.226259	27.3945	0.337674	9.250416	0.000289	47	65.11	65.11113	0.00
	26	2.40E+02	1.20E+03	76.49033333	1.065343	7.00E-06	0.023135559	5.547863	1.301607	7.22114	27.80269	0.332889	9.255202	0.000456	47	65.11	65.11178	0.00
	27	1.77E+02	9.17E+02	78.182	1.065343	1.23E-05	0.031042944	5.50736	1.309709	7.213038	28.45822	0.325481	9.26261	0.000803	47	65.11	65.11166	0.00
	28	1.45E+02	7.62E+02	79.612	1.065343	1.80E-05	0.037821457	5.484176	1.314392	7.208355	28.81993	0.321533	9.266558	0.00117	47	65.11	65.11209	0.00
	29	1.20E+02	6.38E+02	80.725	1.065343	2.59E-05	0.045692339	5.461099	1.319086	7.203661	29.16389	0.317867	9.270224	0.001684	47	65.11	65.11319	0.00
	30	9.74E+01	5.31E+02	81.50066667	1.065343	3.82E-05	0.055781906	5.431063	1.325247	7.1975	29.60259	0.31331	9.274781	0.002486	47	65.11	65.11334	0.00
	31	8.18E+01	4.54E+02	81.99966667	1.065343	5.32E-05	0.066052705	5.404238	1.330798	7.191949	29.95771	0.309716	9.278375	0.003465	47	65.11	65.11436	0.00
	32	7.27E+01	4.07E+02	82.17433333	1.065343	6.68E-05	0.074079469	5.388039	1.334173	7.188574	30.11914	0.308109	9.279981	0.004349	47	65.12	65.1152	0.00
	33	6.53E+01	3.68E+02	82.03966667	1.065343	8.25E-05	0.08225529	5.370741	1.337795	7.184952	30.27944	0.30653	9.28156	0.00537	47	65.12	65.11641	0.00
	34	5.81E+01	3.31E+02	81.67866667	1.065343	1.04E-04	0.092068416	5.348927	1.342392	7.180355	30.4664	0.304709	9.283382	0.006758	47	65.12	65.11778	0.00
	35	5.27E+01	3.03E+02	81.02733333	1.065343	1.26E-04	0.101049591	5.32778	1.346878	7.175869	30.6314	0.303119	9.284971	0.008206	47	65.12	65.11904	0.00
	36	4.81E+01	2.79E+02	80.189	1.065343	1.52E-04	0.110230032	5.304974	1.35175	7.170997	30.79392	0.30157	9.286521	0.009867	47	65.12	65.12072	0.00
	37	4.58E+01	2.67E+02	79.177	1.065343	1.68E-04	0.115458122	5.29306	1.354309	7.168438	30.83253	0.301204	9.286886	0.010964	47	65.12	65.12182	0.00
	38	4.45E+01	2.60E+02	77.965	1.065343	1.81E-04	0.118740615	5.284916	1.356064	7.166683	30.8462	0.301075	9.287016	0.011777	47	65.12	65.12263	0.00
	39	4.35E+01	2.54E+02	76.63266667	1.065343	1.92E-04	0.121370665	5.277729	1.357616	7.165131	30.85355	0.301005	9.287085	0.012518	47	65.12	65.12358	0.00
	40	4.29E+01	2.51E+02	75.17966667	1.065343	2.01E-04	0.122935298	5.272474	1.358754	7.163994	30.85259	0.301014	9.287076	0.013092	47	65.12	65.12393	0.00
	41	4.29E+01	2.51E+02	73.62466667	1.065343	2.05E-04	0.122932955	5.270417	1.359199	7.163548	30.84136	0.301121	9.28697	0.013368	47	65.12	65.12421	0.00
	42	4.32E+01	2.53E+02	72.03066667	1.065343	2.07E-04	0.121972436	5.270395	1.359204	7.163543	30.82428	0.301282	9.286808	0.013451	47	65.12	65.12429	0.00
	43	4.35E+01	2.54E+02	70.44	1.065343	2.09E-04	0.121223198	5.269854	1.359322	7.163426	30.8081	0.301435	9.286655	0.013586	47	65.12	65.12442	0.00
	44	4.42E+01	2.58E+02	68.806	1.065343	2.06E-04	0.119158046	5.27224	1.358804	7.163943	30.78461	0.301658	9.286432	0.013439	47	65.12	65.12428	0.00
	45	4.50E+01	2.63E+02	67.19633333	1.065343	2.04E-04	0.117095349	5.274651	1.358282	7.164465	30.76131	0.30188	9.286211	0.013288	47	65.12	65.12413	0.00
	46	4.58E+01	2.67E+02	65.60233333	1.065343	2.03E-04	0.115275111	5.276515	1.357879	7.164868	30.7393	0.302089	9.286002	0.013191	47	65.12	65.12403	0.00
	47	4.71E+01	2.74E+02	63.975	1.065343	1.96E-04	0.112022506	5.28167	1.356765	7.165983	30.7099	0.302369	9.285722	0.012774	47	65.12	65.1236	0.00
	48	4.89E+01	2.84E+02	62.41133333	1.065343	1.87E-04	0.108077185	5.289776	1.355016	7.167731	30.64958	0.302945	9.285145	0.012188	47	65.12	65.1233	0.00
EOC	49	5.10E+01	2.94E+02	60.885	1.065343	1.78E-04	0.103973501	5.299044	1.353022	7.169725	30.57215	0.303688	9.284402	0.011563	47	65.12	65.12241	0.00

Figure 47 - Excel extract balancing combustion equation and calculation dissociated molar masses for each species at 4000rpm.

	Crank Angle	kCO2	kH2O	Pressure	ϕ	Guessed n5/nt	n5/nt.P ^(1/2)	n1/n3	n3	n1	n2/n4	n4	n2	n5	n6	nt	nt	error
				bar														
SOC	-1	1.00E+25	7.26E+22	46.929	1.078039	1.70E-09	2.82E-04	2.82E+21	3.05E-21	8.624312	2.05E+19	4.73E-19	9.702351	-0.97549	47	64.35	-5.7E+08	-574302951.08
	0	1.57E+10	1.09E+10	47.04266667	1.078039	1.72E+14	89868948.81	1.41E+18	6.11E-18	8.624312	9.79E+17	9.91E-18	9.702351	-0.97549	47	64.35	-5.7E-15	-64.35
	1	7.26E+09	5.03E+09	47.11833333	1.078039	1.72E+14	89941284.49	6.53E+17	1.32E-17	8.624312	4.53E+17	2.14E-17	9.702351	-0.97549	47	64.35	-5.7E-15	-64.35
	2	5.15E+09	3.57E+09	47.13733333	1.078039	8.53E-20	2.00538E-09	10.3206	0.761825	7.862488	7.15745	1.189385	8.512966	0.000117	47	65.33	1.37E+15	##################
	3	3.59E+09	2.49E+09	47.163	1.078039	1.75E-19	2.87241E-09	10.3217	0.761751	7.862562	7.158548	1.189225	8.513126	0	47	65.33	0	-65.33
	4	8.06E+08	5.59E+08	47.24466667	1.078039	3.47E-18	1.27976E-08	10.31837	0.761975	7.862338	7.160085	1.189001	8.51335	-2.8E-16	47	65.33	-80.0661	-145.39
	5	2.03E+05	5.20E+05	47.34433333	1.078039	1.59E-11	2.74E-05	5.558467	1.314989	7.309323	14.25558	0.635987	9.066364	1.04E-09	47	65.33	65.32665	0.00
	6	1.89E+05	4.84E+05	47.54333333	1.078039	1.82E-11	2.94557E-05	5.558044	1.315074	7.309239	14.25762	0.635902	9.066449	1.19E-09	47	65.33	65.32662	0.00
	7	1.74E+05	4.46E+05	47.87333333	1.078039	2.13E-11	3.19702E-05	5.557529	1.315177	7.309135	14.26009	0.635799	9.066552	1.39E-09	47	65.33	65.32667	0.00
	8	1.59E+05	4.07E+05	48.353	1.078039	2.54E-11	3.50574E-05	5.556898	1.315304	7.309009	14.26314	0.635672	9.066679	1.66E-09	47	65.33	65.32662	0.00
	9	1.45E+05	3.72E+05	48.988	1.078039	2.99E-11	3.8301E-05	5.556234	1.315437	7.308875	14.26633	0.635539	9.066812	1.96E-09	47	65.33	65.32666	0.00
	10	1.32E+05	3.39E+05	49.81366667	1.078039	3.56E-11	4.21388E-05	5.555449	1.315594	7.308718	14.27012	0.635382	9.06697	2.33E-09	47	65.33	65.32668	0.00
	11	1.17E+05	3.01E+05	50.85133333	1.078039	4.44E-11	4.74979E-05	5.554353	1.315814	7.308498	14.27541	0.635162	9.06719	2.9E-09	47	65.33	65.32664	0.00
	12	1.04E+05	2.68E+05	52.07266667	1.078039	5.46E-11	5.33227E-05	5.553163	1.316053	7.308259	14.28115	0.634923	9.067429	3.57E-09	47	65.33	65.32666	0.00
	13	9.05E+04	2.33E+05	53.54166667	1.078039	7.03E-11	6.13402E-05	5.551527	1.316382	7.30793	14.28907	0.634594	9.067757	4.59E-09	47	65.33	65.32666	0.00
	14	7.60E+04	1.96E+05	55.261	1.078039	9.65E-11	7.30421E-05	5.549142	1.316861	7.307451	14.30063	0.634115	9.068237	6.31E-09	47	65.33	65.32666	0.00
	15	6.10E+04	1.57E+05	57.22033333	1.078039	1.45E-10	9.09814E-05	5.545492	1.317596	7.306716	14.31837	0.63338	9.068971	9.45E-09	47	65.33	65.32666	0.00
	16	4.46E+04	1.16E+05	59.41533333	1.078039	2.60E-10	0.000124185	5.538757	1.318953	7.305359	14.35126	0.632023	9.070328	1.7E-08	47	65.33	65.32667	0.00
	17	2.81E+04	7.33E+04	61.78533333	1.078039	6.27E-10	0.000196797	5.524128	1.32191	7.302402	14.42343	0.629066	9.073286	4.09E-08	47	65.33	65.32666	0.00
	18	1.08E+04	2.92E+04	64.30466667	1.078039	3.97E-09	0.000505051	5.463492	1.334312	7.290001	14.73359	0.616665	9.085686	2.59E-07	47	65.33	65.32666	0.00
	19	6.81E+02	3.11E+03	66.901	1.078039	7.07E-07	6.88E-03	4.68344	1.517446	7.106867	21.37511	0.433623	9.268729	4.62E-05	47	65.33	65.32671	0.00
	20	5.02E+02	2.35E+03	69.436	1.078039	1.24E-06	0.009267238	4.654699	1.525159	7.099154	21.77659	0.425979	9.276372	8.08E-05	47	65.33	65.32674	0.00
	21	3.40E+02	1.66E+03	71.87133333	1.078039	2.56E-06	0.013555026	4.606803	1.538187	7.086125	22.48539	0.413123	9.289228	0.000167	47	65.33	65.32683	0.00
	22	2.67E+02	1.33E+03	74.17733333	1.078039	3.97E-06	0.017161168	4.587505	1.5435	7.080813	22.78057	0.407995	9.294356	0.000259	47	65.33	65.32692	0.00
	23	1.98E+02	1.01E+03	76.249	1.078039	6.92E-06	0.022968868	4.557136	1.551935	7.072378	23.2592	0.399945	9.302406	0.000452	47	65.33	65.32712	0.00
	24	1.53E+02	8.02E+02	78.03866667	1.078039	1.12E-05	0.029538607	4.52947	1.5597	7.064613	23.70443	0.392737	9.309614	0.00073	47	65.33	65.32739	0.00
	25	1.26E+02	6.68E+02	79.55866667	1.078039	1.62E-05	0.035880766	4.511577	1.564763	7.059549	23.98499	0.388327	9.314024	0.001057	47	65.33	65.32772	0.00
	26	9.99E+01	5.43E+02	80.75133333	1.078039	2.50E-05	0.044901368	4.486145	1.572017	7.052296	24.38412	0.382221	9.32013	0.001631	47	65.33	65.32829	0.00
	27	8.24E+01	4.57E+02	81.58066667	1.078039	3.59E-05	0.054137054	4.463348	1.578577	7.045736	24.7293	0.377093	9.325258	0.002347	47	65.33	65.32901	0.00
	28	7.24E+01	4.05E+02	82.1	1.078039	4.60E-05	0.061444493	4.450835	1.5822	7.042112	24.88782	0.374784	9.327567	0.003004	47	65.33	65.33061	0.00
	29	6.33E+01	3.58E+02	82.29566667	1.078039	5.96E-05	0.070035406	4.435643	1.586622	7.03769	25.07169	0.372141	9.33021	0.003894	47	65.33	65.33138	0.00
	30	5.59E+01	3.20E+02	82.153	1.078039	7.59E-05	0.078988623	4.41922	1.59143	7.032882	25.26026	0.369469	9.332882	0.004962	47	65.33	65.33235	0.00
	31	4.95E+01	2.87E+02	81.75166667	1.078039	9.65E-05	0.08884069	4.400431	1.596967	7.027345	25.46405	0.366624	9.335728	0.006308	47	65.33	65.33361	0.00
	32	4.58E+01	2.67E+02	81.112	1.078039	1.13E-04	0.095909387	4.388277	1.60057	7.023743	25.5654	0.365225	9.337126	0.007409	47	65.33	65.33439	0.00
	33	4.35E+01	2.54E+02	80.227	1.078039	1.27E-04	0.100788013	4.38046	1.602895	7.021417	25.60903	0.364626	9.337725	0.008273	47	65.33	65.33524	0.00
	34	4.18E+01	2.45E+02	79.13633333	1.078039	1.38E-04	0.104606019	4.373898	1.604852	7.01946	25.64076	0.364192	9.338159	0.009034	47	65.34	65.33599	0.00
	35	4.05E+01	2.38E+02	77.89866667	1.078039	1.49E-04	0.107733727	4.368122	1.606579	7.017733	25.66457	0.363867	9.338485	0.009735	47	65.34	65.33667	0.00
	36	3.97E+01	2.34E+02	76.52933333	1.078039	1.58E-04	0.109888183	4.363659	1.607916	7.016396	25.67834	0.363679	9.338672	0.010309	47	65.34	65.33724	0.00
	37	3.92E+01	2.31E+02	75.05566667	1.078039	1.64E-04	0.111106887	4.360539	1.608852	7.015461	25.68289	0.363617	9.338734	0.010746	47	65.34	65.33767	0.00
	38	3.92E+01	2.31E+02	73.49666667	1.078039	1.69E-04	0.111284476	4.359019	1.609308	7.015004	25.67776	0.363687	9.338664	0.011009	47	65.34	65.33792	0.00
	39	3.93E+01	2.31E+02	71.87866667	1.078039	1.71E-04	0.110992407	4.358198	1.609555	7.014758	25.66814	0.363818	9.338533	0.011198	47	65.34	65.33811	0.00
	40	3.99E+01	2.35E+02	70.17933333	1.078039	1.70E-04	0.109162962	4.35993	1.609034	7.015278	25.64525	0.364131	9.338221	0.011094	47	65.34	65.338	0.00
	41	4.10E+01	2.41E+02	68.45733333	1.078039	1.65E-04	0.106432339	4.363203	1.608052	7.01626	25.61483	0.364547	9.337805	0.010812	47	65.34	65.33772	0.00
	42	4.21E+01	2.47E+02	66.76066667	1.078039	1.61E-04	0.103683995	4.366534	1.607055	7.017258	25.58442	0.364964	9.337388	0.010521	47	65.34	65.33743	0.00
	43	4.32E+01	2.53E+02	65.09	1.078039	1.57E-04	0.101050117	4.369693	1.606109	7.018203	25.55509	0.365367	9.336984	0.01025	47	65.34	65.33716	0.00
	44	4.47E+01	2.61E+02	63.42866667	1.078039	1.51E-04	0.097881651	4.373793	1.604884	7.019429	25.52144	0.36583	9.336521	0.009869	47	65.34	65.33678	0.00
EOC	45	4.60E+01	2.68E+02	61.82366667	1.078039	1.46E-04	0.095123662	4.377234	1.603857	7.020456	25.49145	0.366245	9.336107	0.009563	47	65.34	65.33647	0.00

Figure 48 - Excel extract balancing combustion equation and calculation dissociated molar masses for each species at 4500rpm.

	Crank Angle	kCO2	kH2O	Pressure bar	ϕ	Guessed n5/nt	n5/nt.P ^(1/2)	n1/n3	n3	n1	n2/n4	n4	n2	n5	n6	nt	nt	error
SOC	0																	
	1	4.08E+24	2.96E+22	48.797	1.121018	1.31E-46	7.98496E-23	325.7766	0.027444	8.940702	2.365378	2.997929	7.091236	-4.3E-05	47	66.06	-3.3E+41	##################
	2	1.16E+10	8.06E+09	48.71866667	1.121018	6.42E-21	5.59436E-10	6.50578	1.194832	7.773315	4.511558	1.830547	8.258618	-4E-05	47	66.06	-6.2E+15	##################
	3	5.74E+09	3.98E+09	48.58566667	1.121018	2.65E-20	1.13428E-09	6.505863	1.194819	7.773328	4.511838	1.830454	8.258711	-9.3E-05	47	66.06	-3.5E+15	##################
	4	4.88E+09	3.38E+09	48.398	1.121018	3.68E-20	1.33435E-09	6.50532	1.194905	7.773241	4.511539	1.830553	8.258612	0	47	66.06	0	-66.06
	5	2.80E+09	1.94E+09	48.23566667	1.121018	1.12E-19	2.32442E-09	6.504993	1.194957	7.773189	4.511696	1.830501	8.258664	4.33E-15	47	66.06	38655.84	38589.78
	6	7.77E+08	5.39E+08	48.106	1.121018	1.45E-18	8.36E-09	6.499721	1.195797	7.772349	4.510378	1.830939	8.258226	0.000639	47	66.06	4.4E+14	439777144415843.00
	7	2.02E+05	5.17E+05	48.013	1.121018	6.16E-12	1.71973E-05	3.469994	2.0063	6.961847	8.899503	1.019159	9.070006	4.07E-10	47	66.06	66.05755	0.00
	8	1.90E+05	4.87E+05	48.00666667	1.121018	6.96E-12	1.82736E-05	3.469759	2.006405	6.961742	8.900527	1.019053	9.070112	4.59E-10	47	66.06	66.0573	0.00
	9	1.72E+05	4.42E+05	48.13366667	1.121018	8.43E-12	2.0144E-05	3.469351	2.006588	6.961559	8.902307	1.01887	9.070295	5.57E-10	47	66.06	66.05741	0.00
	10	1.59E+05	4.09E+05	48.35766667	1.121018	9.79E-12	2.17608E-05	3.468999	2.006746	6.9614	8.903845	1.018712	9.070453	6.47E-10	47	66.06	66.05733	0.00
	11	1.46E+05	3.75E+05	48.728	1.121018	1.16E-11	2.37373E-05	3.468568	2.00694	6.961207	8.905727	1.018518	9.070647	7.64E-10	47	66.06	66.05731	0.00
	12	1.34E+05	3.43E+05	49.24766667	1.121018	1.37E-11	2.59327E-05	3.468089	2.007155	6.960992	8.907817	1.018304	9.070861	9.02E-10	47	66.06	66.05729	0.00
	13	1.21E+05	3.10E+05	49.94066667	1.121018	1.66E-11	2.87728E-05	3.467471	2.007433	6.960714	8.910521	1.018026	9.071139	1.1E-09	47	66.06	66.05731	0.00
	14	1.07E+05	2.76E+05	50.79866667	1.121018	2.05E-11	3.22711E-05	3.466709	2.007775	6.960372	8.913854	1.017683	9.071482	1.35E-09	47	66.06	66.05727	0.00
	15	9.51E+04	2.45E+05	51.82966667	1.121018	2.56E-11	3.64502E-05	3.465801	2.008183	6.959963	8.917836	1.017275	9.07189	1.69E-09	47	66.06	66.05732	0.00
	16	8.12E+04	2.09E+05	53.07066667	1.121018	3.43E-11	4.26551E-05	3.464452	2.00879	6.959357	8.923753	1.016668	9.072497	2.26E-09	47	66.06	66.05731	0.00
	17	6.72E+04	1.73E+05	54.48833333	1.121018	4.87E-11	5.14906E-05	3.462535	2.009653	6.958494	8.932184	1.015805	9.07336	3.21E-09	47	66.06	66.05731	0.00
	18	5.29E+04	1.37E+05	56.08666667	1.121018	7.62E-11	6.53643E-05	3.459531	2.011007	6.95714	8.94544	1.014451	9.074714	5.03E-09	47	66.06	66.05732	0.00
	19	3.73E+04	9.69E+04	57.862	1.121018	1.48E-10	9.2628E-05	3.453649	2.013663	6.954484	8.971545	1.011796	9.077369	9.8E-09	47	66.06	66.05731	0.00
	20	2.13E+04	5.60E+04	59.74966667	1.121018	4.36E-10	1.61E-04	3.438952	2.02033	6.947817	9.037685	1.005129	9.084036	2.88E-08	47	66.06	66.05731	0.00
	21	5.11E+03	1.46E+04	61.71066667	1.121018	6.93E-09	0.000653906	3.338945	2.066896	6.901251	9.525297	0.958563	9.130602	4.58E-07	47	66.06	66.05731	0.00
	22	6.44E+02	2.95E+03	63.699	1.121018	3.13E-07	0.004462912	2.875806	2.313879	6.654267	13.17774	0.71162	9.377545	2.07E-05	47	66.06	66.05733	0.00
	23	4.79E+02	2.25E+03	65.668	1.121018	5.42E-07	0.005967013	2.855693	2.325949	6.642197	13.42174	0.69958	9.389585	3.58E-05	47	66.06	66.05735	0.00
	24	3.32E+02	1.62E+03	67.55866667	1.121018	1.07E-06	0.008499272	2.825395	2.344371	6.623775	13.81025	0.681228	9.407937	7.06E-05	47	66.06	66.05738	0.00
	25	2.66E+02	1.32E+03	69.308	1.121018	1.61E-06	0.010569061	2.813141	2.351906	6.616241	13.97429	0.673766	9.415399	0.000106	47	66.06	66.05742	0.00
	26	2.02E+02	1.03E+03	70.897	1.121018	2.69E-06	0.01380006	2.794484	2.363469	6.604677	14.23252	0.662344	9.426821	0.000177	47	66.06	66.05749	0.00
	27	1.56E+02	8.13E+02	72.295	1.121018	4.40E-06	0.017837284	2.775269	2.375499	6.592648	14.50889	0.650541	9.438624	0.000291	47	66.06	66.0576	0.00
	28	1.29E+02	6.84E+02	73.44666667	1.121018	6.26E-06	0.021434098	2.764582	2.382242	6.585904	14.66538	0.644042	9.445123	0.000413	47	66.06	66.05772	0.00
	29	1.05E+02	5.65E+02	74.328	1.121018	9.32E-06	0.026318568	2.750303	2.391313	6.576834	14.87903	0.635377	9.453788	0.000616	47	66.06	66.05793	0.00
	30	8.50E+01	4.70E+02	74.93466667	1.121018	1.38E-05	0.032161086	2.734541	2.401405	6.566742	15.12005	0.625877	9.463288	0.000912	47	66.06	66.05822	0.00
	31	7.51E+01	4.19E+02	75.305	1.121018	1.75E-05	0.036316696	2.728153	2.40552	6.562626	15.21395	0.622252	9.466913	0.001157	47	66.06	66.05847	0.00
	32	6.63E+01	3.73E+02	75.412	1.121018	2.23E-05	0.041036254	2.720883	2.41022	6.557927	15.32053	0.618189	9.470976	0.001475	47	66.06	66.05879	0.00
	33	5.86E+01	3.34E+02	75.271	1.121018	2.84E-05	0.046269245	2.7128	2.415467	6.55268	15.43858	0.613749	9.475416	0.001879	47	66.06	66.05919	0.00
	34	5.19E+01	2.99E+02	74.91	1.121018	3.62E-05	0.052079246	2.703793	2.421341	6.546805	15.56948	0.6089	9.480264	0.002392	47	66.06	66.0597	0.00
	35	4.70E+01	2.73E+02	74.34566667	1.121018	4.42E-05	0.057349964	2.696067	2.426403	6.541744	15.67905	0.604901	9.484264	0.002922	47	66.06	66.05958	0.00
	36	4.45E+01	2.60E+02	73.616	1.121018	4.98E-05	0.060549462	2.692812	2.428541	6.539605	15.71784	0.603497	9.485668	0.00329	47	66.06	66.05999	0.00
	37	4.25E+01	2.49E+02	72.71966667	1.121018	5.52E-05	0.063351173	2.689892	2.430463	6.537683	15.75143	0.602287	9.486878	0.003646	47	66.06	66.06038	0.00
	38	4.08E+01	2.40E+02	71.69	1.121018	6.04E-05	0.065790345	2.68728	2.432185	6.535962	15.7803	0.601251	9.487914	0.003988	47	66.06	66.06075	0.00
	39	3.96E+01	2.33E+02	70.542	1.121018	6.51E-05	0.06775182	2.685104	2.433621	6.534526	15.8031	0.600435	9.48873	0.004299	47	66.06	66.06108	0.00
	40	3.88E+01	2.29E+02	69.29133333	1.121018	6.91E-05	0.06919502	2.683417	2.434735	6.533411	15.81941	0.599852	9.489313	0.004565	47	66.06	66.06137	0.00
	41	3.85E+01	2.27E+02	67.946	1.121018	7.15E-05	0.06971731	2.682656	2.435238	6.532908	15.8245	0.599671	9.489494	0.004726	47	66.06	66.06154	0.00
	42	3.85E+01	2.27E+02	66.55733333	1.121018	7.28E-05	0.069600675	2.682549	2.435309	6.532837	15.82185	0.599765	9.4894	0.004808	47	66.06	66.06163	0.00
	43	3.87E+01	2.28E+02	65.164	1.121018	7.39E-05	0.069379025	2.682545	2.435312	6.532835	15.81792	0.599906	9.489259	0.00488	47	66.06	66.06171	0.00
	44	3.89E+01	2.30E+02	63.75466667	1.121018	7.44E-05	0.068885292	2.682822	2.435129	6.533018	15.8107	0.600163	9.489002	0.004917	47	66.06	66.06176	0.00
	45	3.95E+01	2.32E+02	62.32733333	1.121018	7.41E-05	0.067978863	2.683535	2.434658	6.533489	15.79857	0.600597	9.488568	0.004898	47	66.06	66.06174	0.00
	46	4.02E+01	2.37E+02	60.89566667	1.121018	7.31E-05	0.06669963	2.684648	2.433922	6.534224	15.78204	0.601188	9.487977	0.004826	47	66.06	66.06167	0.00
EOC	46	4.11E+01	2.41E+02	59.481	1.121018	7.18E-05	0.0653576	2.685833	2.43314	6.535007	15.76479	0.601807	9.487358	0.004744	47	66.06	66.06184	0.00

Figure 49 - Excel extract balancing combustion equation and calculation dissociated molar masses for each species at 5000rpm.

	Crank Angle	kCO2	kH2O	Pressure	ϕ	Guessed n5/nt	n5/nt.P ^(1/2)	n1/n3	n3	n1	n2/n4	n4	n2	n5	n6	nt	nt	error
				bar														
SOC	-2	3.78E+24	2.74E+22	46.91466667	1.122772	1.53E-46	8.47E-23	319.8794	0.027992	8.954186	2.322561	3.041314	7.063636	-5.8E-16	47	66.09	-3.8E+30	##################
	-1	3.78E+24	2.74E+22	47.09433333	1.122772	1.53E-46	8.48511E-23	320.4145	0.027946	8.954232	2.326446	3.037762	7.067188	-0.0018	47	66.09	-1.2E+43	##################
	0	1.22E+10	8.47E+09	47.22566667	1.122772	5.83E-21	5.2478E-10	6.406815	1.212691	7.769487	4.442919	1.856532	8.248419	-4.2E-05	47	66.09	-7.2E+15	##################
	1	6.12E+09	4.24E+09	47.28033333	1.122772	2.28E-20	1.03774E-09	6.34777	1.222436	7.759742	4.402173	1.870534	8.234416	0.011832	47	66.10	5.19E+17	##################
	2	5.69E+09	3.95E+09	47.274	1.122772	2.68E-20	1.12502E-09	6.406408	1.212758	7.76942	4.442869	1.856548	8.248402	-2.2E-16	47	66.09	-8293.62	-8359.70
	3	2.94E+09	2.04E+09	47.30433333	1.122772	9.90E-20	2.1642E-09	6.356338	1.221012	7.761166	4.408551	1.868328	8.236622	0.010017	47	66.10	1.01E+17	##################
	4	2.39E+08	1.66E+08	47.367	1.122772	1.51E-17	2.68E-08	6.397949	1.214144	7.768034	4.446937	1.855162	8.249788	1.33E-15	47	66.09	88.04361	21.96
	5	1.88E+05	4.82E+05	47.452	1.122772	6.96E-12	1.81732E-05	3.415641	2.034173	6.948005	8.761983	1.035133	9.069817	4.6E-10	47	66.09	66.08717	0.00
	6	1.77E+05	4.54E+05	47.588	1.122772	7.84E-12	1.93095E-05	3.415392	2.034288	6.94789	8.763063	1.035018	9.069932	5.18E-10	47	66.09	66.08717	0.00
	7	1.63E+05	4.19E+05	47.85566667	1.122772	9.12E-12	2.08938E-05	3.415046	2.034447	6.947731	8.764568	1.034859	9.070091	6.03E-10	47	66.09	66.08719	0.00
	8	1.45E+05	3.73E+05	48.276	1.122772	1.15E-11	2.35322E-05	3.414469	2.034713	6.947465	8.767076	1.034593	9.070357	7.58E-10	47	66.09	66.0871	0.00
	9	1.33E+05	3.41E+05	48.802	1.122772	1.36E-11	2.57518E-05	3.413985	2.034936	6.947242	8.769186	1.03437	9.07058	8.98E-10	47	66.09	66.08706	0.00
	10	1.19E+05	3.06E+05	49.50733333	1.122772	1.66E-11	2.8641E-05	3.413354	2.035227	6.946951	8.771933	1.034079	9.070871	1.1E-09	47	66.09	66.08717	0.00
	11	1.07E+05	2.74E+05	50.396	1.122772	2.03E-11	3.19745E-05	3.412627	2.035563	6.946615	8.775104	1.033743	9.071207	1.34E-09	47	66.09	66.08715	0.00
	12	9.13E+04	2.35E+05	51.507	1.122772	2.71E-11	3.73584E-05	3.411453	2.036104	6.946074	8.780228	1.033202	9.071748	1.79E-09	47	66.09	66.08713	0.00
	13	7.77E+04	2.00E+05	52.77533333	1.122772	3.65E-11	4.38741E-05	3.410034	2.036759	6.945419	8.786433	1.032547	9.072403	2.41E-09	47	66.09	66.08714	0.00
	14	6.41E+04	1.65E+05	54.25033333	1.122772	5.22E-11	5.32083E-05	3.408004	2.037697	6.944481	8.79533	1.031609	9.073341	3.45E-09	47	66.09	66.08715	0.00
	15	4.91E+04	1.27E+05	55.947	1.122772	8.59E-11	6.93058E-05	3.404512	2.039313	6.942865	8.810694	1.029993	9.074957	5.67E-09	47	66.09	66.08714	0.00
	16	3.35E+04	8.73E+04	57.82933333	1.122772	1.77E-10	0.000101307	3.397601	2.042518	6.93966	8.841317	1.026788	9.078162	1.17E-08	47	66.09	66.08713	0.00
	17	1.76E+04	4.66E+04	59.86433333	1.122772	6.13E-10	0.000191516	3.378339	2.051503	6.930674	8.928202	1.017803	9.087148	4.05E-08	47	66.09	66.08713	0.00
	18	1.15E+03	4.44E+03	62.02233333	1.122772	1.08E-07	2.59E-03	2.971567	2.26162	6.720557	11.51077	0.8077	9.29725	7.16E-06	47	66.09	66.08676	0.00
	19	5.93E+02	2.73E+03	64.24333333	1.122772	3.54E-07	0.004765681	2.824093	2.348839	6.633339	13.02464	0.720514	9.384436	2.34E-05	47	66.09	66.08715	0.00
	20	4.22E+02	2.01E+03	66.41766667	1.122772	6.63E-07	0.006635187	2.799291	2.364172	6.618006	13.32876	0.705222	9.399728	4.38E-05	47	66.09	66.08717	0.00
	21	3.08E+02	1.51E+03	68.507	1.122772	1.18E-06	0.009004856	2.775525	2.379054	6.603124	13.63619	0.690409	9.414541	7.82E-05	47	66.09	66.08721	0.00
	22	2.40E+02	1.20E+03	70.47133333	1.122772	1.87E-06	0.011484678	2.760901	2.388305	6.593873	13.83299	0.681249	9.423702	0.000124	47	66.09	66.08725	0.00
	23	1.75E+02	9.06E+02	72.26233333	1.122772	3.38E-06	0.015632098	2.737207	2.403447	6.578731	14.16562	0.666306	9.438644	0.000223	47	66.09	66.08735	0.00
	24	1.43E+02	7.50E+02	73.83533333	1.122772	4.95E-06	0.019116125	2.725166	2.411215	6.570963	14.3397	0.658745	9.446205	0.000327	47	66.09	66.08746	0.00
	25	1.17E+02	6.24E+02	75.131	1.122772	7.21E-06	0.023276872	2.712858	2.419209	6.562969	14.52099	0.651051	9.4539	0.000477	47	66.09	66.0876	0.00
	26	9.22E+01	5.05E+02	76.17	1.122772	1.12E-05	0.029244934	2.695553	2.430537	6.551641	14.78273	0.640253	9.464697	0.000742	47	66.09	66.08787	0.00
	27	7.87E+01	4.38E+02	76.933	1.122772	1.51E-05	0.034114666	2.685901	2.436901	6.545277	14.92825	0.634404	9.470546	0.001	47	66.09	66.08813	0.00
	28	6.84E+01	3.84E+02	77.42066667	1.122772	1.98E-05	0.039153764	2.678168	2.442025	6.540153	15.04219	0.629898	9.475052	0.001309	47	66.09	66.08844	0.00
	29	5.98E+01	3.40E+02	77.57933333	1.122772	2.57E-05	0.044666403	2.669698	2.447661	6.534517	15.16678	0.625044	9.479906	0.0017	47	66.09	66.08883	0.00
	30	5.24E+01	3.02E+02	77.47166667	1.122772	3.32E-05	0.050738629	2.66035	2.453912	6.528266	15.30393	0.619786	9.485164	0.002196	47	66.09	66.08932	0.00
	31	4.67E+01	2.72E+02	77.145	1.122772	4.17E-05	0.056743993	2.651751	2.45969	6.522487	15.42727	0.615132	9.489818	0.002758	47	66.09	66.08911	0.00
	32	4.38E+01	2.56E+02	76.59133333	1.122772	4.78E-05	0.06051948	2.647997	2.462222	6.519956	15.47353	0.613405	9.491545	0.00316	47	66.09	66.08956	0.00
	33	4.14E+01	2.43E+02	75.81533333	1.122772	5.39E-05	0.063930452	2.644531	2.464563	6.517615	15.51491	0.611868	9.493082	0.003563	47	66.09	66.09001	0.00
	34	3.96E+01	2.33E+02	74.85	1.122772	5.95E-05	0.06673438	2.641604	2.466544	6.515634	15.5485	0.610626	9.494324	0.003932	47	66.09	66.09041	0.00
	35	3.83E+01	2.26E+02	73.74366667	1.122772	6.43E-05	0.068844589	2.639322	2.468091	6.514087	15.57335	0.609711	9.495239	0.004248	47	66.09	66.09076	0.00
	36	3.72E+01	2.20E+02	72.549	1.122772	6.94E-05	0.070980164	2.636967	2.469689	6.512489	15.59825	0.608796	9.496154	0.00459	47	66.09	66.09113	0.00
	37	3.65E+01	2.16E+02	71.22466667	1.122772	7.31E-05	0.072148562	2.635559	2.470646	6.511532	15.61122	0.608321	9.49663	0.00483	47	66.09	66.09139	0.00
	38	3.63E+01	2.15E+02	69.817	1.122772	7.55E-05	0.07261855	2.634845	2.471131	6.511047	15.61564	0.608159	9.496791	0.004992	47	66.09	66.09157	0.00
	39	3.64E+01	2.16E+02	68.34833333	1.122772	7.67E-05	0.072390344	2.634841	2.471134	6.511044	15.61159	0.608307	9.496643	0.005067	47	66.09	66.09165	0.00
	40	3.67E+01	2.17E+02	66.846	1.122772	7.72E-05	0.071833275	2.635173	2.470908	6.51127	15.60356	0.608602	9.496349	0.005102	47	66.09	66.09169	0.00
	41	3.73E+01	2.20E+02	65.30333333	1.122772	7.66E-05	0.070732443	2.636071	2.470298	6.51188	15.589	0.609135	9.495815	0.005063	47	66.09	66.09166	0.00
	42	3.84E+01	2.27E+02	63.73166667	1.122772	7.40E-05	0.068657621	2.638002	2.468986	6.513192	15.56287	0.610097	9.494854	0.004888	47	66.09	66.09148	0.00
	43	3.93E+01	2.32E+02	62.21833333	1.122772	7.24E-05	0.067123655	2.639372	2.468057	6.514121	15.54323	0.610821	9.494129	0.004786	47	66.09	66.09138	0.00
EOC	44	4.03E+01	2.37E+02	60.71733333	1.122772	7.06E-05	0.065478265	2.640865	2.467045	6.515133	15.5223	0.611595	9.493355	0.004667	47	66.09	66.09126	0.00

Figure 50 - Excel extract balancing combustion equation and calculation dissociated molar masses for each species at 5500rpm.

	Crank Angle	kCO2	kH2O	Pressure	ϕ	Guessed n5/nt	n5/nt.P ^(1/2)	n1/n3	n3	n1	n2/n4	n4	n2	n5	n6	nt	nt	error
				bar														
SOC	-2	1.38E+09	9.56E+08	44.37466667	1.148358	3.25E-19	3.79867E-09	5.23257	1.474009	7.712858	3.629923	2.232267	8.102959	-0.00134	47	66.52	-4.1E+15	##################
	-1	7.32E+02	3.32E+03	44.67566667	1.148358	2.18E-07	0.003118628	2.281693	2.799429	6.387438	10.36288	0.90956	9.425666	1.45E-05	47	66.52	66.52211	0.00
	0	1.27E+05	3.25E+05	44.80733333	1.148358	1.07E-11	2.19005E-05	2.771169	2.436079	6.750788	7.119551	1.272881	9.062344	7.12E-10	47	66.52	66.52211	0.00
	1	1.11E+09	7.73E+08	44.94233333	1.148358	4.82E-12	1.47189E-05	16400.15	0.00056	9.186307	11378.15	0.000908	10.33432	-1.85375	47	64.67	-3.8E+11	-384553793508.80
	2	1.88E+05	4.82E+05	45.242	1.148358	4.82E-12	1.47679E-05	2.772783	2.435038	6.75183	7.112912	1.273923	9.061303	3.21E-10	47	66.52	66.52211	0.00
	3	1.53E+05	3.92E+05	45.585	1.148358	7.23E-12	1.81537E-05	2.772017	2.435532	6.751335	7.116063	1.273428	9.061797	4.81E-10	47	66.52	66.52206	0.00
	4	1.45E+05	3.72E+05	45.91033333	1.148358	7.97E-12	1.91313E-05	2.771795	2.435675	6.751193	7.116973	1.273286	9.06194	5.3E-10	47	66.52	66.52212	0.00
	5	1.43E+05	3.67E+05	46.33366667	1.148358	8.11E-12	1.9383E-05	2.771739	2.435712	6.751156	7.117207	1.273249	9.061977	5.39E-10	47	66.52	66.52205	0.00
	6	1.36E+05	3.50E+05	46.96233333	1.148358	8.81E-12	2.03366E-05	2.771523	2.435851	6.751017	7.118095	1.27311	9.062116	5.86E-10	47	66.52	66.52202	0.00
	7	1.13E+05	2.90E+05	47.844	1.148358	1.26E-11	2.45199E-05	2.770578	2.436462	6.750406	7.121991	1.272499	9.062727	8.36E-10	47	66.52	66.52214	0.00
	8	1.05E+05	2.70E+05	48.76633333	1.148358	1.43E-11	2.6391E-05	2.770155	2.436735	6.750133	7.123734	1.272226	9.063	9.5E-10	47	66.52	66.52212	0.00
	9	9.25E+04	2.38E+05	49.95933333	1.148358	1.79E-11	2.99289E-05	2.769357	2.437251	6.749617	7.127032	1.27171	9.063516	1.19E-09	47	66.52	66.5221	0.00
	10	8.06E+04	2.08E+05	51.38766667	1.148358	2.29E-11	3.43283E-05	2.768365	2.437892	6.748975	7.131134	1.271068	9.064158	1.53E-09	47	66.52	66.52209	0.00
	11	6.30E+04	1.63E+05	53.102	1.148358	3.64E-11	4.39367E-05	2.766201	2.439293	6.747575	7.140103	1.269668	9.065558	2.42E-09	47	66.52	66.5221	0.00
	12	4.91E+04	1.27E+05	54.92833333	1.148358	5.77E-11	5.63147E-05	2.763421	2.441095	6.745772	7.151673	1.267866	9.06736	3.84E-09	47	66.52	66.52208	0.00
	13	3.54E+04	9.20E+04	56.97133333	1.148358	1.07E-10	7.79813E-05	2.758572	2.444244	6.742623	7.171972	1.264716	9.07051	7.1E-09	47	66.52	66.52209	0.00
	14	1.91E+04	5.03E+04	59.25766667	1.148358	3.49E-10	0.000143712	2.743999	2.453758	6.73311	7.233908	1.255203	9.080023	2.32E-08	47	66.52	66.5221	0.00
	15	1.65E+03	5.73E+03	61.66766667	1.148358	3.69E-08	0.00150751	2.485388	2.635824	6.551044	8.630811	1.073142	9.262084	2.45E-06	47	66.52	66.5221	0.00
	16	6.11E+02	2.81E+03	64.08733333	1.148358	2.16E-07	0.00372038	2.272919	2.806934	6.379934	10.45742	0.902055	9.43317	1.44E-05	47	66.52	66.52212	0.00
	17	4.40E+02	2.09E+03	66.52933333	1.148358	3.93E-07	0.005116181	2.253072	2.824059	6.362808	10.67883	0.884954	9.450272	2.62E-05	47	66.52	66.52213	0.00
	18	3.14E+02	1.54E+03	68.88333333	1.148358	7.33E-07	7.10E-03	2.230511	2.843781	6.343086	10.94442	0.865277	9.469949	4.87E-05	47	66.52	66.52214	0.00
	19	2.45E+02	1.23E+03	71.05633333	1.148358	1.15E-06	0.009038896	2.218308	2.854564	6.332303	11.09436	0.854549	9.480677	7.65E-05	47	66.52	66.52217	0.00
	20	1.81E+02	9.33E+02	72.99466667	1.148358	2.02E-06	0.012146143	2.199284	2.871539	6.315329	11.33776	0.837691	9.497535	0.000134	47	66.52	66.52223	0.00
	21	1.47E+02	7.73E+02	74.66233333	1.148358	2.96E-06	0.014860417	2.188136	2.88158	6.305287	11.48556	0.827774	9.507452	0.000197	47	66.52	66.52229	0.00
	22	1.22E+02	6.52E+02	76.059	1.148358	4.16E-06	0.017798417	2.178885	2.889965	6.296902	11.61086	0.81955	9.515676	0.000277	47	66.52	66.52237	0.00
	23	9.90E+01	5.39E+02	77.17833333	1.148358	6.20E-06	0.021874071	2.166298	2.901454	6.285414	11.78587	0.808332	9.526894	0.000412	47	66.52	66.52251	0.00
	24	8.26E+01	4.58E+02	77.991	1.148358	8.73E-06	0.026087348	2.155429	2.911448	6.275419	11.94049	0.798673	9.536552	0.00058	47	66.52	66.52267	0.00
	25	7.34E+01	4.10E+02	78.50433333	1.148358	1.09E-05	0.029312561	2.150321	2.916169	6.270698	12.0126	0.794248	9.540978	0.000728	47	66.52	66.52282	0.00
	26	6.51E+01	3.67E+02	78.72533333	1.148358	1.38E-05	0.032923039	2.144627	2.921449	6.265419	12.09344	0.789344	9.545882	0.000916	47	66.52	66.52301	0.00
	27	5.77E+01	3.29E+02	78.67233333	1.148358	1.75E-05	0.037067996	2.138121	2.927506	6.259361	12.18641	0.783778	9.551447	0.001162	47	66.52	66.52326	0.00
	28	5.15E+01	2.97E+02	78.33566667	1.148358	2.19E-05	0.041392926	2.131362	2.933825	6.253042	12.28357	0.778046	9.55718	0.001455	47	66.52	66.52355	0.00
	29	4.71E+01	2.74E+02	77.75866667	1.148358	2.62E-05	0.045138418	2.125898	2.938953	6.247914	12.36175	0.773494	9.561732	0.001743	47	66.52	66.52384	0.00
	30	4.48E+01	2.61E+02	76.99033333	1.148358	2.92E-05	0.047416486	2.123728	2.940994	6.245873	12.39017	0.771852	9.563374	0.001943	47	66.52	66.52404	0.00
	31	4.31E+01	2.52E+02	76.01566667	1.148358	3.19E-05	0.049260725	2.121947	2.942673	6.244195	12.41305	0.770535	9.564691	0.002124	47	66.52	66.52422	0.00
	32	4.18E+01	2.45E+02	74.882	1.148358	3.44E-05	0.050775258	2.120458	2.944076	6.242791	12.4317	0.769465	9.565761	0.00229	47	66.52	66.52438	0.00
	33	4.09E+01	2.40E+02	73.60566667	1.148358	3.65E-05	0.051835503	2.119385	2.94509	6.241778	12.44458	0.768728	9.566498	0.002428	47	66.52	66.52452	0.00
	34	4.04E+01	2.37E+02	72.21233333	1.148358	3.81E-05	0.05245602	2.118716	2.945721	6.241147	12.4519	0.76831	9.566916	0.002535	47	66.52	66.52463	0.00
	35	4.05E+01	2.38E+02	70.718	1.148358	3.87E-05	0.052309543	2.118772	2.945669	6.241199	12.44962	0.76844	9.566786	0.002574	47	66.52	66.52467	0.00
	36	4.07E+01	2.39E+02	69.19933333	1.148358	3.92E-05	0.05209795	2.118886	2.945561	6.241306	12.4465	0.768618	9.566608	0.002609	47	66.52	66.5247	0.00
	37	4.10E+01	2.41E+02	67.639	1.148358	3.95E-05	0.051698753	2.119176	2.945287	6.24158	12.44103	0.768931	9.566295	0.002629	47	66.52	66.52472	0.00
	38	4.17E+01	2.45E+02	66.023	1.148358	3.91E-05	0.050787426	2.119957	2.944549	6.242318	12.42919	0.769609	9.565617	0.002599	47	66.52	66.52469	0.00
EOC	39	4.27E+01	2.50E+02	64.38866667	1.148358	3.83E-05	0.049633332	2.120974	2.94359	6.243277	12.41434	0.770461	9.564765	0.002545	47	66.52	66.52464	0.00

Figure 51 - Excel extract balancing combustion equation and calculation dissociated molar masses for each species at 6000rpm.

	Crank Angle	kCO2	kH2O	Pressure	ϕ	Guessed n5/nt	n5/nt.P ^(1/2)	n1/n3	n3	n1	n2/n4	n4	n2	n5	n6	nt	nt	error
				bar														
SOC	-6	3.16E+24	2.29E+22	37.20666667	1.140882	5.00E-40	1.36E-19	4.30E+05	2.12E-05	9.127036	3125.718	0.003284	10.26466	-1.75937	47	64.635622	-3.52E+39	############
	-5	1.38E+09	9.55E+08	37.93433333	1.140882	4.25E-19	4.0148E-09	5.5276373	1.3982176	7.72884	3.834617	2.123837	8.144103	-4.4E-16	47	66.394997	-1045.142	-1111.53700
	-4	1.71E+05	4.38E+05	38.651	1.140882	7.64E-12	1.71885E-05	2.9359988	2.318867	6.808191	7.533945	1.203188	9.064752	5.08E-10	47	66.394997	66.395165	0.00017
	-3	4.52E+04	1.17E+05	39.44466667	1.140882	1.06E-10	6.46945E-05	2.9254071	2.3251238	6.801934	7.578556	1.196931	9.071009	7.05E-09	47	66.394997	66.394998	0.00000
	-2	1.17E+05	3.02E+05	39.969	1.140882	1.56E-11	2.49775E-05	2.9342551	2.3198947	6.807163	7.541241	1.20216	9.06578	1.04E-09	47	66.394997	66.395049	0.00005
	-1	1.20E+05	3.10E+05	40.825	1.140882	1.45E-11	2.43639E-05	2.9343923	2.3198138	6.807244	7.540666	1.202241	9.065699	9.65E-10	47	66.394997	66.394953	-0.00004
	0	9.61E+04	2.47E+05	41.94766667	1.140882	2.22E-11	3.05138E-05	2.93E+00	2.32E+00	6.806433	7.546432	1.20143	9.06651	1.47E-09	47	66.395	66.395	-0.00001
	1	7.38E+04	1.90E+05	43.19666667	1.140882	3.65E-11	3.97023E-05	2.9309663	2.3218356	6.805222	7.555054	1.200219	9.067721	2.42E-09	47	66.394997	66.40	0.00001
	2	6.03E+04	1.56E+05	44.53833333	1.140882	5.29E-11	4.85447E-05	2.9289961	2.3229999	6.804058	7.56336	1.199055	9.068885	3.51E-09	47	66.394997	66.394998	0.00000
	3	5.97E+04	1.54E+05	46.05033333	1.140882	5.23E-11	4.90942E-05	2.9288738	2.3230722	6.803985	7.563877	1.198983	9.068957	3.48E-09	47	66.394997	66.394989	-0.00001
	4	4.58E+04	1.19E+05	48.02266667	1.140882	8.50E-11	6.38778E-05	2.9255883	2.3250165	6.802041	7.577787	1.197038	9.070901	5.64E-09	47	66.394997	66.395003	0.00001
	5	2.42E+04	6.34E+04	50.30433333	1.140882	2.88E-10	0.000120296	2.9131426	2.3324112	6.794646	7.631105	1.189644	9.078296	1.91E-08	47	66.394997	66.394998	0.00000
	6	1.15E+04	3.08E+04	52.65966667	1.140882	1.21E-09	0.000251904	2.8846737	2.3495043	6.777553	7.756926	1.172551	9.095389	8E-08	47	66.394997	66.394997	0.00000
	7	7.22E+02	3.28E+03	55.30533333	1.140882	2.04E-07	0.003354828	2.4220449	2.6671356	6.459922	11.01004	0.854946	9.412993	1.35E-05	47	66.395011	66.395016	0.00000
	8	5.78E+02	2.67E+03	58.17433333	1.140882	2.99E-07	0.004171748	2.4103781	2.6762597	6.450798	11.13941	0.845835	9.422105	1.99E-05	47	66.395017	66.395022	0.00000
	9	3.81E+02	1.84E+03	61.29933333	1.140882	6.37253E-07	0.006250052	2.3817391	2.6989242	6.428133	11.47297	0.823215	9.444724	4.23E-05	47	66.39504	66.395044	0.00000
	10	2.88E+02	1.42E+03	64.37633333	1.140882	1.04924E-06	0.008218662	2.3650947	2.7122736	6.414784	11.67771	0.809921	9.458019	6.97E-05	47	66.395067	66.395068	0.00000
	11	2.20E+02	1.11E+03	67.41633333	1.140882	1.69048E-06	0.010675476	2.3500367	2.7244649	6.402593	11.87009	0.797814	9.470125	0.000112	47	66.39511	66.395111	0.00000
	12	1.59E+02	8.28E+02	70.40533333	1.140882	3.06147E-06	0.014681411	2.3285575	2.7420459	6.385012	12.15702	0.780415	9.487524	0.000203	47	66.395201	66.395201	0.00000
	13	1.28E+02	6.79E+02	73.15366667	1.140882	4.48725E-06	0.018117914	2.3178777	2.7508722	6.376185	12.30426	0.771778	9.496161	0.000298	47	66.395295	66.395296	0.00000
	14	9.85E+01	5.36E+02	75.623	1.140882	7.22282E-06	0.023371168	2.3019123	2.7641733	6.362884	12.53109	0.758841	9.509099	0.00048	47	66.395477	66.395477	0.00000
	15	7.94E+01	4.41E+02	77.727	1.140882	1.07075E-05	0.028848955	2.2891694	2.7748822	6.352175	12.71629	0.748595	9.519345	0.000711	47	66.395708	66.395708	0.00000
	16	6.84E+01	3.84E+02	79.409	1.140882	1.40101E-05	0.033354624	2.2821553	2.7808122	6.346245	12.81765	0.743103	9.524837	0.00093	47	66.395928	66.395928	0.00000
	17	5.83E+01	3.32E+02	80.75466667	1.140882	1.88489E-05	0.039014555	2.2733954	2.7882539	6.338804	12.94525	0.736304	9.531636	0.001251	47	66.396249	66.396249	0.00000
	18	4.85E+01	2.81E+02	81.74066667	1.140882	2.66165E-05	0.046643901	2.2616696	2.7982778	6.32878	13.11766	0.727312	9.540628	0.001767	47	66.396765	66.396765	0.00000
	19	4.40E+01	2.57E+02	82.297	1.140882	3.19897E-05	0.051309405	2.2569137	2.8023639	6.324694	13.18343	0.723939	9.544001	0.002124	47	66.397121	66.397121	0.00000
	20	4.06E+01	2.38E+02	82.483	1.140882	3.73756E-05	0.055523413	2.2529603	2.8057698	6.321288	13.23634	0.721248	9.546691	0.002482	47	66.397479	66.397479	0.00000
	21	3.76E+01	2.22E+02	82.355	1.140882	4.34932E-05	0.059848811	2.2488593	2.8093114	6.317746	13.29042	0.718519	9.549421	0.002888	47	66.397885	66.397885	0.00000
	22	3.52E+01	2.09E+02	81.91733333	1.140882	4.96068E-05	0.063746826	2.2451158	2.8125522	6.314505	13.33889	0.71609	9.55185	0.003294	47	66.398291	66.398291	0.00000
	23	3.29E+01	1.97E+02	81.22633333	1.140882	5.70788E-05	0.068090372	2.2408921	2.8162177	6.31084	13.39262	0.713417	9.554523	0.00379	47	66.398787	66.398787	0.00000
	24	3.14E+01	1.89E+02	80.214	1.140882	6.31248E-05	0.071158249	2.2378348	2.8188769	6.308181	13.43016	0.711561	9.556379	0.004191	47	66.399189	66.399189	0.00000
	25	3.07E+01	1.85E+02	78.959	1.140882	6.7173E-05	0.072827972	2.2360879	2.8203985	6.306659	13.45015	0.710577	9.557363	0.00446	47	66.399458	66.399458	0.00000
	26	3.04E+01	1.83E+02	77.53666667	1.140882	6.99074E-05	0.073623254	2.2351632	2.8212046	6.305853	13.45916	0.710134	9.557806	0.004642	47	66.399639	66.399639	0.00000
	27	3.01E+01	1.82E+02	75.97333333	1.140882	7.2364E-05	0.074146701	2.2344785	2.8218019	6.305256	13.46468	0.709863	9.558077	0.004805	47	66.399802	66.399802	0.00000
	28	3.07E+01	1.85E+02	74.22733333	1.140882	7.14105E-05	0.072805278	2.2356112	2.820814	6.306244	13.44715	0.710724	9.557216	0.004742	47	66.399739	66.399739	0.00000
	29	3.18E+01	1.91E+02	72.383	1.140882	6.82591E-05	0.070290811	2.2379	2.8188201	6.308237	13.4152	0.712299	9.55564	0.004532	47	66.39953	66.39953	0.00000
EOC	30	3.33E+01	1.99E+02	70.507	1.140882	6.43731E-05	0.067370289	2.2405955	2.8164754	6.310582	13.37829	0.714128	9.553812	0.004274	47	66.399272	66.399272	0.00000

Figure 52 - Excel extract balancing combustion equation and calculation dissociated molar masses for each species at 6500rpm.

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