

NOx Modelling and Combustion Analysis Using Cylinder Pressure Data

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Introduction

This project focuses on the formation of NO_x molecules during the combustion process inside a Ford 1L EcoBoost engine. Nitrogen Dioxide, NO_2 , is an odourless, colourless gas, that inflames the lining of the lungs and can cause problems such as wheezing coughing, colds, flu and bronchitis.

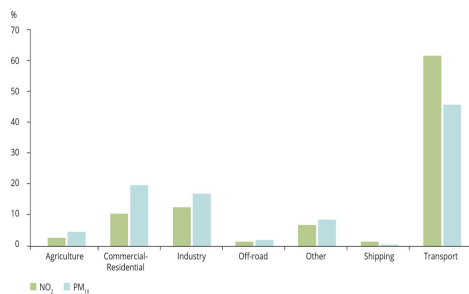
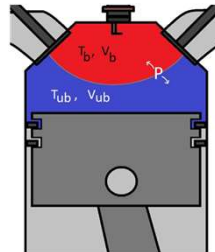
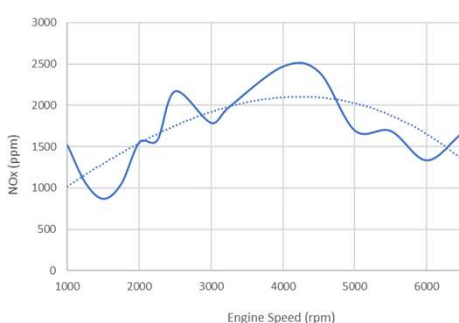


Figure 1 - Air Quality Report 2018, biggest contributors to NO₂ emissions [1]

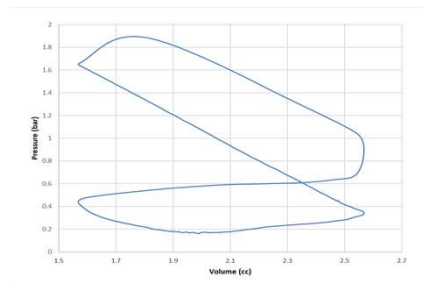
The graph above is from the European Environment Agency Air Quality 2018 report which shows that the transport sector is by far the biggest contributor of Nitrogen Dioxide. With the problem set, designers use NO_x formation models to calibrate engines with emissions in mind.

Test Engine

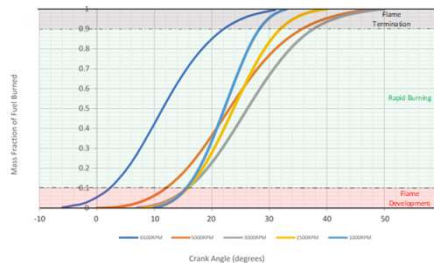
This work focuses the model around a Ford EcoBoost engine, particularly the 1L Fox variant. This engine is a compact, efficient, turbo charged, direct injection engine. Real test data for this engine is used as a comparison to the calculations. Below shows the real NO_x PPM output across the rev range for full load.



The combustion pressure data is used to create a Two-Zone model assessing gas temperatures and volumes in an 'unburned zone' and a 'burned zone.'



Log P vs Log V diagrams, like the one above, are used to determine the polytropic index and thus the start and end of combustion from which a mass fraction burned (below) can be established for each degree.



Two Zone Model

NO_x formation is dependant on the temperature. The below equations are used to determine the properties of each zone;

$$T_{1unburne} = \frac{p \times V}{R \times \text{mass of air and fuel}}$$

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

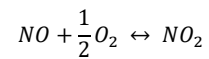
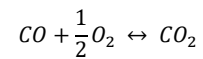
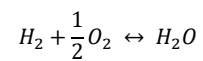
$$V_{Ub} = \frac{(1 - MFB) \times \text{Mass} \times R_{un} \times T_{un}}{\text{Pressure}}$$

$$V_B = \text{Volume}_{cylinder} - \text{Volume}_{unburned}$$

$$T_b = \frac{\text{Pressure} \times \text{Volume}_{burned}}{MFB \times \text{Mass} \times R_{burned}}$$

Dissociation

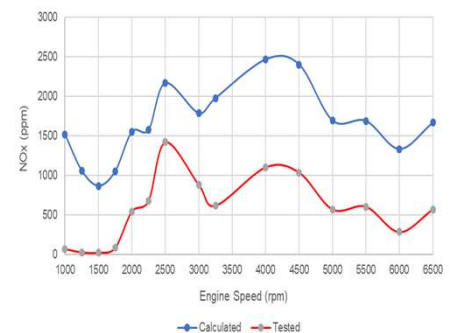
At high temperatures during combustion, molecules split into their smaller elements. These smaller dissociated species can then recombine to form other compounds [2].



Zeldovich Mechanism

The concentrations of N_2 and O_2 are used with the NO_x formation rate equation [3];

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



Acknowledgements

I would like to express my gratitude to Malcolm McDonald who really captivated me with this topic of combustion and NO_x formation, and kept me on track throughout the project.

References

1. "Air Quality in Europe – 2018 Report" European Environmental Agency.
2. Heywood, J. B. (1988). "Internal Combustion Engine Fundamentals". New York, McGraw-Hill.
3. 30. Merker, G. P.; Schwarz, C.; Stiesch, G.; Otto, F. (2004). "Simulating Combustion". Springer. 2nd Edition