

University of Wales Trinity St David

School of Engineering

The Utilisation of a Two Zone NO<sub>x</sub> Model in the  
Measurement of Nitrogen Oxides and an  
Investigation into Two Zone Modelling Accuracy &  
NO<sub>x</sub> Reduction Methods



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## *Declaration of Authenticity*

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:

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## List of Abbreviations

NO<sub>x</sub> – Nitrogen Oxides

TZNM – Two Zone NO<sub>x</sub> Model/Models/Modelling

NEDC – New European Drive Cycle

CO<sub>2</sub> – Carbon Dioxide

CO – Carbon Monoxide

H<sub>2</sub>O – Water / Water Vapour

O<sub>2</sub> – Oxygen

N<sub>2</sub> – Nitrogen

EUDC – Extra Urban Drive Cycle

WLTP - World Standardised Light-Vehicle Testing Procedure

RDE – Random Driving Emissions

PEMS – Portable Emissions Measuring System

EGR – Exhaust Gas Recirculation

T<sub>B</sub> – Burned Zone Temperature

T<sub>UB</sub> – Unburned Zone Temperature

SOC – Start of Combustion

EOC – End of Combustion

TDC – Top Dead Centre (*B or A ahead refers to before or after*)

BDC – Bottom Dead Centre (*B or A ahead refers to before or after*)

C<sub>p</sub> – Specific Heat at Constant Pressure

C<sub>v</sub> – Specific Heat at Constant Volume

PPEC – Partial Pressure Equilibrium Constants

PPM – Parts per Million

HCCI – Homogenous Charge Compression Ignition

## 0.0 Abstract

This report contains an overview of the work carried out in constructing a Two Zone NO<sub>x</sub> model. Research into NO<sub>x</sub> creation, dangers and legislation is carried out. The overall construction of the model is covered with any pitfalls discussed and any supporting literature used to support the point. The models results are analysed with each model discrepancy discussed further. NO<sub>x</sub> formation and model accuracy is followed by a short section covering methods of reducing NO<sub>x</sub> for future legislation. The appendix shows all investigative work carried out that is not shown in the report.

## 1.0 Aims & Objectives of the Project

The overall aim of this project is to develop a Two Zone NO<sub>x</sub> Model (TZNM) that provides accurate results, but to also understand the limitations and pitfalls of the Two Zone Model.

TZNM are a method of measuring NO<sub>x</sub> and by carrying out this investigation it will be possible to conclude whether the practice of using TZNM as a method of NO<sub>x</sub> calibration is viable. Through discussing each major step of model creation the issues will be found at source and methods of mitigating them can be sought. Literature will be used to understand what work has been carried out and used this to assist this investigation.

To fully understand the importance of reducing NO<sub>x</sub> research will be carried out, discussing the types of NO<sub>x</sub>, the hazards they pose as well as legislation that exists to reduce NO<sub>x</sub>. Upon completing the model methods of reducing NO<sub>x</sub> will be discussed as well as the feasibility of the methods.

The project will be completed utilising primary data, Microsoft Excel, Matlab as well as the laws of thermodynamics.

## 2.0 Project Planning

To ensure the success of the project a clear plan must be created. With short, medium and long term goals created the progress can be tracked which will allow any necessary adaptations to be made. The creation of a clear plan will also ensure any problems can be easily overcome by realigning priorities and task plans.

### 2.1 Goals

Short Term –

- Constant weekly progress
- Weekly meeting with appropriate mentor
- At least an hour a day / full day a week devoted to investigation
- Ongoing research to cover new developments

Medium Term -

- Methodical progress on reports
- Completion of one section of model factor weekly

Long Term –

- Creation of an accurate model
- Utilisation of Matlab where appropriate
- Clear understanding of model issues
- Clear understanding of methods of NO<sub>x</sub> reduction
- Investigate methods of NO<sub>x</sub> reduction to meet legislation

### 2.2 Deadlines

Proposal – October 14<sup>th</sup> 2016

Technical Poster Seminar 1 – 10<sup>th</sup> November 2016

Technical Presentation 1 – 12<sup>th</sup> December 2016

Technical Poster Seminar 2 – 15<sup>th</sup> March 2017

Final Report Submission – 25<sup>th</sup> April 2017

Technical Presentation 2 – 4<sup>th</sup> May 2017

These deadline are fixed and cannot be missed and thus form bottlenecks by which time certain targets must have been met.

## 2.3 Gantt Chart

With deadlines and goals understood a Gantt chart could be created to act as a visual task tracker. The Gantt could be utilised to plan around issues and ensure progress was being made at a necessary pace.

### Two Zone NOx Model

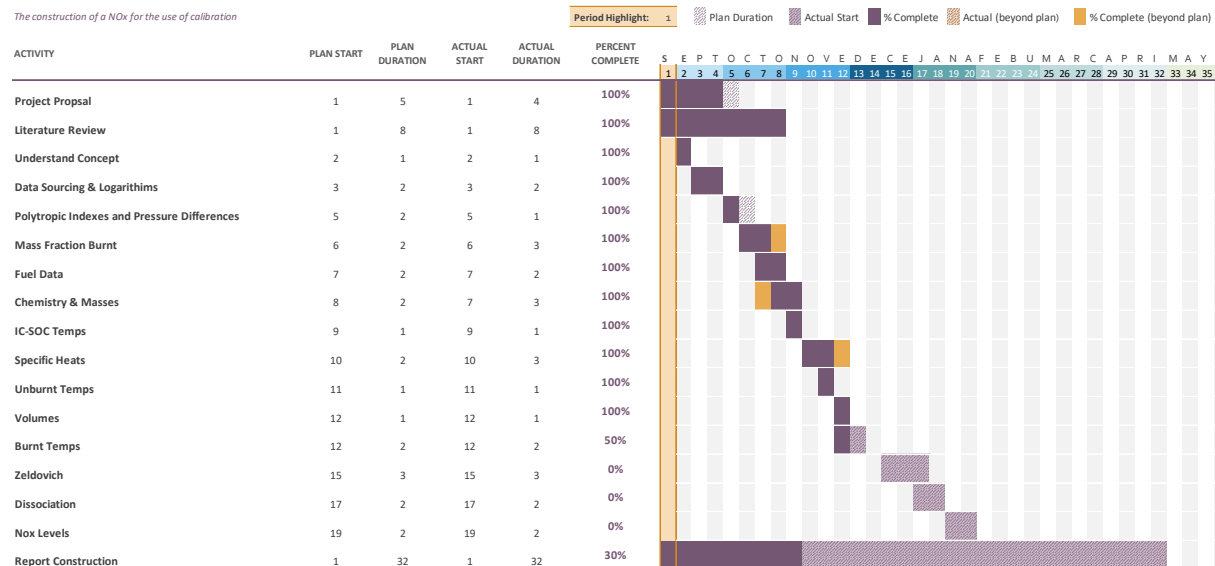


Figure 1 - Gantt Chart

Figure 1 shows the Gantt chart as it stood at period 13 (first week of December)

## 2.4 Planning Conclusion and Project Initiation

With the project planned and a method ensuring fluid progress finalised the project could be started. The first step was to investigate the dangers of NOx and why they need to be decreased, the legislation surrounding reduction, issues the industry faces. In addition to this a literature review would be carried out to understand what work had been done on TZNM. This would provide some insight and invaluable understanding of any potential issues before the struck.

## *Part 1 – Literature Review*

### 3.0 Relevance of the Project & Emissions Literature Review

The measurement of vehicle emissions has become a major area of interest in recent years. Since the introduction of the New European Drive Cycle (NEDC) by the EU in 1970 car manufacturers have been responsible for ensuring their vehicles meet emissions legislation.

#### 3.1 Emissions

Emissions became a major concern as the understanding of the damage they can cause grew in the second half of the 20<sup>th</sup> century. The five main emissions from the internal combustion engine are –

- Carbon Dioxide (CO<sub>2</sub>)
- Carbon Monoxide (CO)
- Water Vapour (H<sub>2</sub>O)
- Nitrogen Oxides (NO<sub>x</sub>)
- Soot

Each of the emissions has different adverse climatic, environmental and potential health impacts.

NO<sub>x</sub> refers to oxides of nitrogen. The different types of NO<sub>x</sub> are described by Charles Baukal 'NO<sub>x</sub> generally include nitrogen monoxide, also known as nitric oxide (NO), and nitrogen dioxide (NO<sub>2</sub>). They may also include nitrous oxide (N<sub>2</sub>O), also known as laughing gas, as well as other less common combinations of nitrogen and oxygen, such as nitrogen tetroxide (N<sub>2</sub>O<sub>4</sub>) and nitrogen pentoxide (N<sub>2</sub>O<sub>5</sub>).' (Baukal, 2005).

NO<sub>x</sub> are particularly dangerous in the way that they destroy the earth's protective ozone and creates it causing health impacts.

Nitrogen Oxides high up in the atmosphere can destroy the Ozone layer which protects the earth from the sun's ultra violet radiation. The US Environmental describes how NO<sub>x</sub> creates ozone 'NO<sub>2</sub> reacts in the presence of air and ultraviolet light (UV) in sunlight to form ozone and nitric oxide (NO). The NO then reacts with free radicals in the atmosphere, which are also created by the UV acting on volatile organic compounds (VOC). The free radicals then recycle NO to NO<sub>2</sub>.' (United States Environmental Protection Agency, 2010).

In the lower atmosphere NO<sub>x</sub> creates ozone which has adverse effects on the respiratory system. NO<sub>x</sub> can react with ammonia to create nitric acid vapour causing emphysema and bronchitis. NO<sub>x</sub> aggravates asthma and also contributes to acid rain, water quality deterioration and well as causing visibility problems. The great London fog (smog) of 1952 which killed around 4000 people was caused partly by NO<sub>x</sub>. This led to the creation of Clean Air Acts in 1952.

NO<sub>x</sub> is produced in engines at temperatures over 1500°C. With two billion vehicles projected to be on the roads by 2020 (Sperling, 2009) the importance of reducing NO<sub>x</sub> emissions of each individual vehicle is understandable. Any slight gain on each would accumulate into a huge reduction worldwide.

| Characteristics | Unit | Phase 1 (ECE15) | Phase 2 (EUDC) |
|-----------------|------|-----------------|----------------|
| Distance        | Km   | 4x1.013 = 4.052 | 6.955          |
| Duration        | Sec  | 4x195 = 780     | 400            |
| Average Speed   | Km/h | 18.7 inc idling | 62.6           |
| Maximum Speed   | Km/h | 50              | 120            |

Figure 2 - NEDC Drive Cycle Parameters

### 3.2 Emissions Legislation

The NEDC was introduced by the European Union in 1970 and has gradually become more stringent. Under the current regulations cars are tested in a drive cycle under identical conditions as laid out in Figure 2.

The drive cycle is made up of 4 consecutive ECE cycles and then followed by an Extra Urban Drive Cycle (EUDC) which is designed to represent more aggressive and high speed driving. The drive cycle is graphically shown in Figure 3, where the 4 ECE cycles and one

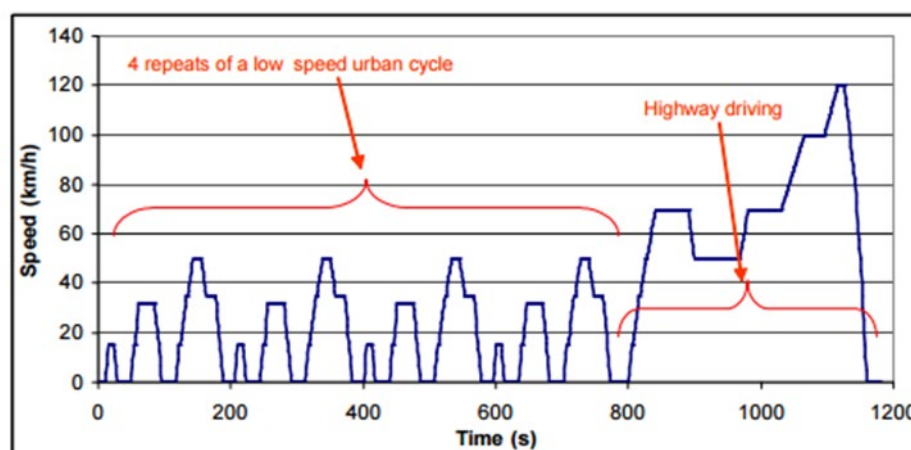


Figure 3 - NEDC Drive Cycle

EUDC can be seen. During the Euro 4 phase between 2000 and 2014 on-road emissions dropped by 40%, however despite this in 2011 road vehicles were responsible for 40% of worldwide NO<sub>x</sub> emissions (Department for Transport, 2016).

Figure X shows the legislative targets for emissions from the original NEDC in 1970 to Euro 4 from 2004. The data is sourced from (Elisabeta, 2005).

Despite the clear improvement in automotive emission levels there have been criticisms of the NEDC. Critics state that the test does not represent realistic driving condition that the car would experience during its everyday use. The test is carried out at low loads where car manufacturers map their vehicles to run efficiently, and once the car reaches higher load sites the map is changed to improve performance at the cost of efficiency. This has become known as cycle beating. The gear changes are also stipulated by the test cycle and the car is short shifted keeping it within the low load sites because the test was conceived when cars were smaller and less powerful (Barlow, 2009). Figure 6 shows a more realistic drive

| Class           | Year | CO<br>[g/km] | HC<br>[g/km] | NO <sub>x</sub><br>[g/km] | HC+NO <sub>x</sub><br>[g/km] | Particles<br>[g/km] |
|-----------------|------|--------------|--------------|---------------------------|------------------------------|---------------------|
| <b>Gasoline</b> |      |              |              |                           |                              |                     |
| FAV 1           | 1987 | 2.10         | 0.25         | 0.62                      | -                            | -                   |
| Euro 1          | 1991 | 3.16         | -            | -                         | 1.13                         | -                   |
| Euro 2          | 1994 | 2.20         | -            | -                         | 0.50                         | -                   |
| Euro 3          | 1998 | 2.30         | 0.20         | 0.15                      | -                            | -                   |
| Euro 4          | 2006 | 1.00         | 0.10         | 0.08                      | -                            | -                   |
| <b>Diesel</b>   |      |              |              |                           |                              |                     |
| FAV 1           | 1987 | 2.10         | 0.25         | 0.62                      | -                            | 0.370               |
| FAV 2           | 1998 | 2.10         | 0.25         | 0.62                      | -                            | 0.124               |
| Euro 2          | 1994 | 1.00         | -            | -                         | 0.70                         | 0.080               |
| Euro 3          | 1998 | 0.64         | -            | 0.50                      | 0.56                         | 0.050               |
| Euro 4          | 2006 | 0.50         | -            | 0.25                      | 0.30                         | 0.025               |
| Euro 5          | 2009 | -            | 0.10         | 0.08                      | -                            | 0.025               |

Figure 4 - Emissions Legislations

cycle which better represents the driving pattern a vehicle follows when driven on the road.

The differences between Figure 3 and Figure 6 are clear.

These criticisms have been supported by independent investigations. A 'Which?' investigation tested various vehicles on the road in a manner that reflected every day driving. The results revealed that found 95% of diesel and 10% of petrol cars exceeded the Euro 6

| rrr w % (Residual gas ratio by internal and external EGR) |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|-----------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|                                                           | 800  | 1000 | 1250 | 1500 | 1750 | 2000 | 2250 | 2500 | 3000 | 3500 | 4000 | 4500 | 5000 | 5500 | 6000 |
| FL                                                        |      | 0.5  | 0.2  | 0.1  | 0.4  | 0.8  | 0.8  | 1.0  | 1.5  | 1.7  | 2.2  | 2.7  | 3.1  | 3.3  | 3.6  |
| 200                                                       |      |      |      |      |      | 0.8  | 0.8  | 1.0  | 1.4  | 1.8  |      |      |      |      | 4.1  |
| 190                                                       |      |      |      |      |      | 0.8  | 0.9  | 1.1  | 1.5  | 1.8  |      |      |      |      |      |
| 180                                                       |      |      |      |      | 0.4  | 0.9  | 0.9  | 1.1  | 1.5  | 1.9  | 2.2  |      |      |      |      |
| 170                                                       |      |      |      | 0.1  | 0.2  | 1.0  | 1.0  | 1.2  | 1.6  | 2.0  | 2.2  | 2.7  |      |      |      |
| 160                                                       |      |      |      | 0.2  | 0.2  | 1.1  | 1.1  | 1.3  | 1.7  | 2.0  | 2.2  | 2.6  | 3.0  |      |      |
| 150                                                       |      |      |      | 0.2  | 0.2  | 1.2  | 1.2  | 1.3  | 1.8  | 2.2  | 2.3  | 2.6  | 3.1  | 3.3  |      |
| 140                                                       |      |      | 0.2  | 0.2  | 0.3  | 1.0  | 1.2  | 1.3  | 2.1  | 2.4  | 2.6  | 2.7  | 3.1  | 3.4  | 3.6  |
| 130                                                       |      |      | 0.3  | 0.3  | 0.5  | 1.1  | 1.2  | 1.5  | 2.3  | 2.5  | 2.7  | 2.9  | 3.2  | 3.4  | 3.7  |
| 120                                                       |      |      | 0.3  | 0.5  | 0.8  | 1.2  | 1.4  | 1.7  | 2.5  | 2.7  | 2.9  | 3.0  | 3.2  | 3.5  | 3.8  |
| 110                                                       |      | 0.6  | 0.5  | 0.8  | 1.0  | 1.3  | 1.5  | 1.9  | 2.6  | 3.0  | 3.1  | 3.1  | 3.2  | 3.7  | 3.9  |
| 100                                                       |      | 1.1  | 0.9  | 1.1  | 1.4  | 1.6  | 1.8  | 2.1  | 2.8  | 3.4  | 3.4  | 3.3  | 3.3  | 3.7  | 4.1  |
| 90                                                        |      | 1.8  | 1.5  | 1.8  | 2.1  | 2.5  | 2.5  | 2.8  | 3.4  | 3.8  | 3.6  | 3.6  | 3.4  | 3.7  | 4.2  |
| 80                                                        |      | 3.5  | 3.0  | 3.2  | 3.3  | 3.2  | 3.5  | 4.7  | 4.9  | 4.6  | 4.3  | 4.1  | 3.6  | 3.8  | 4.4  |
| 70                                                        |      | 5.7  | 5.4  | 6.0  | 6.0  | 5.7  | 6.5  | 6.9  | 6.7  | 6.2  | 5.6  | 5.4  | 4.2  | 4.2  | 4.6  |
| 60                                                        |      | 9.7  | 9.9  | 10.0 | 9.9  | 10.3 | 10.4 | 9.4  | 9.0  | 8.5  | 8.0  | 7.6  | 5.5  | 4.6  | 5.0  |
| 50                                                        |      | 14.1 | 14.7 | 14.7 | 14.4 | 14.6 | 14.2 | 12.9 | 11.5 | 11.1 | 10.3 | 9.6  | 7.3  | 5.1  | 5.4  |
| 40                                                        | 18.6 | 18.1 | 18.4 | 18.6 | 19.3 | 19.5 | 17.0 | 15.2 | 15.1 | 14.3 | 12.7 | 11.2 | 8.9  | 5.7  | 5.9  |
| 30                                                        | 19.9 | 19.3 | 18.6 | 20.7 | 21.7 | 21.3 | 18.6 | 16.5 | 17.7 | 17.1 | 14.2 | 12.5 | 10.6 | 6.7  | 6.7  |
| 20                                                        | 20.6 | 19.0 | 19.0 | 20.1 | 19.8 | 19.5 | 18.5 | 17.4 | 18.0 | 17.2 | 15.5 | 13.1 | 11.4 | 8.6  | 8.3  |
| 10                                                        | 25.6 | 24.7 | 23.4 | 23.1 | 21.9 | 21.3 | 21.4 | 21.8 | 19.9 | 17.9 | 16.5 | 14.5 | 13.3 | 11.7 | 10.8 |

Figure 5 - Ford EGR Data

limit of 0.06g/km (Which?, 2016). Two German research institutes found that there has been no real NO<sub>x</sub> improvement on diesel engines in the past 13 years.

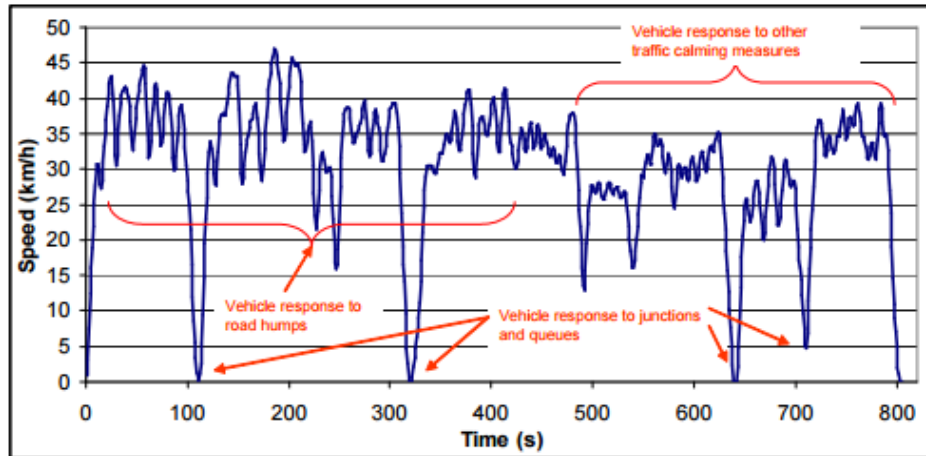


Figure 6 - A Realistic Drive Cycle

Figure 5 shows how the EGR system is used to reduce NO<sub>x</sub>. The higher EGR values are used at lower loads and lower engine speeds. Due to the NEDC only using low loads and low engine speed it ensures the NO<sub>x</sub> emissions pass the drive cycle. At higher loads where a vehicle is usually driven the EGR is reduced. This is a clear example of cycle beating. Steps have been taken to change this, with extra media focus being drawn to such statistics since the Volkswagen emissions scandal. The new drive cycles will ensure car manufacturers cannot map their vehicles to pass drive cycles but perform differently once driven on the road. In addition to the more stringent testing methods, steps were taken to introduce a worldwide standardised test. This has resulted in the creation of the World Standardised Light-Vehicle Testing Procedure (WLTP).

The WLTP has been developed from data collated from all over the world and a variety of highways meaning it is a much more representative test. The German Association of the Automotive Industry describes how the 'WLTP test procedure is much more dynamic since it has many more acceleration and braking cycles than its predecessor. In addition to the actual driving profile, the measurement procedure has also been standardized globally and tailored to current automotive engineering' (Verband der Automobilindustrie, 2016). A comparison of the two tests can be seen in Table 1.

In addition to the WLTP, which forms the legal basis of the Euro exhaust emissions, the Random Driving Emissions (RDE) test will give testing authorities the right to take any vehicle on the road with a portable emissions measuring device (PEMS) and drive the car in

any manner and any setting (May, 2014). The RDE ensures that all driving conditions could make up the basis of the testing. The belief is that this will force car manufacturers to make vehicles efficient throughout their driving range and prevent cycle beating.

The WLTP and RDE are expected to be introduced in September 2017 with a conformity factor, which will be progressively reduced, allowing manufacturer's time to adjust.

The pressure to reduce NOx does not come from the NEDC alone. The Clean Air Acts in London is due to be updated within the next month. The London major Sadiq Khan hopes to introduce a system whereby the highest NOx emitters have to pay £12.50 each day when within the M25 (Crerar, 2017). This follows the worldwide trend on cities clamping down on NOx following pressure from health charities. This pressure translates to car companies with sales likely to reduce if a vehicle does not meet the levels imposed by their local city.

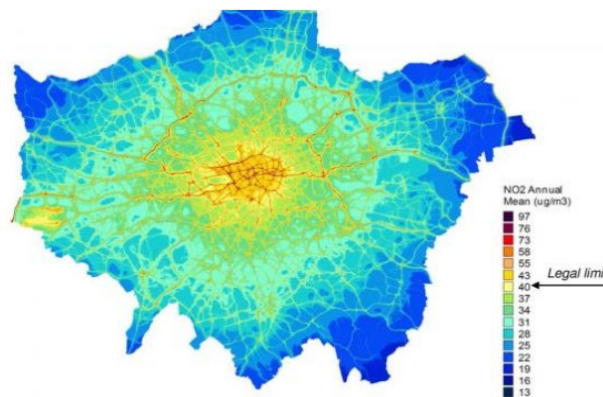


Figure 7 - Concentrations of annual average NO2 in 2013 (Source: LAEI 2013)

### 3.3 Project Relevance Conclusion

Having understood the impact of NOx on the environment, the dangers of NOx to human health, as well as the future stringent testing, it is clear how important accurate emissions testing is. Accurate testing ensures manufacturers can design and calibrate engines to meet the new regulations.

It is also clear how important the WLTP is in ensuring genuine and authentic emissions improvement. It will create a more representative testing method and the world wide implementation will ensure a world-wide improvement.

|                            | NEDC  | WLTP |
|----------------------------|-------|------|
| Start Temperature          | Cold  | Cold |
| Cycle Time (minutes)       | 20    | 30   |
| Stationary Time Proportion | 25%   | 13%  |
| Cycle Length (km)          | 23.25 | 11   |
| Average Speed (km/h)       | 34    | 46.5 |
| Max Speed (km/h)           | 120   | 131  |
| Average Drive Power (kW)   | 4     | 7.5  |
| Max Drive Power (kW)       | 34    | 47   |

Table 1 - WLTP v NEDC Data

## 4.0 Two Zone Modelling Introduction & Literature Review

The next stage was to investigate the model method and research previous work on the area. An improved understanding of the TZNM method will help understand any potential issues.

### 4.1 Two Zone Modelling

Two Zone Modelling is a method of analysing various environments. It is used throughout the engineering world, from fire equipment testing to combustion modelling. It allows a simplification of the problem to reduce the complexity and thus time/computing power required whilst still allowing a high degree of accuracy.

TZNM assumes that the combustion of fuel in the combustion chamber has two distinct separate zones. The burned zone has been ignited by the combustion and has burnt whereas the unburned zone is yet to be ignited and is not yet burnt. This can be seen in Figure 8 which shows the combustion chamber and piston with the burned zone travelling out from the spark plug (red zone) and the unburned zone which has not yet been ignited (blue zone).

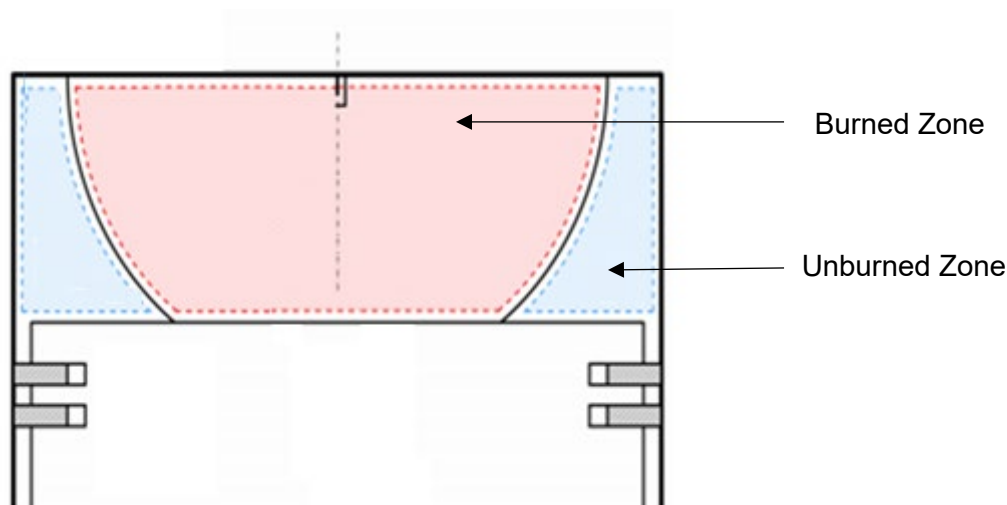


*Figure 8 - Two Zone Model Schematic*

To fully understand the accuracy and potential flaws with the two zone modelling method various literature was consulted. There is a large amount of literature and technical papers on TZNM.

### 4.2 Literature Review

A Two Zone NO<sub>x</sub> model was created by the Division of Combustion Engines at Lund University. Carl Wilhelmsson describes the key criteria of his Two-Zone NO<sub>x</sub> model –

- The ideal gas law is valid for each zone separately and for the complete combustion chamber.
- The number of moles in the combustion chamber is not significantly changed by the combustion.
- The temperature of the unburned zone is assumed to vary according to an isentropic relationship.
- The heating value of the fuel is known.
- The combustion efficiency is 100%.
- NOx emissions mainly consist of nitrogen oxide, NO.

The TZNM created for the purposes of this investigation will follow many of the criteria laid out by Wilhelmsson making his paper particularly useful. During his discussion he states that – ‘Models are, naturally, rarely perfect. Assumptions which have to be made represent simplifications of the real world and will hence infer errors. How large errors can be tolerated varies depending on the purpose of the model. The errors reported for this model are considered as acceptable for control and embedded applications.’ Wilhelmsson continues to suggest potential improvements to improve the accuracy – ‘the model shall be modified so that it includes the use of EGR.’ For the purposes of this investigation Exhaust Gas Recirculation (EGR - deprives the combustion event of some of its oxygen by introducing cooled exhaust gas, which is lower in oxygen, into the intake system, thereby reducing the combustion temperature and lowering NOx production (Ciatti, 2008)) will be considered. The slight cooling impact of EGR has a significant impact on NOx production.

A final point taken from Wilhelmsson is that a TZNM gives sufficiently accurate results considering the coarse nature of the model and that comparing TZNM to more complex multi-zone models ‘is unfair considering the computation times needed to complete the different models’. (Wilhelmsson, A Physical Two-Zone NOx Model Intended for Embedded Implementation, 2009)

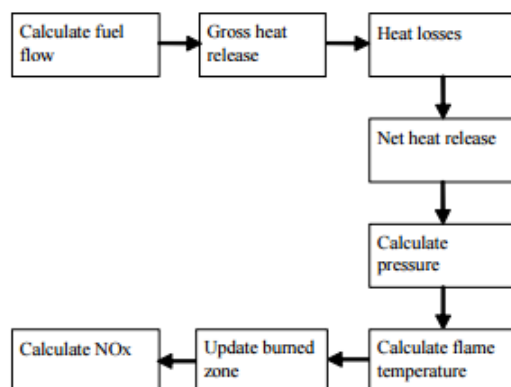
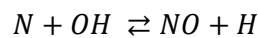
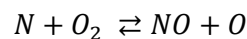
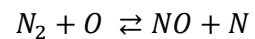


Figure 9 - Model Construction Flow Chart (Claes)

Various other investigations have been carried out including ones by Claes Ericson and Fabrizio Diotallevi. These are not as relevant because Claes's model focuses on the effect of after treatment systems on NO<sub>x</sub> production and Fabrizio's focuses on a diesel multi zone model. Claes once again stated that a TZNM is an effective method however his work is a continuation from a previous TZNM so this is to be expected. Claes's work did have an interesting flow chart which he followed to create the model which is relevant to this investigation and can be seen in Figure 9 (Ericson, 2006). Fabrizio's investigation is interesting because of a particular focus on the Zeldovich model which will be utilised for this model. He states 'the Zeldovich Mechanisms which seems accurate and precise enough to be used as a tool in the simulation of Diesel engines. The results show a good correlation with the experimental data in most of the analyzed cases' (Diotavelli, 2007).

## 5.0 The Zeldovich & Boltzmann Mechanism

Yakov Borisovich Zel'dovich was a Russian physicist who created the Zeldovich mechanism of disassociation. His work focused on the likelihood of a reaction based on the concentration of a gas. The following reaction kinetics to describe the disassociation of nitrogen and oxygen were proposed by Zeldovich in 1947 (American Meteorological Society, 2012). –



*Equation 1 - Zeldovich Reaction Kinetics*

Ludwig Boltzmann was an Austrian physicist who worked on the probability of molecules reacting and their kinetic energies. The Boltzmann function tells you the probability of a molecule having a kinetic energy equal or greater than an activation energy. It can be used with the concentration of Nitrogen and Oxygen to find the probability of dissociation as seen in Equation 1. Westenberg continued Zeldovich's work and proposed that by combining the Zeldovich, Boltzmann and Arrhenius functions you get Equation 2 (ANSYS, n.d.) which will be used in this investigation to calculate the rate of NO<sub>x</sub> production.

$$\frac{d[NO]}{dt} = 4.7 \times 10^{13} [N_2][O_2]^{\frac{1}{2}} e^{-\left(\frac{67837}{T}\right)}$$

*Equation 2 – Zeldovich – Boltzmann Function*

Figure 10 (Flagan, Pollutant Formation and Control in Combustion, 1988) shows how at 3000 degrees kelvin the probability of a reaction to make NO<sub>x</sub> is 100,000 times more likely than at 2000 degrees kelvin. This is because the activation energy required to start a reaction is too high and it cannot be met. This simple graphic provides a primary understanding of why NO<sub>x</sub> is produced at higher temperatures.

| Temperature (°K) | $e^{(-67837/T)}$       |
|------------------|------------------------|
| 2000             | $1.85 \times 10^{-15}$ |
| 3000             | $1.51 \times 10^{-10}$ |

*Figure 10 - Activation Energies*

## Part 2 – Model Construction

### 6.0 The Model

The base for model was two sets of primary data provided by Ford Motor Company for the Fox 1.0L GTDI engine. A basic combustion model was created for the Ford 1.6L EcoBoost as a means of comparing the performance and the associated benefits.

#### 6.1 Model Basis

##### 6.1.1 Fox 1.0L GTDI

The Fox engine is part of the EcoBoost family introduced by Ford to meet the increasingly stringent emissions test. The engines are designed to improve fuel efficiency by up to 30% and reduce greenhouse emissions by 15%. They claim that 'To an EcoBoost engine, every drop of fuel is precious. So precious that it reduces fuel consumption and makes a serious reduction in CO<sub>2</sub> emissions – to as low as 99g/km' (Ford, 2017).

The GTDI refers to the Gasoline Turbo Direct Injection. Turbo engines are considered more efficient because they use the otherwise wasted exhaust gases to power a compressor which forces air in to the cylinder and improves the volumetric efficiency of the engine.

##### 6.1.2 The Primary Data

The first part of the data, which a snapshot of can be seen in Figure 11, was cylinder pressure data over the three cylinders over 720°. The data was collected from a test engine on a dynamometer. Due to the data being over 720 degrees it includes all four strokes of the internal combustion engine – induction, compression, combustion and exhaust. The focus of the model will be on the combustion stroke which is where the NOx is produced.

| Crank Angle<br>(Degrees) | Volume<br>(cc) | Pressure (Bar) |            |            |
|--------------------------|----------------|----------------|------------|------------|
|                          |                | Cylinder 1     | Cylinder 2 | Cylinder 3 |
| -360                     | 39.27          | 0.902          | 0.942      | 0.914      |
| -359                     | 39.31          | 0.892          | 0.932      | 0.908      |

Figure 11 - Primary Cylinder Pressure and Volume example Data

The second part of the data was further data collected from the dynamometer and maps for key factors such as fuel mass, EGR % and importantly the NOx parts per million (PPM).

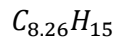
| FUELMASS kg/h | 800 | 1000 | 1250 | 1500 | 1750 | 2000  |
|---------------|-----|------|------|------|------|-------|
| FL            |     | 3.24 | 5.22 | 7.52 | 9.39 | 11.35 |
| 200           |     |      |      |      |      | 11.34 |
| 190           |     |      |      |      |      | 10.77 |
| 180           |     |      |      |      | 9.11 | 10.05 |
| 170           |     |      |      | 7.51 | 8.77 | 9.38  |
| 160           |     |      |      | 7.10 | 8.08 | 8.74  |
| 150           |     |      |      | 6.52 | 7.46 | 8.17  |
| 140           |     |      | 5.19 | 6.04 | 6.84 | 7.63  |
| 130           |     |      | 4.73 | 5.46 | 6.16 | 6.96  |

Figure 12 - Fuel Mass (kg/h) example data

This data would be used to build the model but also compare the model results with that found to actually be produced by the engine. Figure 12 shows a section of the data displaying the fuel mass in kg/h.

### 6.1.3 Fuel Chemistry

The fuel used in this investigation will be Gasoline rather than Iso-Octane. The chemical make-up of gasoline is as follows –



*Equation 3 - Gasoline*

The stoichiometric burning of gasoline can be seen below. It creates the products of Carbon Dioxide, Water Vapour and Nitrogen.



*Equation 4 - Reactants and Products from Stoichiometric burning of Gasoline*

This model will analyse the impact of running lean and rich on the products created, with a particular focus on NOx production.

## 6.2 Model Theory

To understand the accuracy of the model it is important to have an understanding of the model construction to pinpoint any pitfalls.

### 6.2.1 Ideal Gas Law

The model will work on the basis that the ideal gas law is valid for the two separate zones. The ideal gas law can be seen in equation 5.

$$PV = mRT$$

*Equation 5 - Ideal Gas Law*

Where –

P = Pressure

V = Volume

M = mass

R = Gas Constant

T = Temperature

The volumes and pressures have been provided by the base data, meaning the temperature can be found once the mass and gas constant are known.

The mass of the mixture can be calculated by taking the fuel mass and the engines lambda which can be seen in Figure 13.

| LAMBDA UEGO ratio |  | 800  | 1000 | 1250 | 1500 | 1750  | 2000  | 2250  | 2500  | 3000  | 3500  | 4000  | 4500  | 5000  | 5500  | 6000  | 6500 |
|-------------------|--|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|
| FL                |  | 1.04 | 1.09 | 1.13 | 1.02 | 0.98  | 0.98  | 0.98  | 0.93  | 0.96  | 0.95  | 0.94  | 0.91  | 0.90  | 0.89  | 0.89  |      |
| 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 |      |

Figure 13 - Fuel Mass and Lambda Data

Lambda 1 refers to a stoichiometric mixture of 14.7:1 parts air to fuel and is the point of the most effective combustion. Running lean (more than lambda 1) means there are more parts of air to each part of fuel e.g. 15:1. Running rich (less than lambda 1) means there are fewer parts air to each part of fuel e.g. 14:1.

### 6.2.2 Mass

|                     |            |                     |                      |
|---------------------|------------|---------------------|----------------------|
| Fuel Flow (kg/hour) | 3.24       | Fuel Flow (kg/hour) | 3.24                 |
| Fuel Flow (kg/min)  | 0.054      | Fuel Flow (kg/min)  | =B12/60              |
| Fuel Flow (kg/rev)  | 0.000054   | Fuel Flow (kg/rev)  | =B\$12/(60*B7)       |
| Fuel / Cycle (kg)   | 0.000036   | Fuel / Cycle (kg)   | =B\$12/(60*B\$7*1.5) |
| AFR UEGO ratio      | 15.19      | AFR UEGO ratio      | 15.19                |
| Total A/F per cycle | 0.00058284 | Total A/F per cycle | =(B16*B15)+B15       |

Figure 14 Mass per cycle calculation

From Figure 13 the Lambda ratio and fuel mass the mass per cycle can be calculated. As seen in Figure 14 (1000RPM), where the right hand column is B and the top row is 12, the fuel mass in kg/h is divided through to kg/min before the engine speed in revolutions per minute is used to find fuel/cycle. Utilising the Lambda ratio gives the air mass which is then combined with the fuel mass to give the total air and fuel mass per cycle.

One important factor for the mass is the addition of EGR which is where a dead mass from the exhaust is recirculated around. The aim of this is to reduce combustion temperatures and thus the NOx production. This of course increases the mass which means it must be considered.

By taking the EGR percentage and the total air fuel mass, the EGR mass can be found.

| rri w % (Residual gas ratio by internal and external EGR) |  | 800 | 1000 | 1250 | 1500 | 1750 | 2000 | 2250 | 2500 | 3000 | 3500 | 4000 | 4500 | 5000 | 5500 | 6000 | 6500 |
|-----------------------------------------------------------|--|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| FL                                                        |  | 0.5 | 0.2  | 0.1  | 0.4  | 0.8  | 0.8  | 1.0  | 1.5  | 1.7  | 2.2  | 2.7  | 3.1  | 3.3  | 3.6  | 4.1  |      |

Figure 15 - EGR Percentage

### 6.2.3 Gas Constant

The final piece of data needed for the ideal gas law is the Gas Constant. The Gas Constant is a relationship between energy and temperature and is given by –

$$R = \frac{Ru}{M}$$

Equation 6 - Gas Constant Formula

Where  $R_u$  is the universal gas constant of J/kmol.K and  $M$  is the molar mass of the mixture (Heywood, 1988). The calculation of the Gas Constant for 1000RPM can be seen in Figure 16. The original amounts of each molecule are multiplied lambda before being multiplied by their atomic mass to give a total molecular weight for the mixture. Once this is divided by the air mass, Equation 6 can be used to find the Gas Constant.

|                                   |            |
|-----------------------------------|------------|
| No Carbon atoms                   | 8.26       |
| No of Hydrogen Atoms              | 15.5       |
| No of Oxygen Atoms                | 2          |
| No of Nitrogen Atoms              | 7.52       |
| <u>Mixture Molecules</u>          |            |
| No Carbon atoms                   | 7.9296     |
| No of Hydrogen Atoms              | 14.88      |
| No of Oxygen Atoms                | 251        |
| No of Nitrogen Atoms              | 943.76     |
| <u>Atomic Weights</u>             |            |
| Carbon                            | 12         |
| Hydrogen                          | 1          |
| Oxygen                            | 16         |
| Nitrogen                          | 14         |
| <u>Molecular Weight Post Comb</u> |            |
| Carbon                            | 95.1552    |
| Hydrogen                          | 14.88      |
| Oxygen                            | 4016       |
| Nitrogen                          | 13212.64   |
| Mol Wt                            | 17338.6752 |
| Air Wt                            | 598.34     |
| Universal Gas Constant ( $R_u$ )  | 8314       |
| Molar Wt Mixture                  | 28.9779644 |
| Gas Constant $R$                  | 286.907662 |

Figure 16 - Gas Constant Data

### 6.2.4 Unburned Zone Temperature

By transposing the Ideal Gas Law as seen in Equation 5 it is possible to use it to calculate the temperature. This temperature will only be accurate from the point at which the inlet valve closes, when the mass in the cylinder becomes constant. This temperature will also be the Unburned Zone temperature ( $T_{UB}$ ), and will be used to calculate the unburned volume and thus the burned volume.

$$T_{UB} = \frac{PV}{mR}$$

Equation 7 - Unburned Zone Temperature pre-combustion

From the Pressure and Volume data it is possible to create Pressure Volume (PV) diagrams. Figure 17 shows the PV diagram at 6500RPM created using the mean cylinder pressure.

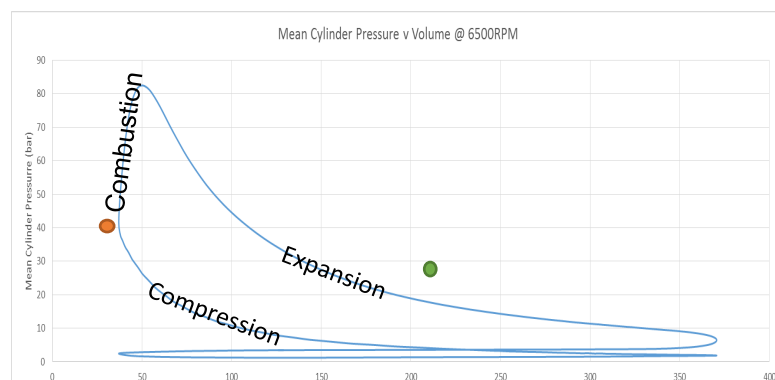


Figure 17 - PV Diagram

The orange point on the PV diagram shows the SOC which on an ideal adiabatic diagram would be completely vertical but in practice the combustion is not instantaneous. The green dot shows where you would expect the expansion line to be but due to heat losses it is lower. The top loop area is the work done and the bottom loop is the pumping losses (Heywood, 1988). Pumping losses are losses from drawing the air and fuel into the chamber and forcing the exhaust gas out. The top loop minus the bottom pumping loop gives the net work done and is mathematically shown in Equation 8.

$$WD = \left( \frac{P_1 + P_2}{2} \right) \times (V_2 - V_1)$$

*Equation 8 - Net Work Done*

As mentioned in 6.1.1 the Fox engine utilises a turbo to improve engine efficiency. This is graphically demonstrated in Figure 18 where the Fox data is compared to the 1.6L Naturally Aspirated Ecoboost. The turbo engine clearly runs at a higher pressure and the area of the top loop is greater meaning there is more work done per cycle. The pumping loop is also smaller indicating the lower pumping losses, thanks to the forced induction. Because of the reduced pumping losses and greater work loop the net work done of the turbo engine is significantly greater.

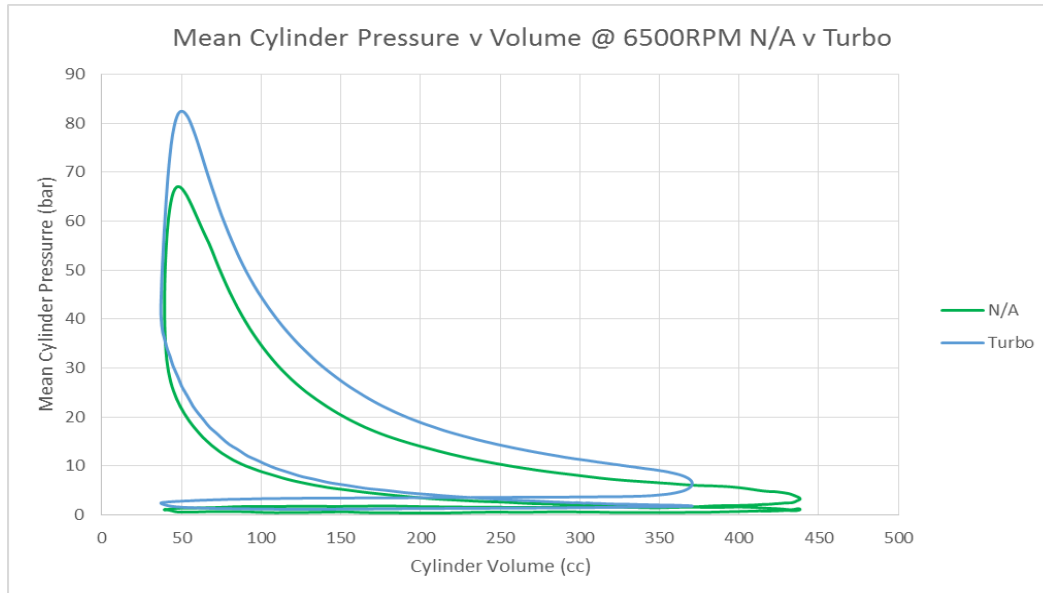


*Figure 18 - PV Diagram Comparison*

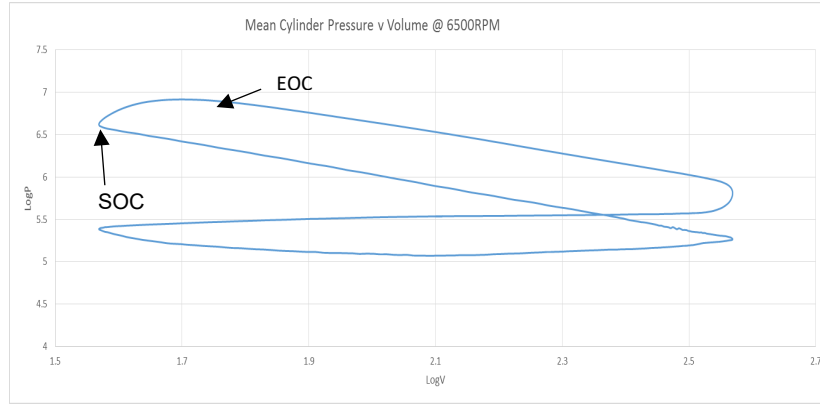


Figure 19 - Log PV Diagram

Figure 19 shows the Log PV diagram which can be used to identify the Start of Combustion (SOC) and End of Combustion (EOC). The point at which the lines stop and restart being parallel are the SOC and EOC respectively. Because the compression of the mixture just before combustion (and the expansion of the exhaust gases just after the combustion) are close to isentropic adiabatic processes the polytropic relationship is applicable. This is shown in Equation 9, where  $n$  is the polytropic index.

$$PV^n = \text{Constant}$$

Equation 9 - Polytropic Relation

#### 6.2.5 Polytropic Indices

As John Heywood states the polytropic index is usually considered to be 1.3, but for the purposes of this investigation's accuracy it will not be assumed. The polytropic index is vitally important because it will be used to calculate the difference in pressure if combustion had stopped at the previous degree, which is used to calculate the Mass Fraction Burned (MFB), which will eventually be used to calculate the burned temperature. The formula for the polytropic index is shown below.

$$n = \frac{\text{Log}P_1 - \text{Log}P_2}{\text{Log}V_1 - \text{Log}V_2}$$

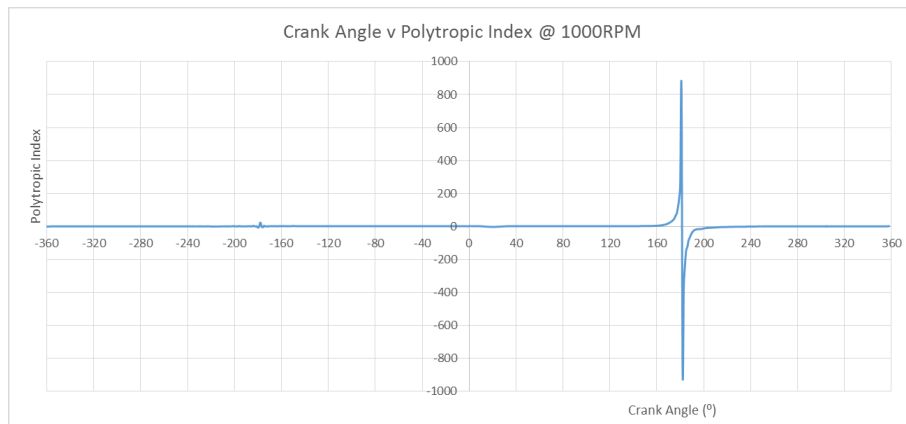


Figure 20 - Polytropic Index

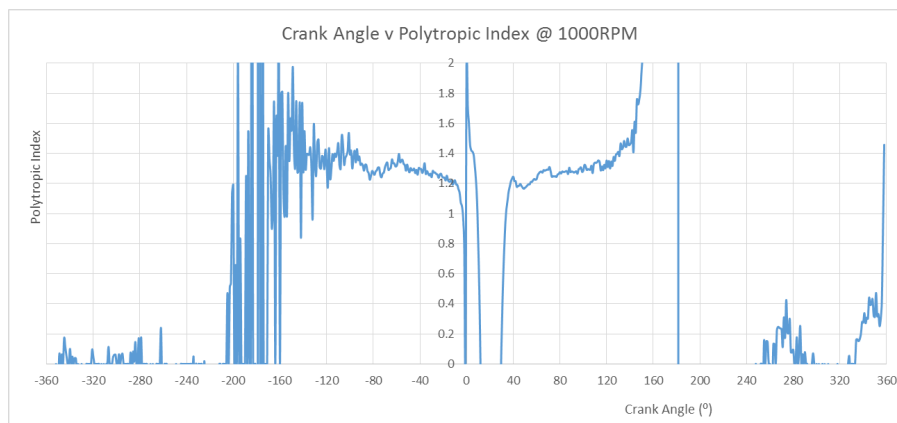


Figure 21 - Polytropic with Y Axis Range Reduced

The compressive and polytropic index will be found by taking the average of the ten degrees before and after combustion. As can be seen from Figure 20 the polytropic index does seem consistent at this point but by zooming in (Figure 21) the variation is clear.

This made finding an appropriate compressive and expansion polytropic index difficult and as a result the average range was increased to 20 degrees take into more of the parallel section on the Log PV diagram. Figure 22 shows the polytropic indices and their calculation at 1000RPM

|       |            |       |                     |
|-------|------------|-------|---------------------|
| nCOMP | 1.28914162 | nCOMP | =AVERAGE(N315:N335) |
| nEXP  | 1.30680561 | nEXP  | =AVERAGE(N305:N325) |

Figure 22 - Polytropic Index of Compression and Expansion

### 6.2.6 Mass Fraction Burned

Mass fraction is an important piece of data which is used to analyse the combustion rate, as well as being a vital part of the temperature calculation. As is described by Mittal 'The mass fraction burned (MFB) shows how the in cylinder combustion progresses as a function of the

crank angle. The rate of combustion inside an engine cylinder is a very important parameter affecting the engine thermal efficiency, peak cycle temperature and pressure, and exhaust emissions' (Mittal, 2008).

Accurate MFB values are vital. With the Polytropic Indices calculated the next step to finding the MFB is to calculate the pressure difference if the combustion had stopped at the previous degree, which gives the compression from combustion alone. This is done by using the appropriate polytropic index depending on whether the engine is in compression or ignition and Equation 11. One issue with this is the fact that the polytropic index is not constant during combustion (Heywood, 1988).

$$P_2^n = P \times \frac{V_1^n}{V_2^n}$$

Equation 11 - Pressure Difference

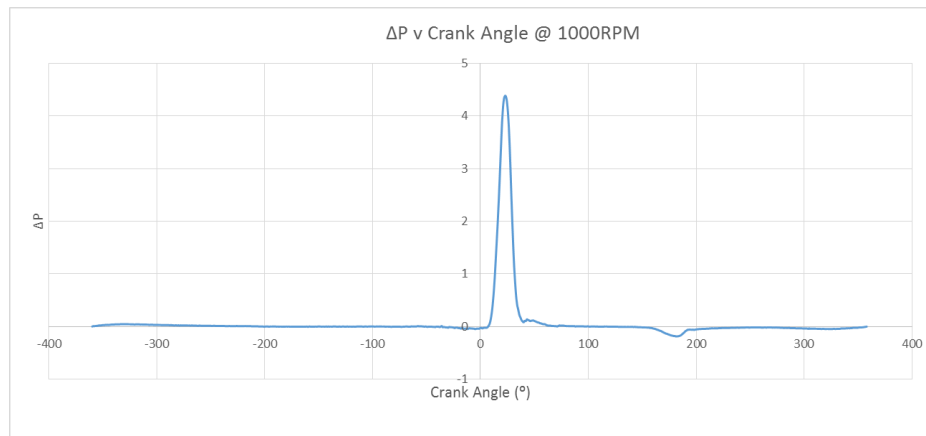


Figure 23 – Delta P v Crank Angle

Figure 23 is a graph of the pressure difference and shows how during combustion there is a peak pressure increase of around 4.4 pascal per degree from combustion alone. This method is also used to find the SOC and EOC. Taking the ignition as SOC is highly inaccurate because of the ignition delay which impacts flame speed, temperature and emissions (Kwon, 1988). The sum of these pressure differences can be calculated and used find the MFB as seen in Equation's 12.

$$MFB = \frac{\sum_{SOC-\theta} \Delta P}{\sum_{SOC-EOC} \Delta P} \text{ or } MFB = \frac{\sum_{SOC-\theta} V_2 \Delta P}{\sum_{SOC-EOC} V_2 \Delta P}$$

Equation 12 – MFB

This is one area where the models validity can be controlled. The equation on the left assumes constant volume which is not true because the piston is moving up and down. This makes the right equation more accurate and is the one used for this model. The difference between the two methods can be clearly seen in Figure 24. The MFB with just pressure shows that the combustion accelerates more rapidly and plateaus off quicker. This would have an impact on burned temperatures with it increasing sooner and potentially reaching a higher peak.

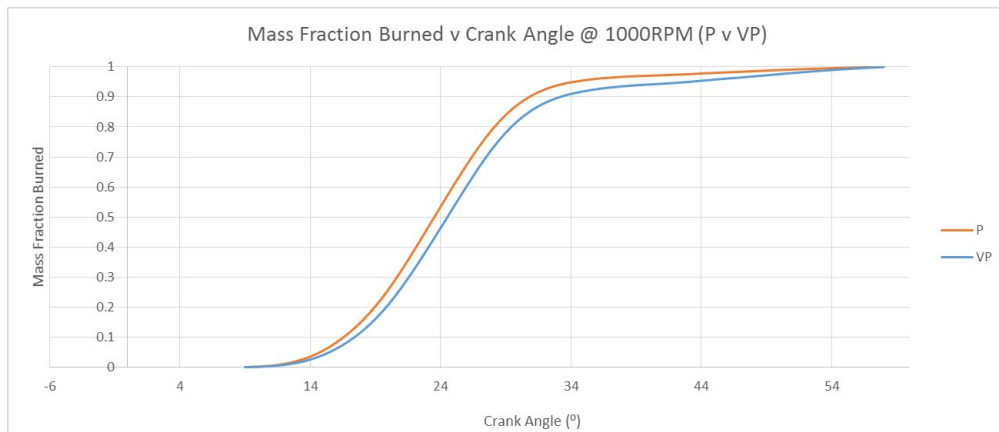


Figure 24 - MFB Comparison

Mittal's research also found that at full load the volume and sum of pressure difference is a highly accurate method for calculating accurate MFB, SOC and EOC values. It was less accurate at part load but this investigation is being carried out at full load. Between Kwon and Mittal's work it is clear that this is a reliable method of plotting MFB, SOC and EOC.

From Figure 25 you can see the relationship between the MFB and the combustion. The sparkplug ignited at 5.7° after top dead centre (ATDC) but SOC did not occur until about 10°. Even after the combustion has begun there is a very slow combustion as the flame area increases before it begins to travel rapidly increasing the pressure greatly and the mass burned. Once the peak pressure is hit the combustion slows as the MFB tails off. The drop in pressure after top dead centre (TDC) (0°) shows that combustion did not start until ATDC.

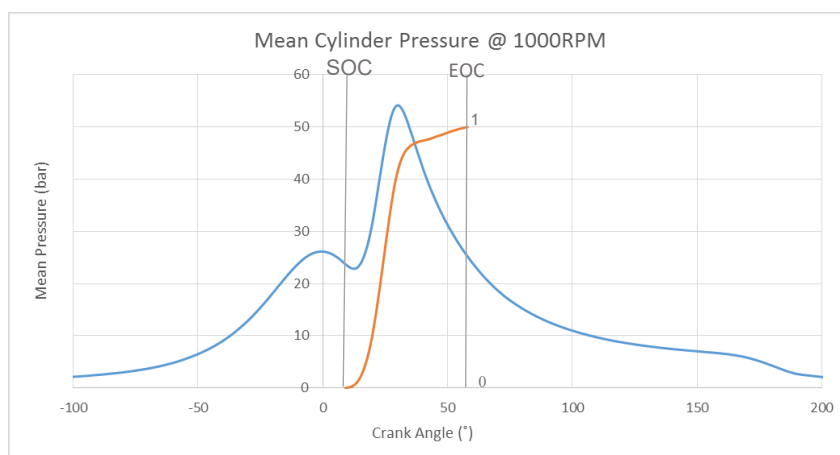


Figure 25 - Pressure Crank & MFB Overlay

### 6.2.7 Gamma

Once combustion has begun using the polytropic index is not a viable or entirely accurate method. The heat release from combustion effects pressure and temperature. The pressure rise is now proportional to the amount of chemical heat released rather than the mass as in Equation 7 (above).

By combining the ideal gas law and Equation 13 (middle) it is possible to transpose to give Equation 13 (right).

$$PV = mRT \quad \text{and} \quad PV^\gamma = \text{Constant} \quad \rightarrow \quad T_2 = T_1 \left( \frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}}$$

*Equation 13 - Unburned Zone Temperature during Combustion*

From Equation 13 it is clear that Gamma ( $\gamma$ ) is need to calculate the temperature. Gamma can be found by dividing the specific heat at constant pressure ( $C_p$ ) by the specific heat at constant volume ( $C_v$ ) (Parthasarathy, 1956) and is shown in Equation 14.

$$\gamma = \frac{c_p}{c_v}$$

*Equation 14 - Gamma*

$C_p$  is the energy required to raise the temperature of a unit of mass of a substance by 1 degree while the pressure remains constant (but the volume can change).  $C_v$  is the opposite, the volume remains constant, but the pressure can change (Kadem, 2007).

R Ebrahimi found during his investigation on the 'effect of specific heat ratio on heat release' that calculating gamma at every degree was vital (R Ebrahimi, 2011). Assuming gamma had a major impact on his results. For the purposes of this investigation gamma will be calculated at every degree.

### 6.2.8 Specific Heats

Using the known values for specific heat at constant pressure for each species (Table 2) sourced from Heywood's Internal Combustion Fundamentals as well as Equation 15 the Specific Heat at  $C_p$  was calculated. This can be seen in the appendix.

$$\frac{c_{p,i}}{R} = a_{i1} + a_{i2}T + a_{i3}T^2 + a_{i4}T^3 + a_{i5}T^4$$

*Equation 15 –  $C_p/R$  for Air Elements*

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

*Equation 16 -  $C_p$  for Gasoline*

Where R is the Gas Constant and ai are the given values.

| Species          | T Range, K | a <sub>1</sub> | a <sub>2</sub> | a <sub>2</sub> T | a <sub>3</sub> | a <sub>3</sub> T <sup>2</sup> | a <sub>4</sub> | a <sub>4</sub> T <sup>3</sup> | a <sub>5</sub> | a <sub>5</sub> T <sup>4</sup> |
|------------------|------------|----------------|----------------|------------------|----------------|-------------------------------|----------------|-------------------------------|----------------|-------------------------------|
| CO <sub>2</sub>  | 1000-5000  | 4.4608         | 0.003098       | 1.23928          | -1.2393E-06    | -0.111537                     | 2.2741E-10     | 0.00614007                    | -1.5526E-14    | -0.000125761                  |
|                  | 300-1000   | 2.4008         | 0.008735       | 2.62053          | -6.6071E-06    | -0.594639                     | 2.0022E-09     | 0.0540594                     | 6.3274E-16     | 5.12519E-06                   |
| H <sub>2</sub> O | 1000-5000  | 2.7168         | 0.002945       | 0.88353          | -8.0224E-07    | -0.0722016                    | 1.0227E-10     | 0.00276129                    | -4.8472E-15    | -3.92623E-05                  |
|                  | 300-1000   | 4.0701         | -0.00111       | -0.33252         | 4.1521E-06     | 0.373689                      | -2.9637E-09    | -0.0800199                    | 8.0702E-13     | 0.006536862                   |
| CO               | 1000-5000  | 2.9841         | 0.001489       | 0.44673          | -0.000000579   | -0.05211                      | 1.0365E-10     | 0.00279855                    | -6.9354E-15    | -5.61767E-05                  |
|                  | 300-1000   | 3.7101         | -0.00162       | -0.48573         | 3.6924E-06     | 0.332316                      | -2.032E-09     | -0.054864                     | 2.3953E-13     | 0.001940193                   |
| H <sub>2</sub>   | 1000-5000  | 3.1002         | 0.000511       | 0.153357         | 5.2644E-08     | 0.00473796                    | -3.491E-11     | -0.00094257                   | 3.63945E-15    | 2.94795E-05                   |
|                  | 300-1000   | 3.0574         | 0.002677       | 0.80295          | -5.8099E-06    | -0.522891                     | 5.52181E-09    | 0.14908887                    | -1.8123E-12    | -0.01467963                   |
| O <sub>2</sub>   | 1000-5000  | 3.622          | 0.000732       | 0.2194854        | -1.9652E-07    | -0.0176868                    | 3.6202E-11     | 0.000977454                   | -2.8946E-15    | -2.34463E-05                  |
|                  | 300-1000   | 3.6256         | -0.00188       | -0.56346         | 7.0555E-06     | 0.634995                      | -6.7635E-09    | -0.1826145                    | 2.1556E-12     | 0.01746036                    |
| N <sub>2</sub>   | 1000-5000  | 2.8963         | 0.001516       | 0.45465          | -5.7235E-07    | -0.0515115                    | 9.9807E-11     | 0.002694789                   | -6.5224E-15    | -5.28314E-05                  |
|                  | 300-1000   | 3.6748         | -0.00121       | -0.36246         | 0.000002324    | 0.20916                       | -6.3128E-10    | -0.01704456                   | -2.2577E-13    | -0.001828737                  |
| OH               | 1000-5000  | 2.9106         | 0.000959       | 0.287796         | -1.9442E-07    | -0.0174978                    | 1.375E-11      | 0.00037125                    | 1.4225E-16     | 1.15223E-06                   |
| NO               | 1000-5000  | 3.189          | 0.001338       | 0.40146          | -5.2899E-07    | -0.0476091                    | 9.5919E-11     | 0.002589813                   | -6.4848E-15    | -5.25269E-05                  |
| O                | 1000-5000  | 2.5421         | -2.8E-05       | -0.0082653       | -3.1028E-09    | -0.000279252                  | 4.5511E-12     | 0.00012288                    | -4.3681E-16    | -3.53816E-06                  |
| H                | 1000-5000  | 2.5            | 0              | 0                | 0              | 0                             | 0              | 0                             | 0              | 0                             |

Table 2 - Cp Data for each Element

From this data a graph was created from which a polynomial formula was created as seen in Figure 26 for the Air mixture and Figure 27 for the Gasoline. The Cp tails off as temperature increases because it takes more energy to vibrate the molecules which causes the temperature increase. Carbon Dioxide has a higher Cp because it has more bonds and degrees of freedom meaning it takes more energy to increase its temperature.

Having calculated Cp the Cv could easily be found by subtracting the universal gas constant. In Figure 27 the calculation of the unburned zone temperature using gamma and the specific heats can be seen. This process may be long winded when gamma could be assumed to be constant at 1.3 but this extra process ensures an increased accuracy.

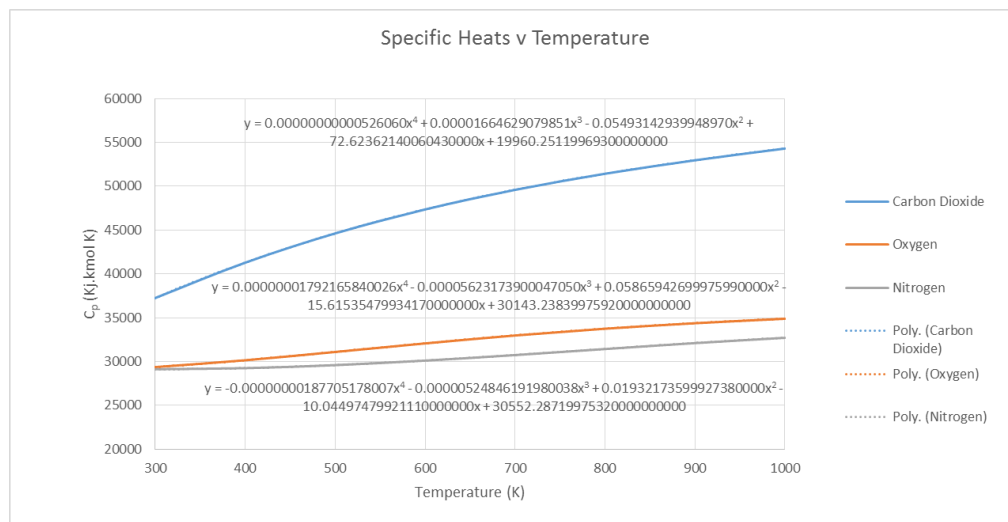


Figure 26 - Cp for CO<sub>2</sub>, O<sub>2</sub> & N<sub>2</sub>

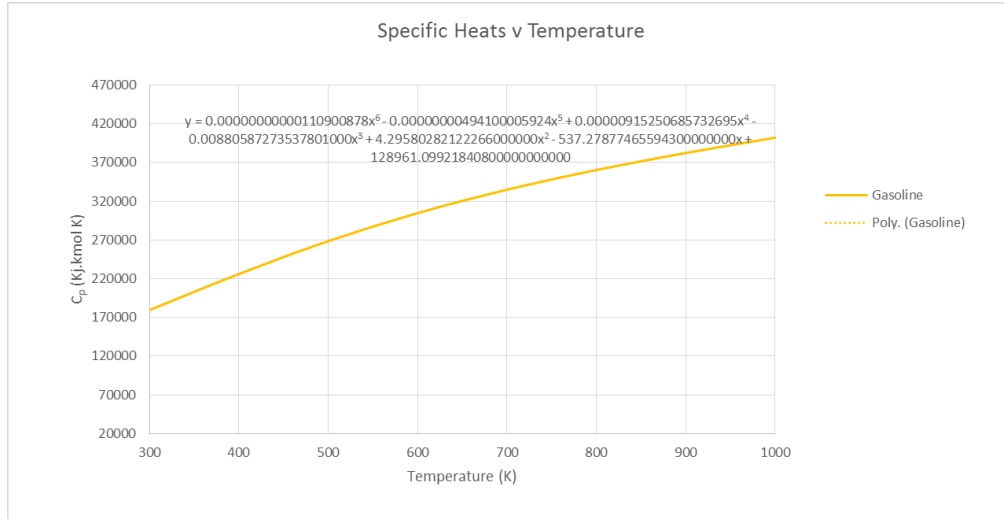


Figure 28 - Cp for Gasoline

|             | Cp Gasoline | Cp Oxygen   | Cp Nitrogen | Cpav     | Cvav     | γ        |
|-------------|-------------|-------------|-------------|----------|----------|----------|
|             | KJ.kmol K   | KJ.kmol K   | KJ.kmol K   |          |          |          |
| 567.7812325 |             |             |             |          |          |          |
| 565.5191457 |             |             |             |          |          |          |
| 563.2379768 | 322232.747  | 31735.40183 | 29909.76307 | 35704.62 | 27390.62 | 1.303535 |
| 561.0715208 | 321347.3925 | 31713.15935 | 29897.44577 | 35674.22 | 27360.22 | 1.303872 |
| 559.32898   | 320503.2005 | 31692.01374 | 29885.81415 | 35645.32 | 27331.32 | 1.304193 |
| 558.2794615 | 319821.814  | 31674.99112 | 29876.50578 | 35622.07 | 27308.07 | 1.304452 |
| 558.3706871 | 319410.3952 | 31664.73247 | 29870.91989 | 35608.06 | 27294.06 | 1.304608 |

Figure 27 - Utilisation of Cp, Cv & Gamma to Calculate Unburned Temperature

## 6.2.9 Cylinder Volumes

Having calculated the unburned zone temperatures it is possible to utilise the Ideal Gas Law to find the unburned volume and thus the burned volume. The unburned air/fuel mass (including the EGR mass) can be found by utilising the MFB –

$$U_B Mass = (1 - MFB)M_{TOTAL}$$

Equation 17 - Unburned Mass

Once the unburned mass has been found the ideal gas law can be applied to the unburned zone –

$$PV = mRT \rightarrow V_{UN} = \frac{(1 - MFB)M_{TOTAL} \times R_{UN}T_{UN}}{P}$$

Equation 18 - Unburned Volume

Where T is the temperature, P the pressure and  $R_{UN}$  is the unburned gas constant which was found by dividing the universal gas constant by the molar weight of the mixture. Once the unburned volume is calculated the burned volume can easily be found by subtracting the

unburned volume from the cylinder volume. This shown in Figure 29 where the volume is also transferred from cc to m<sup>3</sup> for use in future calculations.

| $V_{UB}$<br>m <sup>3</sup> | $V_{UB}$<br>cc | $V_B$<br>cc | $V_B$<br>m <sup>3</sup> | $V_{UB}$<br>m <sup>3</sup>                               | $V_{UB}$<br>cc                         | $V_B$<br>cc        | $V_B$<br>m <sup>3</sup> |
|----------------------------|----------------|-------------|-------------------------|----------------------------------------------------------|----------------------------------------|--------------------|-------------------------|
| 3.61E-05                   | 36.09969       | 1.780315    | 1.78031E-06             | $=((1-V_{364}) * \$B\$17 * \$B\$44 * Y_{364}) / K_{364}$ | $=AG_{364} * 100 = E_{364} - AH_{364}$ | $=AI_{364} / 1000$ |                         |
| 3.5481E-05                 | 35.48145       | 2.098551    | 2.09855E-06             | $=((1-V_{365}) * \$B\$17 * \$B\$44 * Y_{365}) / K_{365}$ | $=AG_{365} * 100 = E_{365} - AH_{365}$ | $=AI_{365} / 1000$ |                         |
| 3.4784E-05                 | 34.78399       | 2.566009    | 2.56601E-06             | $=((1-V_{366}) * \$B\$17 * \$B\$44 * Y_{366}) / K_{366}$ | $=AG_{366} * 100 = E_{366} - AH_{366}$ | $=AI_{366} / 1000$ |                         |
| 3.4341E-05                 | 34.34098       | 2.84902     | 2.84902E-06             | $=((1-V_{367}) * \$B\$17 * \$B\$44 * Y_{367}) / K_{367}$ | $=AG_{367} * 100 = E_{367} - AH_{367}$ | $=AI_{367} / 1000$ |                         |

Figure 29 - Volumes Calculation

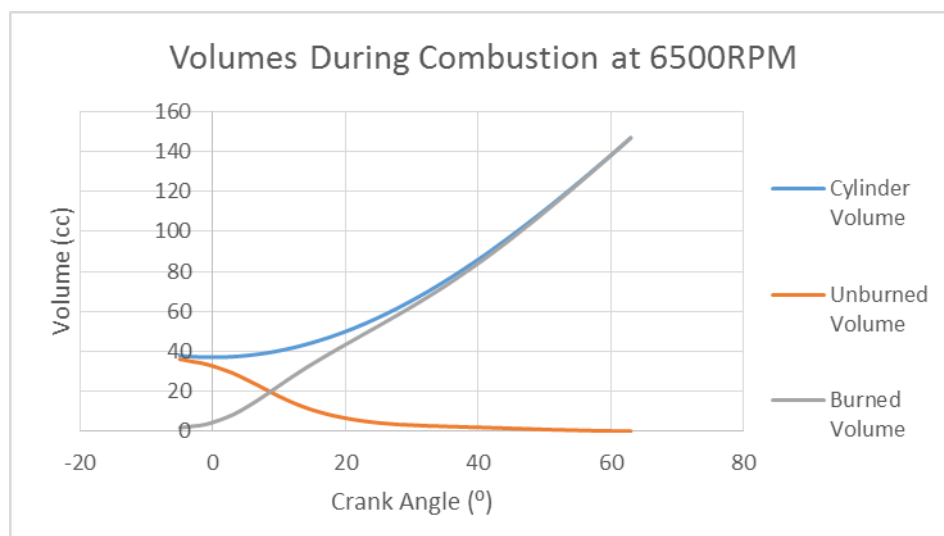


Figure 30 - Volumes during Combustion

Figure 30 shows the various volumes through combustion. The blue line which is the overall cylinder volume increases as the engine travels down from TDC. The unburned volume decreases as the combustion takes place in a similar way to the MFB graph which is vertical. The burned volume increases mirroring the unburned volume before tailing up further to fill the entire cylinder volume which is increasing.

#### 6.2.10 Burned Temperatures

The burned temperatures are the single most influential factor on NO<sub>x</sub> production so an accurate calculation is vital. An understanding of the formation clearly shows how the temperature impacts the NO<sub>x</sub> production.

As the temperature increases the kinetic energy in translation of molecules increases and the degrees of freedom become more active. At a high enough temperature more and more molecules begin to break their bonds and rejoin as described in the Zeldovich mechanism. This is the principle behind NO<sub>x</sub> creation. Oxygen bonds break and they become single

oxygen radicals. When nitrogen molecules break up their radicals can join up with oxygen radicals creating the NO<sub>x</sub> (American Meteorological Society, 2012).

Attilia Biro has carried out extensive work on NO<sub>x</sub> production and his work shows the point at which NO<sub>x</sub> production begins. Figure 31 shows how after 1600°K the NO<sub>x</sub> production increases drastically (Biro, 1965). This is clearly the point at which the heat provides enough kinetic energy for oxygen and nitrogen to split forming the radicals which reform as NO<sub>x</sub>.

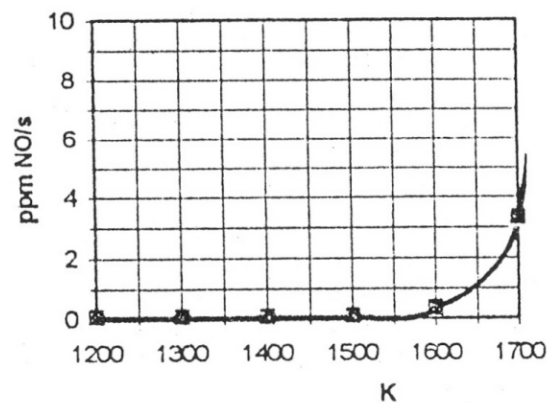


Figure 31 - NO<sub>x</sub> Formation relative to Temperature

This highlights the importance of accurate temperature data, a difference of 100°K can lead to inaccurate data.

Once again the Ideal Gas Law will be transposed to give the burned zone temperature.

$$PV = mRT \rightarrow T_B = \frac{P V_B}{MFB M_{TOTAL} R_B}$$

Equation 19 - Burned Zone Temperature

Where  $R_B$  is the burned gas constant which is found by dividing the universal gas constant by the molar weight of the products as seen in Equation 4. The increase in temperature will cause more disassociation reducing the average molecule weight causing the burned gas constant to increase. Figure 32 shows the burned temperature calculations.

|             | MFB (V*P)     | $V_B$          | $T_B$    |
|-------------|---------------|----------------|----------|
|             | Mass Fraction | m <sup>3</sup> | °K       |
| 2455900     |               |                |          |
| 2415500     |               |                |          |
| 2373933.333 | 0.000318396   | 4.78176E-08    | 2098.824 |
| 2335000     | 0.001301453   | 2.011E-07      | 2124.014 |
| 2304066.667 | 0.003565848   | 5.60572E-07    | 2132.311 |

|                      | MFB (V*P)       | $V_B$          | $T_B$                                       |
|----------------------|-----------------|----------------|---------------------------------------------|
|                      | Mass Fraction B | m <sup>3</sup> | °K                                          |
| 376*10 <sup>-5</sup> |                 |                |                                             |
| 377*10 <sup>-5</sup> |                 |                |                                             |
| 378*10 <sup>-5</sup> | =U378/SU\$427   | =A1378/1000000 | =(K378*AJ378)/(V378*(SB\$17+SB\$46)*SA\$48) |
| 379*10 <sup>-5</sup> | =U379/SU\$427   | =A1379/1000000 | =(K379*AJ379)/(V379*(SB\$17+SB\$46)*SA\$48) |
| 380*10 <sup>-5</sup> | =U380/SU\$427   | =A1380/1000000 | =(K380*AJ380)/(V380*(SB\$17+SB\$46)*SA\$48) |
| 381*10 <sup>-5</sup> | =U381/SU\$427   | =A1381/1000000 | =(K381*AJ381)/(V381*(SB\$17+SB\$46)*SA\$48) |

Figure 32 - Burned Temperature Calculations

Figure 33 shows a comparison of the burned temperature at 6000RPM and 1000RPM. The 1000RPM peaks at below 2400°K and has a shorter combustion. Because of the lower temperatures you would expect less NO<sub>x</sub> production. At the higher RPM the engine is

working faster and has more fuel so the temperature peaks at just below 2700°K. There is less of a temperature rise because the unburned zone will have been hotter. These temperatures follow the expected trend and the addition of the EGR to the mass has clearly cooled the cylinder.

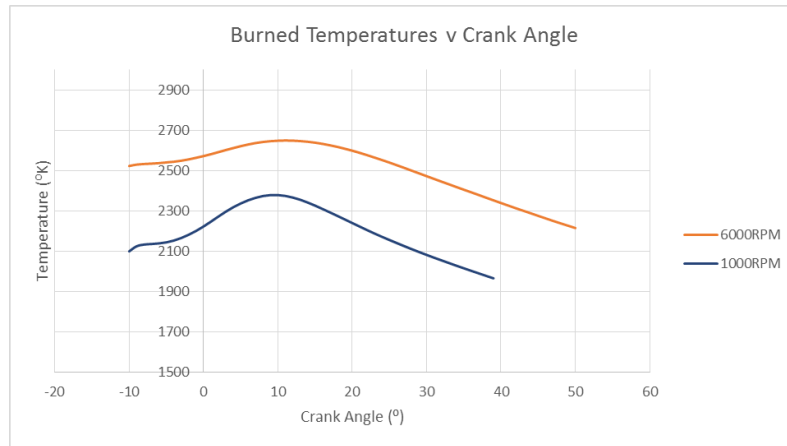


Figure 33 - Burned Zone Temperature Comparison

#### 6.2.11 Disassociation

Now the burned temperatures are known and looking at the Zeldovich Boltzmann Function (below) it can be seen that the remaining required figures are the nitrogen and oxygen concentrations (e represents the exponential function).

$$\frac{d[NO]}{dt} = 4.7 \times 10^{13} [N_2][O_2]^{\frac{1}{2}} e^{-\left(\frac{67837}{T}\right)}$$

As discussed in the previous section, above 1800K the heat energy causes the products to disassociate back to their reactant materials as seen in Equation 20 and shown in Equation 1 above. The rate of this needs to be found and this can be done utilising partial pressure equilibrium constants (PPEC) which were proposed by Avogadro. The PPEC are shown in Table 3.

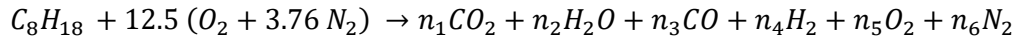


Equation 20 - Reversible Combustion Reaction

| Temp | KCO2   | KH2O   |
|------|--------|--------|
| 2000 | 765.6  | 3467   |
| 2100 | 345.94 | 1686.6 |
| 2200 | 168.27 | 874.98 |
| 2300 | 87.097 | 480.84 |
| 2400 | 47.753 | 277.43 |
| 2500 | 27.543 | 167.49 |
| 2700 | 10.351 | 68.077 |
| 3000 | 3.0549 | 22.029 |

Table 3 - Partial Pressure Equilibrium Constants for Carbon Dioxide and Water Vapour

By utilising the PPEC and molar composition of the fuel/air mix it is possible to find the molar concentration of each element.



The following formulae are used to calculate the concentration of each product

$$n_3 (CO) = \frac{C}{((KCO_2 \times (\frac{n_5}{nT} \times P)^{\frac{1}{2}}) + 1)}$$

$$n_4 (H_2) = \frac{C}{((KH_2O \times (\frac{n_5}{nT} \times P)^{\frac{1}{2}}) + 1)}$$

$$n_2 (H_2O) = H - n_4$$

$$n_1 (CO_2) = C - n_3$$

$$n_5 (O_2) = \frac{O - (2 \times n_1) - n_2 - n_3}{2}$$

$$n_6 (N_2) = N$$

$$nT (Total) = n_1 + n_2 + n_3 + n_4 + n_5 + n_6$$

Equation 21 - Element Concentrations Formulae

N5/NT is a guessed value and Excel was used to calculate the error to 1. This process was used at 10 bar increments and at temperatures where PPEC values were given. The no of kmols for each element is what is referred to by C, H, O & N and thus the values will change at each lambda value.

| Pressure (Bar) | Temperature (K) | N5/NT (Guess) | N3<br>C/(<-+1) | N1<br>C-<- | N4<br>H/2x(<-+1) | N2<br>(H/2)-<- | N6<br>N | N5<br>(Ox2)-2N1-N2-N3/2 | NT<br>Total | Calc N5/NT  | Calc/Guess  |
|----------------|-----------------|---------------|----------------|------------|------------------|----------------|---------|-------------------------|-------------|-------------|-------------|
| 10             | 2000            | 8.24E-03      | 0.03591        | 7.89369    | 0.007466548      | 7.432533       | 45.6276 | 0.507088256             | 61.50429    | 0.008244763 | 1.000119266 |
| 10             | 2100            | 0.008637471   | 0.077234       | 7.852366   | 0.014979326      | 7.425021       | 45.6276 | 0.531506481             | 61.52871    | 0.00863835  | 1.000101756 |
| 10             | 2200            | 0.009329018   | 0.151341       | 7.778259   | 0.027735425      | 7.412265       | 45.6276 | 0.574938409             | 61.57214    | 0.009337639 | 1.000924151 |

Figure 34 - Element Concentration Calculator

The data over the 1000K was then used to create a polynomial to provide the concentrations at each temperature and the relevant pressure as can be seen in Figure 35.

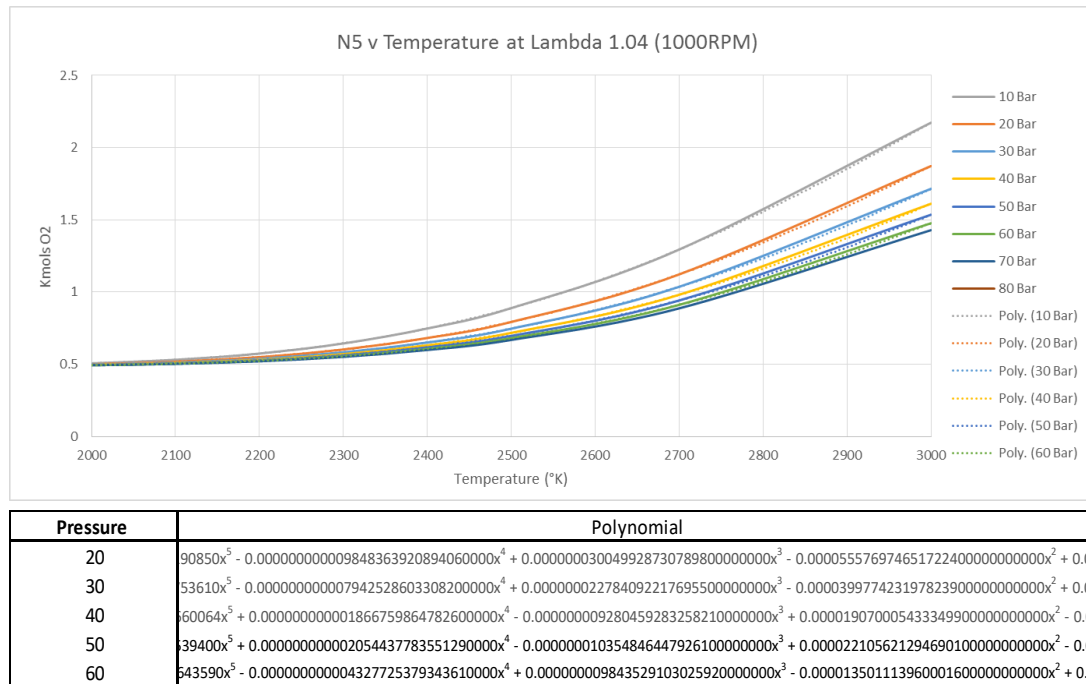


Figure 35 - Element Concentrations over 1000K at 20-80bar & Polynomials

As the temperature increases it can be seen that the amount of oxygen molecules increases. This is as the  $O_2$  dissociates to  $O + O$ . As pressure increases you would expect temperature to increase and the amount of oxygen to increase. However when based on pressure alone the amount of oxygen decreases. This is because the pressure is on the bottom of the equation below which means as pressure rises the amount of oxygen decreases.

$$K_{CO2} = \frac{n_1}{n_3 \left( \frac{n_5}{n_T} P \right)^{\frac{1}{2}}}$$

With the burned pressure and pressure at each degree known it is possible to calculate the specific Oxygen and Nitrogen concentration by linearly interpolating as seen in Figure 36.

| $T_B$       | Pressure   | N5 at Lower P | N5 at Higher P | N5 Actual  | N6      |
|-------------|------------|---------------|----------------|------------|---------|
| $^{\circ}K$ | Bar        | kmols         | kmols          | kmols      | kmols   |
| 2098.823875 | 23.7393333 | 0.51822118    | 0.51237976     | 0.51603688 | 45.6276 |
| 2124.013946 | 23.35      | 0.52458495    | 0.517647934    | 0.52226105 | 45.6276 |
| 2132.310701 | 23.0406667 | 0.52689703    | 0.5195649      | 0.52466757 | 45.6276 |
| 2135.260883 | 22.856     | 0.527746364   | 0.520269481    | 0.52561097 | 45.6276 |

Figure 36 - Oxygen and Nitrogen Concentration Calculations

### 6.2.12 NOx Calculation

Referring back to the Zeldovich Boltzmann function it can be seen all needed data is now calculated.

$$\frac{d[NO]}{dt} = 4.7 \times 10^{13} [N_2][O_2]^{\frac{1}{2}} e^{-\left(\frac{67837}{T}\right)}$$

Firstly however Alpha must be calculated. Alpha ( $\alpha$ ) is a small multiplier to get the correct number of kmols trapped in the cylinder derived from the products and reactants balancing out.

$$\alpha = \frac{\text{Mass of Fuel into Cylinder}}{\phi \times (8.26 \times 12 + 15.5)}$$

*Equation 22 – Alpha*

With Alpha calculated the amount of kmols of oxygen and nitrogen in the cylinder can be calculated in kmols/m<sup>3</sup>.

$$[O_2 \text{ or } N_2] = \frac{(n5 \text{ or } n6) \times \alpha \times MFB}{V_B}$$

*Equation 23 - Oxygen and Nitrogen Concentration*

With the amount of oxygen and nitrogen and burned temperatures known the NOx can be calculated. This is done firstly in NOx per second (Equation 2) before being calculated for each degree using the engine speed (Equation 24).

$$NO / ^\circ = \frac{\left( \frac{\frac{d[NO]}{dt}}{1} \right)}{\left( \frac{1}{6 \times RPM} \right) V_B}$$

*Equation 24 - NOx per degree*

To make an accurate comparison with the Ford data it was necessary to have the NOx in PPM. Parts per million (PPM) is another method of measuring NOx and is the mass of NOx per unit volume. This was done using Equation 25 where nT is the total kmols as found in Equation 21.

$$NOx \text{ PPM} = \frac{\sum NO / ^\circ}{\alpha \times nT} \times 10^6$$

*Equation 25 - NOx PPM*

This entire process is shown in Figure 37. The sum of NOx per degree is taken up to peak pressure (the light yellow line in Figure 37) rather than the end of combustion. This because after peak pressure as the temperature drops reverse reactions take place as seen in

Equation 20. The model does not consider reverse reactions show using the NO<sub>x</sub> per degree after peak pressure would not be entirely accurate.

| $\alpha$    | [O <sub>2</sub> ] | [N <sub>2</sub> ] | EXP         | d[NO]/dt                   | d[NO]/d $\theta$ | NO/°                       | $\Sigma$ NO/° | Calc NO <sub>x</sub> |
|-------------|-------------------|-------------------|-------------|----------------------------|------------------|----------------------------|---------------|----------------------|
|             |                   |                   |             | NO <sub>x</sub> per second |                  | NO <sub>x</sub> per degree |               | PPM                  |
| 3.27168E-07 | 0.001124167       | 0.09939799        | 9.18288E-15 | 0.001438367                | 2.39728E-07      | 1.14632E-14                | 1.14632E-14   | 535.8978             |
| 3.27168E-07 | 0.001105795       | 0.096608336       | 1.34727E-14 | 0.002034244                | 3.39041E-07      | 6.81811E-14                | 7.96443E-14   |                      |
| 3.27168E-07 | 0.001091908       | 0.094957579       | 1.52554E-14 | 0.002249799                | 3.74966E-07      | 2.10196E-13                | 2.8984E-13    |                      |
| 3.27168E-07 | 0.001083605       | 0.094066365       | 1.59409E-14 | 0.00231996                 | 3.8666E-07       | 4.76218E-13                | 7.66058E-13   |                      |
| 3.27168E-07 | 0.001084535       | 0.094002749       | 1.66529E-14 | 0.002422978                | 4.0383E-07       | 9.49348E-13                | 1.71541E-12   |                      |
| 3.27168E-07 | 0.001097732       | 0.09491644        | 1.79981E-14 | 0.002660205                | 4.43368E-07      | 1.7871E-12                 | 3.50251E-12   |                      |
| 3.27168E-07 | 0.001125661       | 0.09694192        | 2.04997E-14 | 0.003133729                | 5.22288E-07      | 3.31306E-12                | 6.81557E-12   |                      |
| 3.27168E-07 | 0.001169716       | 0.100147805       | 2.46763E-14 | 0.003972466                | 6.62078E-07      | 6.12585E-12                | 1.29414E-11   |                      |
| 3.27168E-07 | 0.001230026       | 0.104522846       | 3.10595E-14 | 0.005351317                | 8.91886E-07      | 1.12921E-11                | 2.42335E-11   |                      |
| 3.27168E-07 | 0.001307825       | 0.11012781        | 4.06369E-14 | 0.007606588                | 1.26776E-06      | 2.08918E-11                | 4.51253E-11   |                      |
| 3.27168E-07 | 0.001405463       | 0.117095853       | 5.5148E-14  | 0.011378339                | 1.89639E-06      | 3.92103E-11                | 8.43355E-11   |                      |
| 3.27168E-07 | 0.001525715       | 0.125383268       | 7.66153E-14 | 0.017635567                | 2.93926E-06      | 7.38048E-11                | 1.5814E-10    |                      |
| 3.27168E-07 | 0.001666114       | 0.134868058       | 1.07249E-13 | 0.027749307                | 4.62488E-06      | 1.37142E-10                | 2.95282E-10   |                      |
| 3.27168E-07 | 0.001817439       | 0.144999719       | 1.47097E-13 | 0.042736452                | 7.12274E-06      | 2.4287E-10                 | 5.38153E-10   |                      |
| 3.27168E-07 | 0.001971011       | 0.155191757       | 1.94087E-13 | 0.062850368                | 1.04751E-05      | 4.01614E-10                | 9.39766E-10   |                      |
| 3.27168E-07 | 0.002122532       | 0.165068507       | 2.45489E-13 | 0.08774477                 | 1.46241E-05      | 6.19473E-10                | 1.55924E-09   |                      |
| 3.27168E-07 | 0.002264634       | 0.174373132       | 2.98008E-13 | 0.116226097                | 1.9371E-05       | 8.94418E-10                | 2.45366E-09   |                      |
| 3.27168E-07 | 0.0023912         | 0.182780525       | 3.46579E-13 | 0.145592284                | 2.42654E-05      | 1.20768E-09                | 3.66134E-09   |                      |
| 3.27168E-07 | 0.002498132       | 0.189974994       | 3.85567E-13 | 0.17206861                 | 2.86781E-05      | 1.52435E-09                | 5.18568E-09   |                      |
| 3.27168E-07 | 0.002576044       | 0.19547843        | 4.07509E-13 | 0.190024814                | 3.16708E-05      | 1.78349E-09                | 6.96918E-09   |                      |
| 3.27168E-07 | 0.002618622       | 0.198985002       | 4.07908E-13 | 0.195216874                | 3.25361E-05      | 1.92711E-09                | 8.89628E-09   |                      |
| 3.27168E-07 | 0.002626426       | 0.200502259       | 3.87817E-13 | 0.187295019                | 3.12158E-05      | 1.9331E-09                 | 1.08294E-08   |                      |

Figure 37 - NO<sub>x</sub> Calculation Process

## Part 3 – Discussions and Conclusions

### 7.0 Model Analysis

Having understood the construction of the model and what factors influence the production of NO<sub>x</sub> it is possible to analyse the findings and discuss methods for improving the model accuracy as well as methods of reducing NO<sub>x</sub> production.

#### 7.1 NO<sub>x</sub> Results

The steps discussed in 6.2 were carried out for each RPM with relevant adjustments made for each air fuel ratio. Matlab was utilised for certain factors as can be seen the in the Appendix. The increased computing power of Matlab saved time and allowed a higher degree of accuracy to be ensured in reduced time.

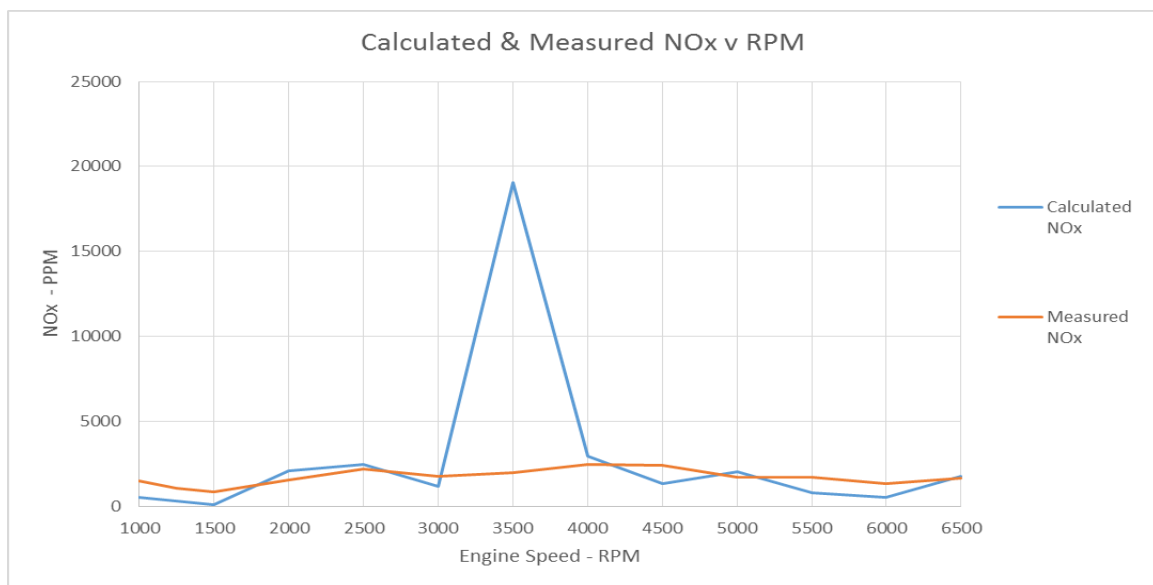


Figure 38 - NO<sub>x</sub> PPM

Looking at Figure 38 and Table 4 there is one apparent issue to be considered before analysing the results. At 3500RPM there is a huge spike in the NO<sub>x</sub>. At spike to just over 19000 PPM which is around 17000PPM greater than the actual data provided by Ford from their dynamometer reading. Throughout the process of constructing the model at 3500RPM, there was no sign of an issues. The PV, delta P's and MFB the data behaved as expected. Despite thorough investigation no apparent issue could be found. For this reason the spike at

| RPM  | PPM NOx Calc | PPM NOx Actual |
|------|--------------|----------------|
| 6500 | 1755.410695  | 1668           |
| 6000 | 527.1629903  | 1335           |
| 5500 | 766.8929196  | 1690           |
| 5000 | 2045.582878  | 1695           |
| 4500 | 1305.665045  | 2404           |
| 4000 | 2925.602498  | 2467           |
| 3500 | 19069.85895  | 1979           |
| 3000 | 1158.051025  | 1787           |
| 2500 | 2476.93802   | 2169           |
| 2000 | 2077.488336  | 1553           |
| 1500 | 89.24674829  | 871            |
| 1250 | 308.4156351  | 1064           |
| 1000 | 535.8977773  | 1518           |

Table 4 - NO<sub>x</sub> PPM Actual v Calculated

3500RPM has been put down as an anomaly and will be disregarded from the analysis as it is clearly not correct.

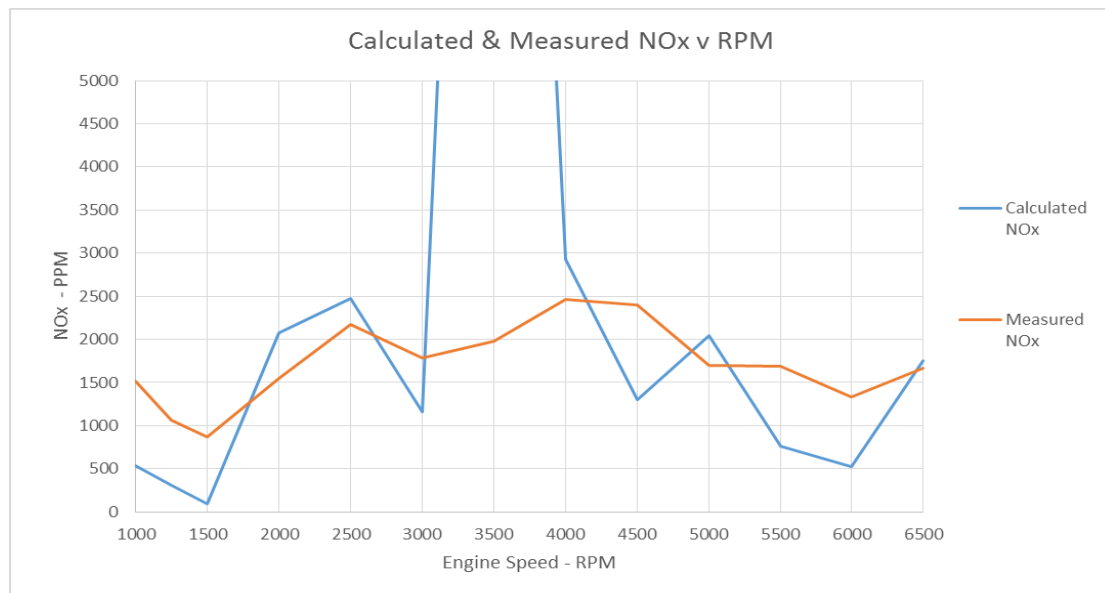


Figure 39 - NOx PPM with reduced Y Axis

Figure 39 shows the NOx PPM with the spike at 3500RPM disregarded. The model answers are not 100% accurate as is to be expected, however promisingly the data does follow the trend. From 1000RPM to 1500RPM it drops before climbing until 2500 and dropping back down at 3000RPM following the measured trend. From 4000RPM to 6000RPM the calculated NOx drops just like the measured NOx. The NOx at 4500, 5500 and 6000 RPM is lower than the measured by around 750PPM. This is however highly accurate when the fact

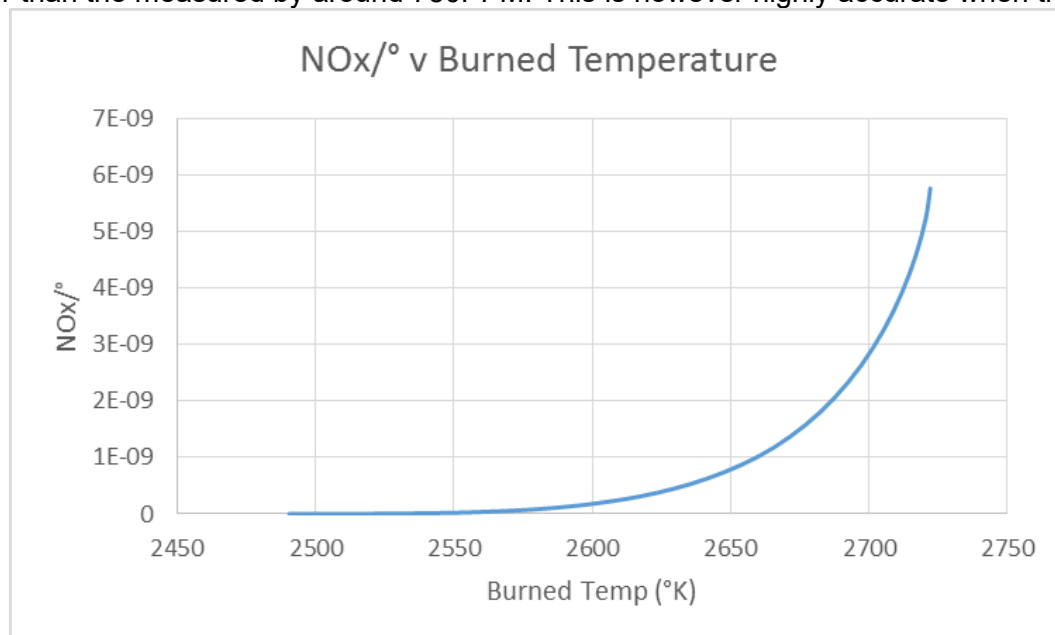


Figure 40 - NOx/degree V Temperature

that these readings were found from just pressure, volume, fuel mass and EGR mass is considered.

Figure 40 shows the relationship between temperature and NO<sub>x</sub> production. As is expected the NO<sub>x</sub> increases with the temperature, with the levels rising drastically over 2600K. This is the point the oxygen and nitrogen dissociating.

## 7.2 Model Discrepancies

In this section any issues with the model will be discussed as well methods to mitigate these issues.

### 7.2.1 Calculating Every Degree

This model has been based on the data provided which gives the pressure and volumes at each degree. For this reason the combustion and the NO<sub>x</sub> have been calculated at every degree. This is not entirely accurate when the combustion is evolving constantly.

For factors such as the concentration of oxygen and nitrogen it is assumed that the oxygen and nitrogen it has fully dissociated in that degree for the given temperature. By calculating the data for every quarter or half degree it would increase the accuracy of the model. This could easily be achieved by using a polynomial to plot the pressure and volume between each degree. It would however increase the computing power required meaning Excel may no longer be a viable tool.

### 7.2.2 Homogenous Mixture

Another potential pitfall of the model is the assumption that the entire mixture is homogenous in the cylinder. Homogenous refers to the entire mixture being identical in that the air and fuel has mixed perfectly throughout. This is highly unlikely and is one of the defining problems with emissions reduction. There will be lack of consistency throughout the combustion with patches of rich and lean, each creating more or less of each emission. This reduces the consistency of emission levels and makes any repeatability in testing difficult. As Budania stated in his work 'The nature of the mixture formation and the followed combustion processes realized in a direct injection engines, indicate a lack of mechanisms for controlling the mixture formation and homogenization of the sequence of process and, hence, do not allow homogeneous combustion. The entire homogenization, however, is necessary for significant reductions of engine emissions in primary combustion' (Budania, 2012).



Figure 41 - Mixture Homogeneity

Figure 41 shows a GDI engine with lean areas and rich areas. This model assumes the entire mixture is perfectly homogenous which would create lower NO<sub>x</sub> emissions. It is impossible to create an accurate model of mixture homogenous without using a different method to the two zone method.

### 7.2.3 Temperature

In continuation to the homogenous issue the temperature is assumed to be constant throughout the burned zone. As the flame front travels it heats the burned zone but not consistently. Rich patches will burn hotter than lean patches. The cylinder walls will have a cooling effect on the burned zone. Carlos Parra carried out work on cylinder wall thermal gradient heat fluxes and found walls can have a noticeable cooling effect on the burned zone. These variations will effect the production of NO<sub>x</sub> because as has been seen even slight temperature changes can cause huge changes in NO<sub>x</sub> levels. Once again the computing power required to analyse the varying temperatures is large and the two zone method is not applicable.

### 7.2.4 Reverse Reactions

As has been discussed, at high temperatures oxygen and nitrogen split back to their base compounds creating oxygen and nitrogen radicals which form the NO<sub>x</sub>. However this process is reversible and they can revert back to O<sub>2</sub> and N<sub>2</sub>. The model does not factor in these reverse reactions which would reduce the levels of NO<sub>x</sub>.

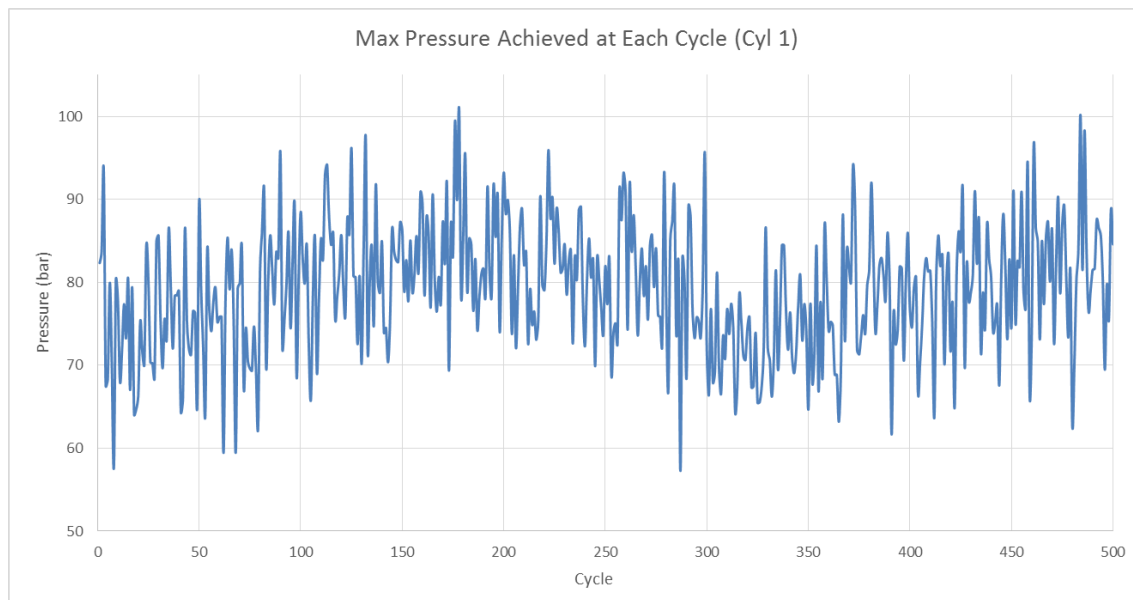


Figure 42 - Cyclic Variation over 500 Cycles

### 7.2.5 Cyclic Variation

Cyclic variation has a major impact on emissions. Cyclic variation is the variation in pressures and rate of pressure change in an engine that may otherwise appear to have identical combustion (Patterson, 1966). This pressure variation is caused by a variety of things however the pressure change causes a better/worse combustion which is warmer/cooler

|       | Max    | Min   | Range |
|-------|--------|-------|-------|
| P Max | 106.71 | 52.08 | 54.63 |
| P Min | 1.56   | 0.7   | 0.86  |

Figure 43 - Cyclic Variation Data

causing an air density drop/increase which changes the level of oxygen for the next combustion. 'It limits the use of lean mixtures, the amount of recycled exhaust and increases the idle speed operation. By eliminating this cyclic variation, the engine power output can be increased by 10 % for the same fuel consumption' (Young, 1981). Figure 42 is a graphical representation of the max pressure variation over 500 cycles which was investigated as an aside to the main project work. Figure 43 shows the max and minimums and the fact there is a range of 54bar. An effective combustion with a max pressure of over 90 bar was usually followed by a max pressure drop of around 15bar. This variation would have an effect on the temperature which is found using the ideal gas law which utilises cylinder pressure. The model does not compensate for cyclic variation, taking the average pressure over the 300 cycles. Although not wholly accurate using the average is the best alternative to using huge amounts of data.

### 7.2.6 Averaging

As mentioned in the previous section the current approach to this model is modelling average of 300 cycles. The ideal method would be calculating NOx for each cycle and taking the average of that. As with most model discrepancies the alternative would involve huge levels of data and computing power.

## 7.3 Model Accuracy Conclusion

Having discussed the model results and the little facets which effect the accuracy it is possible to draw conclusions on the overall viability of the Two Zone method as a means of NOx modelling.

There can be no doubt that the two zone method has many assumptions and does not provide an entirely accurate picture of the combustion composition and temperature. However when this is considered and the calculated NOx is compared with measured NOx it is clear that the two zone method is highly effective. The two zone method is an excellent tool to analyse trends and methods of reducing NOx. The capability to adjust fuelling and EGR makes it useful and means it could be used as an R&D tool to investigate NOx emissions before production. The correlation with measured NOx is reliable.

## 8.0 Methods of Reducing NOx to Meet WLTP

### 8.1 Exhaust Gas Recirculation

As discussed in the emissions legislation car companies have been using various methods, mainly mapping efficiently within the loads the NEDC runs at, to reduce emissions. This cycle beating will be highly difficult under the WLTP legislation and so EGR becomes important throughout the driving range. Exhaust Gas Recirculation (EGR) is a technique used by manufacturers whereby exhaust gas is recirculated into the intake mixture with the aim of reducing the combustion temperature and thus the NOx. EGR gas is mostly an inert dead mass and as a result it effectively dilutes the mixture (Chrysler, 1976). The traditional way to reduce NOx was to retard the ignition which reduces the pressure and temperature. This however reduces the efficiency and MPG so car companies have reverted to using EGR (Flagan, Pollutant Formation and Control in Combustion, 1988).

The effect of EGR can be seen by using the TZNM and increasing the EGR mass further.

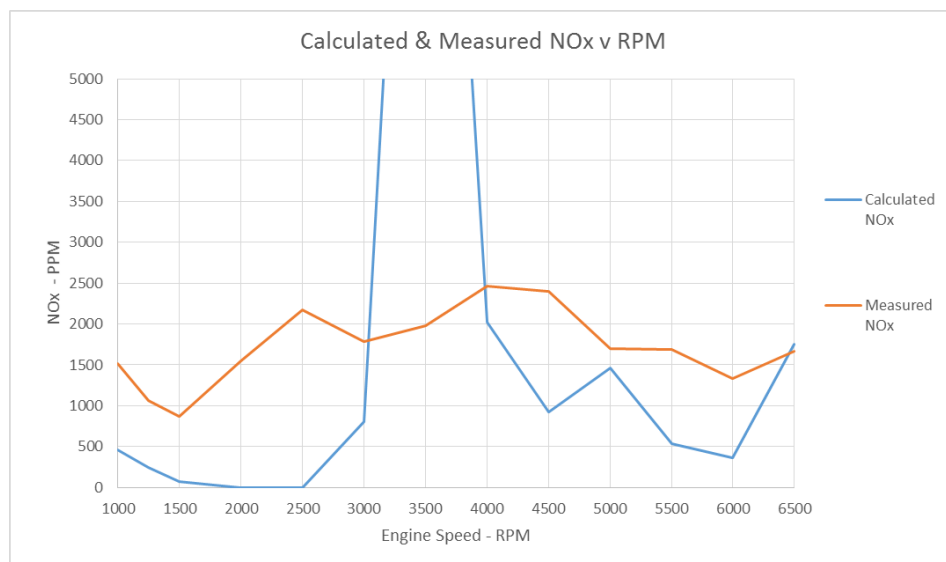


Figure 44 - NOx with 1% EGR Mass Increase

Figure 44 shows a 1% EGR mass increase and the reduction in calculated NOx is clear. As expected the NOx levels dropped with the increase in EGR% as burned zone temperature dropped and thus disassociation levels dropped with fewer radicals forming NOx. A downside to the reduction in combustion temperatures is the increase in soot levels. Soot is formed when fuel droplets have not atomised sufficiently meaning the inner molecules are not exposed to oxygen. This is called pyrolysis. Atomisation is reduced with a temperature drop. Excessive EGR above 25% can cause the engine to reach its misfire limit where the unburnt hydrocarbon levels increase drastically. Increasing EGR also increases the dead mass in the cylinder which slows the flame speed and unfortunately reduces engine power

and can cause misfires which can destroy the catalyst. Utilising EGR alone is clearly not the magic bullet to meeting WLTP targets.

## 8.2 Lean Running

Running lean reduces the temperature of the cylinder and as a result reduces the NO<sub>x</sub> levels. This relationship can be seen in Figure X. One of the issues of running lean is the reduced flame speed and as a result the reduced power. In an ideal world engines would run lean with EGR to reduce the NO<sub>x</sub> levels without causing excessive soot. Running lean while maintaining power is difficult. Homogenous Charge Compression Ignition (HCCI) overcomes these issues by utilising a pre chamber that is rich and is ignited by the compression increasing the temperature (Budania, 2012). The rich chamber detonates under the pressure and these explosion creates multiple points of ignition in the main combustion chamber which is lean. Despite being lean the multiple ignition points overcome the slow flame speed meaning it provides necessary power while keeping emissions low. The lower temperatures mean no NO<sub>x</sub> and power (Dunn-Rankin, 2007). The rapid combustion also increases gamma giving a colder exhaust which will help with reverse reactions. This technology is currently under development but could present a cleaner future for the automotive industry with an internal combustion engine. This engine would theoretically pass the WLTP.

## 9.0 Recommended Further Work

Any potential further work would involve covering the issues discussed in 7.2. Further developing the model and improving its accuracy would involve measuring at every quarter or half degree. There is also the potential to utilise a different method of measurement. The literature review did reveal many multi-zone NO<sub>x</sub> models which were not discussed in this report. An interesting avenue of work could be to compare the two zone model results with a multi zone model results.

## 10.0 Final Conclusion

This project has provided an interesting perspective on the need for NO<sub>x</sub> reduction. The research carried out has shed light on the reasons to reduce NO<sub>x</sub>, how previous legislation allows manufacturers to avoid any real reduction in NO<sub>x</sub> and also how future legislation will be stricter. The model itself is a well-constructed and is an accurate model overall. The model does provide the accuracy required to predict trends and rough figures for NO<sub>x</sub> production. At the start of this project the aim was to understand the pitfalls of the two zone model method and decide whether it is a reliable method. Overall the author concludes that for the NO<sub>x</sub> application the two zone method is reliable, with this investigation providing accurate correlation with measured data. The pitfalls have been understood and the overwhelming conclusion is that without increased computing power and increased data analysis the method cannot be improved. Methods of reducing NO<sub>x</sub> to meet future legislation have been discussed and there are avenues for reducing NO<sub>x</sub> whilst still using the internal combustion engine.

## 11.0 Evaluation

Overall I feel this project has been a success. I have enjoyed creating the model and gaining further insight into the factors which influence the creation of NO<sub>x</sub> as well as potential methods for redesigning/calibrating engines for the reduction. If I was to repeat this work I would focus on carrying out a larger amount on Matlab which would allow more data to be used. This would reduce time and allow for engine comparison and potentially developing the model to include the flame front and analyse the mixture homogeneity. I feel as a whole the project has been a success.

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## 13.0 Appendices

The following section contains the appendices. This includes any data collected during the investigation and any graphs created that were not included in the report. They are ordered as follows –

- Matlab Codes
- Dissociation Data (1000RPM-6500RPM)
- Comparison Tables not included in Report
- Graphs not included in the report
- Specific Heat Data and Graphs
- Combustion Data (1000RPM-6500RPM). The end of combustion is cropped in some circumstances to fit on the page
- Chemistry, EGR & Mass Data (1000RPM-6000RPM)

Any additional data is available on request.

### Matlab Code to Calculate Concentration of each Element

```
clc
clear all

TB=input ('Please enter a matrix of burnt temperatures - ');
KCO2=input ('Enter the CO2 Constant matrix - ');
KH2O=input ('Enter the H2O Constant matrix - ');
P=input ('Enter the cylinder pressure matrix - ');
[R,C]=size(TB);
MX=zeros(R,C);

C=input ('Enter a matrix of Carbon in the mixture - ');
H=input ('Enter a matrix of Hydrogen in the mixture - ');
O=input ('Enter a matrix of Oxygen in the mixture - ');
Ni=45.6276;
N6=Ni;

for n=1:R;
    KC=KCO2(n,:);
    KH=KH2O(n,:);
    Pr=P(n,:);
    Ini=0.0000000000000001;
    G=Ini;
    NP=100;
    NT=0;
while (NP-G)>NP*0.0001 && G<1
    G=G+0.000000000001;
    N5NT=(G);
    N5NTP=N5NT*P
    N5NTPP=power(N5NTP,0.5)
    N1N3=KC*N5NTPP
    N3=(C/(N1N3+1));
    N1=C-N3;
    N2N4=KH*N5NTPP
    N4=(H/2)/(N2N4+1);
    N2=(H/2)-N4;
    N5=(O-(2*N1)-N2-N3)/2;
    NT=N1+N2+N3+N4+N5+N6;
    z=N5/NT;
end

MX(n,1) = (guess);
M1(n,1)=(N1);
M2(n,1)=(N2);
M3(n,1)=(N3);
M4(n,1)=(N4);
M5(n,1)=(NP*NT);
M6(n,1)=(N6);

disp(['Result' num2str(n) ' is ' num2str(M5(n,1))])
disp([num2str(M1(n,1))])
disp([num2str(M2(n,1))])
disp([num2str(M3(n,1))])
disp([num2str(M4(n,1))])
disp([num2str(M5(n,1))])
disp([num2str(M6(n,1))])
NP*NT;
N5=NT*NP;
end
```

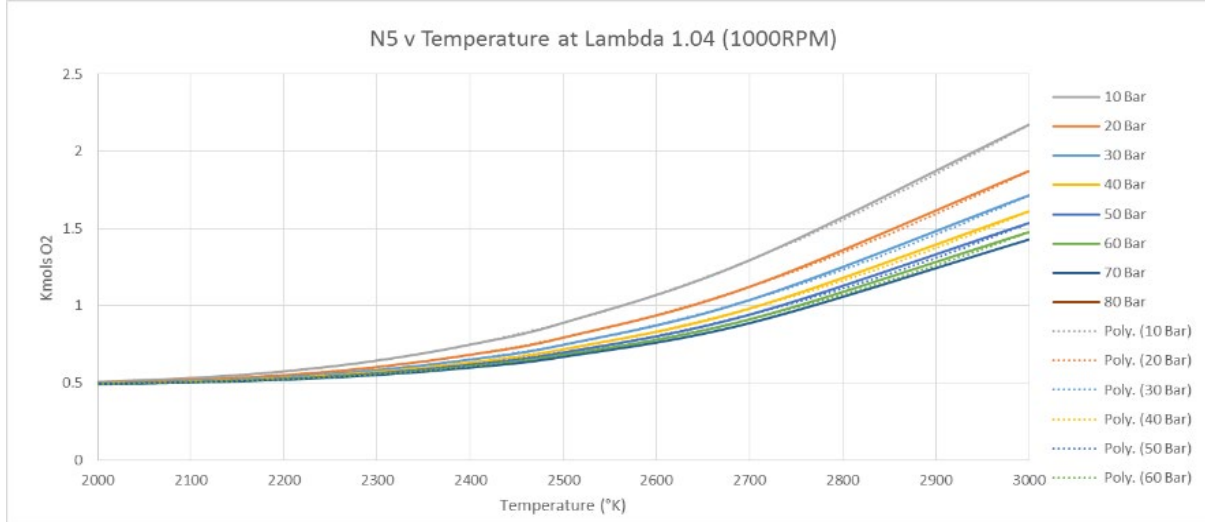
### Matlab Code to Complete Polynomials

```
clear all

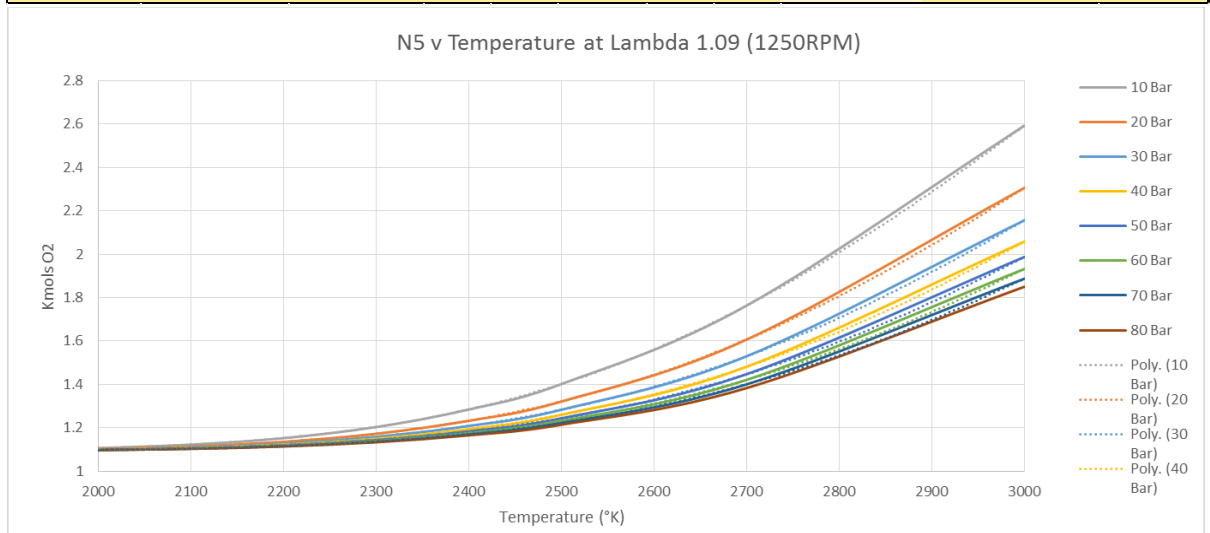
CP=input('Please enter a matrix of cylinder pressure - ');
TB=input('Please enter a matrix of burned zone temperatures - ');
[R,C]=size(TB);
for CP>20 || <=30
    a=-0.000000000000000005093007690130
    b=0.00000000000000071391932838887800
    c=0.000000000414154748747072000000
    d=0.000001274143779710160000000000
    e=0.002194385105910170000000000000
    f=2.007280860434420000000000000000
    g=762.284841894628000000000000000000
else
    for CP>=30 || CP<40
        a=-0.00000000000000004391083884110
        b=0.000000000000006220058316489200
        c=0.000000000364582964312167000000
        d=0.0000011331029997518500000000
        e=0.0019710634688252900000000000
        f=1.8207274432425100000000000000
        g=698.0868268292920000000000000000
    end
    for CP>=40 || CP<50
        a=-0.00000000000000003607094300446
        b=0.0000000000000051420889260964800
        c=0.000000000303191389172476000000
        d=0.000000947564473847477000000000
        e=0.0016569986678445500000000000
        f=1.5382489232325400000000000000
        g=592.5711265033060000000000000000
    end
end

N5I=((a*(power(TB,6)))+(b*(power(TB,5)))+(c*(power(TB,4)))-
(d*(power(TB,3)))+(e*(power(TB,2)))-(f*TB)+g)
disp(N5I)
end
```

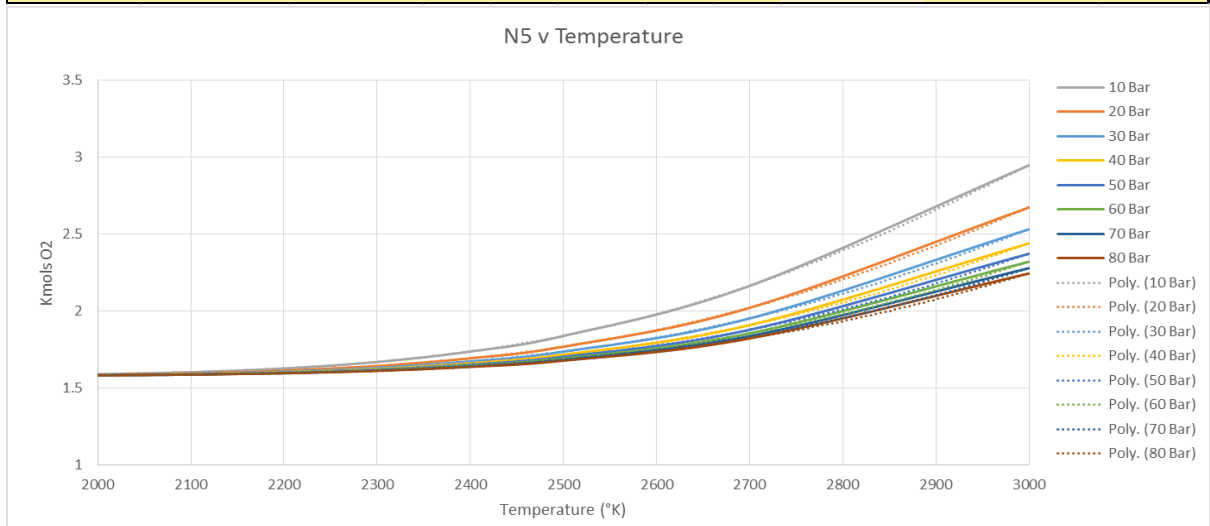
| Lambda 1.04 (1000RPM) |                 |               |                |           |                  |               |         |                          |             |             |             |
|-----------------------|-----------------|---------------|----------------|-----------|------------------|---------------|---------|--------------------------|-------------|-------------|-------------|
| Pressure (Bar)        | Temperature (K) | N5/NT (Guess) | N3<br>C/(<-+1) | N1<br>C-< | N4<br>H/2x(<-+1) | N2<br>(H/2)-< | N6<br>N | N5<br>(Ox2)-2N1-N2-N3)/2 | NT<br>Total | Calc N5/NT  | Calc/Guess  |
| 10                    | 2000            | 8.24E-03      | 0.03591        | 7.89369   | 0.007466548      | 7.432533      | 45.6276 | 0.507088256              | 61.50429    | 0.008244763 | 1.000119266 |
| 10                    | 2100            | 0.008637471   | 0.077234       | 7.852366  | 0.014979326      | 7.425021      | 45.6276 | 0.531506481              | 61.52871    | 0.00863835  | 1.000101756 |
| 10                    | 2200            | 0.009329018   | 0.151341       | 7.778259  | 0.027735425      | 7.412265      | 45.6276 | 0.574938409              | 61.57214    | 0.009337639 | 1.000924151 |
| 10                    | 2300            | 0.010464361   | 0.271797       | 7.657803  | 0.047526174      | 7.392474      | 45.6276 | 0.64506158               | 61.64226    | 0.0104646   | 1.000022788 |
| 10                    | 2400            | 0.012117379   | 0.449962       | 7.479638  | 0.076250246      | 7.36375       | 45.6276 | 0.74850599               | 61.74571    | 0.012122397 | 1.000414121 |
| 10                    | 2500            | 0.014371237   | 0.693063       | 7.236537  | 0.115358715      | 7.324641      | 45.6276 | 0.889610684              | 61.88681    | 0.014374803 | 1.000248133 |
| 10                    | 2700            | 0.020785116   | 1.386514       | 6.543086  | 0.232233087      | 7.207767      | 45.6276 | 1.294773322              | 62.29197    | 0.020785556 | 1.000021173 |
| 10                    | 3000            | 0.034391296   | 2.840605       | 5.088995  | 0.534532403      | 6.905468      | 45.6276 | 2.172968505              | 63.17017    | 0.03439865  | 1.000213823 |
| 20                    | 2000            | 0.008139336   | 0.025588       | 7.904012  | 0.005314951      | 7.434685      | 45.6276 | 0.50085147               | 61.49805    | 0.008144184 | 1.000595618 |
| 20                    | 2100            | 0.008425457   | 0.055449       | 7.874151  | 0.010730557      | 7.429269      | 45.6276 | 0.518489621              | 61.51569    | 0.008428575 | 1.000370099 |
| 20                    | 2200            | 0.008941973   | 0.109889       | 7.819711  | 0.020052615      | 7.419947      | 45.6276 | 0.550370571              | 61.54757    | 0.008942198 | 1.000025145 |
| 20                    | 2300            | 0.009789963   | 0.200548       | 7.729052  | 0.034804102      | 7.405196      | 45.6276 | 0.603075865              | 61.60028    | 0.009790149 | 1.000018964 |
| 20                    | 2400            | 0.011065881   | 0.337931       | 7.591669  | 0.056571365      | 7.383429      | 45.6276 | 0.682651394              | 61.67985    | 0.011067656 | 1.000160399 |
| 20                    | 2500            | 0.012844574   | 0.530053       | 7.399547  | 0.086621004      | 7.353379      | 45.6276 | 0.793736852              | 61.79094    | 0.012845522 | 1.000073793 |
| 20                    | 2700            | 0.018074016   | 1.097772       | 6.831828  | 0.177438194      | 7.262562      | 45.6276 | 1.123005251              | 62.12021    | 0.018077939 | 1.000217046 |
| 20                    | 3000            | 0.029771912   | 2.361896       | 5.567704  | 0.413365496      | 7.026635      | 45.6276 | 1.87303077               | 62.87023    | 0.029792014 | 1.000675202 |
| 30                    | 2000            | 0.008096524   | 0.02096        | 7.90864   | 0.004351661      | 7.435648      | 45.6276 | 0.498055798              | 61.49526    | 0.008099093 | 1.00031724  |
| 30                    | 2100            | 0.008332239   | 0.045583       | 7.884017  | 0.008812612      | 7.431187      | 45.6276 | 0.51259793               | 61.5098     | 0.008333598 | 1.000163122 |
| 30                    | 2200            | 0.008756291   | 0.09089        | 7.83871   | 0.016553383      | 7.423447      | 45.6276 | 0.539121804              | 61.53632    | 0.008761034 | 1.000541696 |
| 30                    | 2300            | 0.009471774   | 0.167193       | 7.762407  | 0.028913787      | 7.411086      | 45.6276 | 0.583453172              | 61.58065    | 0.009474618 | 1.000300233 |
| 30                    | 2400            | 0.010554976   | 0.284507       | 7.645093  | 0.047354062      | 7.392646      | 45.6276 | 0.651330501              | 61.64853    | 0.010565223 | 1.000970879 |
| 30                    | 2500            | 0.012097385   | 0.450732       | 7.478868  | 0.073012077      | 7.366988      | 45.6276 | 0.747271971              | 61.74447    | 0.012102654 | 1.000435569 |
| 30                    | 2700            | 0.016706661   | 0.952157       | 6.977443  | 0.151233559      | 7.288766      | 45.6276 | 1.037095251              | 62.0343     | 0.016718095 | 1.000684426 |
| 30                    | 3000            | 0.027352083   | 2.104862       | 5.824738  | 0.355047398      | 7.084953      | 45.6276 | 1.715354588              | 62.71255    | 0.027352651 | 1.000020742 |
| 40                    | 2000            | 0.008071624   | 0.018186       | 7.911414  | 0.00377475       | 7.436225      | 45.6276 | 0.49638047               | 61.49358    | 0.00807207  | 1.00005518  |
| 40                    | 2100            | 0.008276198   | 0.03964        | 7.88996   | 0.00765893       | 7.432341      | 45.6276 | 0.509049235              | 61.50625    | 0.008276382 | 1.000022268 |
| 40                    | 2200            | 0.008649984   | 0.079312       | 7.850288  | 0.014427602      | 7.425572      | 45.6276 | 0.532270014              | 61.52947    | 0.008650652 | 1.000077209 |
| 40                    | 2300            | 0.009280272   | 0.146666       | 7.782934  | 0.025309414      | 7.414691      | 45.6276 | 0.571387766              | 61.56859    | 0.009280508 | 1.000025431 |
| 40                    | 2400            | 0.010250534   | 0.251114       | 7.678486  | 0.04164649       | 7.398354      | 45.6276 | 0.631780458              | 61.62898    | 0.010251353 | 1.000079894 |
| 40                    | 2500            | 0.011634266   | 0.400701       | 7.528899  | 0.064550574      | 7.375449      | 45.6276 | 0.718025921              | 61.71523    | 0.011634502 | 1.000020256 |
| 40                    | 2700            | 0.015842068   | 0.858198       | 7.071402  | 0.13480179       | 7.305198      | 45.6276 | 0.981899704              | 61.9791     | 0.015842433 | 1.000022987 |
| 40                    | 3000            | 0.025741361   | 1.934113       | 5.995487  | 0.318585309      | 7.121415      | 45.6276 | 1.611748945              | 62.60895    | 0.025743108 | 1.000067877 |
| 50                    | 2000            | 0.008050494   | 0.016291       | 7.913309  | 0.003380846      | 7.436619      | 45.6276 | 0.495236151              | 61.49244    | 0.008053611 | 1.000387149 |
| 50                    | 2100            | 0.008235648   | 0.03556        | 7.89404   | 0.00686793       | 7.433132      | 45.6276 | 0.506614083              | 61.50381    | 0.008237117 | 1.000178252 |
| 50                    | 2200            | 0.008570956   | 0.071338       | 7.858262  | 0.012966347      | 7.427034      | 45.6276 | 0.527552113              | 61.52475    | 0.008574632 | 1.000428931 |
| 50                    | 2300            | 0.009144335   | 0.132396       | 7.797204  | 0.022812747      | 7.417187      | 45.6276 | 0.56300434               | 61.5602     | 0.009145589 | 1.000137169 |
| 50                    | 2400            | 0.01002889    | 0.227763       | 7.701837  | 0.037679319      | 7.402321      | 45.6276 | 0.618120919              | 61.61532    | 0.010031935 | 1.000303677 |
| 50                    | 2500            | 0.011302864   | 0.365323       | 7.564277  | 0.058623162      | 7.381377      | 45.6276 | 0.697373046              | 61.69457    | 0.011303637 | 1.000068366 |
| 50                    | 2700            | 0.015213856   | 0.790753       | 7.138847  | 0.123229412      | 7.316771      | 45.6276 | 0.942391421              | 61.93959    | 0.015214686 | 1.000054533 |
| 50                    | 3000            | 0.024558229   | 1.808276       | 6.121324  | 0.292791294      | 7.147209      | 45.6276 | 1.535933853              | 62.53313    | 0.02456192  | 1.00015032  |
| 60                    | 2000            | 0.008039707   | 0.014885       | 7.914715  | 0.003088468      | 7.436912      | 45.6276 | 0.494386542              | 61.49159    | 0.008039905 | 1.000024731 |
| 60                    | 2100            | 0.008202102   | 0.032541       | 7.897059  | 0.006282836      | 7.433717      | 45.6276 | 0.504811751              | 61.50201    | 0.008208053 | 1.000725551 |
| 60                    | 2200            | 0.008517594   | 0.065376       | 7.864224  | 0.011875365      | 7.428125      | 45.6276 | 0.524025439              | 61.52123    | 0.008517799 | 1.000024047 |
| 60                    | 2300            | 0.009040523   | 0.121719       | 7.807881  | 0.020949581      | 7.41905       | 45.6276 | 0.556734182              | 61.55393    | 0.009044656 | 1.000457217 |
| 60                    | 2400            | 0.009858918   | 0.210181       | 7.719419  | 0.034705528      | 7.405294      | 45.6276 | 0.607843323              | 61.60504    | 0.009866779 | 1.000797324 |
| 60                    | 2500            | 0.011050745   | 0.338473       | 7.591127  | 0.054155165      | 7.385845      | 45.6276 | 0.681713924              | 61.67891    | 0.011052625 | 1.000170123 |
| 60                    | 2700            | 0.014730742   | 0.738924       | 7.190676  | 0.114459368      | 7.325541      | 45.6276 | 0.91209146               | 61.90929    | 0.014732707 | 1.000133433 |
| 60                    | 3000            | 0.023633727   | 1.709776       | 6.219824  | 0.273204891      | 7.166795      | 45.6276 | 1.476890669              | 62.47409    | 0.023640051 | 1.000267553 |
| 70                    | 2000            | 0.008028365   | 0.013792       | 7.915808  | 0.002861472      | 7.437139      | 45.6276 | 0.493726791              | 61.49093    | 0.008029262 | 1.000111738 |
| 70                    | 2100            | 0.008184864   | 0.030168       | 7.899432  | 0.005823258      | 7.434177      | 45.6276 | 0.503395415              | 61.5006     | 0.008185212 | 1.000042552 |
| 70                    | 2200            | 0.008472616   | 0.060722       | 7.868878  | 0.011024858      | 7.428975      | 45.6276 | 0.521273587              | 61.51847    | 0.008473448 | 1.000098221 |
| 70                    | 2300            | 0.008964805   | 0.113287       | 7.816313  | 0.019481134      | 7.420519      | 45.6276 | 0.551783966              | 61.54898    | 0.008964957 | 1.000016866 |
| 70                    | 2400            | 0.009734973   | 0.19618        | 7.73342   | 0.03234528       | 7.407655      | 45.6276 | 0.5996626                | 61.59686    | 0.009735278 | 1.000031397 |
| 70                    | 2500            | 0.010849526   | 0.317146       | 7.612454  | 0.050624929      | 7.389375      | 45.6276 | 0.669285393              | 61.66649    | 0.010853309 | 1.00034863  |
| 70                    | 2700            | 0.01434234    | 0.697323       | 7.232277  | 0.10749614       | 7.332504      | 45.6276 | 0.887809375              | 61.88501    | 0.014346114 | 1.000263144 |
| 70                    | 3000            | 0.022881066   | 1.629527       | 6.300073  | 0.257623934      | 7.182376      | 45.6276 | 1.428975277              | 62.42618    | 0.022890643 | 1.000418532 |



| Lambda 1.09 (1250RPM) |                 |               |               |           |                 |               |         |                          |             |             |             |  |
|-----------------------|-----------------|---------------|---------------|-----------|-----------------|---------------|---------|--------------------------|-------------|-------------|-------------|--|
| Pressure (Bar)        | Temperature (K) | N5/NT (Guess) | N3<br>C/(←+1) | N1<br>C-← | N4<br>H/2x(←+1) | N2<br>(H/2)-← | N6<br>N | N5<br>(Ox2)-2N1-N2-N3)/2 | NT<br>Total | Calc N5/NT  | Calc/Guess  |  |
| 10                    | 2000            | 1.80E-02      | 0.023043      | 7.493557  | 0.004785767     | 7.047714      | 45.6276 | 1.106064493              | 61.30276    | 0.018042653 | 1.000033544 |  |
| 10                    | 2100            | 0.018301629   | 0.050449      | 7.466151  | 0.009760782     | 7.042739      | 45.6276 | 1.122254807              | 61.31895    | 0.018301923 | 1.000016057 |  |
| 10                    | 2200            | 0.018772253   | 0.101704      | 7.414896  | 0.018554219     | 7.033946      | 45.6276 | 1.152279356              | 61.34898    | 0.018782372 | 1.000539033 |  |
| 10                    | 2300            | 0.019599079   | 0.190012      | 7.326588  | 0.03297534      | 7.019525      | 45.6276 | 1.20364361               | 61.40034    | 0.019603206 | 1.000210613 |  |
| 10                    | 2400            | 0.020889794   | 0.329305      | 7.187295  | 0.055183724     | 6.997316      | 45.6276 | 1.284394147              | 61.48109    | 0.02089088  | 1.000051976 |  |
| 10                    | 2500            | 0.022740178   | 0.531797      | 6.984803  | 0.087207442     | 6.965293      | 45.6276 | 1.401652281              | 61.59835    | 0.022754704 | 1.00063878  |  |
| 10                    | 2700            | 0.028435047   | 1.15292       | 6.36368   | 0.189066271     | 6.863434      | 45.6276 | 1.763142996              | 61.95984    | 0.028456221 | 1.000744647 |  |
| 10                    | 3000            | 0.041297894   | 2.536663      | 4.979937  | 0.46530907      | 6.587191      | 45.6276 | 2.593136278              | 62.78984    | 0.041298663 | 1.000018628 |  |
| 20                    | 2000            | 0.017977045   | 0.016338      | 7.500262  | 0.003390832     | 7.049109      | 45.6276 | 1.102014444              | 61.29871    | 0.017977774 | 1.000040574 |  |
| 20                    | 2100            | 0.018162188   | 0.035879      | 7.480721  | 0.006931143     | 7.045569      | 45.6276 | 1.113555206              | 61.31026    | 0.018162626 | 1.000024082 |  |
| 20                    | 2200            | 0.01849404    | 0.072738      | 7.443862  | 0.013228138     | 7.039272      | 45.6276 | 1.135133017              | 61.33183    | 0.018508056 | 1.00075789  |  |
| 20                    | 2300            | 0.019098979   | 0.13709       | 7.37951   | 0.023651762     | 7.028848      | 45.6276 | 1.172520646              | 61.36922    | 0.019106005 | 1.000367893 |  |
| 20                    | 2400            | 0.020059328   | 0.240559      | 7.276041  | 0.039907269     | 7.012593      | 45.6276 | 1.23238305               | 61.42908    | 0.020061883 | 1.000127373 |  |
| 20                    | 2500            | 0.021476953   | 0.394542      | 7.122058  | 0.06366701      | 6.988833      | 45.6276 | 1.321254373              | 61.51795    | 0.021477541 | 1.000027385 |  |
| 20                    | 2700            | 0.025994211   | 0.888132      | 6.628468  | 0.140809055     | 6.911691      | 45.6276 | 1.606620546              | 61.80332    | 0.025995699 | 1.000057265 |  |
| 20                    | 3000            | 0.036894336   | 2.07402       | 5.44258   | 0.353988132     | 6.698512      | 45.6276 | 2.30615413               | 62.50285    | 0.036896781 | 1.000066729 |  |
| 30                    | 2000            | 0.017948138   | 0.013356      | 7.503244  | 0.002771075     | 7.049729      | 45.6276 | 1.100213544              | 61.29691    | 0.017948922 | 1.000043679 |  |
| 30                    | 2100            | 0.018099895   | 0.029371      | 7.487229  | 0.00567         | 7.04683       | 45.6276 | 1.109670599              | 61.30637    | 0.018100413 | 1.000028566 |  |
| 30                    | 2200            | 0.018367051   | 0.0597        | 7.4569    | 0.010841677     | 7.041658      | 45.6276 | 1.127420631              | 61.32412    | 0.01838462  | 1.000956528 |  |
| 30                    | 2300            | 0.018870562   | 0.112976      | 7.403624  | 0.019439751     | 7.03306       | 45.6276 | 1.158358122              | 61.35506    | 0.018879586 | 1.00047824  |  |
| 30                    | 2400            | 0.019674343   | 0.199448      | 7.317152  | 0.032934122     | 7.019566      | 45.6276 | 1.20834128               | 61.40504    | 0.01967821  | 1.000196528 |  |
| 30                    | 2500            | 0.020874289   | 0.329733      | 7.186867  | 0.052810878     | 6.999689      | 45.6276 | 1.283421748              | 61.48012    | 0.020875394 | 1.000052902 |  |
| 30                    | 2700            | 0.024781204   | 0.757346      | 6.759254  | 0.11813657      | 6.934363      | 45.6276 | 1.529891513              | 61.72659    | 0.024784967 | 1.000151823 |  |
| 30                    | 3000            | 0.034583367   | 1.828121      | 5.688479  | 0.300896995     | 6.751603      | 45.6276 | 2.156658931              | 62.35336    | 0.034587695 | 1.000125128 |  |
| 40                    | 2000            | 0.017930874   | 0.011575      | 7.505025  | 0.002401102     | 7.050099      | 45.6276 | 1.099138031              | 61.29584    | 0.017931691 | 1.000045553 |  |
| 40                    | 2100            | 0.018062606   | 0.025476      | 7.491124  | 0.004915956     | 7.047584      | 45.6276 | 1.107345825              | 61.30405    | 0.018063177 | 1.000031609 |  |
| 40                    | 2200            | 0.018309903   | 0.051837      | 7.464763  | 0.009405727     | 7.043094      | 45.6276 | 1.122771153              | 61.31947    | 0.01831019  | 1.000015669 |  |
| 40                    | 2300            | 0.018732239   | 0.098394      | 7.418206  | 0.016903456     | 7.035597      | 45.6276 | 1.149798977              | 61.3465     | 0.018742699 | 1.000558394 |  |
| 40                    | 2400            | 0.019439317   | 0.174364      | 7.342236  | 0.028710948     | 7.023789      | 45.6276 | 1.193687544              | 61.39039    | 0.019444209 | 1.00025165  |  |
| 40                    | 2500            | 0.020502463   | 0.289738      | 7.226862  | 0.046192059     | 7.006308      | 45.6276 | 1.260115043              | 61.45682    | 0.020504073 | 1.000078526 |  |
| 40                    | 2700            | 0.024012772   | 0.674463      | 6.842137  | 0.104143114     | 6.948357      | 45.6276 | 1.481453185              | 61.67815    | 0.024019091 | 1.000263146 |  |
| 40                    | 3000            | 0.033063661   | 1.665471      | 5.851129  | 0.267811763     | 6.784688      | 45.6276 | 2.058791584              | 62.25549    | 0.03307004  | 1.000192931 |  |
| 50                    | 2000            | 0.017919069   | 0.010358      | 7.506242  | 0.002148395     | 7.050352      | 45.6276 | 1.098403222              | 61.2951     | 0.017919918 | 1.000047377 |  |
| 50                    | 2100            | 0.018037087   | 0.02281       | 7.49379   | 0.004400396     | 7.0481        | 45.6276 | 1.105755388              | 61.30246    | 0.018037701 | 1.000034054 |  |
| 50                    | 2200            | 0.018258986   | 0.046462      | 7.470138  | 0.008425632     | 7.044074      | 45.6276 | 1.119593853              | 61.31629    | 0.01825932  | 1.000018305 |  |
| 50                    | 2300            | 0.018636803   | 0.088351      | 7.428249  | 0.015161325     | 7.037339      | 45.6276 | 1.143906271              | 61.34061    | 0.018648434 | 1.000624109 |  |
| 50                    | 2400            | 0.019276296   | 0.156985      | 7.359615  | 0.025798904     | 7.026701      | 45.6276 | 1.18354186               | 61.38024    | 0.019282131 | 1.000302679 |  |
| 50                    | 2500            | 0.020242829   | 0.261814      | 7.254786  | 0.041606757     | 7.010893      | 45.6276 | 1.243860346              | 61.44056    | 0.020244938 | 1.000104177 |  |
| 50                    | 2700            | 0.023465833   | 0.615506      | 6.901094  | 0.094360392     | 6.95814       | 45.6276 | 1.447083426              | 61.64378    | 0.023474929 | 1.000387615 |  |
| 50                    | 3000            | 0.031953022   | 1.546199      | 5.970401  | 0.244502679     | 6.807997      | 45.6276 | 1.987501041              | 62.1842     | 0.031961511 | 1.000265677 |  |
| 60                    | 2000            | 0.017910358   | 0.009459      | 7.507141  | 0.001961737     | 7.050538      | 45.6276 | 1.097860365              | 61.29456    | 0.01791122  | 1.000048161 |  |
| 60                    | 2100            | 0.018018208   | 0.020839      | 7.495761  | 0.004019315     | 7.048481      | 45.6276 | 1.104579316              | 61.30128    | 0.018018862 | 1.000036314 |  |
| 60                    | 2200            | 0.018221268   | 0.04248       | 7.47412   | 0.007700264     | 7.04448       | 45.6276 | 1.117240323              | 61.31394    | 0.018221636 | 1.000020196 |  |
| 60                    | 2300            | 0.018565773   | 0.080889      | 7.435711  | 0.013869329     | 7.038631      | 45.6276 | 1.139528952              | 61.33623    | 0.018578399 | 1.000680086 |  |
| 60                    | 2400            | 0.019154512   | 0.144015      | 7.372585  | 0.023633102     | 7.028867      | 45.6276 | 1.175974087              | 61.37267    | 0.0191612   | 1.000349145 |  |
| 60                    | 2500            | 0.020047918   | 0.240855      | 7.275745  | 0.038184417     | 7.014316      | 45.6276 | 1.231669789              | 61.42837    | 0.020050504 | 1.000129028 |  |
| 60                    | 2700            | 0.023049059   | 0.570622      | 6.945978  | 0.087006017     | 6.965494      | 45.6276 | 1.420964225              | 61.61766    | 0.023060988 | 1.000517552 |  |
| 60                    | 3000            | 0.031089238   | 1.453236      | 6.063364  | 0.226865058     | 6.825635      | 45.6276 | 1.932200301              | 62.1289     | 0.031099863 | 1.000341766 |  |
| 70                    | 2000            | 0.017903576   | 0.00876       | 7.50784   | 0.001816596     | 7.050683      | 45.6276 | 1.097438198              | 61.29414    | 0.017904456 | 1.000049152 |  |
| 70                    | 2100            | 0.01800353    | 0.019305      | 7.497295  | 0.003722835     | 7.048777      | 45.6276 | 1.103664054              | 61.30036    | 0.018004201 | 1.000037269 |  |
| 70                    | 2200            | 0.018191869   | 0.039377      | 7.477223  | 0.007135389     | 7.045365      | 45.6276 | 1.115406345              | 61.31211    | 0.018192269 | 1.000022    |  |
| 70                    | 2300            | 0.018510072   | 0.07506       | 7.44154   | 0.01286165      | 7.039638      | 45.6276 | 1.136110653              | 61.33281    | 0.018523701 | 1.000736292 |  |
| 70                    | 2400            | 0.019059095   | 0.13385       | 7.38275   | 0.021939986     | 7.03056       | 45.6276 | 1.170044837              | 61.36674    | 0.019066431 | 1.00038493  |  |
| 70                    | 2500            | 0.019894424   | 0.224355      | 7.292245  | 0.035501589     | 7.016998      | 45.6276 | 1.222078182              | 61.41878    | 0.019897468 | 1.000153008 |  |
| 70                    | 2700            | 0.022716801   | 0.534881      | 6.981719  | 0.081206419     | 6.971294      | 45.6276 | 1.400193871              | 61.59689    | 0.022731566 | 1.000649986 |  |
| 70                    | 3000            | 0.03038915    | 1.377779      | 6.138821  | 0.212877163     | 6.839623      | 45.6276 | 1.887478227              | 62.08418    | 0.03040192  | 1.000420213 |  |
| 80                    | 2000            | 0.017898103   | 0.008196      | 7.508404  | 0.001699558     | 7.0508        | 45.6276 | 1.097097734              | 61.2938     | 0.017899001 | 1.000050134 |  |
| 80                    | 2100            | 0.017991675   | 0.018067      | 7.498533  | 0.003483659     | 7.049016      | 45.6276 | 1.10292551               | 61.29963    | 0.017992369 | 1.000038598 |  |
| 80                    | 2200            | 0.018168117   | 0.036871      | 7.479729  | 0.006679339     | 7.045821      | 45.6276 | 1.113924929              | 61.31062    | 0.018168546 | 1.000023638 |  |
| 80                    | 2300            | 0.018464683   | 0.070343      | 7.446257  | 0.012047144     | 7.040453      | 45.6276 | 1.133344913              | 61.33004    | 0.01847944  | 1.000799228 |  |
| 80                    | 2400            | 0.018981556   | 0.125601      | 7.390999  | 0.020568863     | 7.031931      | 45.6276 | 1.165234717              | 61.36193    | 0.018989537 | 1.000420476 |  |
| 80                    | 2500            | 0.019769363   | 0.210915      | 7.305685  | 0.033323908     | 7.019176      | 45.6276 | 1.214269667              | 61.41097    | 0.019772846 | 1.000176205 |  |
| 80                    | 2700            | 0.022443257   | 0.505494      | 7.011106  | 0.076475034     | 6.976025      | 45.6276 | 1.38313467               | 61.57983    | 0.022460838 | 1.000783326 |  |
| 80                    | 3000            | 0.029804787   | 1.314733      | 6.201867  | 0.201408134     | 6.851092      | 45.6276 | 1.850220421              | 62.04692    | 0.029819698 | 1.000500292 |  |

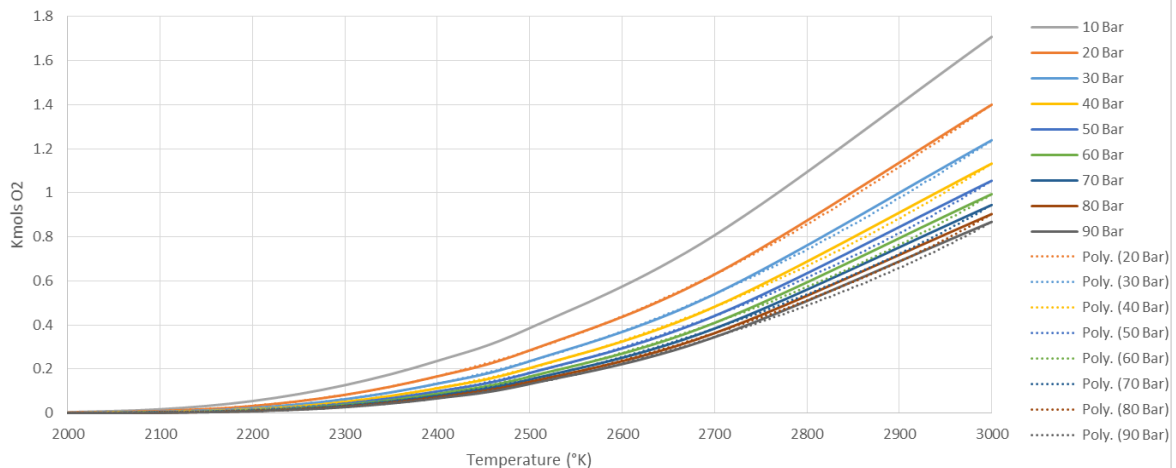


| Lambda 1.13 (1500RPM) |                 |               |               |           |                 |             |         |                          |             |             |             |
|-----------------------|-----------------|---------------|---------------|-----------|-----------------|-------------|---------|--------------------------|-------------|-------------|-------------|
| Pressure (Bar)        | Temperature (K) | N5/NT (Guess) | N3<br>C/(<+1) | N1<br>C-< | N4<br>H/2x(<+1) | N2<br>H/2-< | N6<br>N | N5<br>(Ox2)-2N1-N2-N3)/2 | NT<br>Total | Calc N5/NT  | Calc/Guess  |
| 10                    | 2000            | 2.60E-02      | 0.018368      | 7.167832  | 0.003813268     | 6.738687    | 45.6276 | 1.588640633              | 61.14494    | 0.025981555 | 1.000039209 |
| 10                    | 2100            | 0.026187672   | 0.040365      | 7.145835  | 0.007802927     | 6.734697    | 45.6276 | 1.601633908              | 61.15793    | 0.026188489 | 1.000031233 |
| 10                    | 2200            | 0.026575083   | 0.081899      | 7.104301  | 0.014915017     | 6.727585    | 45.6276 | 1.625956891              | 61.18226    | 0.026575628 | 1.00002049  |
| 10                    | 2300            | 0.027229203   | 0.154713      | 7.031487  | 0.026765506     | 6.715734    | 45.6276 | 1.668289202              | 61.22459    | 0.027248679 | 1.000715265 |
| 10                    | 2400            | 0.028314938   | 0.272099      | 6.914101  | 0.045365717     | 6.697134    | 45.6276 | 1.73628245               | 61.29258    | 0.028327774 | 1.000453339 |
| 10                    | 2500            | 0.029923301   | 0.447275      | 6.738925  | 0.072796897     | 6.669703    | 45.6276 | 1.837585952              | 61.39389    | 0.02993109  | 1.000260314 |
| 10                    | 2700            | 0.035048195   | 1.008172      | 6.178028  | 0.163246319     | 6.579254    | 45.6276 | 2.163259266              | 61.71956    | 0.035049817 | 1.000046297 |
| 10                    | 3000            | 0.04713864    | 2.32006       | 4.86614   | 0.418150443     | 6.32435     | 45.6276 | 2.946654972              | 62.50295    | 0.047144251 | 1.000119032 |
| 20                    | 2000            | 0.025928937   | 0.013011      | 7.173189  | 0.002699516     | 6.7398      | 45.6276 | 1.585405143              | 61.14171    | 0.025930012 | 1.000041456 |
| 20                    | 2100            | 0.026076202   | 0.02865       | 7.15755   | 0.005531148     | 6.736969    | 45.6276 | 1.594640634              | 61.15094    | 0.026077124 | 1.000035328 |
| 20                    | 2200            | 0.026353173   | 0.058347      | 7.127853  | 0.010597617     | 6.731902    | 45.6276 | 1.612022446              | 61.16832    | 0.026353877 | 1.000026716 |
| 20                    | 2300            | 0.026838867   | 0.110878      | 7.075322  | 0.019085004     | 6.723415    | 45.6276 | 1.64253157               | 61.19883    | 0.026839264 | 1.000014784 |
| 20                    | 2400            | 0.027613813   | 0.196948      | 6.989252  | 0.032545277     | 6.709955    | 45.6276 | 1.692296699              | 61.2486     | 0.027629967 | 1.000584985 |
| 20                    | 2500            | 0.028817055   | 0.327989      | 6.858211  | 0.052612644     | 6.689887    | 45.6276 | 1.767851011              | 61.32415    | 0.028827974 | 1.000378895 |
| 20                    | 2700            | 0.032808873   | 0.765727      | 6.420473  | 0.1200895       | 6.62241     | 45.6276 | 2.020458331              | 61.57676    | 0.032812028 | 1.00009618  |
| 20                    | 3000            | 0.042936181   | 1.875854      | 5.310346  | 0.314868684     | 6.427631    | 45.6276 | 2.672911472              | 62.22921    | 0.042952681 | 1.000384287 |
| 30                    | 2000            | 0.025906021   | 0.010631      | 7.175569  | 0.002205282     | 6.740295    | 45.6276 | 1.583968377              | 61.14027    | 0.025907122 | 1.000042489 |
| 30                    | 2100            | 0.026026555   | 0.023432      | 7.162768  | 0.004521146     | 6.737979    | 45.6276 | 1.591526621              | 61.14783    | 0.026027526 | 1.000037298 |
| 30                    | 2200            | 0.026253814   | 0.047801      | 7.138399  | 0.008671757     | 6.733828    | 45.6276 | 1.605786395              | 61.16209    | 0.026254605 | 1.000030104 |
| 30                    | 2300            | 0.026654118   | 0.091099      | 7.095101  | 0.015644753     | 6.726855    | 45.6276 | 1.630921772              | 61.18722    | 0.026654614 | 1.000018607 |
| 30                    | 2400            | 0.027292341   | 0.162548      | 7.023652  | 0.026752226     | 6.715748    | 45.6276 | 1.672200053              | 61.2285     | 0.027310812 | 1.000676772 |
| 30                    | 2500            | 0.028301885   | 0.272418      | 6.913782  | 0.043406905     | 6.699093    | 45.6276 | 1.735462553              | 61.29176    | 0.028314776 | 1.000455504 |
| 30                    | 2700            | 0.031720694   | 0.647551      | 6.538649  | 0.100022503     | 6.642477    | 45.6276 | 1.951336596              | 61.50764    | 0.031725111 | 1.000139251 |
| 30                    | 3000            | 0.0407439     | 1.641641      | 5.544559  | 0.265924718     | 6.476575    | 45.6276 | 2.531332702              | 62.08763    | 0.040770321 | 1.000648451 |
| 40                    | 2000            | 0.025892344   | 0.009211      | 7.176989  | 0.001910418     | 6.74059     | 45.6276 | 1.583110898              | 61.13941    | 0.02589346  | 1.000043116 |
| 40                    | 2100            | 0.025996881   | 0.020313      | 7.165887  | 0.003918012     | 6.738582    | 45.6276 | 1.589665611              | 61.14597    | 0.025997882 | 1.00003852  |
| 40                    | 2200            | 0.026194306   | 0.041481      | 7.144719  | 0.007519773     | 6.73498     | 45.6276 | 1.602050187              | 61.15835    | 0.026195118 | 1.000031004 |
| 40                    | 2300            | 0.026542916   | 0.079192      | 7.107008  | 0.01358127      | 6.728919    | 45.6276 | 1.623936453              | 61.18024    | 0.026543481 | 1.000021298 |
| 40                    | 2400            | 0.027095732   | 0.1417        | 7.0445    | 0.023264088     | 6.719236    | 45.6276 | 1.66003192               | 61.21633    | 0.027117468 | 1.000082189 |
| 40                    | 2500            | 0.027986663   | 0.238413      | 6.947787  | 0.037834039     | 6.704666    | 45.6276 | 1.715673457              | 61.27197    | 0.02800095  | 1.000510479 |
| 40                    | 2700            | 0.031038434   | 0.573358      | 6.612842  | 0.08773092      | 6.654769    | 45.6276 | 1.908094498              | 61.64639    | 0.0310439   | 1.000176087 |
| 40                    | 3000            | 0.039308711   | 1.487629      | 5.698571  | 0.235563182     | 6.506937    | 45.6276 | 2.439146002              | 61.99545    | 0.039343954 | 1.000896591 |
| 50                    | 2000            | 0.025883003   | 0.008242      | 7.177958  | 0.001709089     | 6.740791    | 45.6276 | 1.582525299              | 61.13883    | 0.02588413  | 1.00004355  |
| 50                    | 2100            | 0.025976596   | 0.018181      | 7.168019  | 0.003505959     | 6.738994    | 45.6276 | 1.588393573              | 61.14469    | 0.025977619 | 1.000039377 |
| 50                    | 2200            | 0.02615354    | 0.037153      | 7.149407  | 0.006731917     | 6.735768    | 45.6276 | 1.599492345              | 61.15579    | 0.026154388 | 1.000032441 |
| 50                    | 2300            | 0.026466559   | 0.071015      | 7.115185  | 0.012167523     | 6.730332    | 45.6276 | 1.619141194              | 61.17544    | 0.026467176 | 1.00002334  |
| 50                    | 2400            | 0.026959914   | 0.127318      | 7.058882  | 0.020867819     | 6.721632    | 45.6276 | 1.651643082              | 61.20794    | 0.02698413  | 1.000898206 |
| 50                    | 2500            | 0.027767854   | 0.214809      | 6.971391  | 0.033992326     | 6.708508    | 45.6276 | 1.701950559              | 61.25825    | 0.027783205 | 1.000552863 |
| 50                    | 2700            | 0.030556845   | 0.520949      | 6.665251  | 0.079186398     | 6.663314    | 45.6276 | 1.877617551              | 61.43392    | 0.030563207 | 1.00028213  |
| 50                    | 3000            | 0.038301228   | 1.374679      | 5.811521  | 0.214149626     | 6.52835     | 45.6276 | 2.371964523              | 61.92826    | 0.038301808 | 1.000015158 |
| 60                    | 2000            | 0.025876104   | 0.007525      | 7.178675  | 0.00156042      | 6.74094     | 45.6276 | 1.582092803              | 61.13839    | 0.025877239 | 1.000043872 |
| 60                    | 2100            | 0.025961606   | 0.016606      | 7.169594  | 0.003201557     | 6.739298    | 45.6276 | 1.587453537              | 61.14375    | 0.025962645 | 1.000040021 |
| 60                    | 2200            | 0.026123377   | 0.03395       | 7.15225   | 0.00614945      | 6.736351    | 45.6276 | 1.597599956              | 61.1539     | 0.026124253 | 1.000033541 |
| 60                    | 2300            | 0.026409946   | 0.064952      | 7.121248  | 0.01121006      | 6.731379    | 45.6276 | 1.615586577              | 61.17189    | 0.026410606 | 1.000024967 |
| 60                    | 2400            | 0.026858771   | 0.11662       | 7.06958   | 0.019090506     | 6.723409    | 45.6276 | 1.645405415              | 61.20171    | 0.02688496  | 1.000975076 |
| 60                    | 2500            | 0.027604335   | 0.19717       | 6.98903   | 0.03113563      | 6.711364    | 45.6276 | 1.691702938              | 61.248      | 0.02762054  | 1.000587049 |
| 60                    | 2700            | 0.030192392   | 0.481269      | 6.704931  | 0.07279173      | 6.669708    | 45.6276 | 1.854580224              | 61.41088    | 0.030199538 | 1.000236679 |
| 60                    | 3000            | 0.037497353   | 1.287345      | 5.898855  | 0.198062215     | 6.544438    | 45.6276 | 2.320253418              | 61.87655    | 0.037498104 | 1.000020033 |
| 70                    | 2000            | 0.02587074    | 0.006968      | 7.179232  | 0.001444843     | 6.741055    | 45.6276 | 1.581756537              | 61.13806    | 0.025871881 | 1.000044125 |
| 70                    | 2100            | 0.025949944   | 0.01538       | 7.17082   | 0.002964836     | 6.739535    | 45.6276 | 1.58672232               | 61.14302    | 0.025950996 | 1.000040527 |
| 70                    | 2200            | 0.026099892   | 0.031457      | 7.154743  | 0.005696228     | 6.736804    | 45.6276 | 1.596126674              | 61.15243    | 0.02610079  | 1.000034421 |
| 70                    | 2300            | 0.0263658     | 0.060224      | 7.125976  | 0.010305915     | 6.732194    | 45.6276 | 1.612815099              | 61.16912    | 0.026366494 | 1.000026314 |
| 70                    | 2400            | 0.026806533   | 0.108203      | 7.077997  | 0.017695259     | 6.724805    | 45.6276 | 1.640499261              | 61.1968     | 0.026806945 | 1.0000154   |
| 70                    | 2500            | 0.02747604    | 0.183332      | 7.002868  | 0.028902826     | 6.713597    | 45.6276 | 1.683667481              | 61.23997    | 0.027492952 | 1.000615504 |
| 70                    | 2700            | 0.029903583   | 0.449815      | 6.736385  | 0.06776771      | 6.674732    | 45.6276 | 1.836341367              | 61.39264    | 0.029911425 | 1.000262232 |
| 70                    | 3000            | 0.036848323   | 1.216699      | 5.969501  | 0.185337493     | 6.557163    | 45.6276 | 2.278568245              | 61.83487    | 0.036849246 | 1.000025051 |
| 80                    | 2000            | 0.025866414   | 0.006519      | 7.179681  | 0.001351658     | 6.741148    | 45.6276 | 1.581485398              | 61.13779    | 0.025867561 | 1.000044329 |
| 80                    | 2100            | 0.025940538   | 0.014391      | 7.171809  | 0.002773931     | 6.739726    | 45.6276 | 1.586132507              | 61.14243    | 0.0259416   | 1.00004094  |
| 80                    | 2200            | 0.026080935   | 0.029444      | 7.156756  | 0.005330559     | 6.737169    | 45.6276 | 1.594937487              | 61.15124    | 0.026081851 | 1.000035145 |
| 80                    | 2300            | 0.02633012    | 0.056403      | 7.129797  | 0.009647773     | 6.732852    | 45.6276 | 1.610575409              | 61.16688    | 0.026330843 | 1.000027467 |
| 80                    | 2400            | 0.026743733   | 0.101431      | 7.084769  | 0.016574583     | 6.725925    | 45.6276 | 1.636552598              | 61.19285    | 0.026744179 | 1.000016658 |
| 80                    | 2500            | 0.027371837   | 0.172093      | 7.014107  | 0.027094826     | 6.715405    | 45.6276 | 1.677144102              | 61.23344    | 0.027389348 | 1.000639746 |
| 80                    | 2700            | 0.029667081   | 0.424053      | 6.762147  | 0.063682015     | 6.678818    | 45.6276 | 1.821417397              | 61.37772    | 0.029675548 | 1.000285414 |
| 80                    | 3000            | 0.036308467   | 1.15785       | 6.02835   | 0.174928699     | 6.567571    | 45.6276 | 2.243939587              | 61.80024    | 0.036309561 | 1.000030147 |

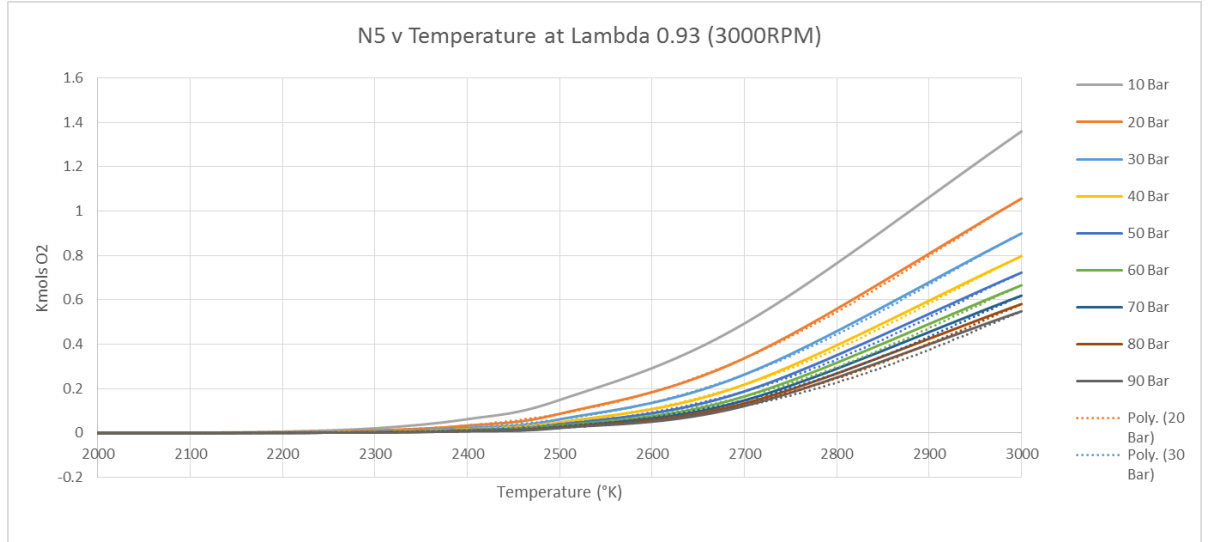


| Lambda 0.98 (2000&2500RPM) |                 |               |               |           |                 |             |         |                          |             |             |             |
|----------------------------|-----------------|---------------|---------------|-----------|-----------------|-------------|---------|--------------------------|-------------|-------------|-------------|
| Pressure (Bar)             | Temperature (K) | N5/NT (Guess) | N3<br>C/(<+1) | N1<br>C-< | N4<br>H/2x(<+1) | N2<br>H/2-< | N6<br>N | N5<br>(Ox2)-2N1-N2-N3)/2 | NT<br>Total | Calc N5/NT  | Calc/Guess  |
| 10                         | 2000            | 6.65E-05      | 0.406195      | 8.019005  | 0.087444738     | 7.817555    | 45.6276 | 0.004120112              | 61.96192    | 6.64943E-05 | 1.000039803 |
| 10                         | 2100            | 0.000283862   | 0.433591      | 7.991609  | 0.087002176     | 7.817998    | 45.6276 | 0.017596519              | 61.9754     | 0.000283927 | 1.000232059 |
| 10                         | 2200            | 0.00088572    | 0.500417      | 7.924783  | 0.094844763     | 7.810155    | 45.6276 | 0.054931122              | 62.01273    | 0.000885804 | 1.000094976 |
| 10                         | 2300            | 0.002044747   | 0.626204      | 7.798996  | 0.113321072     | 7.791679    | 45.6276 | 0.127062454              | 62.08486    | 0.002046593 | 1.000902887 |
| 10                         | 2400            | 0.003810692   | 0.816248      | 7.608952  | 0.143317919     | 7.761682    | 45.6276 | 0.237083061              | 62.19488    | 0.003811938 | 1.000327024 |
| 10                         | 2500            | 0.006193759   | 1.072632      | 7.352568  | 0.185199597     | 7.71198     | 45.6276 | 0.386215699              | 62.34402    | 0.006194912 | 1.000186179 |
| 10                         | 2700            | 0.012856473   | 1.788241      | 6.636959  | 0.311102432     | 7.593898    | 45.6276 | 0.806971487              | 62.76477    | 0.012857077 | 1.000046973 |
| 10                         | 3000            | 0.026799337   | 3.263731      | 5.161469  | 0.637294959     | 7.267705    | 45.6276 | 1.707812844              | 63.66561    | 0.02682473  | 1.000947495 |
| 20                         | 2000            | 3.3822E-05    | 0.402887      | 8.022313  | 0.08670489      | 7.818295    | 45.6276 | 0.002095856              | 61.9599     | 3.3826E-05  | 1.000118821 |
| 20                         | 2100            | 0.000151752   | 0.420037      | 8.005163  | 0.084170313     | 7.82083     | 45.6276 | 0.009403684              | 61.9672     | 0.000151753 | 1.00005839  |
| 20                         | 2200            | 0.000522671   | 0.462815      | 7.962385  | 0.087387007     | 7.817613    | 45.6276 | 0.032400941              | 61.9902     | 0.000522678 | 1.000014335 |
| 20                         | 2300            | 0.001338853   | 0.552389      | 7.872811  | 0.09920536      | 7.805795    | 45.6276 | 0.083097306              | 62.0409     | 0.001339396 | 1.000405517 |
| 20                         | 2400            | 0.002686116   | 0.698131      | 7.727069  | 0.121051214     | 7.783949    | 45.6276 | 0.166890965              | 62.12469    | 0.002686387 | 1.000100816 |
| 20                         | 2500            | 0.004579083   | 0.902521      | 7.522679  | 0.152941009     | 7.752059    | 45.6276 | 0.285030759              | 62.24283    | 0.004579335 | 1.000055071 |
| 20                         | 2700            | 0.010053375   | 1.493447      | 6.931753  | 0.250744607     | 7.654255    | 45.6276 | 0.629395829              | 62.5872     | 0.010056303 | 1.000291288 |
| 20                         | 3000            | 0.022094752   | 2.779906      | 5.645294  | 0.505311399     | 7.399689    | 45.6276 | 1.399908463              | 63.35771    | 0.022095314 | 1.000025428 |
| 30                         | 2000            | 2.26812E-05   | 0.401758      | 8.023442  | 0.086452694     | 7.818547    | 45.6276 | 0.001405596              | 61.95921    | 2.26858E-05 | 1.000203937 |
| 30                         | 2100            | 0.000103711   | 0.41511       | 8.01009   | 0.083142785     | 7.821857    | 45.6276 | 0.006426482              | 61.96423    | 0.000103713 | 1.000016214 |
| 30                         | 2200            | 0.000374244   | 0.447442      | 7.977758  | 0.084354183     | 7.820646    | 45.6276 | 0.02319787               | 61.981      | 0.000374274 | 1.000080733 |
| 30                         | 2300            | 0.001019702   | 0.519         | 7.9062    | 0.092890304     | 7.81211     | 45.6276 | 0.063245086              | 62.02105    | 0.001019736 | 1.000032804 |
| 30                         | 2400            | 0.002149462   | 0.641859      | 7.783341  | 0.110637327     | 7.794363    | 45.6276 | 0.133548334              | 62.09135    | 0.002150836 | 1.000393434 |
| 30                         | 2500            | 0.003788045   | 0.819178      | 7.606022  | 0.137568915     | 7.767431    | 45.6276 | 0.235673322              | 62.19347    | 0.003789358 | 1.000346458 |
| 30                         | 2700            | 0.008636332   | 1.344         | 7.0812    | 0.221727978     | 7.683272    | 45.6276 | 0.540163963              | 62.49796    | 0.008642905 | 1.000761031 |
| 30                         | 3000            | 0.019597171   | 2.520731      | 5.904469  | 0.441845398     | 7.463155    | 45.6276 | 1.238588253              | 63.19639    | 0.019599035 | 1.000095135 |
| 40                         | 2000            | 1.70616E-05   | 0.401189      | 8.024011  | 0.086325503     | 7.818674    | 45.6276 | 0.001057426              | 61.95886    | 1.70666E-05 | 1.000290933 |
| 40                         | 2100            | 7.88E-05      | 0.412555      | 8.012645  | 0.082610334     | 7.82239     | 45.6276 | 0.004882801              | 61.96268    | 7.88023E-05 | 1.00002955  |
| 40                         | 2200            | 0.000292267   | 0.438951      | 7.986429  | 0.08268327      | 7.822317    | 45.6276 | 0.018117365              | 61.97592    | 0.000292329 | 1.00021374  |
| 40                         | 2300            | 0.000830611   | 0.499251      | 7.925949  | 0.089175444     | 7.815825    | 45.6276 | 0.05151333               | 62.00931    | 0.000830735 | 1.00014928  |
| 40                         | 2400            | 0.001818946   | 0.606971      | 7.818229  | 0.104242191     | 7.800758    | 45.6276 | 0.11290656               | 62.07071    | 0.001818999 | 1.000029463 |
| 40                         | 2500            | 0.003290275   | 0.766477      | 7.658723  | 0.127990473     | 7.77701     | 45.6276 | 0.204533647              | 62.16233    | 0.003290315 | 1.000012057 |
| 40                         | 2700            | 0.007729102   | 1.247177      | 7.178023  | 0.203461645     | 7.701538    | 45.6276 | 0.482619226              | 62.44042    | 0.007729276 | 1.000022463 |
| 40                         | 3000            | 0.017943687   | 2.348088      | 6.077112  | 0.40202484      | 7.502975    | 45.6276 | 1.132356487              | 63.09016    | 0.017948228 | 1.000253047 |
| 50                         | 2000            | 1.36738E-05   | 0.400846      | 8.024354  | 0.086248831     | 7.818751    | 45.6276 | 0.000847534              | 61.95865    | 1.3679E-05  | 1.000378747 |
| 50                         | 2100            | 6.35456E-05   | 0.410991      | 8.014209  | 0.082284413     | 7.822716    | 45.6276 | 0.003937574              | 61.96174    | 6.35485E-05 | 1.000044623 |
| 50                         | 2200            | 0.000240011   | 0.433541      | 7.991659  | 0.081619837     | 7.82338     | 45.6276 | 0.014880176              | 61.97268    | 0.000240109 | 1.000406795 |
| 50                         | 2300            | 0.000703589   | 0.485992      | 7.939208  | 0.086689747     | 7.81831     | 45.6276 | 0.043641025              | 62.00144    | 0.000703871 | 1.000400755 |
| 50                         | 2400            | 0.001588478   | 0.582742      | 7.842458  | 0.099828259     | 7.805172    | 45.6276 | 0.098584927              | 62.05638    | 0.001588635 | 1.000098931 |
| 50                         | 2500            | 0.002936996   | 0.729155      | 7.696045  | 0.121272423     | 7.783728    | 45.6276 | 0.182513563              | 62.14031    | 0.00293712  | 1.000042198 |
| 50                         | 2700            | 0.007077253   | 1.177484      | 7.247716  | 0.190563575     | 7.714436    | 45.6276 | 0.441323717              | 62.39912    | 0.007072595 | 1.000048289 |
| 50                         | 3000            | 0.016728246   | 2.220737      | 6.204463  | 0.37381632      | 7.531184    | 45.6276 | 1.054576421              | 63.01238    | 0.01673602  | 1.00046478  |
| 60                         | 2000            | 1.14086E-05   | 0.400617      | 8.024583  | 0.086197567     | 7.818802    | 45.6276 | 0.000707189              | 61.95851    | 1.14139E-05 | 1.000466992 |
| 60                         | 2100            | 5.32421E-05   | 0.409934      | 8.015266  | 0.082064324     | 7.822936    | 45.6276 | 0.00329914               | 61.9611     | 5.32453E-05 | 1.00006078  |
| 60                         | 2200            | 0.000203713   | 0.429783      | 7.995417  | 0.080881995     | 7.824118    | 45.6276 | 0.012632395              | 61.97043    | 0.000203846 | 1.000064863 |
| 60                         | 2300            | 0.00061164    | 0.476403      | 7.948797  | 0.084896253     | 7.820104    | 45.6276 | 0.037949792              | 61.99575    | 0.000612135 | 1.000810658 |
| 60                         | 2400            | 0.001416382   | 0.564659      | 7.860541  | 0.096548544     | 7.808451    | 45.6276 | 0.087903626              | 62.0457     | 0.001416756 | 1.000264374 |
| 60                         | 2500            | 0.002668884   | 0.700828      | 7.724372  | 0.116209241     | 7.788791    | 45.6276 | 0.165818622              | 62.12362    | 0.002669172 | 1.000107827 |
| 60                         | 2700            | 0.006566503   | 1.123782      | 7.301418  | 0.180764193     | 7.724236    | 45.6276 | 0.409573235              | 62.36737    | 0.006567107 | 1.00009199  |
| 60                         | 3000            | 0.015778019   | 2.120965      | 6.304235  | 0.352372049     | 7.552628    | 45.6276 | 0.993968591              | 62.95177    | 0.015789367 | 1.000719267 |
| 70                         | 2000            | 9.7872E-06    | 0.400453      | 8.024747  | 0.086160876     | 7.818839    | 45.6276 | 0.000606736              | 61.95841    | 9.79264E-06 | 1.000555491 |
| 70                         | 2100            | 4.58149E-05   | 0.409172      | 8.016028  | 0.081905701     | 7.823094    | 45.6276 | 0.00283894               | 61.96064    | 4.58184E-05 | 1.000077651 |
| 70                         | 2200            | 0.000177002   | 0.427018      | 7.998182  | 0.080339492     | 7.824661    | 45.6276 | 0.010978797              | 61.96878    | 0.000177167 | 1.000928966 |
| 70                         | 2300            | 0.000541822   | 0.469053      | 7.956147  | 0.083523922     | 7.821476    | 45.6276 | 0.033588679              | 61.99139    | 0.000541828 | 1.00001172  |
| 70                         | 2400            | 0.001281756   | 0.550529      | 7.874671  | 0.093994365     | 7.811006    | 45.6276 | 0.079561592              | 62.03736    | 0.001282479 | 1.000563757 |
| 70                         | 2500            | 0.002456011   | 0.678344      | 7.746856  | 0.112212133     | 7.792788    | 45.6276 | 0.152578136              | 62.11038    | 0.002456564 | 1.00025361  |
| 70                         | 2700            | 0.006159613   | 1.080589      | 7.344611  | 0.172968673     | 7.732031    | 45.6276 | 0.38407906               | 62.34188    | 0.006160852 | 1.00020109  |
| 70                         | 3000            | 0.015004457   | 2.039602      | 6.385598  | 0.335293473     | 7.569707    | 45.6276 | 0.944747713              | 62.90255    | 0.015019228 | 1.000984455 |
| 80                         | 2000            | 8.56934E-06   | 0.400329      | 8.024871  | 0.086133317     | 7.818867    | 45.6276 | 0.000531284              | 61.95833    | 8.57486E-06 | 1.000644152 |
| 80                         | 2100            | 4.02067E-05   | 0.408597      | 8.016603  | 0.081785943     | 7.823214    | 45.6276 | 0.002491458              | 61.96029    | 4.02106E-05 | 1.000095017 |
| 80                         | 2200            | 0.000156524   | 0.424879      | 8.000321  | 0.079919945     | 7.82508     | 45.6276 | 0.009699455              | 61.9675     | 0.000156525 | 1.00005463  |
| 80                         | 2300            | 0.000486672   | 0.463288      | 7.961912  | 0.082448878     | 7.822551    | 45.6276 | 0.030168466              | 61.98797    | 0.000486683 | 1.000022254 |
| 80                         | 2400            | 0.001173282   | 0.539037      | 7.886163  | 0.09192265      | 7.813077    | 45.6276 | 0.072780026              | 62.03058    | 0.001173293 | 1.00009262  |
| 80                         | 2500            | 0.002281477   | 0.659922      | 7.765278  | 0.108951356     | 7.796049    | 45.6276 | 0.141736779              | 62.09954    | 0.002282413 | 1.000410294 |
| 80                         | 2700            | 0.005821986   | 1.044766      | 7.380434  | 0.166560655     | 7.738439    | 45.6276 | 0.362963336              | 62.32076    | 0.005824116 | 1.000365885 |
| 80                         | 3000            | 0.014368059   | 1.970704      | 6.454496  | 0.321109553     | 7.58389     | 45.6276 | 0.903206598              | 62.86101    | 0.014368313 | 1.000017669 |

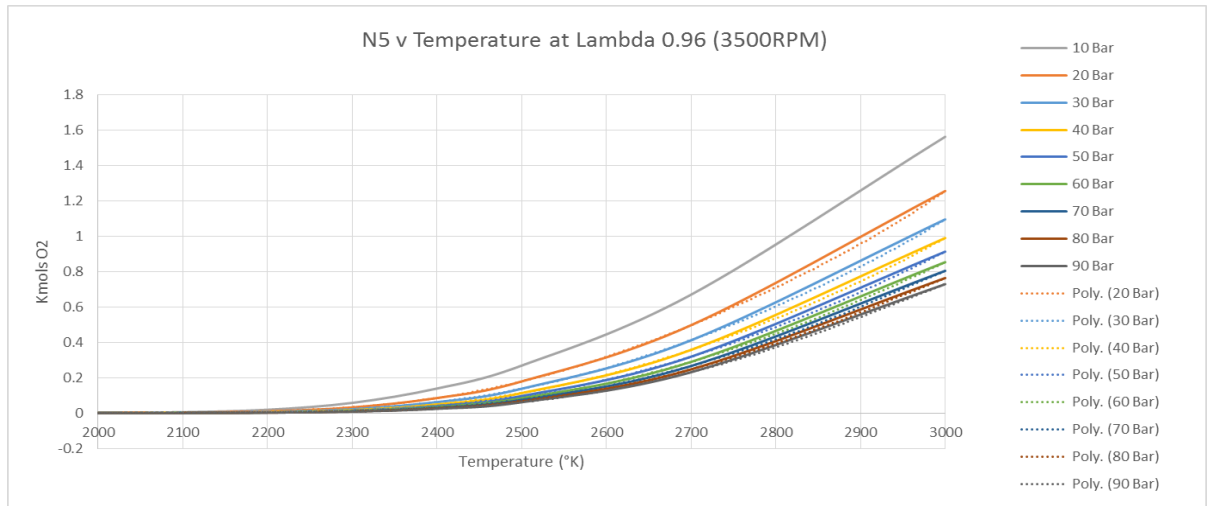
N5 v Temperature at Lambda 0.98 (2000&2500RPM)



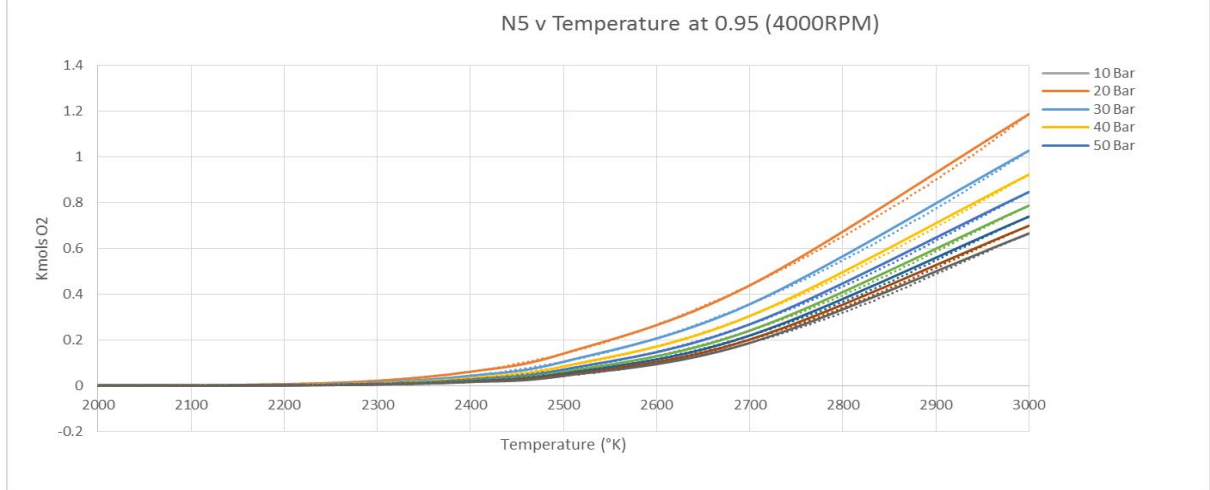
| Lambda 0.93 (3000RPM) |                 |              |               |           |                 |               |         |                          |             |             |              |
|-----------------------|-----------------|--------------|---------------|-----------|-----------------|---------------|---------|--------------------------|-------------|-------------|--------------|
| Pressure (Bar)        | Temperature (K) | N5/NT(Guess) | N3<br>C/(<+1) | N1<br>C-< | N4<br>H/2x(<+1) | N2<br>(H/2)-< | N6<br>N | N5<br>(Ox2)-2N1-N2-N3)/2 | NT<br>Total | Calc N5/NT  | Calc/Guess   |
| 10                    | 2000            | 5.02E-06     | 1.375273      | 7.462927  | 0.324257701     | 7.968242      | 45.6276 | 0.000315298              | 62.75862    | 5.02398E-06 | 1.000024652  |
| 10                    | 2100            | 2.37916E-05  | 1.394928      | 7.443272  | 0.3069593       | 7.985541      | 45.6276 | 0.001493489              | 62.75979    | 2.37969E-05 | 1.000224735  |
| 10                    | 2200            | 9.68268E-05  | 1.417273      | 7.420927  | 0.293781546     | 7.998718      | 45.6276 | 0.006077518              | 62.76438    | 9.68307E-05 | 1.000040246  |
| 10                    | 2300            | 0.000339128  | 1.45555       | 7.38265   | 0.285932591     | 8.006567      | 45.6276 | 0.02129107               | 62.77959    | 0.00033914  | 1.000034023  |
| 10                    | 2400            | 0.000993662  | 1.534371      | 7.303829  | 0.289391571     | 8.003108      | 45.6276 | 0.062431508              | 62.82073    | 0.000993804 | 1.000142838  |
| 10                    | 2500            | 0.002368176  | 1.687143      | 7.151057  | 0.309712468     | 7.982788      | 45.6276 | 0.148977898              | 62.90728    | 0.002368214 | 1.000016004  |
| 10                    | 2700            | 0.00779885   | 2.271643      | 6.566557  | 0.414387364     | 7.878113      | 45.6276 | 0.493565291              | 63.25187    | 0.007803174 | 1.000554452  |
| 10                    | 3000            | 0.021184057  | 3.67332       | 5.16488   | 0.744449818     | 7.54805       | 45.6276 | 1.359434676              | 64.11773    | 0.021202163 | 1.00085471   |
| 20                    | 2000            | 2.513E-06    | 1.375024      | 7.463176  | 0.324191035     | 7.968309      | 45.6276 | 0.000157727              | 62.75846    | 2.51325E-06 | 1.000097417  |
| 20                    | 2100            | 1.19199E-05  | 1.393737      | 7.444463  | 0.306659663     | 7.98584       | 45.6276 | 0.000748186              | 62.75905    | 1.19216E-05 | 1.000136708  |
| 20                    | 2200            | 4.88117E-05  | 1.412405      | 7.425795  | 0.292622833     | 7.999877      | 45.6276 | 0.003063961              | 62.76136    | 4.88192E-05 | 1.00015416   |
| 20                    | 2300            | 0.000174356  | 1.438688      | 7.399512  | 0.282110776     | 8.010389      | 45.6276 | 0.010949259              | 62.76925    | 0.000174437 | 1.000463159  |
| 20                    | 2400            | 0.000535752  | 1.487142      | 7.351058  | 0.279042105     | 8.013458      | 45.6276 | 0.033641985              | 62.79194    | 0.000535769 | 1.0003245    |
| 20                    | 2500            | 0.001380612  | 1.584815      | 7.253385  | 0.287617443     | 8.004883      | 45.6276 | 0.086766303              | 62.84507    | 0.001380638 | 1.000018831  |
| 20                    | 2700            | 0.005341632  | 2.016357      | 6.821843  | 0.356649088     | 7.935851      | 45.6276 | 0.337053064              | 63.09535    | 0.005341963 | 1.000062065  |
| 20                    | 3000            | 0.016548442  | 3.205172      | 5.633028  | 0.60647572      | 7.686024      | 45.6276 | 1.05637391               | 63.81467    | 0.016553777 | 1.000322431  |
| 30                    | 2000            | 1.67557E-06  | 1.374941      | 7.463259  | 0.32416876      | 7.968331      | 45.6276 | 0.000105077              | 62.75841    | 1.67432E-06 | 0.999249565  |
| 30                    | 2100            | 7.95201E-06  | 1.393339      | 7.444861  | 0.306559514     | 7.98594       | 45.6276 | 0.000499048              | 62.7588     | 7.95184E-06 | 0.999978179  |
| 30                    | 2200            | 3.26313E-05  | 1.410764      | 7.427436  | 0.292232463     | 8.000268      | 45.6276 | 0.002048135              | 62.76035    | 3.26342E-05 | 1.00008892   |
| 30                    | 2300            | 0.000117371  | 1.432852      | 7.405348  | 0.280791181     | 8.011709      | 45.6276 | 0.007371365              | 62.76567    | 0.000117443 | 1.000609819  |
| 30                    | 2400            | 0.00036739   | 1.469772      | 7.368428  | 0.275262557     | 8.017237      | 45.6276 | 0.02306732               | 62.78137    | 0.000367423 | 1.000090372  |
| 30                    | 2500            | 0.000981555  | 1.543417      | 7.294783  | 0.27882076      | 8.013679      | 45.6276 | 0.061668717              | 62.81997    | 0.000981674 | 1.000120941  |
| 30                    | 2700            | 0.004175289  | 1.89522       | 6.94298   | 0.330460855     | 7.962039      | 45.6276 | 0.263390595              | 63.02169    | 0.004179364 | 1.000976112  |
| 30                    | 3000            | 0.014126653  | 2.957169      | 5.881031  | 0.540550052     | 7.75195       | 45.6276 | 0.899409665              | 63.65771    | 0.014128841 | 1.000154903  |
| 40                    | 2000            | 1.25677E-06  | 1.3749        | 7.4633    | 0.324157668     | 7.968342      | 45.6276 | 7.88603E-05              | 62.75838    | 1.25657E-06 | 0.999841595  |
| 40                    | 2100            | 5.96603E-06  | 1.393139      | 7.445061  | 0.306509424     | 7.985991      | 45.6276 | 0.003074433              | 62.75867    | 5.96623E-06 | 1.000032538  |
| 40                    | 2200            | 2.45075E-05  | 1.409941      | 7.428259  | 0.292036715     | 8.000463      | 45.6276 | 0.001538649              | 62.75984    | 2.45165E-05 | 1.000365492  |
| 40                    | 2300            | 8.84649E-05  | 1.429884      | 7.408316  | 0.280120839     | 8.012379      | 45.6276 | 0.005552343              | 62.76385    | 8.84655E-05 | 1.000006311  |
| 40                    | 2400            | 0.000279648  | 1.460733      | 7.377467  | 0.273301343     | 8.019199      | 45.6276 | 0.017567158              | 62.77587    | 0.000279839 | 1.000684576  |
| 40                    | 2500            | 0.000763036  | 1.520716      | 7.317484  | 0.274031291     | 8.018469      | 45.6276 | 0.047923681              | 62.80622    | 0.00076304  | 1.000006171  |
| 40                    | 2700            | 0.003465713  | 1.820818      | 7.017382  | 0.3147416       | 7.977758      | 45.6276 | 0.218329716              | 62.97663    | 0.003466837 | 1.00032421   |
| 40                    | 3000            | 0.01254095   | 2.793649      | 6.044551  | 0.499477514     | 7.793022      | 45.6276 | 0.797113263              | 63.55541    | 0.01254202  | 1.000085358  |
| 50                    | 2000            | 1.00546E-06  | 1.374875      | 7.463325  | 0.324151001     | 7.968349      | 45.6276 | 6.31013E-05              | 62.75836    | 1.00547E-06 | 1.000006301  |
| 50                    | 2100            | 4.7738E-06   | 1.39302       | 7.44518   | 0.306479341     | 7.986021      | 45.6276 | 0.00029959               | 62.7586     | 4.77369E-06 | 0.999977861  |
| 50                    | 2200            | 1.96224E-05  | 1.409444      | 7.428756  | 0.291918715     | 8.000581      | 45.6276 | 0.001231489              | 62.75953    | 1.96223E-05 | 0.9999954    |
| 50                    | 2300            | 7.09837E-05  | 1.428095      | 7.410105  | 0.279716834     | 8.012783      | 45.6276 | 0.004455737              | 62.76276    | 7.09933E-05 | 1.000136251  |
| 50                    | 2400            | 0.000225778  | 1.455154      | 7.383046  | 0.272092771     | 8.020407      | 45.6276 | 0.014173332              | 62.77247    | 0.000225789 | 1.00004772   |
| 50                    | 2500            | 0.000624576  | 1.506346      | 7.331854  | 0.271011882     | 8.021488      | 45.6276 | 0.039229082              | 62.79753    | 0.000624691 | 1.000184534  |
| 50                    | 2700            | 0.002977864  | 1.769726      | 7.068474  | 0.304103732     | 7.988396      | 45.6276 | 0.187464678              | 62.94576    | 0.002978194 | 1.000110666  |
| 50                    | 3000            | 0.011387022  | 2.674121      | 6.164079  | 0.470574926     | 7.821925      | 45.6276 | 0.722898085              | 63.4812     | 0.011387594 | 1.000050179  |
| 60                    | 2000            | 8.37906E-07  | 1.374859      | 7.463341  | 0.324146559     | 7.968353      | 45.6276 | 5.26026E-05              | 62.75835    | 8.38177E-07 | 1.000322587  |
| 60                    | 2100            | 3.97871E-06  | 1.39294       | 7.44526   | 0.306459296     | 7.986041      | 45.6276 | 0.000249721              | 62.75855    | 3.97908E-06 | 1.000093165  |
| 60                    | 2200            | 1.63612E-05  | 1.409114      | 7.429086  | 0.291840143     | 8.00066       | 45.6276 | 0.001026949              | 62.75933    | 1.63633E-05 | 1.000130579  |
| 60                    | 2300            | 5.92718E-05  | 1.426894      | 7.411306  | 0.279445883     | 8.013054      | 45.6276 | 0.00372003               | 62.76202    | 5.9272E-05  | 1.00002891   |
| 60                    | 2400            | 0.000189319  | 1.451389      | 7.386811  | 0.271278055     | 8.021222      | 45.6276 | 0.011883598              | 62.77018    | 0.000189319 | 1.000002096  |
| 60                    | 2500            | 0.000528861  | 1.496392      | 7.341808  | 0.268925844     | 8.023574      | 45.6276 | 0.033208856              | 62.79151    | 0.000528875 | 1.000026139  |
| 60                    | 2700            | 0.002618296  | 1.732071      | 7.106129  | 0.296343795     | 7.996156      | 45.6276 | 0.164757504              | 62.92306    | 0.002618396 | 1.000038212  |
| 60                    | 3000            | 0.010493374  | 2.58126       | 6.25694   | 0.448741486     | 7.843759      | 45.6276 | 0.665550807              | 63.42385    | 0.010493699 | 1.000030941  |
| 70                    | 2000            | 7.1822E-07   | 1.374847      | 7.463353  | 0.324143374     | 7.968357      | 45.6276 | 4.50744E-05              | 62.75835    | 7.18221E-07 | 1.000001548  |
| 70                    | 2100            | 3.41065E-06  | 1.392883      | 7.445317  | 0.306444958     | 7.986055      | 45.6276 | 0.000214049              | 62.75851    | 3.41068E-06 | 1.000007324  |
| 70                    | 2200            | 1.40295E-05  | 1.408877      | 7.429323  | 0.291783883     | 8.000716      | 45.6276 | 0.000880483              | 62.75918    | 1.40296E-05 | 1.000006825  |
| 70                    | 2300            | 5.08774E-05  | 1.426036      | 7.412164  | 0.279252221     | 8.013248      | 45.6276 | 0.003194093              | 62.76149    | 5.08926E-05 | 1.000298552  |
| 70                    | 2400            | 0.000163001  | 1.448675      | 7.389525  | 0.2706912       | 8.021809      | 45.6276 | 0.010233309              | 62.76853    | 0.000163032 | 1.000190299  |
| 70                    | 2500            | 0.00045864   | 1.48914       | 7.34906   | 0.267408944     | 8.025091      | 45.6276 | 0.028824277              | 62.78712    | 0.000459079 | 1.000957321  |
| 70                    | 2700            | 0.002340617  | 1.702984      | 7.135216  | 0.290395318     | 8.002105      | 45.6276 | 0.147239722              | 62.90554    | 0.002340648 | 1.000013164  |
| 70                    | 3000            | 0.009772144  | 2.506135      | 6.332065  | 0.431460687     | 7.861039      | 45.6276 | 0.619347739              | 63.37765    | 0.009772337 | 1.000019734  |
| 80                    | 2000            | 6.28452E-07  | 1.374838      | 7.463362  | 0.324140993     | 7.968359      | 45.6276 | 3.9445E-05               | 62.75834    | 6.28521E-07 | 1.0000110242 |
| 80                    | 2100            | 2.98454E-06  | 1.39284       | 7.44536   | 0.306434214     | 7.986066      | 45.6276 | 0.000187317              | 62.75849    | 2.98473E-06 | 1.000064947  |
| 80                    | 2200            | 1.22794E-05  | 1.4087        | 7.4295    | 0.291741774     | 8.000758      | 45.6276 | 0.000770854              | 62.75907    | 1.22827E-05 | 1.000268878  |
| 80                    | 2300            | 4.4566E-05   | 1.425388      | 7.412812  | 0.279106054     | 8.013394      | 45.6276 | 0.002797087              | 62.7611     | 4.45672E-05 | 1.000028048  |
| 80                    | 2400            | 0.000143112  | 1.446619      | 7.391581  | 0.27024676      | 8.022253      | 45.6276 | 0.00898297               | 62.76728    | 0.000143115 | 1.000026933  |
| 80                    | 2500            | 0.00040497   | 1.483528      | 7.354672  | 0.266236855     | 8.026263      | 45.6276 | 0.025432401              | 62.78373    | 0.000405079 | 1.000270707  |
| 80                    | 2700            | 0.002118457  | 1.679866      | 7.158334  | 0.285695856     | 8.006804      | 45.6276 | 0.13333117               | 62.89163    | 0.002120014 | 1.000735042  |
| 80                    | 3000            | 0.009172671  | 2.443573      | 6.394627  | 0.41732328      | 7.875177      | 45.6276 | 0.580998115              | 63.3393     | 0.009172791 | 1.000012981  |



| Lambda 0.96 (3500RPM) |                 |              |               |           |                 |               |         |                          |             |             |             |
|-----------------------|-----------------|--------------|---------------|-----------|-----------------|---------------|---------|--------------------------|-------------|-------------|-------------|
| Pressure (Bar)        | Temperature (K) | N5/NT(Guess) | N3<br>C/(C+1) | N1<br>C<- | N4<br>H/2x(C+1) | N2<br>(H/2)<- | N6<br>N | N5<br>(Ox2)-2N1-N2-N3)/2 | NT<br>Total | Calc N5/NT  | Calc/Guess  |
| 10                    | 2000            | 1.64E-05     | 0.795262      | 7.795138  | 0.177579946     | 7.88242       | 45.62   | 0.00102084               | 62.27142    | 1.63934E-05 | 1.000104313 |
| 10                    | 2100            | 7.67794E-05  | 0.811511      | 7.778889  | 0.168851854     | 7.891148      | 45.62   | 0.004781523              | 62.27518    | 7.67806E-05 | 1.000015469 |
| 10                    | 2200            | 0.00029843   | 0.842826      | 7.747574  | 0.165167138     | 7.894833      | 45.62   | 0.01859652               | 62.289      | 0.000298552 | 1.000409944 |
| 10                    | 2300            | 0.00092596   | 0.915717      | 7.674683  | 0.170510907     | 7.889489      | 45.62   | 0.057713809              | 62.32811    | 0.000925968 | 1.00008059  |
| 10                    | 2400            | 0.002222802  | 1.057993      | 7.532407  | 0.190263904     | 7.869736      | 45.62   | 0.13872843               | 62.40913    | 0.002222887 | 1.000038376 |
| 10                    | 2500            | 0.004288582  | 1.281413      | 7.308987  | 0.225863171     | 7.834137      | 45.62   | 0.268238051              | 62.53864    | 0.004289157 | 1.000134174 |
| 10                    | 2700            | 0.010640097  | 1.962888      | 6.627512  | 0.347321781     | 7.712678      | 45.62   | 0.669704734              | 62.9401     | 0.01064035  | 1.00002381  |
| 10                    | 3000            | 0.024487279  | 3.420146      | 5.170254  | 0.677255864     | 7.382744      | 45.62   | 1.563300872              | 63.8337     | 0.024490212 | 1.000119799 |
| 20                    | 2000            | 8.21452E-06  | 0.794441      | 7.795959  | 0.177382414     | 7.882618      | 45.62   | 0.000511638              | 62.27091    | 8.21632E-06 | 1.000219545 |
| 20                    | 2100            | 3.87962E-05  | 0.807649      | 7.782751  | 0.167983291     | 7.892017      | 45.62   | 0.002416046              | 62.27282    | 3.87978E-05 | 1.000039288 |
| 20                    | 2200            | 0.000155161  | 0.828091      | 7.762309  | 0.162035792     | 7.897964      | 45.62   | 0.009663473              | 62.28006    | 0.000155162 | 1.00004669  |
| 20                    | 2300            | 0.000514936  | 0.873112      | 7.717288  | 0.161857526     | 7.898142      | 45.62   | 0.032084832              | 62.30248    | 0.000514985 | 1.000095426 |
| 20                    | 2400            | 0.001359582  | 0.967996      | 7.622404  | 0.1724142       | 7.887586      | 45.62   | 0.084805195              | 62.35521    | 0.001360034 | 1.000332665 |
| 20                    | 2500            | 0.002860517  | 1.132115      | 7.458285  | 0.196291394     | 7.863709      | 45.62   | 0.178803104              | 62.4492     | 0.002863177 | 1.000929777 |
| 20                    | 2700            | 0.007918315  | 1.678072      | 6.912328  | 0.286920327     | 7.77308       | 45.62   | 0.497096234              | 62.7675     | 0.007919644 | 1.00016782  |
| 20                    | 3000            | 0.019771917  | 2.94087       | 5.64953   | 0.542662578     | 7.517337      | 45.62   | 1.256366523              | 63.52677    | 0.019776963 | 1.000255216 |
| 30                    | 2000            | 5.48052E-06  | 0.794166      | 7.796234  | 0.177316376     | 7.882684      | 45.62   | 0.00034139               | 62.27074    | 5.48235E-06 | 1.000334974 |
| 30                    | 2100            | 2.59567E-05  | 0.806343      | 7.784057  | 0.167689828     | 7.89231       | 45.62   | 0.001616479              | 62.27202    | 2.59584E-05 | 1.000063861 |
| 30                    | 2200            | 0.000104883  | 0.822924      | 7.767476  | 0.160939891     | 7.89906       | 45.62   | 0.006531867              | 62.27693    | 0.000104884 | 1.00009667  |
| 30                    | 2300            | 0.000357961  | 0.856837      | 7.733563  | 0.158572045     | 7.901428      | 45.62   | 0.02230439               | 62.2927     | 0.000358058 | 1.000271021 |
| 30                    | 2400            | 0.000992457  | 0.929716      | 7.660684  | 0.164924937     | 7.895075      | 45.62   | 0.061920533              | 62.33232    | 0.000993394 | 1.00094361  |
| 30                    | 2500            | 0.002203608  | 1.062941      | 7.527459  | 0.182914818     | 7.877085      | 45.62   | 0.137528153              | 62.40793    | 0.002203697 | 1.000040436 |
| 30                    | 2700            | 0.006563216  | 1.535906      | 7.054494  | 0.2582686       | 7.801731      | 45.62   | 0.411687222              | 62.68209    | 0.006567861 | 1.000707696 |
| 30                    | 3000            | 0.017286743  | 2.684536      | 5.905864  | 0.477941898     | 7.582058      | 45.62   | 1.095838928              | 63.36624    | 0.017293735 | 1.000040429 |
| 40                    | 2000            | 4.11196E-06  | 0.794029      | 7.796371  | 0.177283321     | 7.882717      | 45.62   | 0.00025617               | 62.27066    | 4.11381E-06 | 1.000450453 |
| 40                    | 2100            | 1.95025E-05  | 0.805687      | 7.784713  | 0.167542337     | 7.892458      | 45.62   | 0.001214562              | 62.27161    | 1.95043E-05 | 1.000088647 |
| 40                    | 2200            | 7.92228E-05  | 0.820286      | 7.770114  | 0.160380983     | 7.899619      | 45.62   | 0.004933702              | 62.27533    | 7.9224E-05  | 1.000015168 |
| 40                    | 2300            | 0.000274584  | 0.848192      | 7.742208  | 0.156831451     | 7.903169      | 45.62   | 0.017111701              | 62.28751    | 0.000274721 | 1.000500025 |
| 40                    | 2400            | 0.000784917  | 0.907941      | 7.682459  | 0.160691786     | 7.899308      | 45.62   | 0.048916397              | 62.31932    | 0.000784932 | 1.000018076 |
| 40                    | 2500            | 0.001809128  | 1.021538      | 7.568862  | 0.175003976     | 7.884996      | 45.62   | 0.11287113               | 62.38327    | 0.001809317 | 1.000104446 |
| 40                    | 2700            | 0.005705413  | 1.445008      | 7.145392  | 0.240440893     | 7.819559      | 45.62   | 0.357324411              | 62.62772    | 0.005705531 | 1.000020714 |
| 40                    | 3000            | 0.015646701  | 2.514175      | 6.076225  | 0.437388746     | 7.622611      | 45.62   | 0.990381793              | 63.26078    | 0.015655541 | 1.000565021 |
| 50                    | 2000            | 3.29032E-06  | 0.793947      | 7.796453  | 0.177263476     | 7.882737      | 45.62   | 0.000205006              | 62.27061    | 3.29218E-06 | 1.000565954 |
| 50                    | 2100            | 1.56189E-05  | 0.805292      | 7.785108  | 0.167453597     | 7.892546      | 45.62   | 0.000972722              | 62.27137    | 1.56207E-05 | 1.000113523 |
| 50                    | 2200            | 6.36525E-05  | 0.818686      | 7.771714  | 0.160041981     | 7.899958      | 45.62   | 0.003964002              | 62.27436    | 6.36538E-05 | 1.000020916 |
| 50                    | 2300            | 0.000222784  | 0.842821      | 7.747579  | 0.155751679     | 7.904248      | 45.62   | 0.013886531              | 62.28429    | 0.000222954 | 1.000761901 |
| 50                    | 2400            | 0.000650234  | 0.89387       | 7.69653   | 0.157966691     | 7.902033      | 45.62   | 0.040518374              | 62.31092    | 0.000650261 | 1.000041533 |
| 50                    | 2500            | 0.001541656  | 0.993457      | 7.596943  | 0.169678606     | 7.890321      | 45.62   | 0.096167629              | 62.36657    | 0.001541974 | 1.000206379 |
| 50                    | 2700            | 0.00509283   | 1.380356      | 7.210044  | 0.22798614      | 7.832014      | 45.62   | 0.318770945              | 62.58917    | 0.005093069 | 1.000046861 |
| 50                    | 3000            | 0.014444512  | 2.388762      | 6.201638  | 0.408699442     | 7.651301      | 45.62   | 0.913330914              | 63.18373    | 0.014455516 | 1.000737316 |
| 60                    | 2000            | 2.74235E-06  | 0.793892      | 7.796508  | 0.177250241     | 7.88275       | 45.62   | 0.000170884              | 62.27057    | 2.74422E-06 | 1.000681464 |
| 60                    | 2100            | 1.30252E-05  | 0.805028      | 7.785372  | 0.167394334     | 7.892606      | 45.62   | 0.000811206              | 62.27121    | 1.3027E-05  | 1.000138446 |
| 60                    | 2200            | 5.3198E-05   | 0.817611      | 7.772789  | 0.159814419     | 7.900186      | 45.62   | 0.003312925              | 62.27371    | 5.31994E-05 | 1.000026795 |
| 60                    | 2300            | 0.000187464  | 0.839139      | 7.751261  | 0.155012085     | 7.904988      | 45.62   | 0.011675711              | 62.28208    | 0.000187465 | 1.000003191 |
| 60                    | 2400            | 0.000555492  | 0.883971      | 7.706429  | 0.156054351     | 7.903946      | 45.62   | 0.03461255               | 62.30501    | 0.000555534 | 1.000075008 |
| 60                    | 2500            | 0.001346599  | 0.972976      | 7.617424  | 0.16581494      | 7.894185      | 45.62   | 0.083995467              | 62.3544     | 0.001347066 | 1.000346595 |
| 60                    | 2700            | 0.004626512  | 1.331098      | 7.259302  | 0.21861987      | 7.84138       | 45.62   | 0.28945901               | 62.55986    | 0.004626913 | 1.000086642 |
| 60                    | 3000            | 0.013507314  | 2.290679      | 6.299721  | 0.386914607     | 7.673085      | 45.62   | 0.853396726              | 63.1238     | 0.013519414 | 1.000895793 |
| 70                    | 2000            | 2.35084E-06  | 0.793852      | 7.796548  | 0.177240785     | 7.882759      | 45.62   | 0.000146505              | 62.27055    | 2.35272E-06 | 1.00079698  |
| 70                    | 2100            | 1.11702E-05  | 0.804839      | 7.785561  | 0.167351953     | 7.892648      | 45.62   | 0.000695695              | 62.2711     | 1.1172E-05  | 1.000163396 |
| 70                    | 2200            | 4.56935E-05  | 0.81684       | 7.77356   | 0.159651099     | 7.900349      | 45.62   | 0.002845576              | 62.27325    | 4.5695E-05  | 1.000032768 |
| 70                    | 2300            | 0.000161819  | 0.836478      | 7.753922  | 0.154477954     | 7.905522      | 45.62   | 0.010078194              | 62.28048    | 0.000161819 | 1.000004396 |
| 70                    | 2400            | 0.000485087  | 0.876614      | 7.713786  | 0.154635719     | 7.905364      | 45.62   | 0.030224747              | 62.30062    | 0.000485144 | 1.000117467 |
| 70                    | 2500            | 0.001197261  | 0.957296      | 7.633104  | 0.162868466     | 7.897132      | 45.62   | 0.074682437              | 62.34508    | 0.001197888 | 1.000523635 |
| 70                    | 2700            | 0.00425554   | 1.29189       | 7.29851   | 0.211239103     | 7.848761      | 45.62   | 0.266164534              | 62.53656    | 0.004256143 | 1.000141515 |
| 70                    | 3000            | 0.012754366  | 2.210303      | 6.380097  | 0.369473126     | 7.690527      | 45.62   | 0.804488088              | 63.07489    | 0.012754491 | 1.000009795 |
| 80                    | 2000            | 2.05716E-06  | 0.793823      | 7.796577  | 0.177233692     | 7.882766      | 45.62   | 0.000128217              | 62.27053    | 2.05903E-06 | 1.000912503 |
| 80                    | 2100            | 9.77774E-06  | 0.804698      | 7.785702  | 0.167320139     | 7.89268       | 45.62   | 0.000608984              | 62.27101    | 9.77958E-06 | 1.000188362 |
| 80                    | 2200            | 4.00447E-05  | 0.816259      | 7.774141  | 0.159528179     | 7.900472      | 45.62   | 0.002493796              | 62.27289    | 4.00462E-05 | 1.000038797 |
| 80                    | 2300            | 0.000142352  | 0.834459      | 7.755941  | 0.154072692     | 7.905927      | 45.62   | 0.008865619              | 62.27927    | 0.000142353 | 1.000056994 |
| 80                    | 2400            | 0.000430648  | 0.870925      | 7.719475  | 0.153540286     | 7.90646       | 45.62   | 0.026832688              | 62.29723    | 0.00043072  | 1.000167707 |
| 80                    | 2500            | 0.001078854  | 0.944866      | 7.645534  | 0.160539583     | 7.89946       | 45.62   | 0.067302738              | 62.3377     | 0.001079647 | 1.00073502  |
| 80                    | 2700            | 0.00395101   | 1.259692      | 7.330708  | 0.205226845     | 7.854773      | 45.62   | 0.247059635              | 62.51746    | 0.00395185  | 1.0002126   |
| 80                    | 3000            | 0.012118467  | 2.143358      | 6.447042  | 0.355219387     | 7.704781      | 45.62   | 0.763888603              | 63.03429    | 0.01211862  | 1.000012652 |

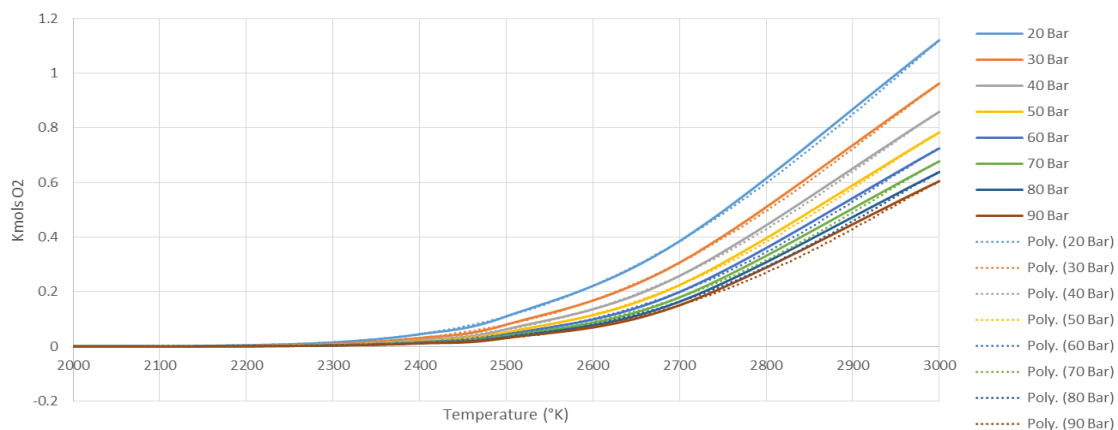


| Lambda 0.95 (4000RPM) |                 |              |               |           |                 |               |         |                          |             |             |             |
|-----------------------|-----------------|--------------|---------------|-----------|-----------------|---------------|---------|--------------------------|-------------|-------------|-------------|
| Pressure (Bar)        | Temperature (K) | N5/NT(Guess) | N3<br>C/(<+1) | N1<br>C-< | N4<br>H/2x(<+1) | N2<br>(H/2)-< | N6<br>N | N5<br>(Ox2)-2N1-N2-N3)/2 | NT<br>Total | Calc N5/NT  | Calc/Guess  |
| 10                    | 2000            | 1.03E-05     | 0.989713      | 7.683287  | 0.225071232     | 7.912429      | 45.6276 | 0.000641989              | 62.43874    | 1.02819E-05 | 1.00003248  |
| 10                    | 2100            | 4.85085E-05  | 1.006241      | 7.666759  | 0.213320768     | 7.924179      | 45.6276 | 0.003030851              | 62.44113    | 4.85393E-05 | 1.000634936 |
| 10                    | 2200            | 0.00019372   | 1.031742      | 7.641258  | 0.205955224     | 7.931545      | 45.6276 | 0.012098839              | 62.4502     | 0.000193736 | 1.000083289 |
| 10                    | 2300            | 0.000641143  | 1.087663      | 7.585337  | 0.206004657     | 7.931495      | 45.6276 | 0.040083699              | 62.47818    | 0.000641563 | 1.000655292 |
| 10                    | 2400            | 0.00168543   | 1.204669      | 7.468331  | 0.21983083      | 7.917669      | 45.6276 | 0.105499716              | 62.5436     | 0.001686819 | 1.000824109 |
| 10                    | 2500            | 0.003527382  | 1.405003      | 7.267997  | 0.250717544     | 7.886782      | 45.6276 | 0.221110261              | 62.65921    | 0.003528775 | 1.000394905 |
| 10                    | 2700            | 0.009624484  | 2.059495      | 6.613505  | 0.36788361      | 7.769616      | 45.6276 | 0.606939138              | 63.04504    | 0.009627072 | 1.000268905 |
| 10                    | 3000            | 0.023357202  | 3.502245      | 5.170755  | 0.698710218     | 7.43879       | 45.6276 | 1.49372768               | 63.93183    | 0.023364383 | 1.000307423 |
| 20                    | 2000            | 5.14696E-06  | 0.9892        | 7.6838    | 0.224943153     | 7.912557      | 45.6276 | 0.00032137               | 62.43842    | 5.14699E-06 | 1.00000676  |
| 20                    | 2100            | 2.43881E-05  | 1.003796      | 7.669204  | 0.212749864     | 7.92475       | 45.6276 | 0.001522787              | 62.43962    | 2.43882E-05 | 1.000001372 |
| 20                    | 2200            | 9.89571E-05  | 1.022046      | 7.650954  | 0.203815985     | 7.933684      | 45.6276 | 0.006180911              | 62.44428    | 9.89828E-05 | 1.000259618 |
| 20                    | 2300            | 0.000342364  | 1.056765      | 7.616235  | 0.199503938     | 7.937996      | 45.6276 | 0.021384363              | 62.45948    | 0.000342372 | 1.000023661 |
| 20                    | 2400            | 0.000975528  | 1.130747      | 7.542253  | 0.204709375     | 7.932791      | 45.6276 | 0.060978362              | 62.49908    | 0.000975668 | 1.000143842 |
| 20                    | 2500            | 0.002238161  | 1.27033       | 7.40267   | 0.22334364      | 7.914166      | 45.6276 | 0.140082047              | 62.57818    | 0.002238513 | 1.000156884 |
| 20                    | 2700            | 0.00697332   | 1.782513      | 6.890487  | 0.307964585     | 7.829535      | 45.6276 | 0.438488949              | 62.87659    | 0.006973803 | 1.000069217 |
| 20                    | 3000            | 0.018663691  | 3.025719      | 5.647281  | 0.562803372     | 7.574697      | 45.6276 | 1.187511271              | 63.62561    | 0.018664045 | 1.000018947 |
| 30                    | 2000            | 3.43265E-06  | 0.989028      | 7.683972  | 0.224900395     | 7.9126        | 45.6276 | 0.000214331              | 62.43831    | 3.43268E-06 | 1.000010276 |
| 30                    | 2100            | 1.62888E-05  | 1.002976      | 7.670024  | 0.212558464     | 7.924942      | 45.6276 | 0.001017062              | 62.43912    | 1.62889E-05 | 1.000002192 |
| 30                    | 2200            | 6.64606E-05  | 1.01872       | 7.65428   | 0.203083307     | 7.934417      | 45.6276 | 0.004151824              | 62.44225    | 6.64906E-05 | 1.000452244 |
| 30                    | 2300            | 0.00023385   | 1.045555      | 7.627445  | 0.197155872     | 7.940344      | 45.6276 | 0.014605422              | 62.45271    | 0.000233864 | 1.000060006 |
| 30                    | 2400            | 0.000691128  | 1.101183      | 7.571817  | 0.198728399     | 7.938772      | 45.6276 | 0.043205698              | 62.48131    | 0.000691498 | 1.000534994 |
| 30                    | 2500            | 0.001668635  | 1.210901      | 7.462099  | 0.211506433     | 7.925994      | 45.6276 | 0.104453567              | 62.54255    | 0.00167012  | 1.000890156 |
| 30                    | 2700            | 0.005669897  | 1.646029      | 7.026971  | 0.279861661     | 7.857638      | 45.6276 | 0.356195561              | 62.7943     | 0.005672419 | 1.000444784 |
| 30                    | 3000            | 0.01619358   | 2.77158       | 5.90142   | 0.497578983     | 7.639921      | 45.6276 | 1.027829598              | 63.46593    | 0.016194982 | 1.00008661  |
| 40                    | 2000            | 2.57499E-06  | 0.988893      | 7.684057  | 0.224879004     | 7.912621      | 45.6276 | 0.00016078               | 62.43826    | 2.57502E-06 | 1.000013793 |
| 40                    | 2100            | 1.2228E-05   | 1.002564      | 7.670436  | 0.21246251      | 7.925037      | 45.6276 | 0.000763502              | 62.43886    | 1.2228E-05  | 1.000003016 |
| 40                    | 2200            | 5.00323E-05  | 1.017039      | 7.655961  | 0.20271309      | 7.934787      | 45.6276 | 0.003126111              | 62.44123    | 5.00648E-05 | 1.00065002  |
| 40                    | 2300            | 0.000177623  | 1.039746      | 7.633254  | 0.195941238     | 7.941559      | 45.6276 | 0.011093557              | 62.44919    | 0.000177641 | 1.000104423 |
| 40                    | 2400            | 0.000536187  | 1.085019      | 7.587981  | 0.195474293     | 7.942026      | 45.6276 | 0.033496664              | 62.4716     | 0.00053619  | 1.000005781 |
| 40                    | 2500            | 0.001338706  | 1.176226      | 7.496774  | 0.204675756     | 7.932824      | 45.6276 | 0.083700707              | 62.5218     | 0.001338744 | 1.000028881 |
| 40                    | 2700            | 0.004852285  | 1.559831      | 7.113169  | 0.26256886      | 7.874931      | 45.6276 | 0.304450128              | 62.74255    | 0.004852371 | 1.000017756 |
| 40                    | 3000            | 0.014565794  | 2.603086      | 6.069914  | 0.456782967     | 7.680717      | 45.6276 | 0.923184361              | 63.36128    | 0.014570165 | 1.000300061 |
| 50                    | 2000            | 2.06023E-06  | 0.988891      | 7.684109  | 0.224866166     | 7.912634      | 45.6276 | 0.000128639              | 62.43823    | 2.06027E-06 | 1.00001731  |
| 50                    | 2100            | 9.78782E-06  | 1.002317      | 7.670683  | 0.212404855     | 7.925095      | 45.6276 | 0.000611141              | 62.43871    | 9.78786E-06 | 1.000003841 |
| 50                    | 2200            | 4.01165E-05  | 1.016024      | 7.656976  | 0.202489692     | 7.93501       | 45.6276 | 0.002507027              | 62.44061    | 4.01506E-05 | 1.000850044 |
| 50                    | 2300            | 0.000143208  | 1.03619       | 7.63681   | 0.195198491     | 7.942302      | 45.6276 | 0.008944316              | 62.44704    | 0.00014323  | 1.000153322 |
| 50                    | 2400            | 0.000438297  | 1.074829      | 7.598171  | 0.193428579     | 7.944071      | 45.6276 | 0.027378735              | 62.46548    | 0.000438302 | 1.000011873 |
| 50                    | 2500            | 0.001120577  | 1.153395      | 7.519605  | 0.200206321     | 7.937294      | 45.6276 | 0.070050591              | 62.50815    | 0.001120663 | 1.000077364 |
| 50                    | 2700            | 0.004274925  | 1.49908       | 7.17392   | 0.250586367     | 7.886914      | 45.6276 | 0.268083432              | 62.70618    | 0.004275231 | 1.0000717   |
| 50                    | 3000            | 0.013373543  | 2.479365      | 6.193635  | 0.427980784     | 7.709519      | 45.6276 | 0.846922691              | 63.28502    | 0.013382672 | 1.000682601 |
| 60                    | 2000            | 1.71699E-06  | 0.988857      | 7.684143  | 0.224857606     | 7.912642      | 45.6276 | 0.000107208              | 62.43821    | 1.71703E-06 | 1.000020827 |
| 60                    | 2100            | 8.15955E-06  | 1.002153      | 7.670847  | 0.212366385     | 7.925134      | 45.6276 | 0.000509473              | 62.43861    | 8.15959E-06 | 1.000004668 |
| 60                    | 2200            | 3.34813E-05  | 1.015342      | 7.657658  | 0.202339439     | 7.935161      | 45.6276 | 0.002090584              | 62.44019    | 3.34814E-05 | 1.000001027 |
| 60                    | 2300            | 0.000119971  | 1.033789      | 7.639211  | 0.194697258     | 7.942803      | 45.6276 | 0.007493182              | 62.44559    | 0.000119995 | 1.000204955 |
| 60                    | 2400            | 0.000370759  | 1.067797      | 7.605203  | 0.192019571     | 7.94548       | 45.6276 | 0.02315851               | 62.46126    | 0.000370766 | 1.000019919 |
| 60                    | 2500            | 0.000964933  | 1.137102      | 7.535898  | 0.197030307     | 7.94047       | 45.6276 | 0.060316234              | 62.49842    | 0.000965084 | 1.000156371 |
| 60                    | 2700            | 0.003839353  | 1.453236      | 7.219764  | 0.241653783     | 7.895846      | 45.6276 | 0.240694712              | 62.67879    | 0.00384013  | 1.000202224 |
| 60                    | 3000            | 0.012453369  | 2.382246      | 6.290754  | 0.406021219     | 7.731479      | 45.6276 | 0.787383694              | 63.22548    | 0.012453581 | 1.000017031 |
| 70                    | 2000            | 1.47179E-06  | 0.988832      | 7.684168  | 0.22485149      | 7.912649      | 45.6276 | 9.18983E-05              | 62.43819    | 1.47183E-06 | 1.000024344 |
| 70                    | 2100            | 6.99576E-06  | 1.002035      | 7.670965  | 0.212338889     | 7.925161      | 45.6276 | 0.000436807              | 62.43854    | 6.9958E-06  | 1.000005495 |
| 70                    | 2200            | 2.87295E-05  | 1.014855      | 7.658145  | 0.202232393     | 7.935268      | 45.6276 | 0.001793866              | 62.43989    | 2.87295E-05 | 1.000001243 |
| 70                    | 2300            | 0.000103224  | 1.032059      | 7.640941  | 0.19433618      | 7.943164      | 45.6276 | 0.006447438              | 62.44455    | 0.000103251 | 1.00025832  |
| 70                    | 2400            | 0.000321314  | 1.062649      | 7.610351  | 0.190989286     | 7.946511      | 45.6276 | 0.020069297              | 62.45817    | 0.000321324 | 1.0000296   |
| 70                    | 2500            | 0.000847942  | 1.124856      | 7.548144  | 0.194650383     | 7.94285       | 45.6276 | 0.053002977              | 62.4911     | 0.000848168 | 1.000266493 |
| 70                    | 2700            | 0.003495694  | 1.41708       | 7.25592   | 0.234674697     | 7.902825      | 45.6276 | 0.219127486              | 62.65723    | 0.003497242 | 1.000442903 |
| 70                    | 3000            | 0.011702719  | 2.303608      | 6.369392  | 0.388642663     | 7.748857      | 45.6276 | 0.739375316              | 63.17748    | 0.011703148 | 1.000036616 |
| 80                    | 2000            | 1.28787E-06  | 0.988814      | 7.684186  | 0.224846903     | 7.912653      | 45.6276 | 8.04146E-05              | 62.43818    | 1.28791E-06 | 1.000027862 |
| 80                    | 2100            | 6.12251E-06  | 1.001946      | 7.671054  | 0.212318258     | 7.925182      | 45.6276 | 0.000382283              | 62.43848    | 6.12255E-06 | 1.000006322 |
| 80                    | 2200            | 2.51588E-05  | 1.01449       | 7.65851   | 0.202151963     | 7.935348      | 45.6276 | 0.001570909              | 62.43967    | 2.51588E-05 | 1.000001461 |
| 80                    | 2300            | 9.0581E-05   | 1.030752      | 7.642248  | 0.194063667     | 7.943436      | 45.6276 | 0.005657989              | 62.44376    | 9.06094E-05 | 1.000312891 |
| 80                    | 2400            | 0.000283536  | 1.058716      | 7.614284  | 0.190202799     | 7.947297      | 45.6276 | 0.017709192              | 62.45581    | 0.000283548 | 1.000040619 |
| 80                    | 2500            | 0.000756633  | 1.115298      | 7.557702  | 0.192797402     | 7.944703      | 45.6276 | 0.047297715              | 62.4854     | 0.00075694  | 1.000406352 |
| 80                    | 2700            | 0.003215736  | 1.387658      | 7.285342  | 0.229037445     | 7.908463      | 45.6276 | 0.20159776               | 62.6397     | 0.003218371 | 1.000819388 |
| 80                    | 3000            | 0.011075932  | 2.237833      | 6.435167  | 0.374374848     | 7.763125      | 45.6276 | 0.699353939              | 63.13745    | 0.011076689 | 1.000068309 |

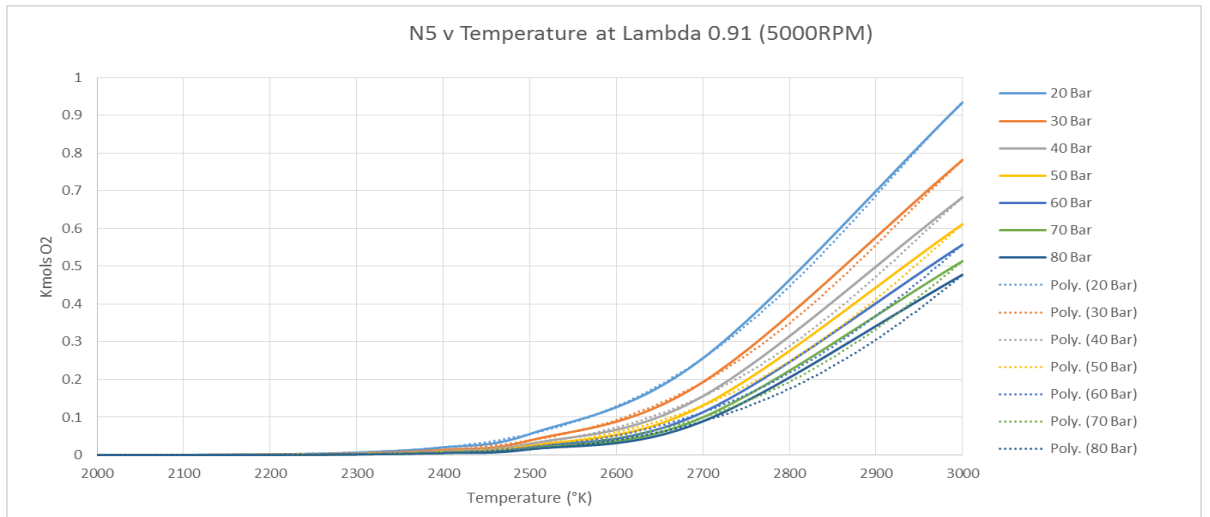


| Lambda 0.94 (4000RPM) |                 |              |               |           |                 |               |         |                          |             |             |             |
|-----------------------|-----------------|--------------|---------------|-----------|-----------------|---------------|---------|--------------------------|-------------|-------------|-------------|
| Pressure (Bar)        | Temperature (K) | N5/NT(Guess) | N3<br>C/(<+1) | N1<br>C-< | N4<br>H/2x(<+1) | N2<br>(H/2)-< | N6<br>N | N5<br>(Ox2)-2N1-N2-N3)/2 | NT<br>Total | Calc N5/NT  | Calc/Guess  |
| 10                    | 2000            | 6.99E-06     | 1.183102      | 7.572498  | 0.273973077     | 7.941027      | 45.6276 | 0.000437674              | 62.59864    | 6.99174E-06 | 1.000358381 |
| 10                    | 2100            | 3.30662E-05  | 1.200941      | 7.554659  | 0.259399127     | 7.955601      | 45.6276 | 0.002070103              | 62.60027    | 3.30686E-05 | 1.000071208 |
| 10                    | 2200            | 0.000133726  | 1.22398       | 7.53162   | 0.248964165     | 7.966036      | 45.6276 | 0.008372199              | 62.60657    | 0.000133727 | 1.000011608 |
| 10                    | 2300            | 0.000458831  | 1.268984      | 7.486616  | 0.244707493     | 7.970293      | 45.6276 | 0.028745511              | 62.62695    | 0.000458996 | 1.000359273 |
| 10                    | 2400            | 0.001286694  | 1.364493      | 7.391107  | 0.253005994     | 7.961994      | 45.6276 | 0.080649367              | 62.67885    | 0.001286708 | 1.000010864 |
| 10                    | 2500            | 0.002891284  | 1.54057       | 7.21503   | 0.27866706      | 7.936333      | 45.6276 | 0.181518678              | 62.77972    | 0.002891359 | 1.000025867 |
| 10                    | 2700            | 0.008678939  | 2.162192      | 6.593408  | 0.390159148     | 7.824841      | 45.6276 | 0.548075716              | 63.14628    | 0.008679462 | 1.000060326 |
| 10                    | 3000            | 0.022256464  | 3.586593      | 5.169007  | 0.721084137     | 7.493916      | 45.6276 | 1.425738416              | 64.02394    | 0.022268833 | 1.000555744 |
| 20                    | 2000            | 3.49699E-06  | 1.182755      | 7.572845  | 0.273883185     | 7.941117      | 45.6276 | 0.000219066              | 62.59842    | 3.49954E-06 | 1.00072794  |
| 20                    | 2100            | 1.65862E-05  | 1.19928       | 7.55632   | 0.258996578     | 7.956003      | 45.6276 | 0.001038444              | 62.59924    | 1.65888E-05 | 1.000153201 |
| 20                    | 2200            | 6.77243E-05  | 1.217256      | 7.538344  | 0.247423459     | 7.967577      | 45.6276 | 0.004239838              | 62.60244    | 6.77264E-05 | 1.000031168 |
| 20                    | 2300            | 0.000239248  | 1.246386      | 7.509214  | 0.239774748     | 7.975225      | 45.6276 | 0.014980124              | 62.61318    | 0.000239249 | 1.000004147 |
| 20                    | 2400            | 0.0007144    | 1.305242      | 7.450358  | 0.240472762     | 7.974527      | 45.6276 | 0.044757138              | 62.64296    | 0.000714448 | 1.000112339 |
| 20                    | 2500            | 0.00175245   | 1.422188      | 7.333412  | 0.253890756     | 7.961109      | 45.6276 | 0.109939406              | 62.70814    | 0.001753192 | 1.000423397 |
| 20                    | 2700            | 0.006114458  | 1.895262      | 6.860338  | 0.331164046     | 7.883836      | 45.6276 | 0.385112954              | 62.98331    | 0.006114524 | 1.00001069  |
| 20                    | 3000            | 0.017589098  | 3.113769      | 5.641831  | 0.58404627      | 7.630954      | 45.6276 | 1.120807408              | 63.71901    | 0.017589844 | 1.000042419 |
| 30                    | 2000            | 2.33186E-06  | 1.182639      | 7.572961  | 0.273853129     | 7.941147      | 45.6276 | 0.00014597               | 62.59835    | 2.33186E-06 | 1.000000193 |
| 30                    | 2100            | 1.10694E-05  | 1.198724      | 7.556876  | 0.258861848     | 7.956138      | 45.6276 | 0.000693094              | 62.59889    | 1.1072E-05  | 1.000235477 |
| 30                    | 2200            | 4.53466E-05  | 1.214976      | 7.540624  | 0.246901528     | 7.968098      | 45.6276 | 0.002838888              | 62.60104    | 4.53489E-05 | 1.000051633 |
| 30                    | 2300            | 0.000161897  | 1.238429      | 7.517171  | 0.238043564     | 7.976956      | 45.6276 | 0.010136199              | 62.60834    | 0.000161899 | 1.00000882  |
| 30                    | 2400            | 0.000496197  | 1.282638      | 7.472962  | 0.235733691     | 7.979266      | 45.6276 | 0.03108601               | 62.62929    | 0.000496349 | 1.000360309 |
| 30                    | 2500            | 0.001272361  | 1.372098      | 7.383502  | 0.243601408     | 7.971399      | 45.6276 | 0.079749938              | 62.67795    | 0.001272376 | 1.000011811 |
| 30                    | 2700            | 0.004875244  | 1.765742      | 6.989858  | 0.303864273     | 7.911136      | 45.6276 | 0.306703155              | 62.96049    | 0.004875664 | 1.000086187 |
| 30                    | 3000            | 0.015138823  | 2.862476      | 5.893124  | 0.5184363       | 7.696564      | 45.6276 | 0.962356247              | 63.56056    | 0.015140778 | 1.000129114 |
| 40                    | 2000            | 1.74909E-06  | 1.182581      | 7.573019  | 0.273883129     | 7.941162      | 45.6276 | 0.00010949               | 62.59831    | 1.74909E-06 | 1.000000259 |
| 40                    | 2100            | 8.3065E-06   | 1.198446      | 7.557154  | 0.258794381     | 7.956206      | 45.6276 | 0.000520142              | 62.59872    | 8.30914E-06 | 1.000317828 |
| 40                    | 2200            | 3.40846E-05  | 1.213829      | 7.541771  | 0.246638943     | 7.968361      | 45.6276 | 0.002133863              | 62.60033    | 3.40871E-05 | 1.000072363 |
| 40                    | 2300            | 0.000122357  | 1.234361      | 7.521239  | 0.23715964      | 7.97784       | 45.6276 | 0.007660357              | 62.60586    | 0.000122358 | 1.000014038 |
| 40                    | 2400            | 0.000380425  | 1.270644      | 7.484956  | 0.23322831      | 7.981772      | 45.6276 | 0.023836264              | 62.62204    | 0.000380637 | 1.000556824 |
| 40                    | 2500            | 0.001002273  | 1.343944      | 7.411656  | 0.237867433     | 7.977133      | 45.6276 | 0.062805584              | 62.66101    | 0.001002307 | 1.000034551 |
| 40                    | 2700            | 0.00410673   | 1.685301      | 7.070299  | 0.287321127     | 7.927679      | 45.6276 | 0.258210928              | 62.85641    | 0.004107949 | 1.000296782 |
| 40                    | 3000            | 0.013529333  | 2.696253      | 6.059347  | 0.477463038     | 7.737537      | 45.6276 | 0.858757993              | 63.45696    | 0.013532921 | 1.000265158 |
| 50                    | 2000            | 1.39937E-06  | 1.182546      | 7.573054  | 0.273829128     | 7.941171      | 45.6276 | 8.75981E-05              | 62.59829    | 1.39937E-06 | 1.000000324 |
| 50                    | 2100            | 6.64735E-06  | 1.198279      | 7.557321  | 0.258753866     | 7.956246      | 45.6276 | 0.000416281              | 62.59862    | 6.65001E-06 | 1.000400208 |
| 50                    | 2200            | 2.73038E-05  | 1.213138      | 7.542462  | 0.246480867     | 7.968519      | 45.6276 | 0.001709373              | 62.59991    | 2.73063E-05 | 1.000093207 |
| 50                    | 2300            | 9.8343E-05   | 1.23189       | 7.52371   | 0.236623153     | 7.978377      | 45.6276 | 0.00615682               | 62.60436    | 9.83449E-05 | 1.000019531 |
| 50                    | 2400            | 0.000308552  | 1.263198      | 7.492402  | 0.231676135     | 7.983324      | 45.6276 | 0.019337011              | 62.61754    | 0.000308811 | 1.000841545 |
| 50                    | 2500            | 0.000827997  | 1.32577       | 7.42983   | 0.234185006     | 7.980815      | 45.6276 | 0.051877725              | 62.65008    | 0.000828055 | 1.00007084  |
| 50                    | 2700            | 0.003571281  | 1.62925       | 7.12635   | 0.275975002     | 7.939025      | 45.6276 | 0.224512645              | 62.82271    | 0.00357375  | 1.000691232 |
| 50                    | 3000            | 0.01235434   | 2.574421      | 6.181179  | 0.448571601     | 7.766428      | 45.6276 | 0.783396234              | 63.3816     | 0.012359995 | 1.000457725 |
| 60                    | 2000            | 1.16619E-06  | 1.182523      | 7.573077  | 0.273823126     | 7.941177      | 45.6276 | 7.30017E-05              | 62.59827    | 1.16619E-06 | 1.000000039 |
| 60                    | 2100            | 5.54065E-06  | 1.198167      | 7.557433  | 0.258726842     | 7.956273      | 45.6276 | 0.000347004              | 62.59855    | 5.54333E-06 | 1.000482604 |
| 60                    | 2200            | 2.27733E-05  | 1.212676      | 7.542924  | 0.246375263     | 7.968625      | 45.6276 | 0.00142576               | 62.59963    | 2.27759E-05 | 1.000114109 |
| 60                    | 2300            | 8.22101E-05  | 1.230231      | 7.525369  | 0.236262873     | 7.978737      | 45.6276 | 0.005146754              | 62.60335    | 8.22121E-05 | 1.00002518  |
| 60                    | 2400            | 0.000259571  | 1.258093      | 7.497507  | 0.230613367     | 7.984387      | 45.6276 | 0.016252951              | 62.61445    | 0.000259572 | 1.00000362  |
| 60                    | 2500            | 0.000705864  | 1.313032      | 7.442568  | 0.231612559     | 7.983387      | 45.6276 | 0.044222331              | 62.64242    | 0.000705949 | 1.000119522 |
| 60                    | 2700            | 0.003173086  | 1.587175      | 7.168425  | 0.267553528     | 7.947446      | 45.6276 | 0.199264417              | 62.79746    | 0.003173128 | 1.000013477 |
| 60                    | 3000            | 0.011441536  | 2.479545      | 6.276055  | 0.426706947     | 7.788293      | 45.6276 | 0.725025891              | 63.32323    | 0.011449604 | 1.000705204 |
| 70                    | 2000            | 9.99627E-07  | 1.182506      | 7.573094  | 0.273818839     | 7.941181      | 45.6276 | 6.25749E-05              | 62.59826    | 9.99627E-07 | 1.000000455 |
| 70                    | 2100            | 4.74986E-06  | 1.198087      | 7.557513  | 0.258707533     | 7.956292      | 45.6276 | 0.000297502              | 62.59885    | 4.75255E-06 | 1.000565007 |
| 70                    | 2200            | 1.95323E-05  | 1.212346      | 7.543254  | 0.246299723     | 7.9687        | 45.6276 | 0.001222874              | 62.59942    | 1.95349E-05 | 1.000135046 |
| 70                    | 2300            | 7.06249E-05  | 1.229039      | 7.526561  | 0.236004225     | 7.978996      | 45.6276 | 0.004421439              | 62.60262    | 7.06271E-05 | 1.000030923 |
| 70                    | 2400            | 0.000224019  | 1.254406      | 7.501194  | 0.229846698     | 7.985153      | 45.6276 | 0.014026406              | 62.61223    | 0.00022402  | 1.000004961 |
| 70                    | 2500            | 0.000615378  | 1.303593      | 7.452007  | 0.229711039     | 7.985289      | 45.6276 | 0.038552154              | 62.63675    | 0.000615488 | 1.000178895 |
| 70                    | 2700            | 0.002861526  | 1.554435      | 7.201165  | 0.261056317     | 7.953944      | 45.6276 | 0.179645646              | 62.77785    | 0.002861609 | 1.00028866  |
| 70                    | 3000            | 0.010708581  | 2.40214       | 6.35346   | 0.409264499     | 7.805736      | 45.6276 | 0.677602274              | 63.2758     | 0.010708711 | 1.000012172 |
| 80                    | 2000            | 8.74695E-07  | 1.182494      | 7.573106  | 0.273815623     | 7.941184      | 45.6276 | 5.47544E-05              | 62.59825    | 8.74695E-07 | 1.000000521 |
| 80                    | 2100            | 4.15661E-06  | 1.198028      | 7.557572  | 0.258693048     | 7.956307      | 45.6276 | 0.000260366              | 62.59846    | 4.1593E-06  | 1.000647417 |
| 80                    | 2200            | 1.70989E-05  | 1.212098      | 7.543502  | 0.246243009     | 7.968757      | 45.6276 | 0.001070543              | 62.59927    | 1.71015E-05 | 1.000156005 |
| 80                    | 2300            | 6.19019E-05  | 1.228141      | 7.527459  | 0.235809517     | 7.97919       | 45.6276 | 0.003875329              | 62.60208    | 6.19042E-05 | 1.000036733 |
| 80                    | 2400            | 0.000197041  | 1.251609      | 7.503991  | 0.229265287     | 7.985735      | 45.6276 | 0.012336914              | 62.61054    | 0.000197042 | 1.00006409  |
| 80                    | 2500            | 0.000545585  | 1.296313      | 7.459287  | 0.228246961     | 7.986753      | 45.6276 | 0.034179763              | 62.63238    | 0.00054572  | 1.000247274 |
| 80                    | 2700            | 0.00261022   | 1.528014      | 7.227586  | 0.255848486     | 7.959152      | 45.6276 | 0.16383141               | 62.76203    | 0.002610359 | 1.000053286 |
| 80                    | 3000            | 0.010094041  | 2.337817      | 6.417783  | 0.395032336     | 7.819968      | 45.6276 | 0.638324648              | 63.23652    | 0.01009424  | 1.000019692 |

N5 v Temperature at Lambda 0.94 (4500RPM)

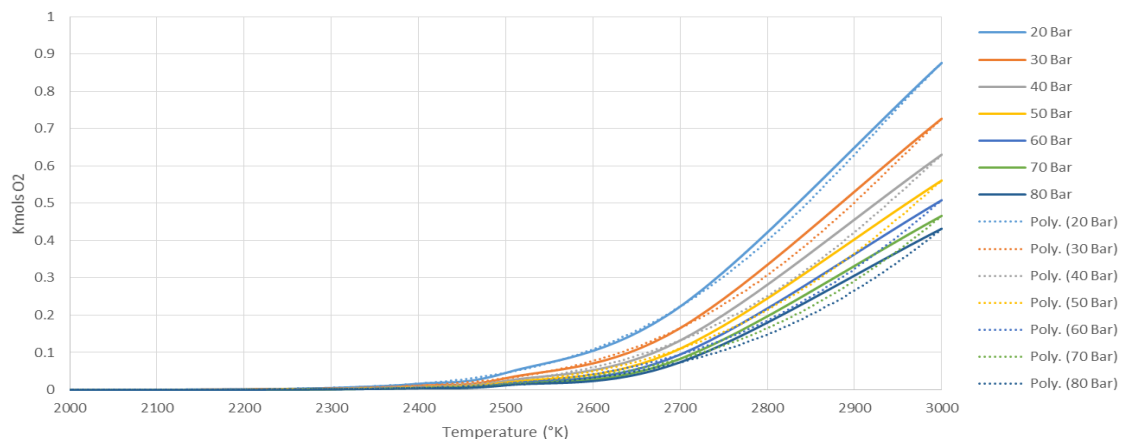


| Lambda 0.91 (5000RPM) |                 |              |               |           |                 |               |         |                          |             |             |             |
|-----------------------|-----------------|--------------|---------------|-----------|-----------------|---------------|---------|--------------------------|-------------|-------------|-------------|
| Pressure (Bar)        | Temperature (K) | N5/NT(Guess) | N3<br>C/(<+1) | N1<br>C-< | N4<br>H/2x(<+1) | N2<br>(H/2)-< | N6<br>N | N5<br>(Ox2)-2N1-N2-N3)/2 | NT<br>Total | Calc N5/NT  | Calc/Guess  |
| 10                    | 2000            | 2.91E-06     | 1.755722      | 7.247678  | 0.428944547     | 8.018555      | 45.6276 | 0.000183387              | 63.07868    | 2.90727E-06 | 1.000007486 |
| 10                    | 2100            | 1.37666E-05  | 1.779694      | 7.223706  | 0.406342757     | 8.041157      | 45.6276 | 0.00068392               | 63.07937    | 1.37667E-05 | 1.000001613 |
| 10                    | 2200            | 5.63072E-05  | 1.80324       | 7.20016   | 0.388167487     | 8.059333      | 45.6276 | 0.003553956              | 63.08205    | 5.63386E-05 | 1.00055875  |
| 10                    | 2300            | 0.000201095  | 1.835275      | 7.168125  | 0.374402326     | 8.073098      | 45.6276 | 0.012688908              | 63.09119    | 0.00020112  | 1.000122882 |
| 10                    | 2400            | 0.000619166  | 1.892447      | 7.110953  | 0.370014981     | 8.077485      | 45.6276 | 0.039080975              | 63.11758    | 0.000619177 | 1.000018847 |
| 10                    | 2500            | 0.001602931  | 2.006492      | 6.996908  | 0.380425628     | 8.067074      | 45.6276 | 0.101308953              | 63.17981    | 0.001603502 | 1.000356262 |
| 10                    | 2700            | 0.006251558  | 2.509258      | 6.494142  | 0.468749008     | 7.978751      | 45.6276 | 0.396853533              | 63.47535    | 0.006252089 | 1.000084833 |
| 10                    | 3000            | 0.019144429  | 3.853121      | 5.150279  | 0.794039086     | 7.653461      | 45.6276 | 1.231429803              | 64.30993    | 0.019148362 | 1.000205447 |
| 20                    | 2000            | 1.45392E-06  | 1.75558       | 7.24782   | 0.42890354      | 8.018596      | 45.6276 | 9.17124E-05              | 63.07859    | 1.45394E-06 | 1.000015037 |
| 20                    | 2100            | 6.8899E-06   | 1.779011      | 7.224389  | 0.406157848     | 8.041342      | 45.6276 | 0.00043609               | 63.07893    | 6.88993E-06 | 1.000003293 |
| 20                    | 2200            | 2.82639E-05  | 1.800422      | 7.202978  | 0.387443897     | 8.060056      | 45.6276 | 0.001782897              | 63.08028    | 2.82639E-05 | 1.000000787 |
| 20                    | 2300            | 0.000101944  | 1.825223      | 7.178177  | 0.371943305     | 8.075557      | 45.6276 | 0.006432982              | 63.08493    | 0.000101973 | 1.000291165 |
| 20                    | 2400            | 0.000322476  | 1.862134      | 7.141266  | 0.362863751     | 8.084636      | 45.6276 | 0.020349119              | 63.09885    | 0.000322496 | 1.000062671 |
| 20                    | 2500            | 0.00088248   | 1.932418      | 7.070982  | 0.36331229      | 8.084188      | 45.6276 | 0.055715141              | 63.13422    | 0.000882487 | 1.00008314  |
| 20                    | 2700            | 0.004046118  | 2.2825        | 6.7209    | 0.414789211     | 8.032711      | 45.6276 | 0.25649474               | 63.33499    | 0.004049811 | 1.000912655 |
| 20                    | 3000            | 0.014585542  | 3.397561      | 5.605839  | 0.654950533     | 7.792549      | 45.6276 | 0.934105947              | 64.01261    | 0.014592531 | 1.000479177 |
| 30                    | 2000            | 9.69343E-07  | 1.755532      | 7.247868  | 0.428889868     | 8.01861       | 45.6276 | 6.11462E-05              | 63.07856    | 9.69365E-07 | 1.000022588 |
| 30                    | 2100            | 4.59474E-06  | 1.778784      | 7.224616  | 0.406096139     | 8.041404      | 45.6276 | 0.000289832              | 63.07879    | 4.59476E-06 | 1.000004974 |
| 30                    | 2200            | 1.88673E-05  | 1.799478      | 7.203922  | 0.387201799     | 8.060298      | 45.6276 | 0.001190145              | 63.07969    | 1.88673E-05 | 1.000001214 |
| 30                    | 2300            | 6.82823E-05  | 1.821809      | 7.181591  | 0.371109584     | 8.07639       | 45.6276 | 0.004309429              | 63.08281    | 6.83138E-05 | 1.000462622 |
| 30                    | 2400            | 0.000218118  | 1.851468      | 7.151932  | 0.360358572     | 8.087141      | 45.6276 | 0.013763119              | 63.09226    | 0.000218143 | 1.000112271 |
| 30                    | 2500            | 0.00061053   | 1.904447      | 7.098953  | 0.356924457     | 8.090576      | 45.6276 | 0.038535625              | 63.11704    | 0.000610542 | 1.00001983  |
| 30                    | 2700            | 0.003050843  | 2.179207      | 6.824193  | 0.391170618     | 8.056329      | 45.6276 | 0.193038672              | 63.27154    | 0.003050956 | 1.000036892 |
| 30                    | 3000            | 0.012229853  | 3.158632      | 5.844768  | 0.588947427     | 7.858553      | 45.6276 | 0.781639706              | 63.86014    | 0.012239868 | 1.000818906 |
| 40                    | 2000            | 7.27032E-07  | 1.755509      | 7.247891  | 0.428883031     | 8.018617      | 45.6276 | 4.58615E-05              | 63.07855    | 7.27054E-07 | 1.000030139 |
| 40                    | 2100            | 3.4466E-06   | 1.77867       | 7.22473   | 0.40606527      | 8.041435      | 45.6276 | 0.000217409              | 63.07872    | 3.44663E-06 | 1.000006654 |
| 40                    | 2200            | 1.41598E-05  | 1.799006      | 7.204394  | 0.387080528     | 8.060419      | 45.6276 | 0.000893192              | 63.07939    | 1.41598E-05 | 1.000001642 |
| 40                    | 2300            | 5.1333E-05   | 1.82009       | 7.18331   | 0.370689998     | 8.07681       | 45.6276 | 0.003240233              | 63.08174    | 5.13656E-05 | 1.000635041 |
| 40                    | 2400            | 0.000164807  | 1.846017      | 7.157383  | 0.359081005     | 8.088419      | 45.6276 | 0.010399195              | 63.0889     | 0.000164834 | 1.000063968 |
| 40                    | 2500            | 0.00046702   | 1.889679      | 7.113721  | 0.353568163     | 8.093932      | 45.6276 | 0.029473651              | 63.10797    | 0.000467035 | 1.0000338   |
| 40                    | 2700            | 0.002464524  | 2.118464      | 6.884936  | 0.377549537     | 8.06995       | 45.6276 | 0.155856755              | 63.23436    | 0.002464748 | 1.000090914 |
| 40                    | 3000            | 0.010707686  | 3.001848      | 6.001552  | 0.547936811     | 7.899563      | 45.6276 | 0.682742544              | 63.76124    | 0.010707799 | 1.00001048  |
| 50                    | 2000            | 5.81637E-07  | 1.755494      | 7.247906  | 0.428878929     | 8.018621      | 45.6276 | 3.66902E-05              | 63.07854    | 5.81659E-07 | 1.00003769  |
| 50                    | 2100            | 2.75755E-06  | 1.778601      | 7.224799  | 0.406046745     | 8.041453      | 45.6276 | 0.000173944              | 63.07867    | 2.75757E-06 | 1.000008335 |
| 50                    | 2200            | 1.13323E-05  | 1.798722      | 7.204678  | 0.387007694     | 8.060492      | 45.6276 | 0.000714833              | 63.07921    | 1.13323E-05 | 1.000002069 |
| 50                    | 2300            | 4.1125E-05   | 1.819055      | 7.184345  | 0.370437363     | 8.077063      | 45.6276 | 0.002596307              | 63.0811     | 4.11582E-05 | 1.000807664 |
| 50                    | 2400            | 0.000132442  | 1.842708      | 7.160692  | 0.358306018     | 8.089194      | 45.6276 | 0.008357155              | 63.08686    | 0.000132471 | 1.000216722 |
| 50                    | 2500            | 0.000378226  | 1.88054       | 7.12286   | 0.351496587     | 8.096003      | 45.6276 | 0.023868129              | 63.10237    | 0.000378245 | 1.000049155 |
| 50                    | 2700            | 0.002073533  | 2.077914      | 6.925486  | 0.36856434      | 8.078936      | 45.6276 | 0.131089079              | 63.20959    | 0.00207388  | 1.000167401 |
| 50                    | 3000            | 0.009604841  | 2.888454      | 6.114946  | 0.519352326     | 7.928165      | 45.6276 | 0.611744793              | 63.69024    | 0.009605    | 1.00001653  |
| 60                    | 2000            | 4.84704E-07  | 1.755485      | 7.247915  | 0.428876194     | 8.018624      | 45.6276 | 3.05758E-05              | 63.07853    | 4.84726E-07 | 1.000045241 |
| 60                    | 2100            | 2.2981E-06   | 1.778556      | 7.224844  | 0.406034393     | 8.041466      | 45.6276 | 0.000144963              | 63.07864    | 2.29813E-06 | 1.000010016 |
| 60                    | 2200            | 9.44606E-06  | 1.798533      | 7.204867  | 0.386959108     | 8.060541      | 45.6276 | 0.00059585               | 63.0791     | 9.44608E-06 | 1.000002497 |
| 60                    | 2300            | 3.43035E-05  | 1.818363      | 7.185037  | 0.370268569     | 8.077231      | 45.6276 | 0.002166012              | 63.08067    | 3.43372E-05 | 1.000980704 |
| 60                    | 2400            | 0.000110704  | 1.840486      | 7.162914  | 0.35778578      | 8.089714      | 45.6276 | 0.00698568               | 63.08549    | 0.000110734 | 1.00026976  |
| 60                    | 2500            | 0.000317837  | 1.874323      | 7.129077  | 0.35008989      | 8.09741       | 45.6276 | 0.020056352              | 63.09856    | 0.000317858 | 1.000065429 |
| 60                    | 2700            | 0.001792495  | 2.048748      | 6.954652  | 0.362154205     | 8.085346      | 45.6276 | 0.113300912              | 63.1918     | 0.001792969 | 1.000263932 |
| 60                    | 3000            | 0.008756968  | 2.800987      | 6.202413  | 0.497852369     | 7.949648      | 45.6276 | 0.557269843              | 63.63577    | 0.008757179 | 1.000024069 |
| 70                    | 2000            | 4.15465E-07  | 1.755478      | 7.247922  | 0.428872776     | 8.018627      | 45.6276 | 2.62083E-05              | 63.07853    | 4.15487E-07 | 1.000052793 |
| 70                    | 2100            | 1.96989E-06  | 1.778523      | 7.224877  | 0.406025569     | 8.041474      | 45.6276 | 0.00012426               | 63.07862    | 1.96991E-06 | 1.000011697 |
| 70                    | 2200            | 8.09815E-06  | 1.798397      | 7.205003  | 0.38692439      | 8.060576      | 45.6276 | 0.000510825              | 63.07901    | 8.09817E-06 | 1.000002925 |
| 70                    | 2300            | 2.94232E-05  | 1.817865      | 7.185535  | 0.370146983     | 8.077353      | 45.6276 | 0.00185603               | 63.08036    | 2.94233E-05 | 1.000000787 |
| 70                    | 2400            | 9.5096E-05   | 1.83889       | 7.16451   | 0.3574124       | 8.090088      | 45.6276 | 0.006001024              | 63.0845     | 9.51268E-05 | 1.000323204 |
| 70                    | 2500            | 0.000274092  | 1.869819      | 7.133581  | 0.349072006     | 8.098428      | 45.6276 | 0.017295444              | 63.0958     | 0.000274114 | 1.000082207 |
| 70                    | 2700            | 0.001580029  | 2.026688      | 6.976712  | 0.357334879     | 8.090165      | 45.6276 | 0.099861483              | 63.17836    | 0.001580628 | 1.000378979 |
| 70                    | 3000            | 0.008077334  | 2.730702      | 6.272698  | 0.480942213     | 7.966558      | 45.6276 | 0.513672198              | 63.59217    | 0.008077601 | 1.000033112 |
| 80                    | 2000            | 3.63534E-07  | 1.755473      | 7.247927  | 0.428872776     | 8.018627      | 45.6276 | 2.29326E-05              | 63.07852    | 3.63556E-07 | 1.000060344 |
| 80                    | 2100            | 1.72371E-06  | 1.778499      | 7.224901  | 0.40601895      | 8.041481      | 45.6276 | 0.000108731              | 63.07861    | 1.72374E-06 | 1.000013378 |
| 80                    | 2200            | 7.08688E-06  | 1.798296      | 7.205104  | 0.386898343     | 8.060602      | 45.6276 | 0.000447034              | 63.07895    | 7.0869E-06  | 1.000003354 |
| 80                    | 2300            | 2.57585E-05  | 1.817493      | 7.185907  | 0.370056314     | 8.077444      | 45.6276 | 0.001624853              | 63.08012    | 2.57586E-05 | 1.000000909 |
| 80                    | 2400            | 8.33458E-05  | 1.837688      | 7.165712  | 0.357131381     | 8.090369      | 45.6276 | 0.005259749              | 63.08376    | 8.33772E-05 | 1.000376989 |
| 80                    | 2500            | 0.000240939  | 1.866405      | 7.136995  | 0.34830121      | 8.099199      | 45.6276 | 0.01520322               | 63.0937     | 0.000240963 | 1.00009941  |
| 80                    | 2700            | 0.001413424  | 2.009384      | 6.994016  | 0.353571841     | 8.093928      | 45.6276 | 0.089328113              | 63.16783    | 0.001414139 | 1.000505935 |
| 80                    | 3000            | 0.007516063  | 2.672546      | 6.330854  | 0.4671811       | 7.980319      | 45.6276 | 0.47771336               | 63.55621    | 0.007516391 | 1.000043664 |

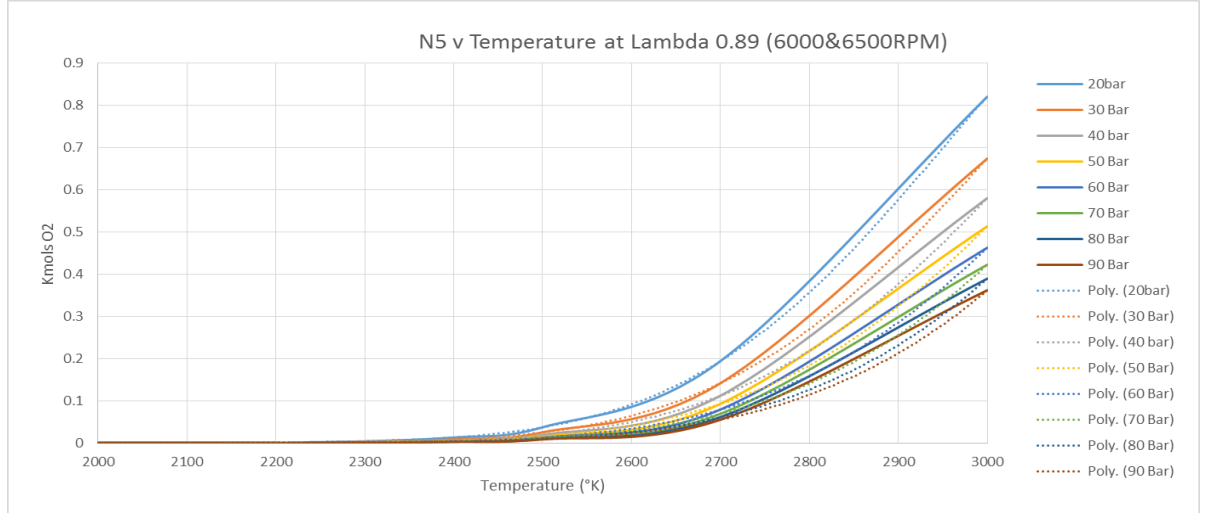


| Lambda 0.9 (5500RPM) |                 |              |               |           |                 |               |         |                          |             |             |             |
|----------------------|-----------------|--------------|---------------|-----------|-----------------|---------------|---------|--------------------------|-------------|-------------|-------------|
| Pressure (Bar)       | Temperature (K) | N5/NT(Guess) | N3<br>C/(<+1) | N1<br>C-< | N4<br>H/2x(<+1) | N2<br>(H/2)-< | N6<br>N | N5<br>(Ox2)-2N1-N2-N3)/2 | NT<br>Total | Calc N5/NT  | Calc/Guess  |
| 10                   | 2000            | 2.30E-06     | 1.943949      | 7.142051  | 0.483342984     | 8.041657      | 45.6276 | 0.000145762              | 63.23875    | 2.30495E-06 | 1.000895459 |
| 10                   | 2100            | 1.08993E-05  | 1.970244      | 7.115756  | 0.458134097     | 8.066866      | 45.6276 | 0.000689275              | 63.23929    | 1.08995E-05 | 1.000011728 |
| 10                   | 2200            | 4.46156E-05  | 1.995053      | 7.090947  | 0.437590759     | 8.087409      | 45.6276 | 0.002821801              | 63.24142    | 4.46195E-05 | 1.000088427 |
| 10                   | 2300            | 0.000160073  | 2.026012      | 7.059988  | 0.421237872     | 8.103762      | 45.6276 | 0.010125059              | 63.24873    | 0.000160083 | 1.000065382 |
| 10                   | 2400            | 0.00049964   | 2.076595      | 7.009405  | 0.413630027     | 8.111137      | 45.6276 | 0.031612438              | 63.27021    | 0.000499642 | 1.00000285  |
| 10                   | 2500            | 0.00132955   | 2.175831      | 6.910169  | 0.419689818     | 8.10531       | 45.6276 | 0.084260299              | 63.32286    | 0.001330646 | 1.000824261 |
| 10                   | 2700            | 0.005579133  | 2.637503      | 6.448497  | 0.499124263     | 8.025876      | 45.6276 | 0.354813396              | 63.59341    | 0.005579405 | 1.000048794 |
| 10                   | 3000            | 0.018163508  | 3.947075      | 5.138925  | 0.82062163      | 7.704378      | 45.6276 | 1.170348423              | 64.40895    | 0.018170587 | 1.000389777 |
| 20                   | 2000            | 1.15161E-06  | 1.943836      | 7.142164  | 0.483309463     | 8.041691      | 45.6276 | 7.28302E-05              | 63.23867    | 1.15167E-06 | 1.000050935 |
| 20                   | 2100            | 5.45347E-06  | 1.969707      | 7.116293  | 0.457983027     | 8.067017      | 45.6276 | 0.000344872              | 63.23894    | 5.45347E-06 | 1.000000399 |
| 20                   | 2200            | 2.23716E-05  | 1.992831      | 7.093169  | 0.436998548     | 8.088001      | 45.6276 | 0.001414848              | 63.24001    | 2.23727E-05 | 1.00005001  |
| 20                   | 2300            | 8.08543E-05  | 2.01802       | 7.06798   | 0.419206887     | 8.105793      | 45.6276 | 0.005113683              | 63.24371    | 8.08568E-05 | 1.0000308   |
| 20                   | 2400            | 0.000257642  | 2.052004      | 7.033996  | 0.407605512     | 8.117394      | 45.6276 | 0.016304888              | 63.2549     | 0.000257765 | 1.000477287 |
| 20                   | 2500            | 0.000717615  | 2.11318       | 6.97282   | 0.404690525     | 8.120309      | 45.6276 | 0.045435371              | 63.28404    | 0.000717959 | 1.000480403 |
| 20                   | 2700            | 0.003516877  | 2.426031      | 6.659969  | 0.447392553     | 8.077607      | 45.6276 | 0.223211713              | 63.46181    | 0.00351726  | 1.000109017 |
| 20                   | 3000            | 0.013666728  | 3.498457      | 5.587543  | 0.681069869     | 7.84393       | 45.6276 | 0.876263615              | 64.11486    | 0.01366709  | 1.00026524  |
| 30                   | 2000            | 7.67779E-07  | 1.943799      | 7.142201  | 0.483298305     | 8.041702      | 45.6276 | 4.85534E-05              | 63.23865    | 7.6778E-07  | 1.000000577 |
| 30                   | 2100            | 3.63649E-06  | 1.969528      | 7.116472  | 0.457932709     | 8.067067      | 45.6276 | 0.000230153              | 63.23883    | 3.63942E-06 | 1.000086144 |
| 30                   | 2200            | 1.49286E-05  | 1.992088      | 7.093912  | 0.436800467     | 8.0882        | 45.6276 | 0.000944137              | 63.23954    | 1.49295E-05 | 1.000060943 |
| 30                   | 2300            | 5.40887E-05  | 2.01532       | 7.07068   | 0.418521486     | 8.106479      | 45.6276 | 0.003420892              | 63.24202    | 5.40921E-05 | 1.000062411 |
| 30                   | 2400            | 0.000173625  | 2.043447      | 7.042553  | 0.405516745     | 8.119483      | 45.6276 | 0.010981706              | 63.24958    | 0.000173625 | 1.00002468  |
| 30                   | 2500            | 0.000492289  | 2.09008       | 6.99592   | 0.399214124     | 8.125786      | 45.6276 | 0.031147227              | 63.26975    | 0.000492293 | 1.000007716 |
| 30                   | 2700            | 0.002608333  | 2.332431      | 6.753569  | 0.425328867     | 8.099671      | 45.6276 | 0.165380154              | 63.40398    | 0.002608356 | 1.000008955 |
| 30                   | 3000            | 0.011351359  | 3.265158      | 5.820842  | 0.615291783     | 7.909708      | 45.6276 | 0.726725003              | 63.96533    | 0.011361234 | 1.000869872 |
| 40                   | 2000            | 5.75849E-07  | 1.94378       | 7.14222   | 0.483292726     | 8.041707      | 45.6276 | 3.64159E-05              | 63.23864    | 5.75849E-07 | 1.000000078 |
| 40                   | 2100            | 2.72769E-06  | 1.969438      | 7.116562  | 0.45790742      | 8.067093      | 45.6276 | 0.000172496              | 63.23877    | 2.72769E-06 | 1.000001064 |
| 40                   | 2200            | 1.12018E-05  | 1.991716      | 7.094284  | 0.436701417     | 8.088299      | 45.6276 | 0.000708736              | 63.23931    | 1.12072E-05 | 1.000480323 |
| 40                   | 2300            | 4.06367E-05  | 2.013965      | 7.072035  | 0.418177663     | 8.106822      | 45.6276 | 0.002571423              | 63.24117    | 4.06606E-05 | 1.000587777 |
| 40                   | 2400            | 0.000130935  | 2.039105      | 7.046895  | 0.404458464     | 8.120542      | 45.6276 | 0.008281566              | 63.24688    | 0.00013094  | 1.000041599 |
| 40                   | 2500            | 0.000374789  | 2.078052      | 7.007948  | 0.396373918     | 8.128626      | 45.6276 | 0.023713003              | 63.26231    | 0.000374836 | 1.000126871 |
| 40                   | 2700            | 0.002083283  | 2.278312      | 6.807688  | 0.412794932     | 8.112205      | 45.6276 | 0.132053431              | 63.37065    | 0.002083826 | 1.000260656 |
| 40                   | 3000            | 0.009863074  | 3.112907      | 5.973093  | 0.57450672      | 7.950409      | 45.6276 | 0.630248831              | 63.86885    | 0.00986786  | 1.000485233 |
| 50                   | 2000            | 4.60686E-07  | 1.943769      | 7.142231  | 0.483289379     | 8.041711      | 45.6276 | 2.91331E-05              | 63.23863    | 4.60686E-07 | 1.000000091 |
| 50                   | 2100            | 2.1823E-06   | 1.969384      | 7.116616  | 0.457892295     | 8.067108      | 45.6276 | 0.000138011              | 63.23874    | 2.18238E-06 | 1.000033534 |
| 50                   | 2200            | 8.96404E-06  | 1.991492      | 7.094508  | 0.436641732     | 8.088358      | 45.6276 | 0.000566883              | 63.23917    | 8.96411E-06 | 1.000006724 |
| 50                   | 2300            | 3.25434E-05  | 2.013146      | 7.072854  | 0.417969936     | 8.10703       | 45.6276 | 0.002058103              | 63.24066    | 3.2544E-05  | 1.000019172 |
| 50                   | 2400            | 0.000105096  | 2.036485      | 7.049515  | 0.403820543     | 8.121179      | 45.6276 | 0.006652927              | 63.24525    | 0.000105193 | 1.000922152 |
| 50                   | 2500            | 0.000302615  | 2.070655      | 7.015345  | 0.39463105      | 8.130369      | 45.6276 | 0.019142892              | 63.25774    | 0.000302617 | 1.00000833  |
| 50                   | 2700            | 0.001738182  | 2.24262       | 6.84338   | 0.404616381     | 8.120384      | 45.6276 | 0.110118154              | 63.34872    | 0.001738285 | 1.000059275 |
| 50                   | 3000            | 0.008792991  | 3.003056      | 6.082944  | 0.546244467     | 7.978756      | 45.6276 | 0.561150383              | 63.79975    | 0.008795495 | 1.000284731 |
| 60                   | 2000            | 3.83908E-07  | 1.943761      | 7.142239  | 0.483287148     | 8.041713      | 45.6276 | 2.42778E-05              | 63.23862    | 3.83908E-07 | 1.00000005  |
| 60                   | 2100            | 1.81867E-06  | 1.969348      | 7.116652  | 0.457882207     | 8.067118      | 45.6276 | 0.00011501               | 63.23872    | 1.81867E-06 | 1.000000167 |
| 60                   | 2200            | 7.47147E-06  | 1.991343      | 7.094657  | 0.436602101     | 8.088398      | 45.6276 | 0.000472688              | 63.23907    | 7.47462E-06 | 1.00042182  |
| 60                   | 2300            | 2.71383E-05  | 2.012603      | 7.073397  | 0.417832247     | 8.107168      | 45.6276 | 0.001717813              | 63.24032    | 2.71633E-05 | 1.000920993 |
| 60                   | 2400            | 8.77763E-05  | 2.034714      | 7.051286  | 0.403389443     | 8.121611      | 45.6276 | 0.005551877              | 63.24415    | 8.77848E-05 | 1.000097329 |
| 60                   | 2500            | 0.000253761  | 2.06566       | 7.02034   | 0.393455886     | 8.131544      | 45.6276 | 0.01605789               | 63.25466    | 0.000253861 | 1.000393896 |
| 60                   | 2700            | 0.001492831  | 2.217249      | 6.868751  | 0.398844651     | 8.126155      | 45.6276 | 0.094546936              | 63.33315    | 0.001492851 | 1.000013265 |
| 60                   | 3000            | 0.007973608  | 2.918725      | 6.167275  | 0.525037243     | 7.999963      | 45.6276 | 0.508381273              | 63.74698    | 0.007974986 | 1.000172776 |
| 70                   | 2000            | 3.29067E-07  | 1.943756      | 7.142244  | 0.483285563     | 8.041714      | 45.6276 | 2.08301E-05              | 63.23862    | 3.29389E-07 | 1.000978819 |
| 70                   | 2100            | 1.55891E-06  | 1.969322      | 7.116678  | 0.457875004     | 8.067125      | 45.6276 | 9.85869E-05              | 63.2387     | 1.55897E-06 | 1.000034607 |
| 70                   | 2200            | 6.40499E-06  | 1.991236      | 7.094764  | 0.436573645     | 8.088426      | 45.6276 | 0.000405054              | 63.23901    | 6.40512E-06 | 1.000020308 |
| 70                   | 2300            | 2.3273E-05   | 2.012211      | 7.073789  | 0.417732762     | 8.107267      | 45.6276 | 0.001471922              | 63.24007    | 2.32752E-05 | 1.000091722 |
| 70                   | 2400            | 7.53574E-05  | 2.03345       | 7.05255   | 0.40308179      | 8.121918      | 45.6276 | 0.004765901              | 63.24337    | 7.53581E-05 | 1.00000932  |
| 70                   | 2500            | 0.000218499  | 2.062038      | 7.023962  | 0.392604682     | 8.132395      | 45.6276 | 0.013821566              | 63.25242    | 0.000218514 | 1.000068832 |
| 70                   | 2700            | 0.001308892  | 2.198315      | 6.887685  | 0.394559674     | 8.13044       | 45.6276 | 0.082937498              | 63.32154    | 0.001309783 | 1.000680866 |
| 70                   | 3000            | 0.007319364  | 2.851255      | 6.234745  | 0.508404609     | 8.016595      | 45.6276 | 0.466329656              | 63.70493    | 0.00732015  | 1.000107372 |
| 80                   | 2000            | 2.87935E-07  | 1.943752      | 7.142248  | 0.483284359     | 8.041716      | 45.6276 | 1.82102E-05              | 63.23862    | 2.8796E-07  | 1.000087493 |
| 80                   | 2100            | 1.36408E-06  | 1.969303      | 7.116697  | 0.457869599     | 8.06713       | 45.6276 | 8.62628E-05              | 63.23869    | 1.36408E-06 | 1.000000593 |
| 80                   | 2200            | 5.60495E-06  | 1.991157      | 7.094843  | 0.436552356     | 8.088448      | 45.6276 | 0.000354451              | 63.23895    | 5.60495E-06 | 1.000000788 |
| 80                   | 2300            | 2.03715E-05  | 2.011918      | 7.074082  | 0.417658475     | 8.107342      | 45.6276 | 0.001288302              | 63.23989    | 2.03717E-05 | 1.000008154 |
| 80                   | 2400            | 6.60167E-05  | 2.032506      | 7.053494  | 0.402852022     | 8.122148      | 45.6276 | 0.004178786              | 63.24278    | 6.60753E-05 | 1.000887556 |
| 80                   | 2500            | 0.000191844  | 2.059306      | 7.026694  | 0.391962878     | 8.133037      | 45.6276 | 0.012134403              | 63.25073    | 0.000191846 | 1.000011407 |
| 80                   | 2700            | 0.001165926  | 2.183464      | 6.902536  | 0.391211877     | 8.133788      | 45.6276 | 0.073837788              | 63.31244    | 0.001166245 | 1.000273589 |
| 80                   | 3000            | 0.006781084  | 2.795652      | 6.290348  | 0.494915184     | 8.030085      | 45.6276 | 0.431783577              | 63.67038    | 0.006781545 | 1.000067926 |

N5 v Temperature at Lambda 0.9 (5500RPM)



| Lambda 0.89 (6000&6500RPM) |                 |              |               |            |                 |                |         |                          |             |             |             |
|----------------------------|-----------------|--------------|---------------|------------|-----------------|----------------|---------|--------------------------|-------------|-------------|-------------|
| Pressure (Bar)             | Temperature (K) | N5/NT(Guess) | N3<br>C/(<+1) | N1<br>C-<- | N4<br>H/2x(<+1) | N2<br>(H/2)-<- | N6<br>N | N5<br>(Ox2)-2N1-N2-N3)/2 | NT<br>Total | Calc N5/NT  | Calc/Guess  |
| 10                         | 2000            | 1.86E-06     | 2.130825      | 7.037775   | 0.539110926     | 8.063389       | 45.6276 | 0.000118019              | 63.39882    | 1.86153E-06 | 1.00022711  |
| 10                         | 2100            | 8.80273E-06  | 2.159498      | 7.009102   | 0.511318041     | 8.091182       | 45.6276 | 0.000558091              | 63.39926    | 8.8028E-06  | 1.00007995  |
| 10                         | 2200            | 3.60428E-05  | 2.185812      | 6.982788   | 0.48846064      | 8.114039       | 45.6276 | 0.002286217              | 63.40099    | 3.60596E-05 | 1.000466704 |
| 10                         | 2300            | 0.000129688  | 2.216482      | 6.952118   | 0.469668489     | 8.132832       | 45.6276 | 0.008225181              | 63.40693    | 0.000129721 | 1.000251621 |
| 10                         | 2400            | 0.000408652  | 2.262369      | 6.906231   | 0.459168203     | 8.143332       | 45.6276 | 0.02591879               | 63.42462    | 0.000408655 | 1.00007042  |
| 10                         | 2500            | 0.001110513  | 2.349414      | 6.819186   | 0.461253999     | 8.141246       | 45.6276 | 0.07048378               | 63.46918    | 0.00111052  | 1.00005923  |
| 10                         | 2700            | 0.004971809  | 2.771628      | 6.396972   | 0.531691151     | 8.070809       | 45.6276 | 0.316809533              | 63.71551    | 0.004972251 | 1.000088978 |
| 10                         | 3000            | 0.017212445  | 4.043639      | 5.124961   | 0.848425832     | 7.754074       | 45.6276 | 1.11118217               | 64.50988    | 0.017224991 | 1.00072891  |
| 20                         | 2000            | 9.30656E-07  | 2.130735      | 7.037865   | 0.539083067     | 8.063417       | 45.6276 | 5.90024E-05              | 63.39876    | 9.30656E-07 | 1.000000079 |
| 20                         | 2100            | 4.40367E-06  | 2.159066      | 7.009534   | 0.511192208     | 8.091308       | 45.6276 | 0.000279193              | 63.39898    | 4.40375E-06 | 1.000017308 |
| 20                         | 2200            | 1.80602E-05  | 2.184024      | 6.984576   | 0.487965964     | 8.114534       | 45.6276 | 0.001145015              | 63.39985    | 1.80602E-05 | 1.000002792 |
| 20                         | 2300            | 6.53448E-05  | 2.210023      | 6.958577   | 0.467963261     | 8.134537       | 45.6276 | 0.004143072              | 63.40284    | 6.53452E-05 | 1.000006446 |
| 20                         | 2400            | 0.000209234  | 2.242206      | 6.926394   | 0.454037085     | 8.148463       | 45.6276 | 0.013271693              | 63.41197    | 0.000209293 | 1.000283666 |
| 20                         | 2500            | 0.000590192  | 2.2965        | 6.8721     | 0.448116039     | 8.154384       | 45.6276 | 0.037458005              | 63.43616    | 0.000590484 | 1.000493319 |
| 20                         | 2700            | 0.00305623   | 2.576087      | 6.592513   | 0.482447833     | 8.120052       | 45.6276 | 0.194417651              | 63.59312    | 0.003057212 | 1.000321194 |
| 20                         | 3000            | 0.012782616  | 3.60313       | 5.56547    | 0.708706049     | 7.893794       | 45.6276 | 0.821068156              | 64.21977    | 0.012785287 | 1.000208967 |
| 30                         | 2000            | 6.2046E-07   | 2.130705      | 7.037895   | 0.539073784     | 8.063426       | 45.6276 | 3.93368E-05              | 63.39874    | 6.20466E-07 | 1.000009473 |
| 30                         | 2100            | 2.93629E-06  | 2.158922      | 7.009678   | 0.511150235     | 8.09135        | 45.6276 | 0.000186158              | 63.39889    | 2.9363E-06  | 1.00002682  |
| 30                         | 2200            | 1.20488E-05  | 2.183427      | 6.985173   | 0.487800791     | 8.114699       | 45.6276 | 0.000763886              | 63.39946    | 1.20488E-05 | 1.000001819 |
| 30                         | 2300            | 4.36763E-05  | 2.207849      | 6.960751   | 0.467389774     | 8.13511        | 45.6276 | 0.002769171              | 63.40147    | 4.36768E-05 | 1.000010088 |
| 30                         | 2400            | 0.000140638  | 2.235269      | 6.933331   | 0.45227714      | 8.150223       | 45.6276 | 0.008923173              | 63.40762    | 0.000140727 | 1.000636258 |
| 30                         | 2500            | 0.000402345  | 2.277339      | 6.891261   | 0.443397995     | 8.159102       | 45.6276 | 0.025518534              | 63.42422    | 0.000402347 | 1.00005384  |
| 30                         | 2700            | 0.002233962  | 2.491693      | 6.676907   | 0.461909539     | 8.14059        | 45.6276 | 0.141951103              | 63.54065    | 0.00223402  | 1.00005866  |
| 30                         | 3000            | 0.010523065  | 3.375226      | 5.793374   | 0.643066151     | 7.959434       | 45.6276 | 0.674295989              | 64.073      | 0.010523872 | 1.000076702 |
| 40                         | 2000            | 4.65354E-07  | 2.13069       | 7.03791    | 0.539069146     | 8.063431       | 45.6276 | 2.95119E-05              | 63.39873    | 4.65497E-07 | 1.00030902  |
| 40                         | 2100            | 2.20241E-06  | 2.15885       | 7.00975    | 0.511129244     | 8.091371       | 45.6276 | 0.000139631              | 63.39884    | 2.20242E-06 | 1.00005649  |
| 40                         | 2200            | 9.03982E-06  | 2.183128      | 6.985472   | 0.487718125     | 8.114782       | 45.6276 | 0.000573126              | 63.39927    | 9.03994E-06 | 1.000014032 |
| 40                         | 2300            | 3.27999E-05  | 2.206757      | 6.961843   | 0.467102085     | 8.135398       | 45.6276 | 0.002079756              | 63.40078    | 3.28033E-05 | 1.000103707 |
| 40                         | 2400            | 0.000105919  | 2.231747      | 6.936853   | 0.451384658     | 8.151115       | 45.6276 | 0.006715922              | 63.40542    | 0.00010592  | 1.000012964 |
| 40                         | 2500            | 0.00030527   | 2.267451      | 6.901149   | 0.440971394     | 8.161529       | 45.6276 | 0.019361284              | 63.41806    | 0.000305296 | 1.000084687 |
| 40                         | 2700            | 0.001766855  | 2.443804      | 6.724796   | 0.450439612     | 8.15206        | 45.6276 | 0.112271871              | 63.51097    | 0.001767756 | 1.000509894 |
| 40                         | 3000            | 0.009073254  | 3.227943      | 5.940657   | 0.602792455     | 7.999708       | 45.6276 | 0.580517976              | 63.97922    | 0.00907354  | 1.000031541 |
| 50                         | 2000            | 3.72287E-07  | 2.130681      | 7.037919   | 0.539066357     | 8.063434       | 45.6276 | 2.36025E-05              | 63.39872    | 3.72286E-07 | 0.999997589 |
| 50                         | 2100            | 1.76202E-06  | 2.158807      | 7.009793   | 0.51111665      | 8.091383       | 45.6276 | 0.000111715              | 63.39881    | 1.7621E-06  | 1.000043643 |
| 50                         | 2200            | 7.23341E-06  | 2.182949      | 6.985651   | 0.487668551     | 8.114831       | 45.6276 | 0.000458723              | 63.39916    | 7.23548E-06 | 1.000285186 |
| 50                         | 2300            | 2.62605E-05  | 2.206101      | 6.962499   | 0.466929006     | 8.135571       | 45.6276 | 0.001664928              | 63.40036    | 2.62606E-05 | 1.00000147  |
| 50                         | 2400            | 8.49482E-05  | 2.229628      | 6.938972   | 0.450847976     | 8.151652       | 45.6276 | 0.005387947              | 63.40409    | 8.49779E-05 | 1.00034978  |
| 50                         | 2500            | 0.000245954  | 2.261404      | 6.907196   | 0.439490088     | 8.16301        | 45.6276 | 0.015597093              | 63.4143     | 0.000245955 | 1.00000406  |
| 50                         | 2700            | 0.001463821  | 2.412572      | 6.756028   | 0.443029471     | 8.159471       | 45.6276 | 0.092950526              | 63.49165    | 0.00146398  | 1.00019004  |
| 50                         | 3000            | 0.008037176  | 3.122211      | 6.046389   | 0.574852925     | 8.027647       | 45.6276 | 0.513682185              | 63.91238    | 0.008037287 | 1.000013857 |
| 60                         | 2000            | 3.10241E-07  | 2.130675      | 7.037925   | 0.5390645       | 8.063436       | 45.6276 | 1.96689E-05              | 63.39872    | 3.10241E-07 | 0.999998829 |
| 60                         | 2100            | 1.4684E-06   | 2.158778      | 7.009822   | 0.511108272     | 8.091392       | 45.6276 | 9.31437E-05              | 63.39879    | 1.46917E-06 | 1.00052377  |
| 60                         | 2200            | 6.02871E-06  | 2.182829      | 6.985771   | 0.4876354       | 8.114865       | 45.6276 | 0.000382217              | 63.39908    | 6.02875E-06 | 1.000005529 |
| 60                         | 2300            | 2.18952E-05  | 2.205663      | 6.962937   | 0.466813608     | 8.135686       | 45.6276 | 0.001388321              | 63.40009    | 2.18978E-05 | 1.000117479 |
| 60                         | 2400            | 7.09097E-05  | 2.228204      | 6.940396   | 0.45048763      | 8.152012       | 45.6276 | 0.004496015              | 63.4032     | 7.09115E-05 | 1.000024896 |
| 60                         | 2500            | 0.000205945  | 2.257331      | 6.911269   | 0.43849351      | 8.164006       | 45.6276 | 0.013062295              | 63.41176    | 0.000205992 | 1.000226485 |
| 60                         | 2700            | 0.001250461  | 2.390606      | 6.777994   | 0.43785099      | 8.164649       | 45.6276 | 0.079378682              | 63.47808    | 0.00125049  | 1.000022588 |
| 60                         | 3000            | 0.007245751  | 3.041747      | 6.126853   | 0.554111098     | 8.048389       | 45.6276 | 0.46307917               | 63.86178    | 0.007251273 | 1.000762076 |
| 70                         | 2000            | 2.65923E-07  | 2.130671      | 7.037929   | 0.539063173     | 8.063437       | 45.6276 | 1.68591E-05              | 63.39872    | 2.65922E-07 | 0.999998884 |
| 70                         | 2100            | 1.25866E-06  | 2.158757      | 7.009843   | 0.511102251     | 8.091398       | 45.6276 | 7.97978E-05              | 63.39878    | 1.25866E-06 | 1.000001751 |
| 70                         | 2200            | 5.168E-06    | 2.182744      | 6.985856   | 0.48761183      | 8.114888       | 45.6276 | 0.000327824              | 63.39903    | 5.1708E-06  | 1.000542681 |
| 70                         | 2300            | 1.87743E-05  | 2.20535       | 6.96325    | 0.466731001     | 8.135769       | 45.6276 | 0.001190298              | 63.39989    | 1.87745E-05 | 1.00006111  |
| 70                         | 2400            | 6.08532E-05  | 2.227186      | 6.941414   | 0.450230027     | 8.15227        | 45.6276 | 0.003858254              | 63.40256    | 6.08533E-05 | 1.000001552 |
| 70                         | 2500            | 0.000177136  | 2.25439       | 6.91421    | 0.437774584     | 8.164725       | 45.6276 | 0.011232521              | 63.40993    | 0.000177141 | 1.000031481 |
| 70                         | 2700            | 0.00109174   | 2.374374      | 6.794226   | 0.434041383     | 8.168459       | 45.6276 | 0.069357665              | 63.46806    | 0.001092796 | 1.000967937 |
| 70                         | 3000            | 0.006619731  | 2.977268      | 6.191332   | 0.537803981     | 8.064696       | 45.6276 | 0.422685894              | 63.82139    | 0.006622951 | 1.000486309 |
| 80                         | 2000            | 2.32683E-07  | 2.130667      | 7.037933   | 0.539062179     | 8.063438       | 45.6276 | 1.47518E-05              | 63.39871    | 2.32682E-07 | 0.999995859 |
| 80                         | 2100            | 1.10135E-06  | 2.158742      | 7.009858   | 0.511097756     | 8.091402       | 45.6276 | 6.98342E-05              | 63.39877    | 1.10151E-06 | 1.000142712 |
| 80                         | 2200            | 4.52235E-06  | 2.182679      | 6.985921   | 0.48759402      | 8.114906       | 45.6276 | 0.000286721              | 63.39899    | 4.52249E-06 | 1.000031387 |
| 80                         | 2300            | 1.64321E-05  | 2.205116      | 6.963484   | 0.466669389     | 8.135831       | 45.6276 | 0.001042598              | 63.39974    | 1.64448E-05 | 1.00077227  |
| 80                         | 2400            | 5.32948E-05  | 2.226423      | 6.942177   | 0.450036816     | 8.152463       | 45.6276 | 0.003379832              | 63.40208    | 5.33079E-05 | 1.000245951 |
| 80                         | 2500            | 0.000155399  | 2.252174      | 6.916426   | 0.437233072     | 8.165267       | 45.6276 | 0.009853639              | 63.40855    | 0.000155399 | 1.000004085 |
| 80                         | 2700            | 0.000969179  | 2.361681      | 6.806919   | 0.431072682     | 8.171427       | 45.6276 | 0.061526896              | 63.46023    | 0.000969535 | 1.000366988 |
| 80                         | 3000            | 0.006166667  | 2.924381      | 6.244219   | 0.524632101     | 8.077868       | 45.6276 | 0.389656713              | 63.78836    | 0.006108587 | 1.000314416 |



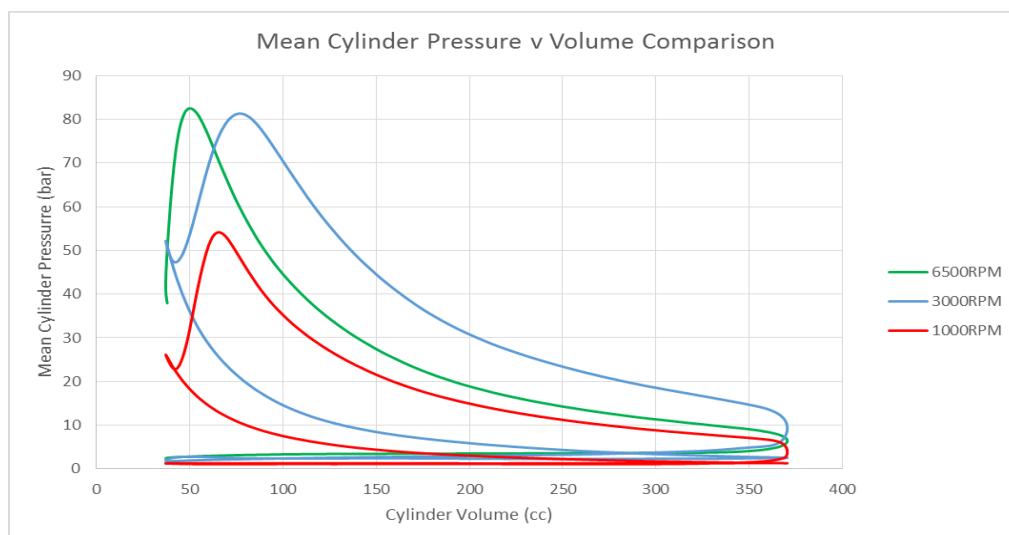
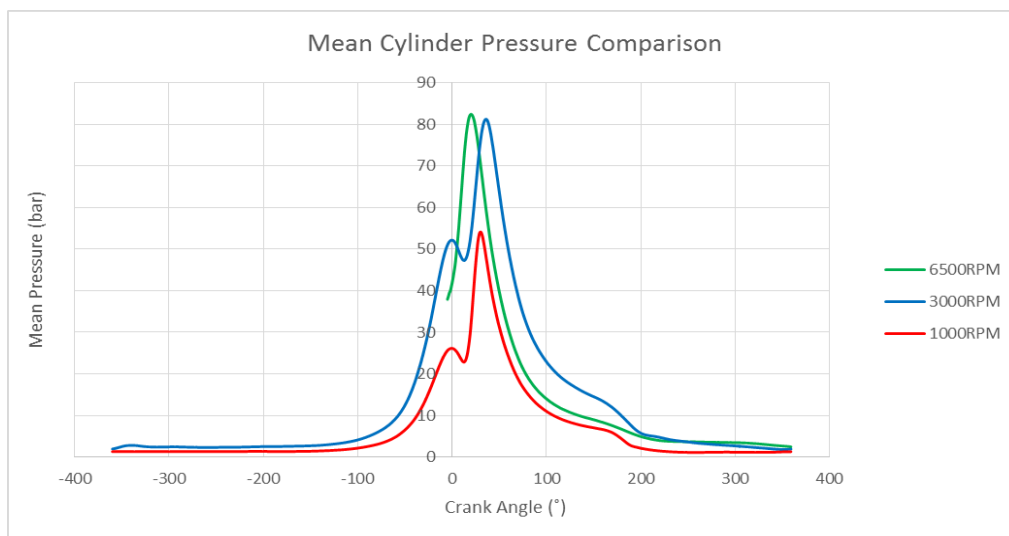
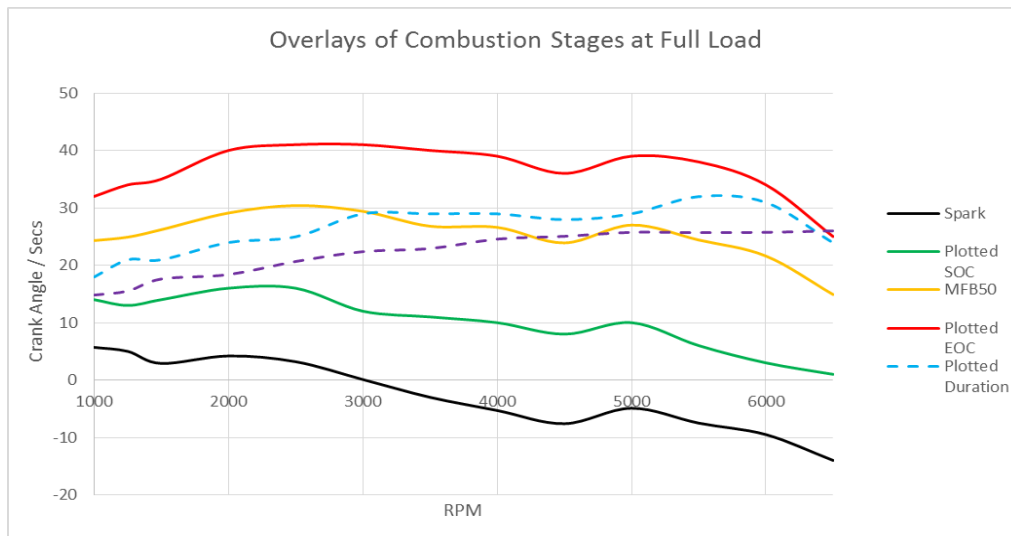
|      | Spark | Plotted SOC | MFB50 | EOC | Plotted Dur | Dur   |
|------|-------|-------------|-------|-----|-------------|-------|
| 1000 | 5.7   | 14          | 24.3  | 32  | 18          | 14.84 |
| 1250 | 5     | 13          | 24.9  | 34  | 21          | 15.55 |
| 1500 | 2.9   | 14          | 26.2  | 35  | 21          | 17.65 |
| 2000 | 4.2   | 16          | 29.1  | 40  | 24          | 18.42 |
| 2500 | 3.2   | 16          | 30.4  | 41  | 25          | 20.71 |
| 3000 | 0.1   | 12          | 29.4  | 41  | 29          | 22.43 |
| 3500 | -3    | 11          | 26.8  | 40  | 29          | 22.96 |
| 4000 | -5.3  | 10          | 26.6  | 39  | 29          | 24.62 |
| 4500 | -7.6  | 8           | 23.9  | 36  | 28          | 25.11 |
| 5000 | -4.9  | 10          | 27    | 39  | 29          | 25.81 |
| 5500 | -7.5  | 6           | 24.4  | 38  | 32          | 25.75 |
| 6000 | -9.5  | 3           | 21.6  | 34  | 31          | 25.81 |
| 6500 | -14   | 1           | 14.9  | 25  | 24          | 26.06 |

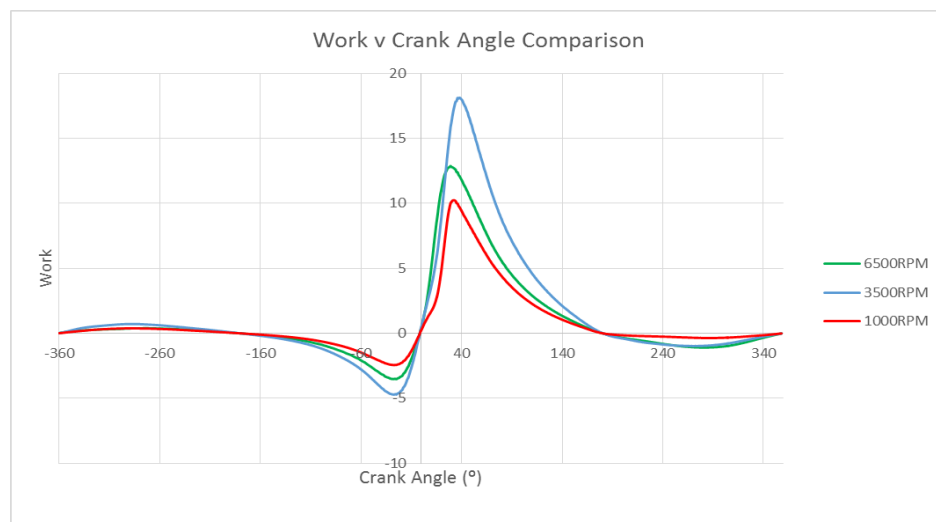
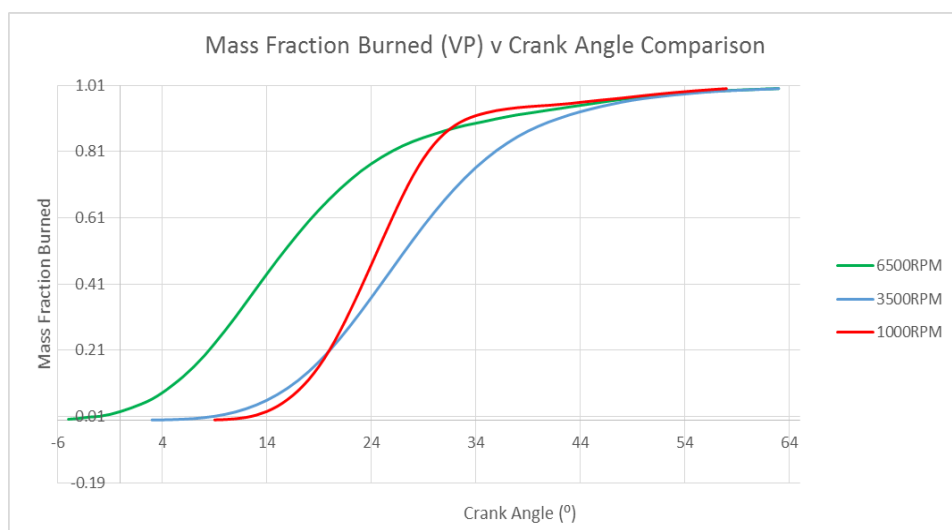
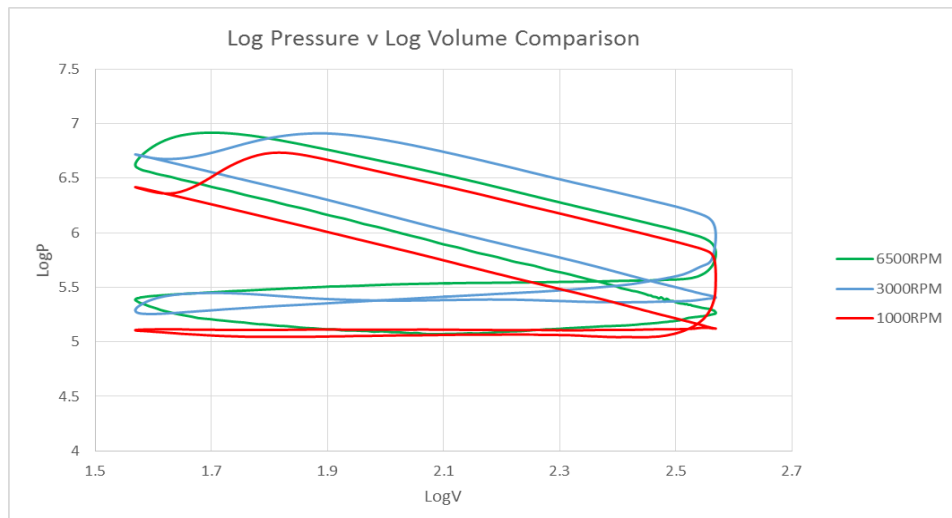
| RPM     | nEXP        | nCOMP       |
|---------|-------------|-------------|
| 6500    | 1.263536993 | 1.248135868 |
| 6000    | 1.271120441 | 1.265341299 |
| 5500    | 1.3         | 1.3         |
| 5000    | 1.351679161 | 1.257252365 |
| 4500    | 1.4         | 1.260602001 |
| 4000    | 1.273270532 | 1.259647315 |
| 3500    | 1.28839887  | 1.246385785 |
| 3000    | 1.329775885 | 1.226771141 |
| 2500    | 1.31514785  | 1.203917084 |
| 2000    | 1.31514785  | 1.203917084 |
| 1500    | 1.332245505 | 1.322546338 |
| 1250    | 1.329452633 | 1.239222133 |
| 1000    | 1.306805611 | 1.289141617 |
| Average | 1.313583179 | 1.255606156 |

| RPM     | IMEP        | $\Sigma$ WD/° (J) |
|---------|-------------|-------------------|
| 6500    | 1793639.89  | 597.2820833       |
| 6000    | 2033567.391 | 677.1779412       |
| 5500    | 2167093.427 | 721.6421113       |
| 5000    | 2275137.058 | 757.6206402       |
| 4500    | 2383889.678 | 793.8352628       |
| 4000    | 2553685.562 | 850.3772922       |
| 3500    | 2715892.388 | 904.3921652       |
| 3000    | 2695122.14  | 897.4756727       |
| 2500    | 2706794.841 | 901.362682        |
| 2000    | 2650152.675 | 882.5008408       |
| 1500    | 2230732.009 | 742.8337588       |
| 1250    | 1876682.223 | 624.9351802       |
| 1000    | 1468290.262 | 488.9406573       |
| Average | 2273129.196 | 756.9520222       |

| RPM  | Temp @ TDC  | Temp @ SOC  |
|------|-------------|-------------|
| 6500 | 52.63389787 | 830.7567129 |
| 6000 | 52.49672799 | 844.6674761 |
| 5500 | 48.37590694 | 839.8066134 |
| 5000 | 41.83749687 | 819.4029555 |
| 4500 | 34.04336479 | 783.3997928 |
| 4000 | 31.60389478 | 759.0997535 |
| 3500 | 30.5543522  | 768.7925178 |
| 3000 | 26.93070523 | 718.834347  |
| 2500 | 22.65307775 | 703.6033152 |
| 2000 | 26.95127647 | 659.0255395 |
| 1500 | 24.29612195 | 532.692496  |
| 1250 | 26.78658106 | 555.7346254 |
| 1000 | 28.3821863  | 565.5191457 |

| RPM  | A/F Mass Per Cycle | EGR Mass    |
|------|--------------------|-------------|
| 6500 | 0.000601782        | 2.4673E-05  |
| 6000 | 0.000710959        | 2.55945E-05 |
| 5500 | 0.000759595        | 2.50666E-05 |
| 5000 | 0.000806812        | 2.50112E-05 |
| 4500 | 0.000810859        | 2.18932E-05 |
| 4000 | 0.000890918        | 1.96002E-05 |
| 3500 | 0.00089855         | 1.52753E-05 |
| 3000 | 0.00097632         | 1.46448E-05 |
| 2500 | 0.000971933        | 9.71933E-06 |
| 2000 | 0.000963489        | 7.70791E-06 |
| 1500 | 0.000970916        | 9.70916E-07 |
| 1250 | 0.000783696        | 1.56739E-06 |
| 1000 | 0.00058284         | 2.9142E-06  |





| RPM  | T (degrees C) | T (kelvin) | Species     | C <sub>p</sub> /R | C <sub>p</sub> /R | R    | C <sub>p</sub> |
|------|---------------|------------|-------------|-------------------|-------------------|------|----------------|
| 1000 | 728           | 1001 CO2   | 4.480755525 | 6.53823076        |                   | 8314 | 54313.89105    |
| 1000 | 728           | 1001 H2O   | 4.037785962 | 4.958710317       |                   | 8314 | 41226.71757    |
| 1000 | 728           | 1001 O2    | 3.53198086  | 4.1908409         |                   | 8314 | 34842.65125    |
| 1000 | 728           | 1001 N2    | 3.502626703 | 3.933378419       |                   | 8314 | 32702.10818    |
| 1000 | 827           | 1100 CO2   | 4.480755525 | 6.649218093       |                   | 8314 | 55281.59923    |
| 1000 | 827           | 1100 H2O   | 4.037785962 | 5.114724184       |                   | 8314 | 42523.81687    |
| 1000 | 827           | 1100 O2    | 3.53198086  | 4.232937478       |                   | 8314 | 35192.64219    |
| 1000 | 827           | 1100 N2    | 3.502626703 | 3.994100171       |                   | 8314 | 33206.94882    |
| 1000 | 927           | 1200 CO2   | 4.480755525 | 6.754817766       |                   | 8314 | 56159.55491    |
| 1000 | 927           | 1200 H2O   | 4.037785962 | 5.262365806       |                   | 8314 | 43751.30931    |
| 1000 | 927           | 1200 O2    | 3.53198086  | 4.273507613       |                   | 8314 | 35529.9423     |
| 1000 | 927           | 1200 N2    | 3.502626703 | 4.049657647       |                   | 8314 | 33668.85368    |
| 1000 | 1027          | 1300 CO2   | 4.480755525 | 6.849318961       |                   | 8314 | 56945.23785    |
| 1000 | 1027          | 1300 H2O   | 4.037785962 | 5.400487502       |                   | 8314 | 44899.55309    |
| 1000 | 1027          | 1300 O2    | 3.53198086  | 4.312235127       |                   | 8314 | 35852.0725     |
| 1000 | 1027          | 1300 N2    | 3.502626703 | 4.09982852        |                   | 8314 | 34085.95214    |
| 1000 | 1127          | 1400 CO2   | 4.480755525 | 6.933620358       |                   | 8314 | 57646.11966    |
| 1000 | 1127          | 1400 H2O   | 4.037785962 | 5.52957476        |                   | 8314 | 45972.74086    |
| 1000 | 1127          | 1400 O2    | 3.53198086  | 4.349304393       |                   | 8314 | 36160.11672    |
| 1000 | 1127          | 1400 N2    | 3.502626703 | 4.145007956       |                   | 8314 | 34461.59615    |
| 1000 | 1227          | 1500 CO2   | 4.480755525 | 7.008583375       |                   | 8314 | 58269.36218    |
| 1000 | 1227          | 1500 H2O   | 4.037785962 | 5.6500323         |                   | 8314 | 46974.36854    |
| 1000 | 1227          | 1500 O2    | 3.53198086  | 4.384784838       |                   | 8314 | 36455.10114    |
| 1000 | 1227          | 1500 N2    | 3.502626703 | 4.185591475       |                   | 8314 | 34799.00752    |
| 1000 | 1327          | 1600 CO2   | 4.480755525 | 7.075032166       |                   | 8314 | 58821.81743    |
| 1000 | 1327          | 1600 H2O   | 4.037785962 | 5.76235691        |                   | 8314 | 47908.23535    |
| 1000 | 1327          | 1600 O2    | 3.53198086  | 4.418810941       |                   | 8314 | 36737.99417    |
| 1000 | 1327          | 1600 N2    | 3.502626703 | 4.221948271       |                   | 8314 | 35101.27793    |
| 1000 | 1427          | 1700 CO3   | 4.480755525 | 7.133753625       |                   | 8314 | 59310.02764    |
| 1000 | 1427          | 1700 H2O   | 4.037785962 | 5.866964611       |                   | 8314 | 48777.94377    |
| 1000 | 1427          | 1700 O3    | 3.53198086  | 4.451492237       |                   | 8314 | 37009.70646    |
| 1000 | 1427          | 1700 N3    | 3.502626703 | 4.254434554       |                   | 8314 | 35371.36888    |

| RPM  | T (degrees C) | T (kelvin) | Species     | C <sub>p</sub> /R | C <sub>p</sub> /R | R    | C <sub>p</sub> |
|------|---------------|------------|-------------|-------------------|-------------------|------|----------------|
| 1000 | 27            | 300 CO2    | 4.480755525 | 4.480755525       |                   | 8314 | 37253.00144    |
| 1000 | 27            | 300 H2O    | 4.037785962 | 4.037785962       |                   | 8314 | 33570.15249    |
| 1000 | 27            | 300 O2     | 3.53198086  | 3.53198086        |                   | 8314 | 29364.88887    |
| 1000 | 27            | 300 N2     | 3.502626703 | 3.502626703       |                   | 8314 | 29120.83841    |
| 1000 | 127           | 400 CO2    | 4.480755525 | 4.965860998       |                   | 8314 | 41286.16834    |
| 1000 | 127           | 400 H2O    | 4.037785962 | 4.122058912       |                   | 8314 | 34270.79779    |
| 1000 | 127           | 400 O2     | 3.53198086  | 3.62551936        |                   | 8314 | 30142.56796    |
| 1000 | 127           | 400 N2     | 3.502626703 | 3.517178368       |                   | 8314 | 29241.82095    |
| 1000 | 227           | 500 CO2    | 4.480755525 | 5.366889546       |                   | 8314 | 44620.31969    |
| 1000 | 227           | 500 H2O    | 4.037785962 | 4.23390125        |                   | 8314 | 35200.65499    |
| 1000 | 227           | 500 O2     | 3.53198086  | 3.7396625         |                   | 8314 | 31091.55403    |
| 1000 | 227           | 500 N2     | 3.502626703 | 3.558679375       |                   | 8314 | 29586.86032    |
| 1000 | 327           | 600 CO2    | 4.480755525 | 5.695861203       |                   | 8314 | 47555.39004    |
| 1000 | 327           | 600 H2O    | 4.037785962 | 4.364246592       |                   | 8314 | 36284.34617    |
| 1000 | 327           | 600 O2     | 3.53198086  | 3.85710976        |                   | 8314 | 32068.01054    |
| 1000 | 327           | 600 N2     | 3.502626703 | 3.620903728       |                   | 8314 | 30104.19359    |
| 1000 | 427           | 700 CO2    | 4.480755525 | 5.964797521       |                   | 8314 | 49591.32659    |
| 1000 | 427           | 700 H2O    | 4.037785962 | 4.505965402       |                   | 8314 | 37462.59635    |
| 1000 | 427           | 700 O2     | 3.53198086  | 3.96573406        |                   | 8314 | 32971.11297    |
| 1000 | 427           | 700 N2     | 3.502626703 | 3.697083583       |                   | 8314 | 30737.55291    |
| 1000 | 527           | 800 CO2    | 4.480755525 | 6.18572157        |                   | 8314 | 51428.08914    |
| 1000 | 527           | 800 H2O    | 4.037785962 | 4.653864992       |                   | 8314 | 38692.23354    |
| 1000 | 527           | 800 O2     | 3.53198086  | 4.05858176        |                   | 8314 | 33743.04875    |
| 1000 | 527           | 800 N2     | 3.502626703 | 3.779909248       |                   | 8314 | 31426.16549    |
| 1000 | 627           | 900 CO2    | 4.480755525 | 6.370657941       |                   | 8314 | 52965.65012    |
| 1000 | 627           | 900 H2O    | 4.037785962 | 4.804689522       |                   | 8314 | 39946.18869    |
| 1000 | 627           | 900 O2     | 3.53198086  | 4.13387266        |                   | 8314 | 34369.0173     |
| 1000 | 627           | 900 N2     | 3.502626703 | 3.861529183       |                   | 8314 | 32104.75363    |
| 1000 | 727           | 1000 CO2   | 4.480755525 | 6.53163274        |                   | 8314 | 54303.9946     |
| 1000 | 727           | 1000 H2O   | 4.037785962 | 4.95712           |                   | 8314 | 41213.49568    |
| 1000 | 727           | 1000 O2    | 3.53198086  | 4.195             |                   | 8314 | 34877.23       |
| 1000 | 727           | 1000 N2    | 3.502626703 | 3.93355           |                   | 8314 | 32703.5347     |

