

University of Wales Trinity Saint David

Wales Institute of Science & Art



Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

CFD and Emissions Modelling

Engine Performance and Emissions (ACHA7002)

Koa Brook

2203480

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1. Introduction

Internal combustion engines (ICEs) continue to play a significant role in road transport, despite increasing efforts to transition toward electrified powertrains. While many policies propose a phase-out of ICE vehicles by 2035, uncertainty remains regarding the full implementation of these regulations and the long-term viability of alternative technologies . As a result, it is necessary to consider scenarios in which ICEs remain in use beyond this timeframe. Concurrently, emissions regulations have become progressively stricter, placing tighter limits on pollutants such as nitrogen oxides, carbon monoxide, and unburned hydrocarbons. If ICE technology persists, it is expected that these standards will continue to tighten further.

Alternative fuels present a potential pathway to meet these future requirements, particularly through the use of bio fuels, synthetic fuels, and non-carbon based fuels that can reduce overall emissions. This report investigates the combustion behaviour, performance, and emissions characteristics of selected fuels using Ricardo WAVE and ANSYS Forte. The aim is to evaluate their feasibility for future road vehicle applications under increasingly stringent emissions constraints.

2. Emissions Context and Targets

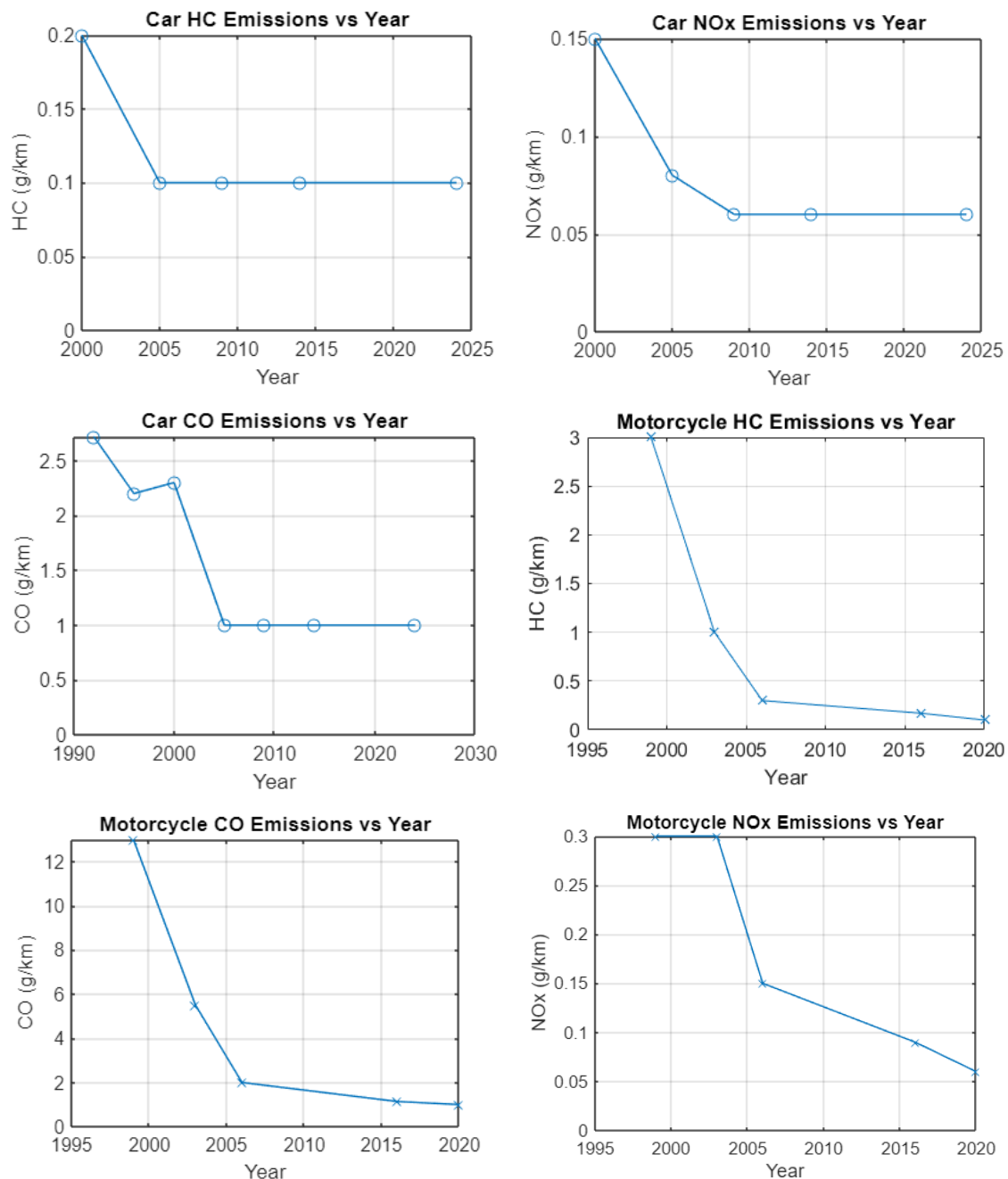


Figure 1: Euro emissions limits (Euro 1 to current) for CO, HC, and NOx for M1/N1-I vehicles (cars) and L-category vehicles (motorcycles).

Emissions regulations have played a central role in the development of internal combustion engines for both M1/N1-I vehicles and L-category vehicles. Legislation introduced limits on carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx), which have been progressively tightened through successive Euro standards. For M1/N1-I vehicles, this regulatory development is defined through a series of directives and regulations (European Parliament and the Council of the European Union, 1998;

European Parliament and the Council of the European Union, 2007; European Parliament and the Council of the European Union, 2024; European Communities, 2002). In contrast, L-category vehicles are governed through a separate regulatory framework with their own staged progression (European Parliament and the Council of the European Union, 1997; European Parliament and the Council of the European Union, 2002; European Parliament and the Council of the European Union, 2013).

As shown in Figure 1, emissions limits differ between M1/N1-I and L-category vehicles, reflecting these distinct regulatory pathways (The same numerical data used to generate Figure 1 is provided in table form in Appendix 1). Passenger vehicles exhibit significant early reductions in CO and NO_x, followed by minimal change in later stages. In comparison, L-category vehicles begin with higher allowable limits and demonstrate a more gradual but consistent reduction across all pollutants. These differing trends define future targets for each category. If internal combustion engines remain in use beyond 2035, emission limits are expected to reduce further to approximately; CO = 0.6 g/km, HC = 0.06 g/km, NO_x = 0.025 g/km for M1/N1-I vehicles and CO = 0.6 g/km, HC = 0.05 g/km, NO_x = 0.025 g/km for L-category vehicles.

3. Methodology

3.1 Ricardo WAVE Model Setup

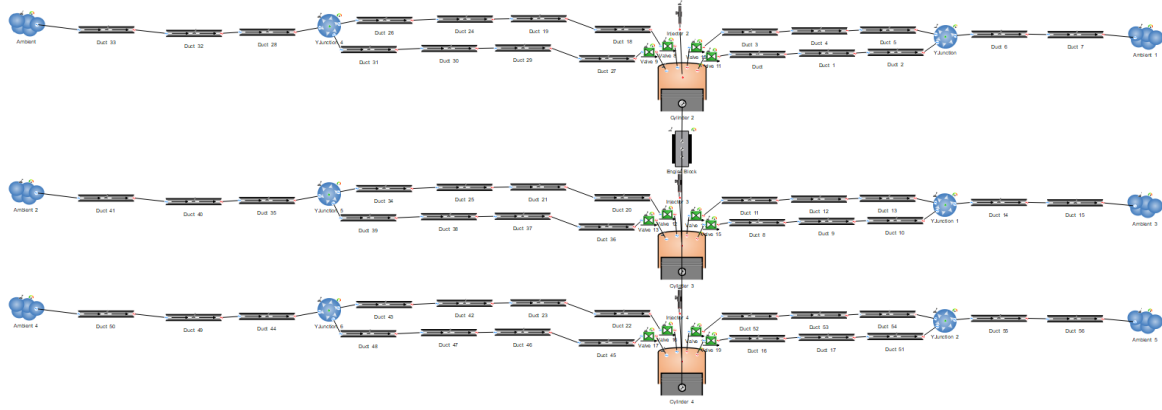


Figure 2: Realis WAVE model (based on triumph 675 engine)

A one-dimensional Ricardo WAVE model of a Triumph 675 engine was developed using measured geometry and manufacturer data. Cylinder head port geometries, valve diameters, and cam profiles were measured directly, allowing realistic valve lift curves to be implemented. Flow domains were limited to the cylinder head, with no full intake or exhaust systems included. Simulations were conducted at three engine speeds to match the available experimental dataset. Where required, fuel files were created using WAVE's existing database to represent mixtures not directly available.

Combustion was modelled using a Wiebe function based on a mass fraction burned (MFB) profile. The MFB profile was obtained from ANSYS Forte fuel mass fraction data and expressed as a function of crank angle. This profile was then curve fitted in MATLAB to determine the Wiebe parameters, including start of combustion, burn duration, and exponent, m , with the fitting process shown in Appendix 2. These parameters enable reconstruction of heat release and in-cylinder pressure within Ricardo WAVE (Giglio and Di Gaeta, 2020). While computationally efficient, this approach is dependent on the conditions from which parameters are derived and is not inherently predictive without correlation to engine operating variables (Giglio and Di Gaeta, (2020)). Model accuracy is also sensitive to input data and boundary conditions (Richardson, D.J. (2021)).

Additionally, Ricardo WAVE does not allow the Wiebe efficiency parameter, a , to be

directly specified, introducing an inherent source of error in the combustion representation. The model configuration is shown in Figure 2.

3.2 ANSYS Forte Baseline Setup

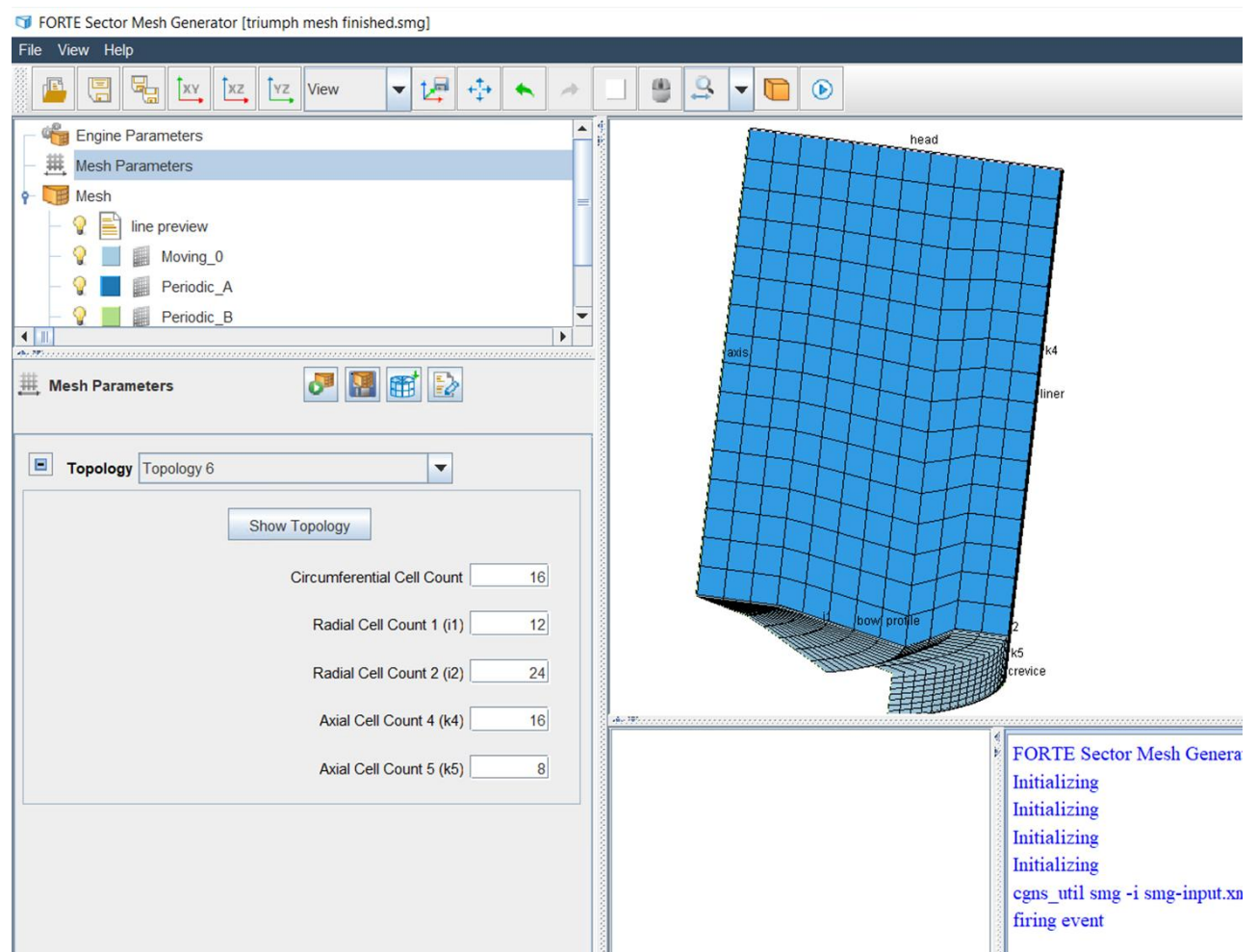


Figure 3: ANSYS Forte sector mesh (Triumph 675)

The ANSYS Forte model was developed as a 45° sector simulation of the Triumph 675 combustion chamber to reduce computational cost while maintaining a representative in-cylinder domain. The base simulation was derived from a Jaguar V8 model; however, an imported Triumph 675 mesh, revised spark location, and updated operating variables were used to create a to-scale section model of the Triumph 675 engine.

The piston profile was simplified due to variation across the crown, with a section containing the exhaust valve cut-outs selected as a balance between deeper cut-out regions and non-cut sections. Curved piston features were simplified into sharp transitions to enable stable mesh generation. The mesh and meshing sizing values are shown in Figures 3.

Simulations were conducted with closed valves, with initial in-cylinder conditions aligned to the corresponding valve operating points (Cameretti, De Robbio and Palomba, 2023). ANSYS Forte was used to solve the governing flow equations, with chemical kinetics handled through CHEMKIN, consistent with its application in engine CFD simulations (Cameretti, De Robbio and Palomba, 2023). A sector-based domain was used to reduce computational cost while retaining in-cylinder flow characteristics, as supported by similar CFD approaches.

Turbulence within the cylinder was modelled using the RANS RNG $k-\epsilon$ model, selected to represent in-cylinder flow behaviour during compression and combustion.

Combustion was described using laminar flame speed models, specifically the Power Law and fuel table library (fuel dependent), allowing the progression of combustion to be captured within the simulation. Boundary conditions were specified based on the defined operating conditions, with initial pressure and temperature applied over a crank angle range of -150° to 110° . This approach enables analysis of in-cylinder processes such as fuel-air mixing, ignition development, and heat release, consistent with established CFD methodologies for engine simulation (Cameretti, De Robbio and Palomba, 2023).

4. Baseline Model Results and Validation

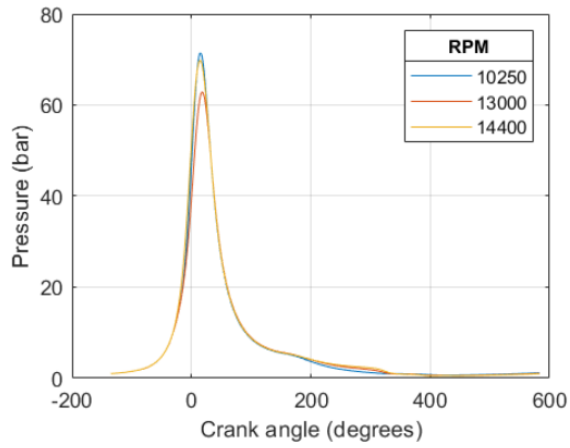


Figure 5: simulation Pressure(octane)

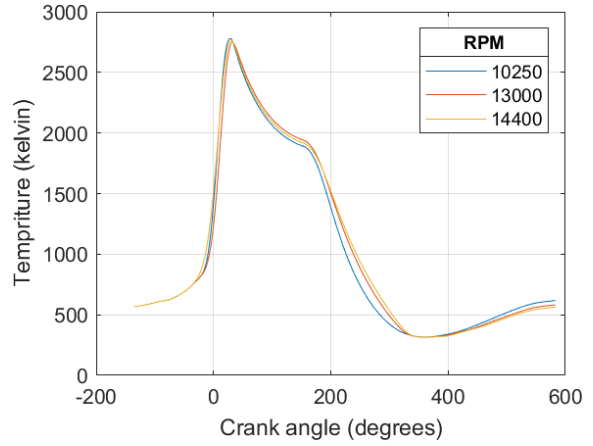


Figure 4:simulation temperature (octane)

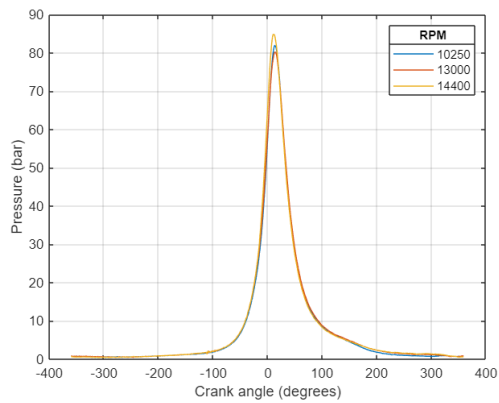


Figure 7: real data pressure

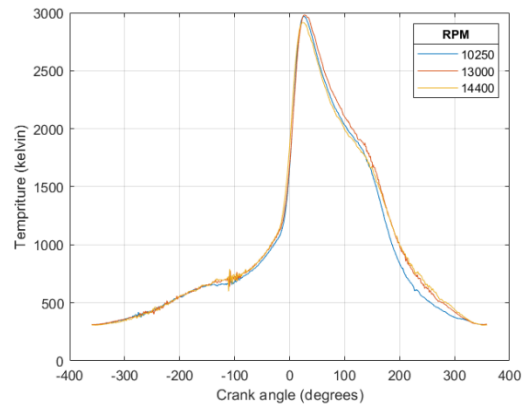


Figure 6: real data temperature

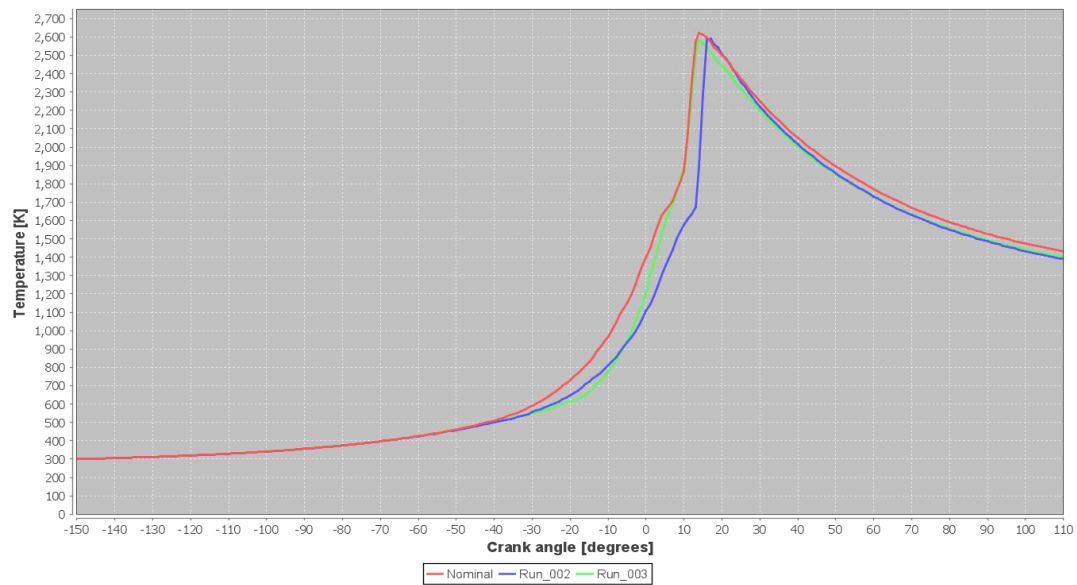


Figure 8: ANSYS Forte temperature (octane)

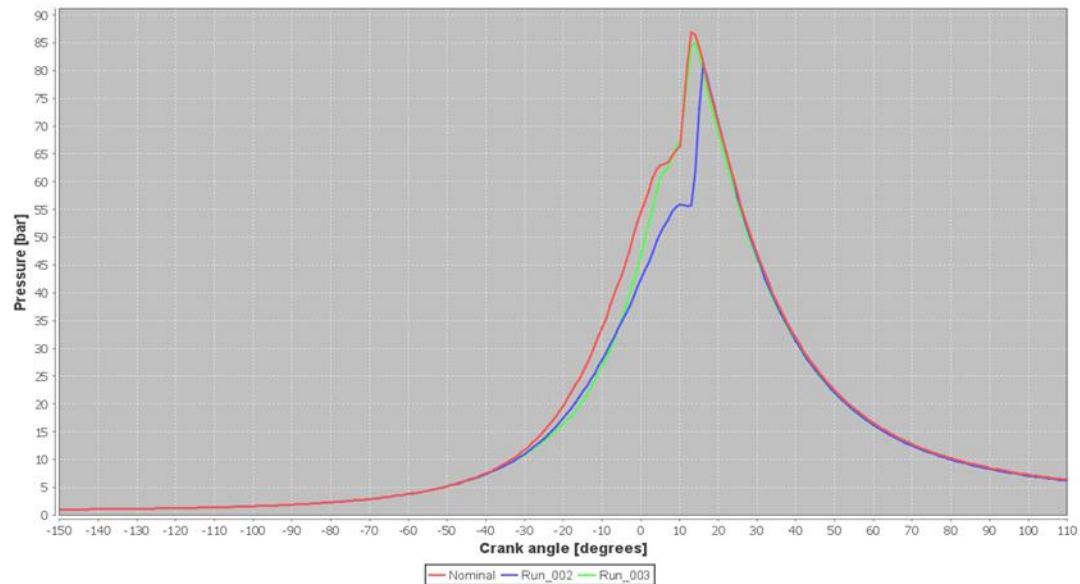


Figure 9: ANSYS Forte Pressure (octane)

The baseline simulation results were evaluated against experimental data using separate cylinder pressure and temperature traces. The WAVE simulation results are shown in Figures 5 (pressure) and 4 (temperature), while the corresponding experimental data are presented in Figures 6 and 7. ANSYS Forte results are shown in Figures 9 (pressure) and 8 (temperature).

The model reproduces overall combustion trends and general cycle behaviour, with good agreement during compression and similar curve shape. However, discrepancies are observed during combustion and expansion. The WAVE simulation underpredicts peak cylinder pressure ($\sim 68\text{--}72$ bar compared to $\sim 82\text{--}85$ bar experimentally) and predicts it slightly earlier, indicating weaker and marginally advanced combustion. This is supported by the temperature traces, where peak values are approximately $200\text{--}300$ K lower than the experimental case ($\sim 2700\text{--}2800$ K vs ~ 3000 K), confirming reduced heat release. The rate of pressure rise is also lower ($\sim 2.0\text{--}2.5$ bar/deg vs $\sim 2.8\text{--}3$ bar/deg), indicating a slower combustion process.

Polytropic analysis highlights non-physical behaviour. While compression is reasonably accurate ($n \approx 1.33$ vs ~ 1.36), the expansion index is significantly lower than expected ($n \approx 1.27$ vs ~ 1.41), indicating excessive energy loss during expansion. This is reflected in the P-V diagram, where the expansion curve lies below the experimental data.

The ANSYS Forte results show significantly improved agreement, with peak pressure within ~ 3 bar and peak timing within ~ 3 crank angle degrees of the experimental data. This indicates that the primary source of error originates from the transfer of combustion behaviour into the 1D model. The use of a Wiebe function introduced limitations, as the combustion behaviour from the CFD model could not be fully represented by fixed parameters, particularly due to variation in a and m .

These discrepancies impact emissions predictions, with lower temperatures leading to underprediction of NO_x and slower combustion increasing CO and unburnt hydrocarbons. These limitations are carried through subsequent simulations and must be considered in later analysis. Despite this, the model captures overall trends and remains suitable for comparative evaluation between fuel cases.

5. Alternative Fuel Simulations

5.1 Fuel Selection and Justification

Three fuels were selected to represent bio-based, synthetic oxygenated, and non-carbon combustion strategies: E85, an MTBE–gasoline blend (M25), and hydrogen. Their key properties and operating conditions are summarised in Table X .

E85 was selected as a bio-based fuel with established use in spark ignition engines. It consists of approximately 86% ethanol and 14% gasoline and operates close to stoichiometric conditions ($\lambda \approx 1$ –1.1). Ethanol blends are widely reported to reduce CO and HC emissions due to their oxygen content, which promotes more complete combustion (Liu et al., 2023; Jin et al., 2017). E85 also represents a practical, real-world fuel with demonstrated compatibility in SI engines (Schifter et al., 2018), with further validation provided through multi-fuel comparison studies (Badawy et al., 2024).

The MTBE blend (M25) was selected as a gasoline fuel containing a synthetic oxygenate. A concentration of approximately 25% MTBE was chosen as it provides the optimal balance in reducing regulated emissions, achieving significant reductions in CO and HC without the diminishing returns observed at higher blend ratios (Topgül, 2015). MTBE has been shown to be compatible with SI engine operation (Schifter et al., 2017) and provides consistent emissions benefits compared to conventional gasoline (Song et al., 2006). It also represents a widely studied oxygenated fuel category (Schifter et al., 2017).

Hydrogen was selected as a non-carbon fuel to represent an alternative combustion pathway. It was operated under lean conditions ($\lambda \approx 1.5$) due to its wide flammability limits and high flame speed. Hydrogen combustion produces negligible carbon-based emissions (CO, HC, CO₂), while NO_x formation remains dependent on combustion temperature and mixture strength (Kahraman et al., 2007; Krishnanunni et al., 2017). Lean operation significantly reduces NO_x formation, with near-zero emissions achievable under sufficiently lean conditions (Sementa et al., 2022; Silveira et al., 2024).

These fuels provide a structured comparison across different combustion characteristics and emissions behaviours, enabling evaluation of both oxygenated and non-carbon fuel strategies under consistent engine conditions.

5.2 Simulation Setup for Alternative Fuels

Alternative fuel simulations were generated by modifying the baseline model while keeping geometry and operating conditions constant to ensure fair comparison. In ANSYS Forte, in-cylinder species and mass fractions were adjusted for each fuel. The laminar flame speed model remained Power Law, except for hydrogen, which required the fuel table library. Spark energy and radius were adjusted for all fuels, with ignition retarded for hydrogen and slightly advanced for E85 and MTBE due to delayed combustion. In Ricardo WAVE, each fuel used fitted Wiebe parameters, with fuel files updated accordingly. A custom MTBE 25 file was created using 25% MTBE and 75% octane by volume.

6. Results and Comparison

The brake specific emissions for all fuels are shown in Figures 10–13, with additional engine characteristic data provided in Appendix 3. Emissions trends are strongly linked to combustion behaviour, particularly temperature, burn rate, and combustion efficiency.

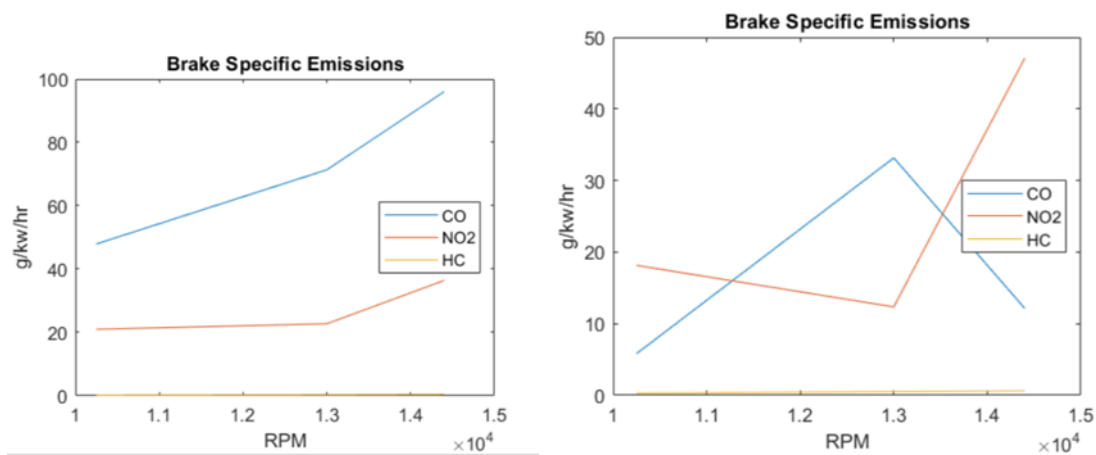


Figure 10: E85 emissions

Figure 11: Octane emissions

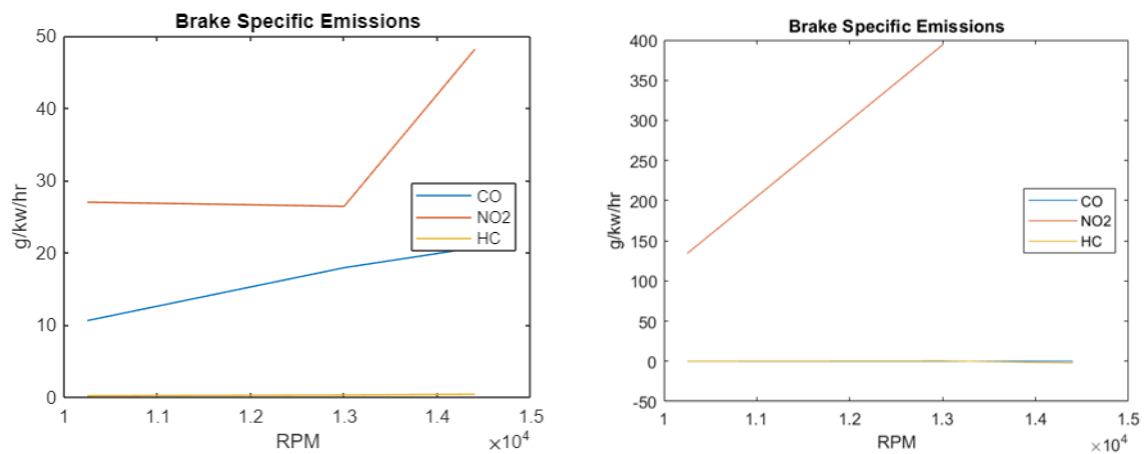


Figure 12: H2 emissions

Figure 13: MTBE 25 emissions

6.1. Octane

Octane represents the baseline case and produces the highest CO emissions, increasing significantly with engine speed (≈ 50 to 95 g/kWh), alongside moderate NO_2 formation. This reflects reduced combustion completeness at higher RPM, where shorter residence times limit full oxidation. Despite high peak temperatures (~ 3000 K), which promote thermal NO_2 formation, incomplete oxidation leads to increasing CO. This establishes the reference behaviour for comparison with alternative fuels.

6.2. E85

Relative to the octane baseline, E85 exhibits significantly lower CO emissions at low and mid RPM, with values increasing to a mid-range peak before reducing again at higher speeds. This behaviour is consistent with ethanol's oxygen content, which enhances oxidation and reduces CO and HC emissions (Liu et al., 2023; Jin et al., 2017). NO_2 formation is reduced compared to the baseline at low–mid RPM due to lower combustion temperatures, but increases sharply at higher speeds, suggesting more aggressive combustion phasing (Schifter et al., 2018; Badawy et al., 2024).

6.3. MTBE 25

Compared to the octane baseline, MTBE 25 shows reduced CO emissions across all operating conditions, increasing steadily with RPM but remaining significantly lower than octane. This reflects improved oxidation due to the oxygenated nature of MTBE (Topgöl, 2015; Song et al., 2006). However, NO_2 levels remain closer to the baseline case, particularly at low–mid RPM, due to similar combustion temperatures and thermodynamic behaviour (Schifter et al., 2017).

6.4. Hydrogen ($\lambda = 1.5$) (H₂)

In contrast to the octane baseline, hydrogen eliminates CO and HC emissions due to the absence of carbon in the fuel (Kahraman et al., 2007; Krishnanunni et al., 2017). However, NO₂ emissions are significantly higher and increase sharply with RPM. This is attributed to rapid combustion and concentrated heat release near TDC, producing high local temperatures that promote NO₂ formation, even under lean operation (Sementa et al., 2022; Silveira et al., 2024).

The 14400 RPM case did not produce a valid NO₂ result. The simulation returned an extremely large negative value, which is non-physical and was therefore excluded. This likely indicates numerical instability or limitations in the emissions model under these conditions.

6.5. Overall Comparison

Relative to the octane baseline, oxygenated fuels (E85 and MTBE) reduce CO emissions through improved oxidation, while NO₂ formation remains primarily governed by combustion temperature and heat release intensity. Hydrogen demonstrates that removal of carbon eliminates CO and HC, but can significantly increase NO₂ due to high-intensity combustion.

However, these results must be considered alongside the limitations identified in Section 4. The underprediction of peak temperature and pressure in the WAVE model, combined with the simplified Wiebe combustion representation, introduces systematic error. As a result, emissions may be inaccurately predicted in absolute terms. The improved agreement observed in the ANSYS Forte model confirms that these discrepancies originate from the 1D combustion modelling approach.

Despite this, the model provides consistent comparative trends relative to the octane baseline, allowing valid evaluation of emissions behaviour across different fuel strategies.

8. Feasibility Against Emissions Targets

The analysed engine was developed under EURO 3 regulations; therefore, feasibility is assessed by comparing the required percentage reductions to the predicted 2035 limits with the percentage change between each fuel and the octane baseline simulation.

Carbon monoxide requires a 70% reduction, while hydrocarbons and nitrogen oxides require 83.3%. E85 achieves a 76% CO reduction, meeting the target, but NO₂ decreases by only 4%. MTBE 25 achieves 77% CO reduction, but NO₂ increases by 26%. Hydrogen achieves 100% reductions in CO and HC, exceeding both targets, but NO₂ increases by 850–900%.

Overall, E85 and MTBE 25 meet only the CO target, while hydrogen meets CO and HC targets but fails significantly for NO₂. No fuel achieves all required reductions, and none meet the 2035 limits. Therefore the predicted limits are not feasible based on these results,

9. Conclusion

This study evaluated alternative fuels against future emissions targets using coupled CFD and 1D combustion modelling. E85 provided the most balanced performance, achieving a 76% reduction in CO while maintaining manageable NO_x levels, making it the most viable option. MTBE 25 showed similar CO reductions but offered limited overall improvement compared to the baseline. Hydrogen eliminated carbon-based emissions entirely but produced significantly increased NO_x, making it unsuitable under current conditions. A major limitation was the curve fitting of the Wiebe functions to input into WAVE, which reduced simulation accuracy by approximately 20%, exceeding acceptable limits. Improving combustion model reliability would likely alter emissions results and may enable certain fuels to meet future regulatory targets.

10. References

- Richardson, D.J. (2021) *An investigation to determine the complexity and feasibility of combustion & NOx modelling in modern GTDI engines*, MSC - Motorsport Engineering Major Project - Dissertation.
- Cameretti, M.C., De Robbio, R. and Palomba, M. (2023) 'Numerical Analysis of Dual Fuel Combustion in a Medium Speed Marine Engine Supplied with Methane/Hydrogen Blends,' *Energies*, 16(18), p. 6651.
<https://doi.org/10.3390/en16186651>.
- Giglio, V. and Di Gaeta, A. (2020) ' Novel regression models for wiebe parameters aimed at 0D combustion simulation in spark ignition engines,' *Energy*, 210, p. 118442. <https://doi.org/10.1016/j.energy.2020.118442>.
- *DIRECTIVE 97/24/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on certain components and characteristics of two or three-wheel motor vehicles (1997) Official Journal of the European Communities.*
- European Communities (2002) 'STATEMENT BY THE COMMISSION,' *Official Journal of the European Communities*, p. 31.
- European Parliament and Council of the European Union (1998) 'DIRECTIVE 98/69/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL relating to measures to be taken against air pollution by emissions from motor vehicles and amending Council Directive 70/220/EEC,' *Official Journal of the European Communities* [Preprint].
- *REGULATION (EU) No 168/2013 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL (2013) Official Journal of the European Union.*
https://www.legislation.gov.uk/eur/2013/168/pdfs/eur_20130168_2020-11-14_en.pdf?utm_.

- THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION (2002) *DIRECTIVE 2002/51/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL*, *Official Journal of the European Communities*. directive, pp. 20–20.
- THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION (2007) *REGULATION (EC) No 715/2007 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL*, *Official Journal of the European Union*.
- THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION (2024) *REGULATION (EU) 2024/1257 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL*, *Official Journal of the European Union*. report.
<http://data.europa.eu/eli/reg/2024/1257/oj>.
- Badawy, T. *et al.* (2024) 'Performance and emissions evaluation of a multi-cylinder research engine fueled with ethanol, methanol, gasoline Euro-6, E85, and iso-stoichiometric ternary GEM mixtures operated at lean conditions,' *Fuel*, 363, p. 130962. <https://doi.org/10.1016/j.fuel.2024.130962>.
- Jin, D. *et al.* (2017) 'The impact of various ethanol-gasoline blends on particulates and unregulated gaseous emissions characteristics from a spark ignition direct injection (SIDI) passenger vehicle,' *Fuel*, 209, pp. 702–712.
<https://doi.org/10.1016/j.fuel.2017.08.063>.
- Liu, S. *et al.* (2023) 'Experimental study on combustion and emission characteristics of ethanol-gasoline blends in a high compression ratio SI engine,' *Energy*, 274, p. 127398. <https://doi.org/10.1016/j.energy.2023.127398>.
- Schifter, I. *et al.* (2018) 'From actual ethanol contents in gasoline to mid-blends and E-85 in conventional technology vehicles. Emission control issues and consequences,' *Fuel*, 219, pp. 239–247.
<https://doi.org/10.1016/j.fuel.2018.01.118>.

- Schifter, I. *et al.* (2016) 'Experimental and vehicle (on road) test investigations of spark-ignited engine performance and emissions using high concentration of MTBE as oxygenated additive,' *Fuel*, 187, pp. 276–284.
<https://doi.org/10.1016/j.fuel.2016.09.044>.
- Schifter, I. *et al.* (2017) 'Comparison of performance and emissions for gasoline-oxygenated blends up to 20 percent oxygen and implications for combustion on a spark-ignited engine,' *Fuel*, 208, pp. 673–681.
<https://doi.org/10.1016/j.fuel.2017.07.065>.
- Song, C.-L. *et al.* (2005) 'Comparative effects of MTBE and ethanol additions into gasoline on exhaust emissions,' *Atmospheric Environment*, 40(11), pp. 1957–1970. <https://doi.org/10.1016/j.atmosenv.2005.11.028>.
- Topgöl, T. (2015) 'The effects of MTBE blends on engine performance and exhaust emissions in a spark ignition engine,' *Fuel Processing Technology*, 138, pp. 483–489. <https://doi.org/10.1016/j.fuproc.2015.06.024>.
- Kahraman, E., Özcanlı, S.C. and Ozerdem, B. (2006) 'An experimental study on performance and emission characteristics of a hydrogen fuelled spark ignition engine,' *International Journal of Hydrogen Energy*, 32(12), pp. 2066–2072.
<https://doi.org/10.1016/j.ijhydene.2006.08.023>.
- Krishnanunni, J., Bhatia, D. and Das, L.M. (2017) 'Experimental and modelling investigations on the performance and emission characteristics of a single cylinder hydrogen engine,' *International Journal of Hydrogen Energy*, 42(49), pp. 29574–29584. <https://doi.org/10.1016/j.ijhydene.2017.10.018>.
- Sementa, P. *et al.* (2022) 'Exploring the potentials of lean-burn hydrogen SI engine compared to methane operation,' *International Journal of Hydrogen*

Energy, 47(59), pp. 25044–25056.

<https://doi.org/10.1016/j.ijhydene.2022.05.250>.

- Silveira, J.P. *et al.* (2024) 'Hydrogen-fueled PFI SI engine investigation for near-zero NO_x emissions in de-throttled and supercharged ultra-lean burn conditions,' *International Journal of Hydrogen Energy*, 91, pp. 800–813.
<https://doi.org/10.1016/j.ijhydene.2024.10.198>.

Appendix

1. Emissions Tables

CAR

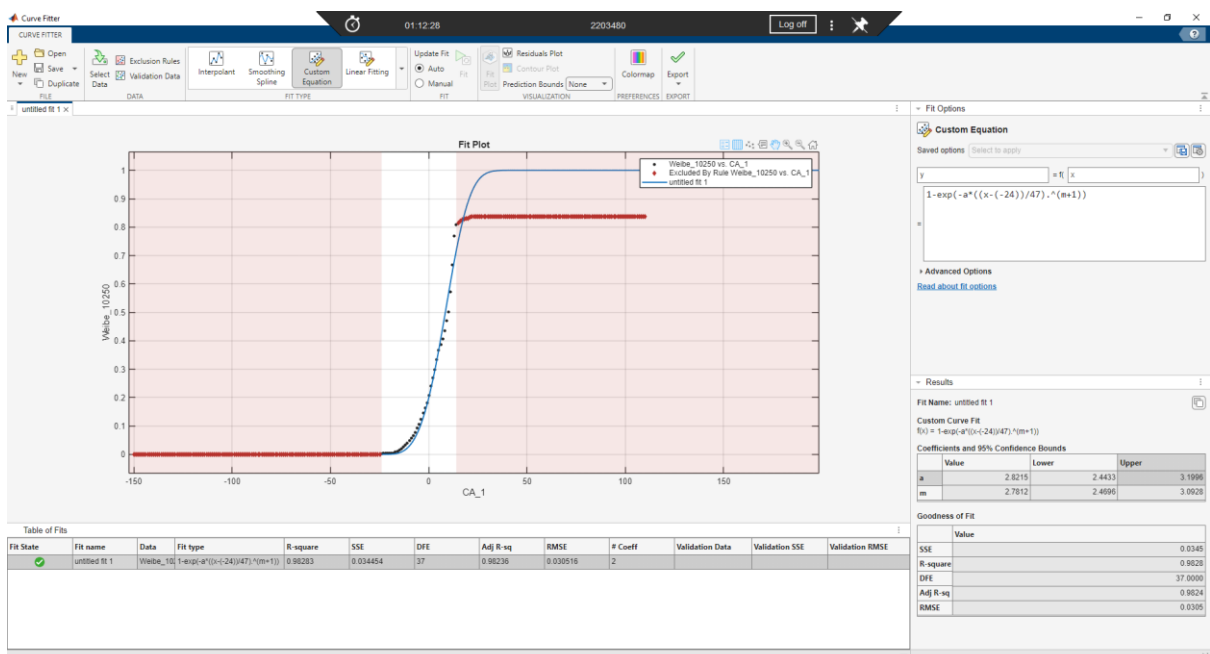
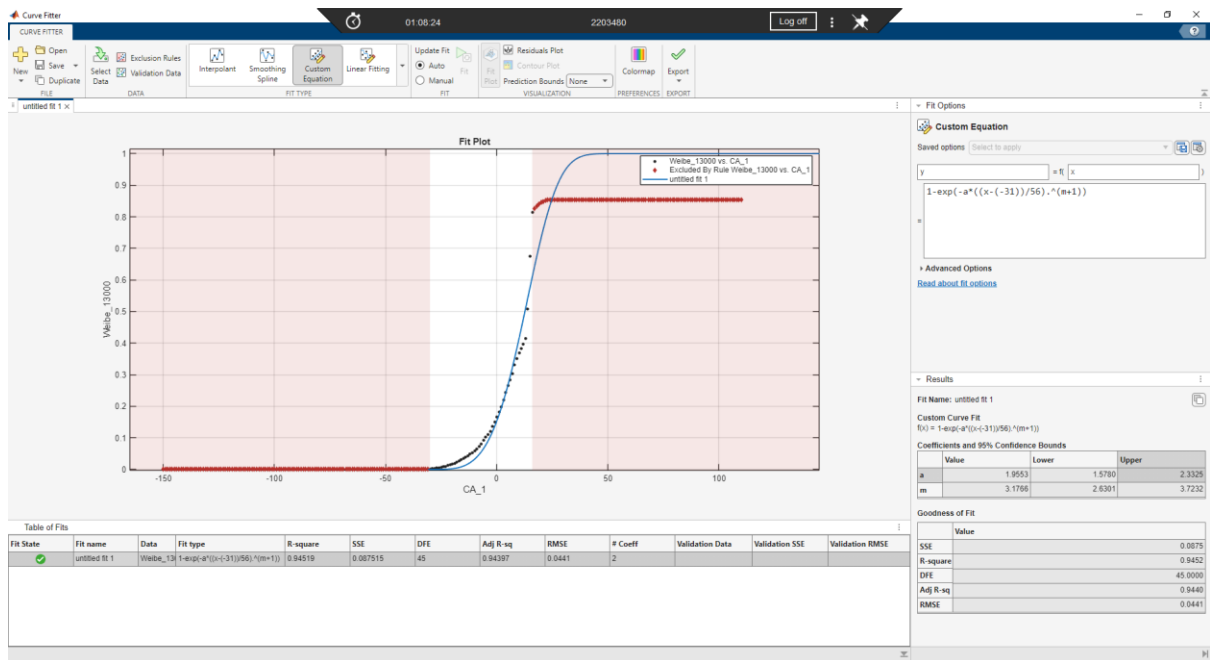
EURO	YEAR	HC (G/KM)	CO (G/KM)	NOX (G/KM)
EURO 1	1992	—	2.72	—
EURO 2	1996	—	2.20	—
EURO 3	2000	0.20	2.30	0.15
EURO 4	2005	0.10	1.00	0.08
EURO 5	2009	0.10	1.00	0.06
EURO 6	2014	0.10	1.00	0.06
EURO 7	2024	0.10	1.00	0.06

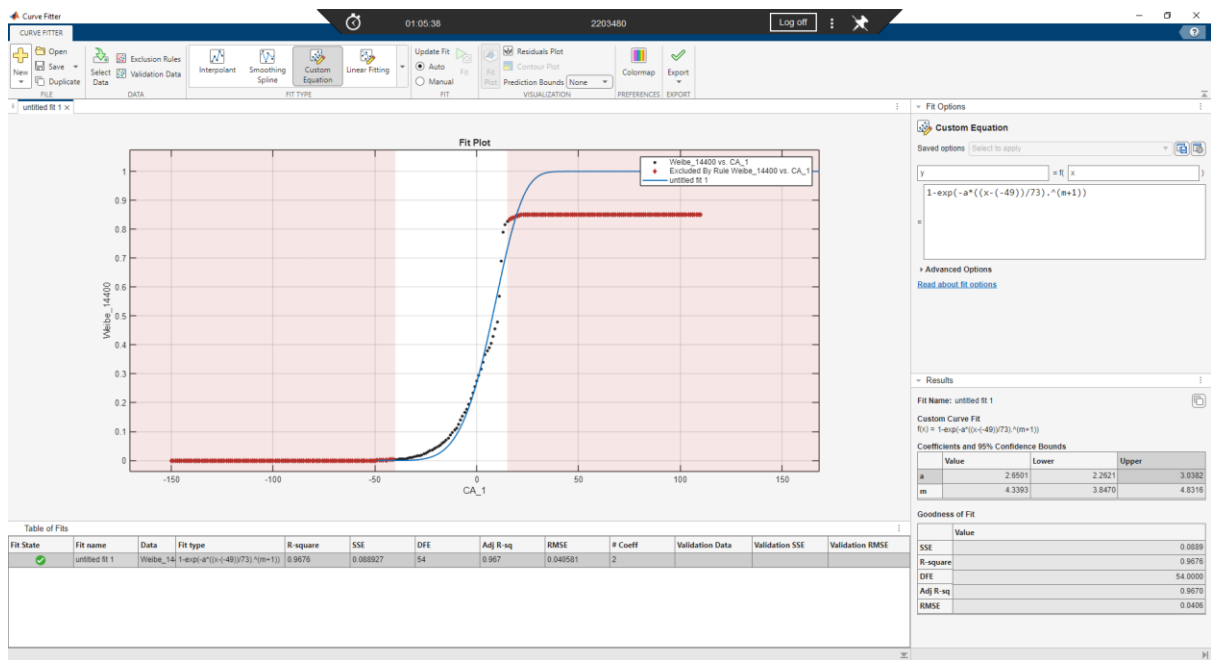
Motorcycle

EURO	YEAR	HC (G/KM)	CO (G/KM)	NOX (G/KM)
EURO 1	1999	3.00	13.00	0.30
EURO 2	2003	1.00	5.50	0.30
EURO 3	2006	0.30	2.00	0.15
EURO 4	2016	0.17	1.14	0.09
EURO 5	2020	0.10	1.00	0.06

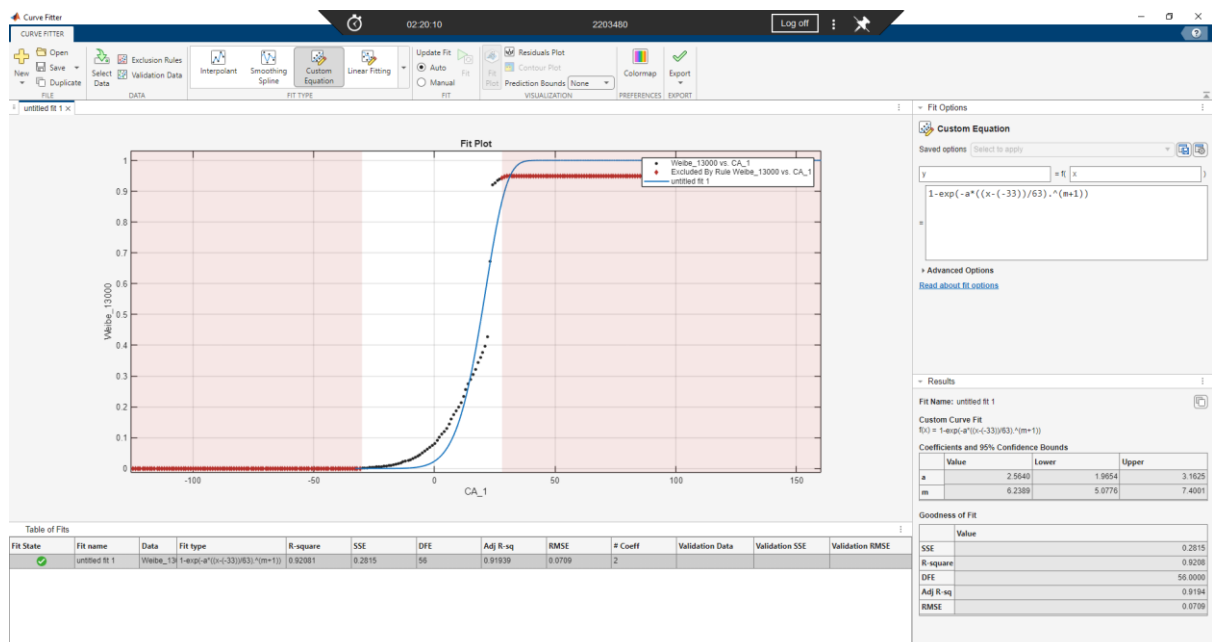
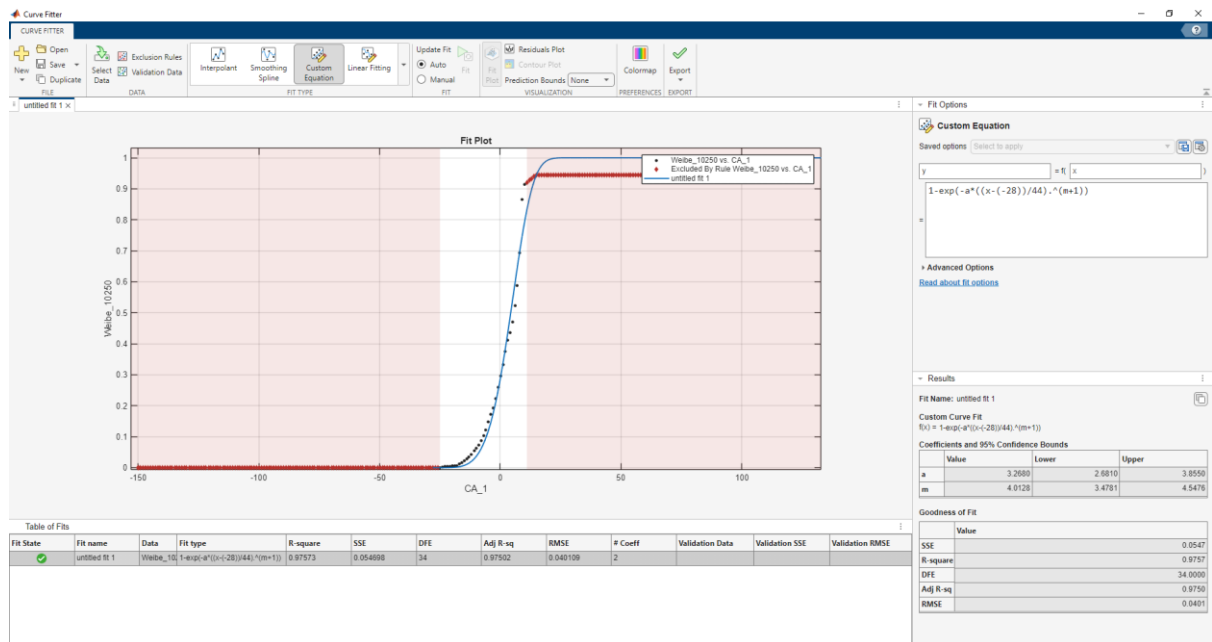
2. CF tool (Wiebe)

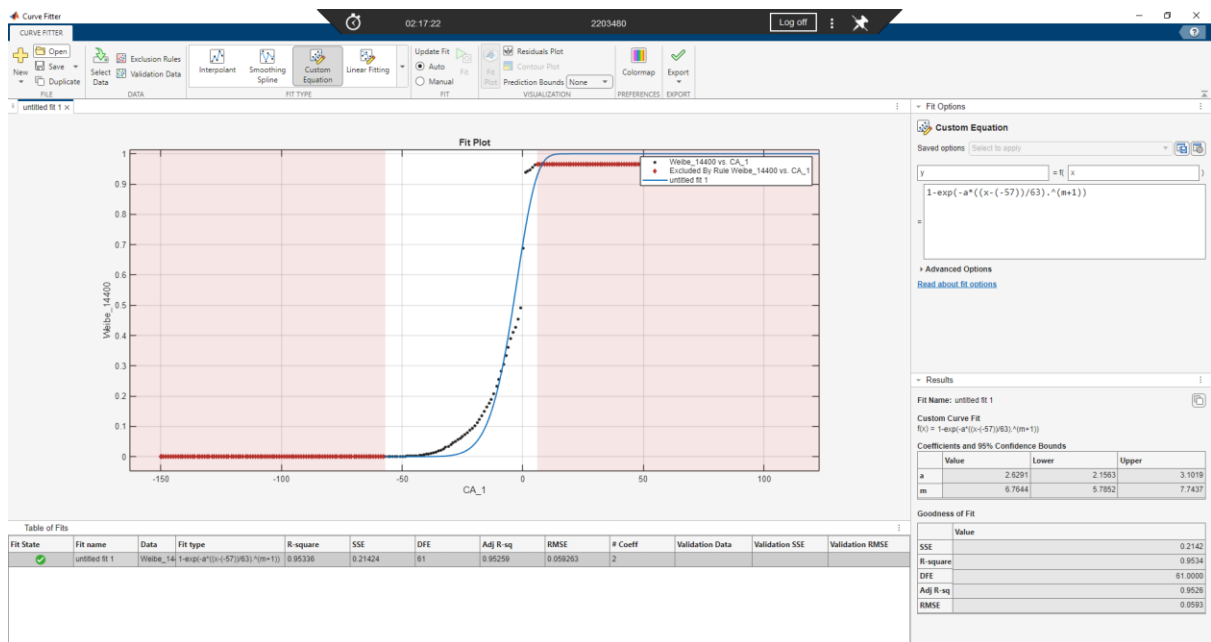
2.1. Octane



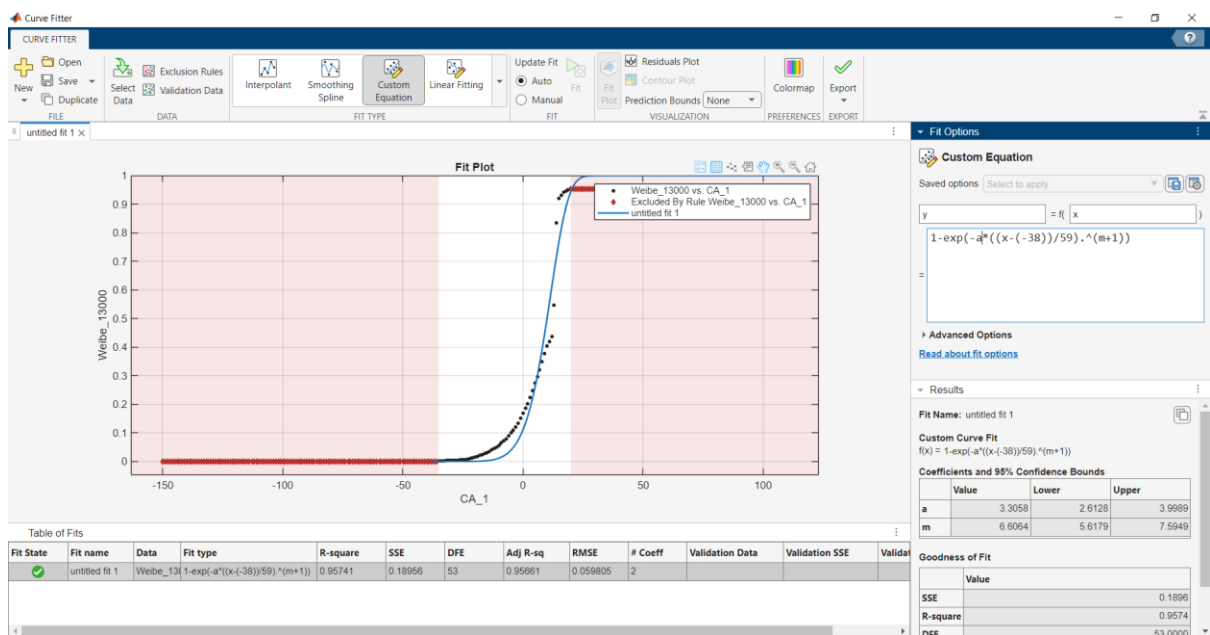
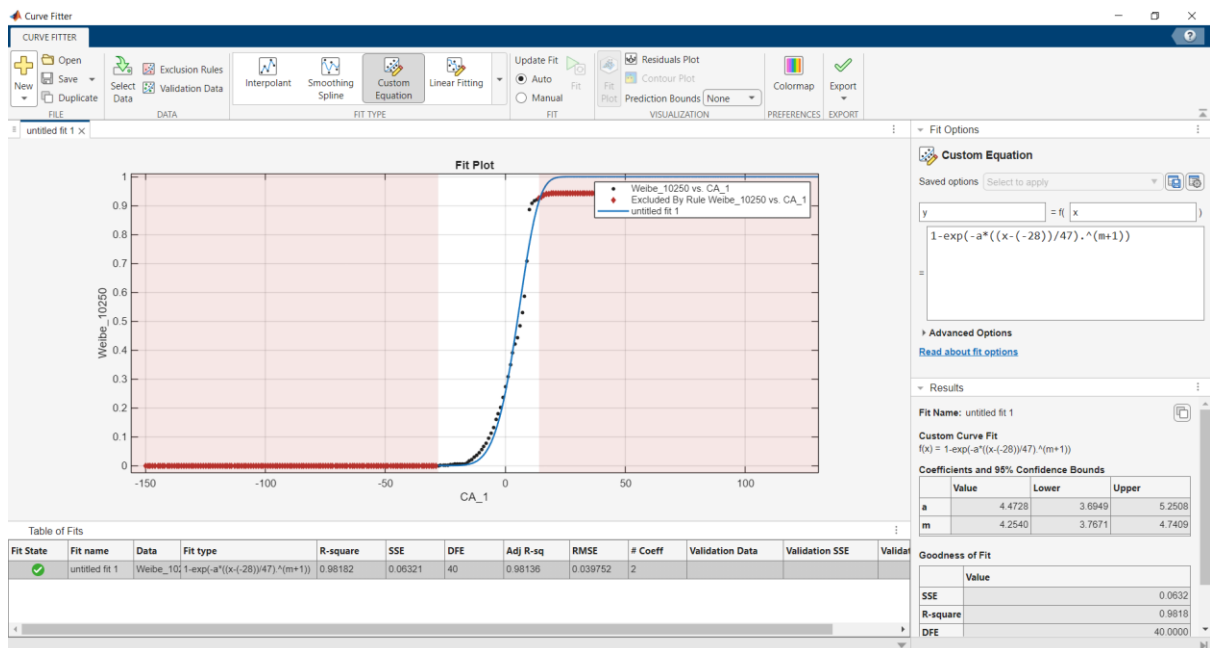


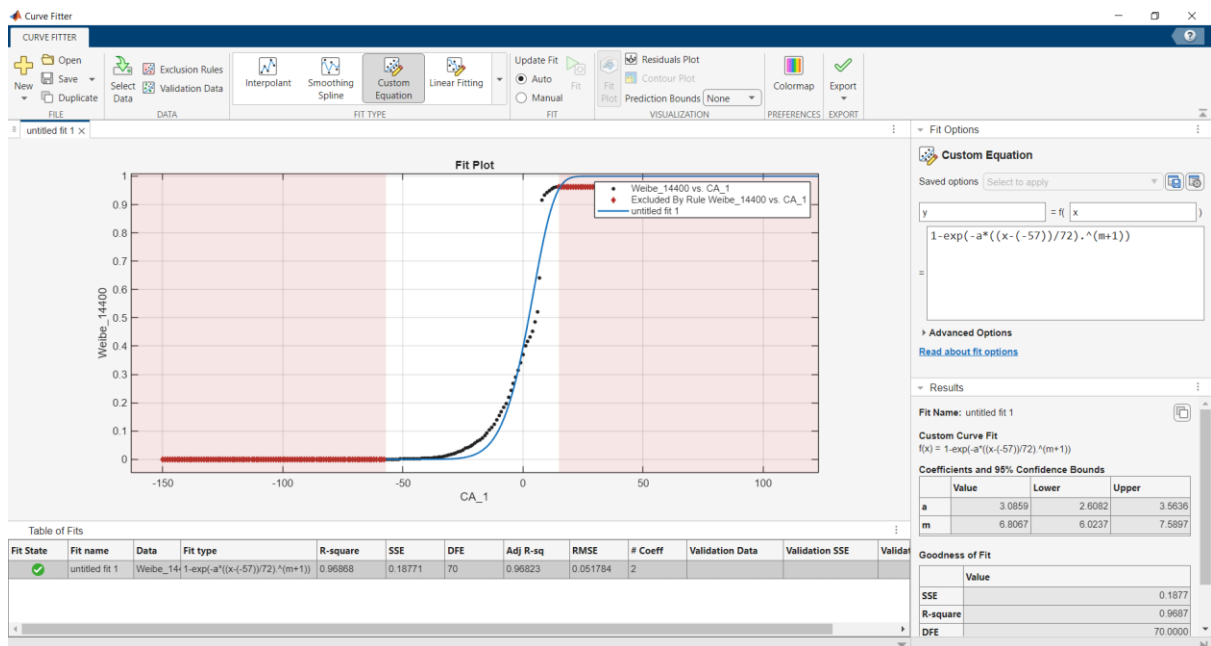
2.2. E85



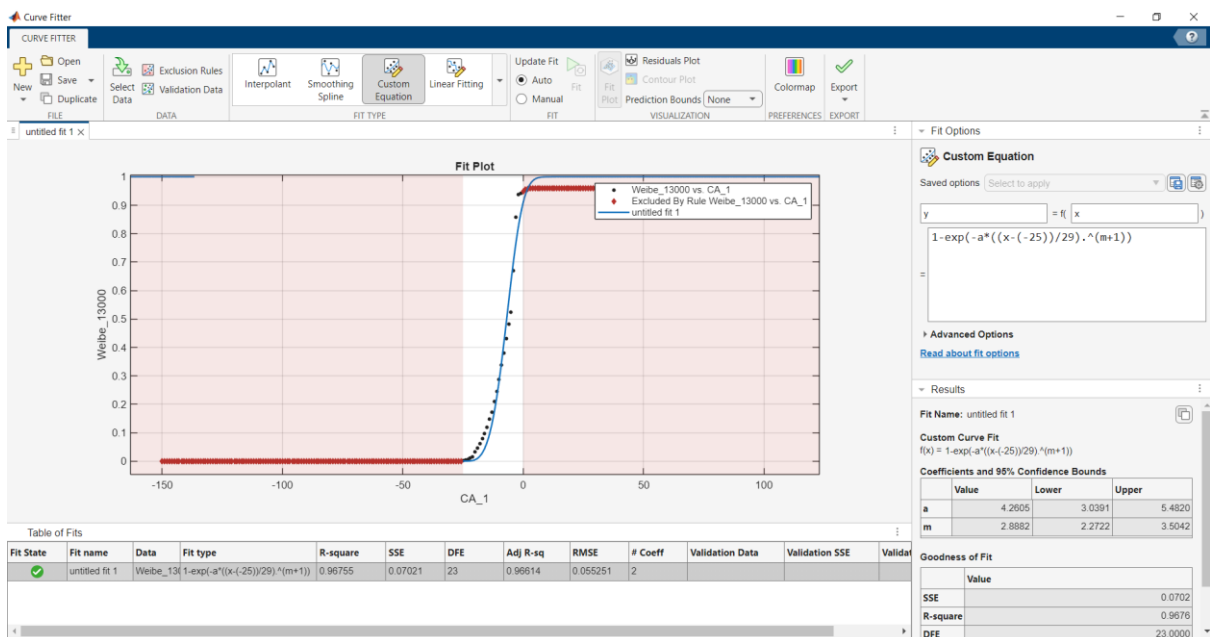
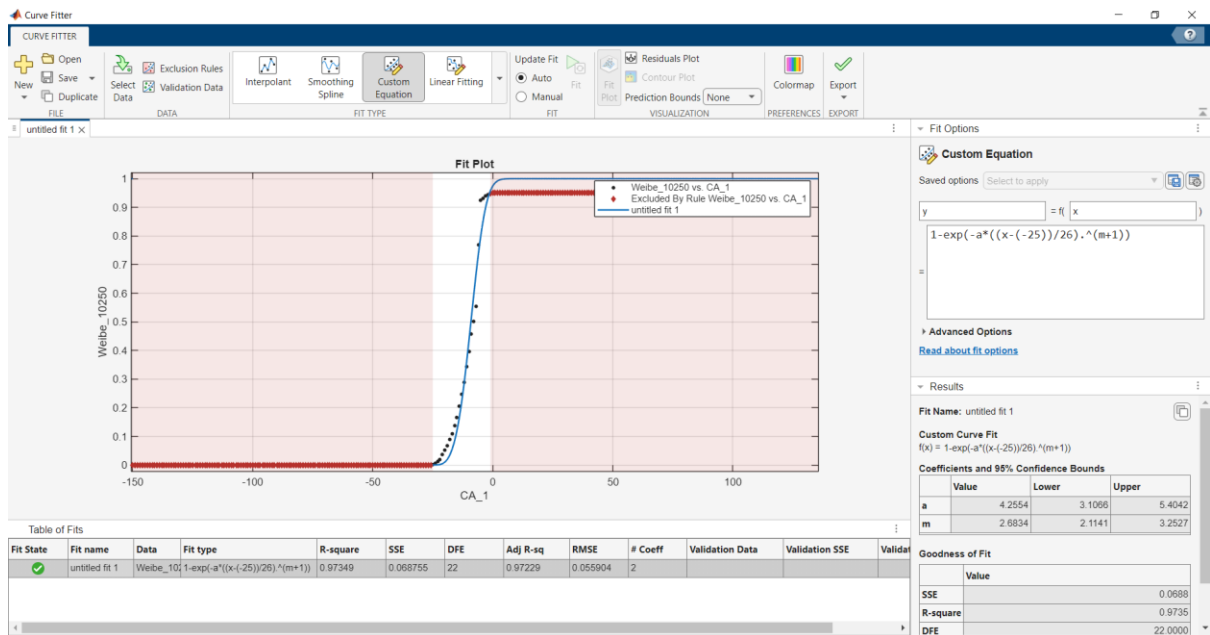


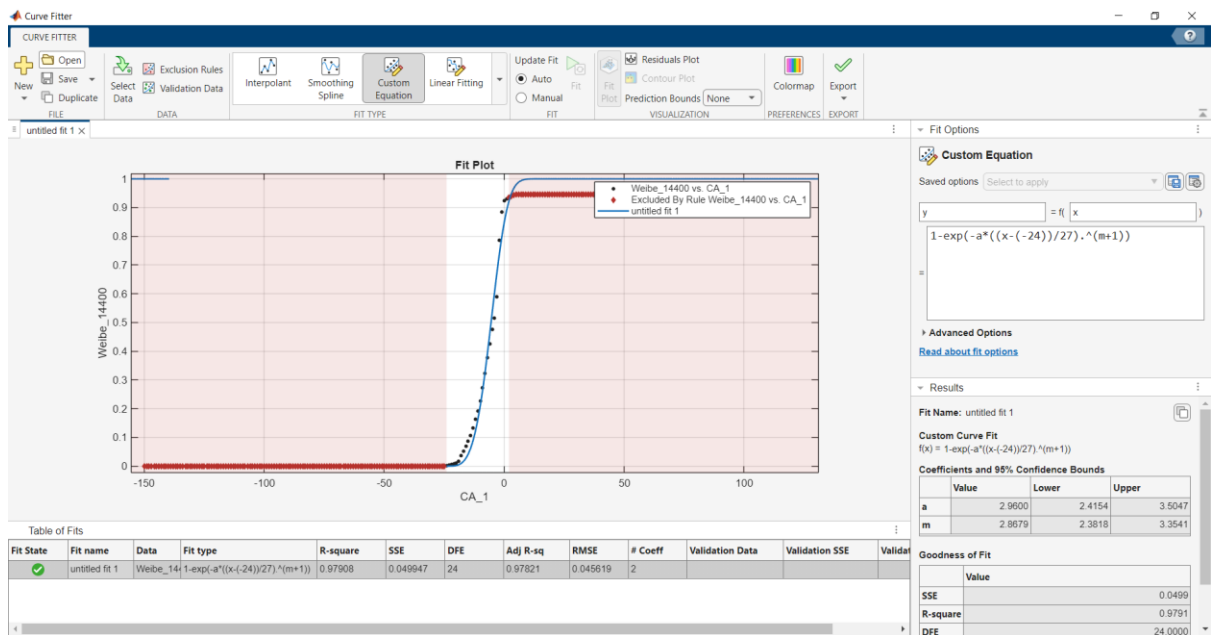
2.3. MTBE 25





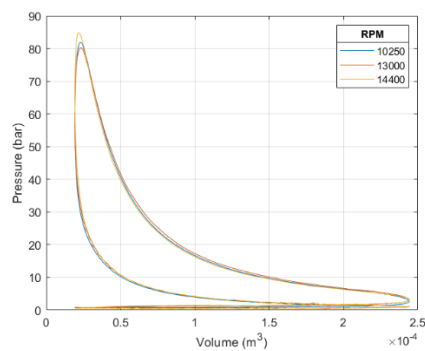
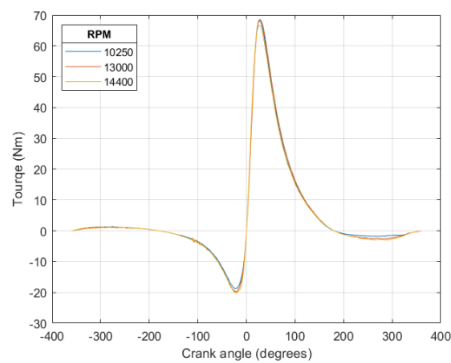
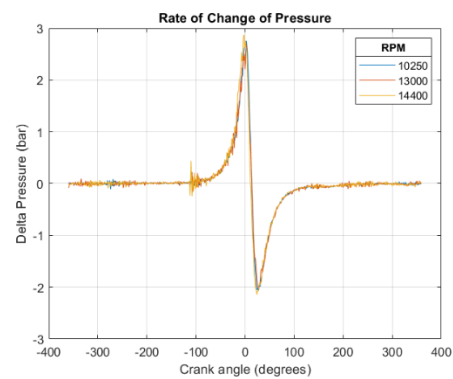
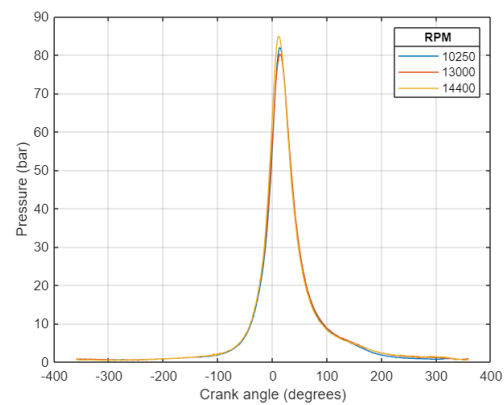
2.4. H2

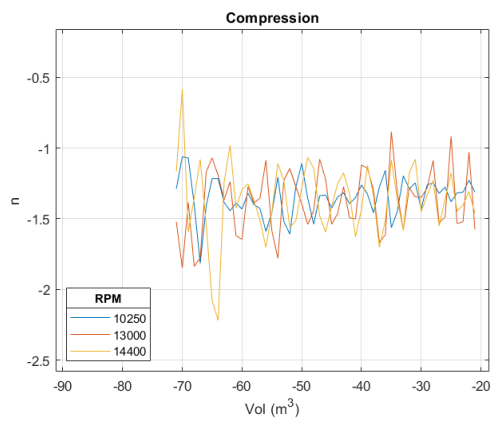
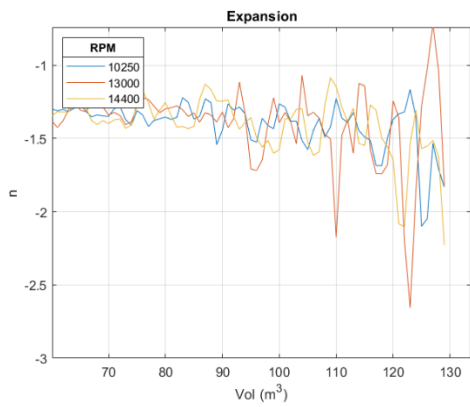
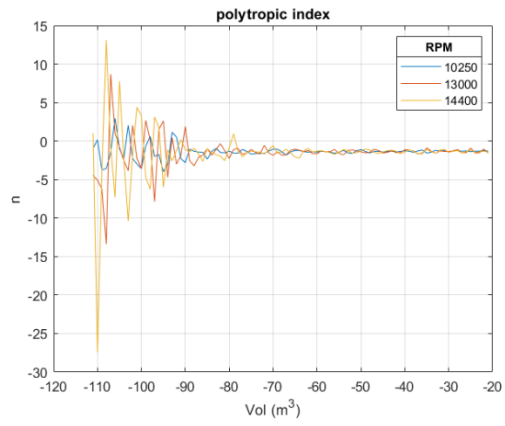
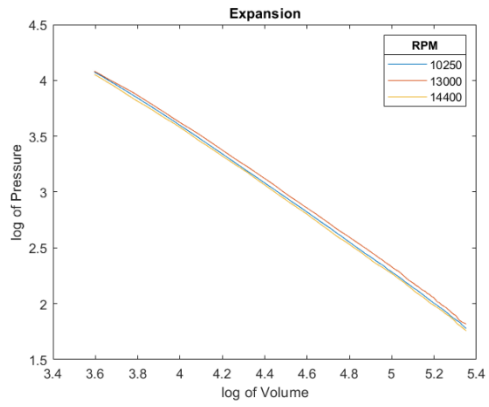
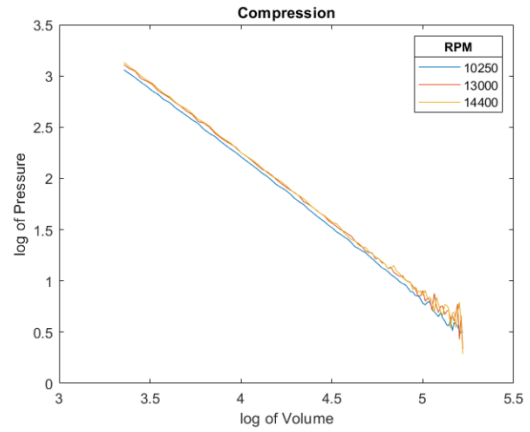
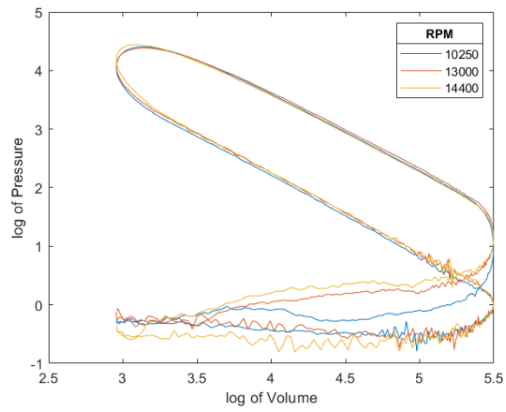


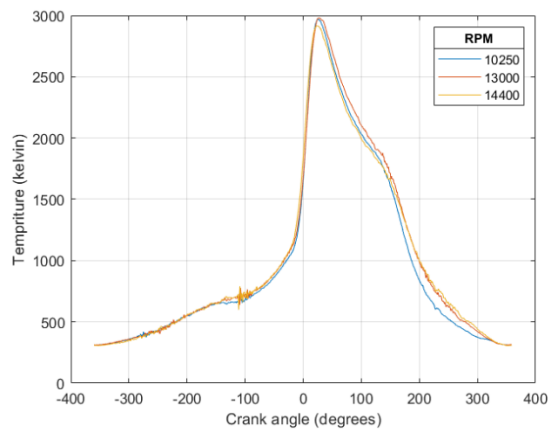


3. Engine Characteristics graphs

3.1. Real







```

nCompMax = 1x3
          -1.0622  -0.8850  -0.5860

nCompMin = 1x3
          -1.8153  -1.8472  -2.2184

nCompMean = 1x3
          -1.3475  -1.3780  -1.3669

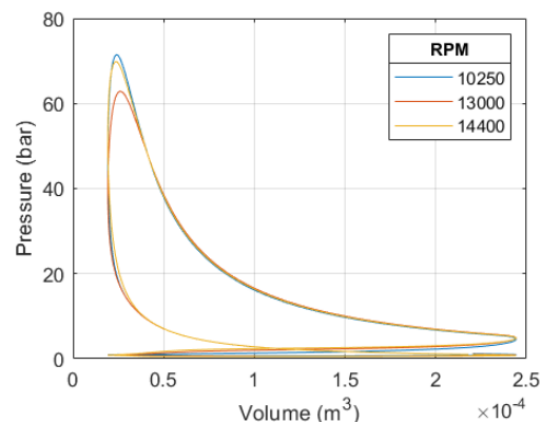
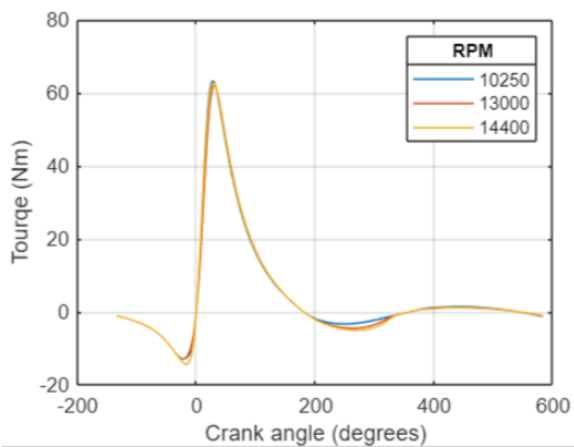
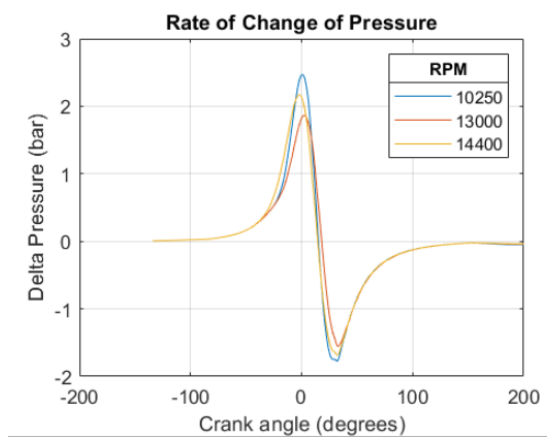
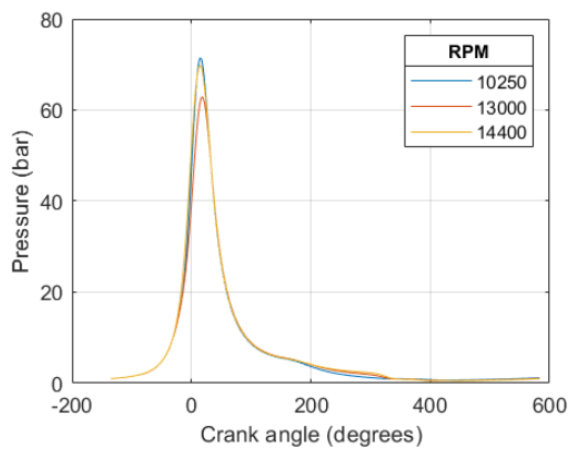
nExpMax = 1x3
          -1.1651  -0.7202  -1.0851

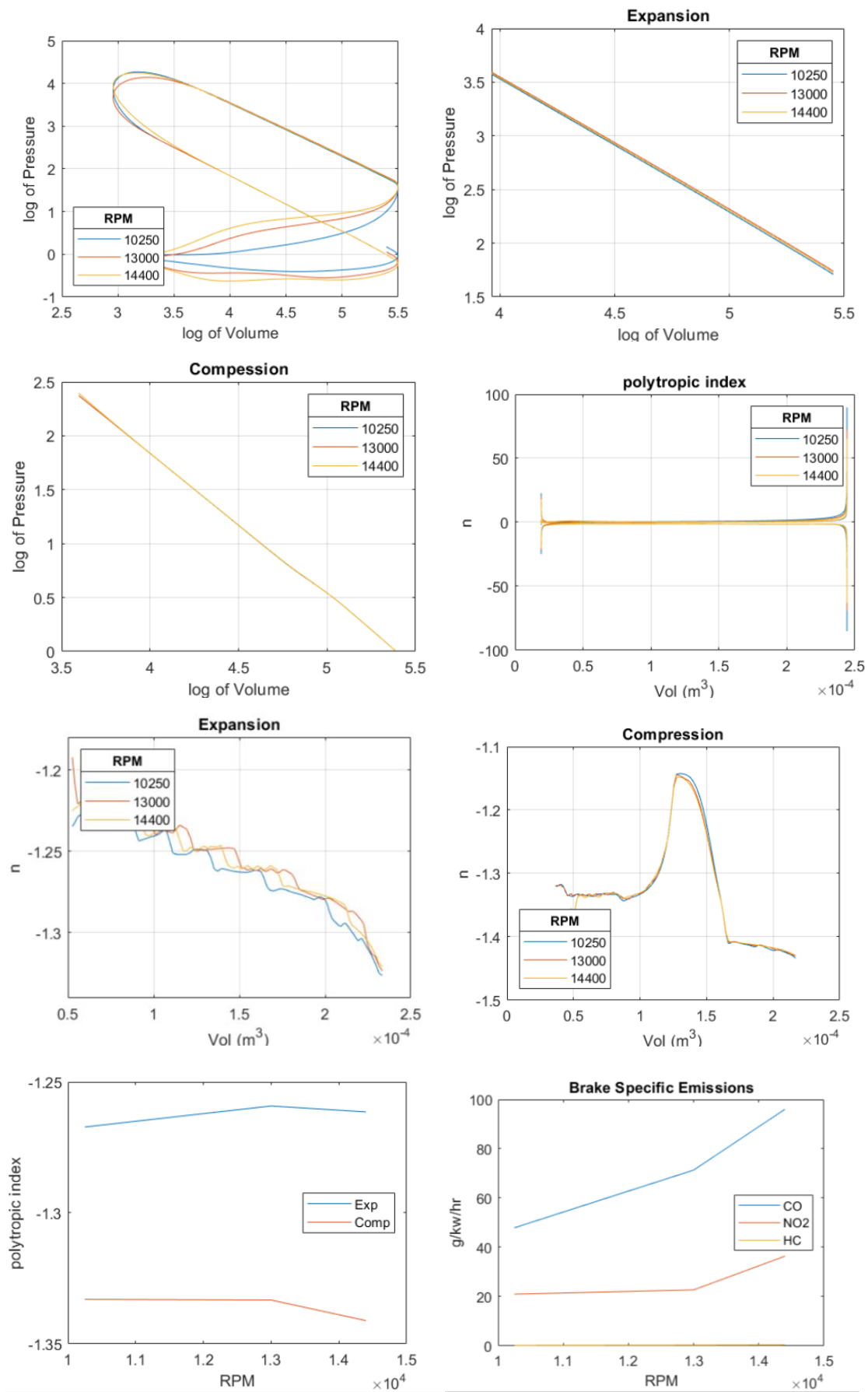
nExpMin = 1x3
          -2.1004  -2.6553  -2.2279

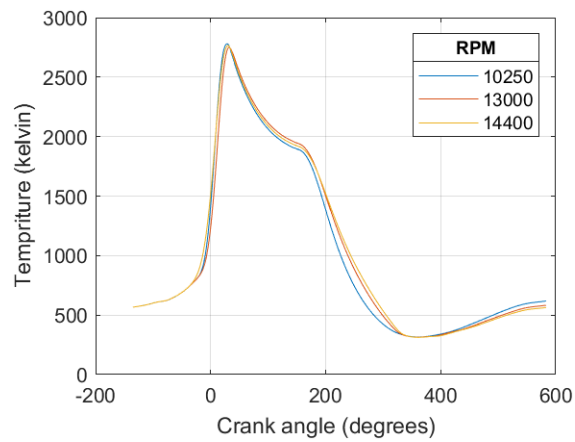
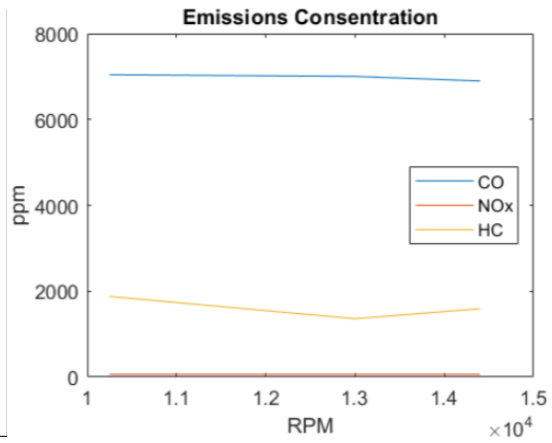
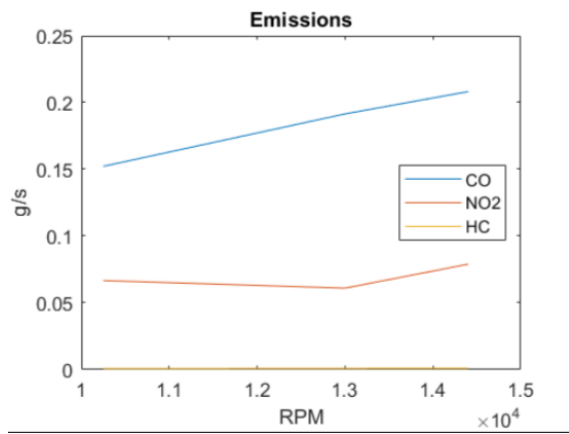
nExpMean = 1x3
          -1.4030  -1.4038  -1.4108

```

3.2. Octane Simulation







```

nCompMax = 1x3
-1.1424 -1.1442 -1.1481

nCompMin = 1x3
-1.4337 -1.4298 -1.4675

nCompMean = 1x3
-1.3330 -1.3333 -1.3411

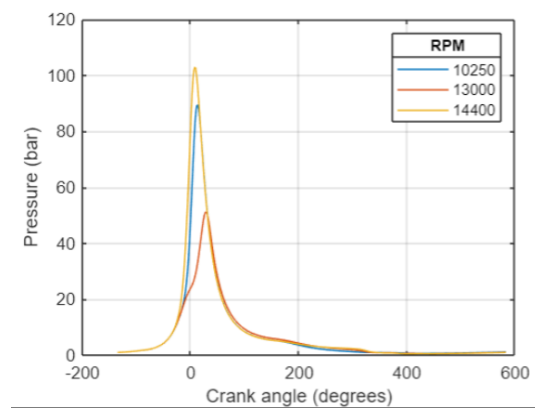
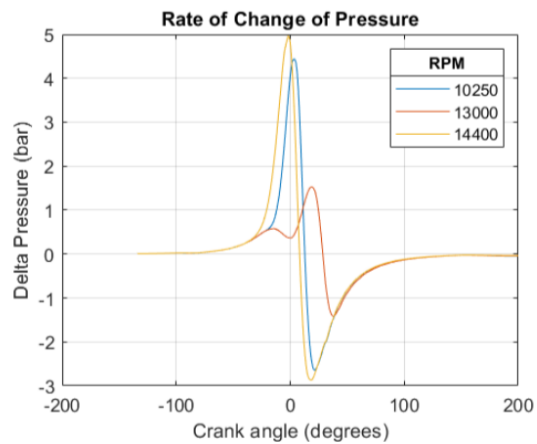
nExpMax = 1x3
-1.2248 -1.1923 -1.2207

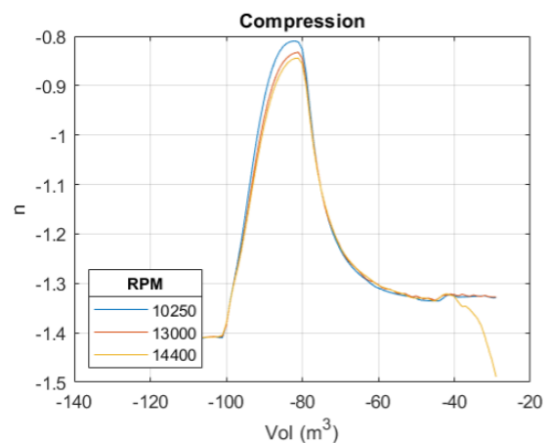
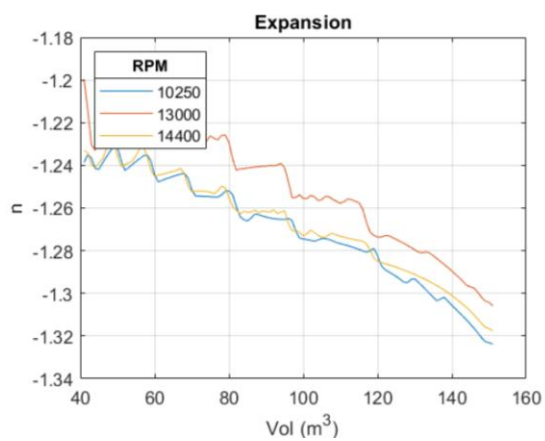
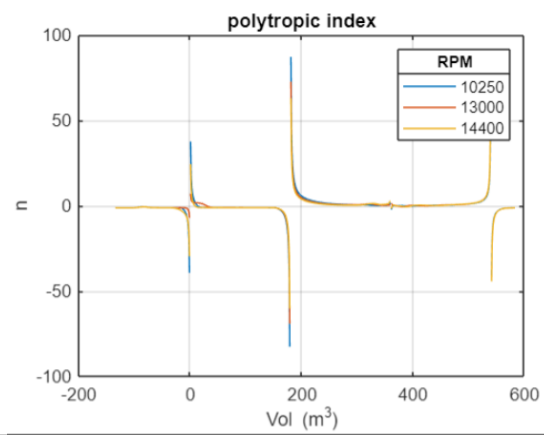
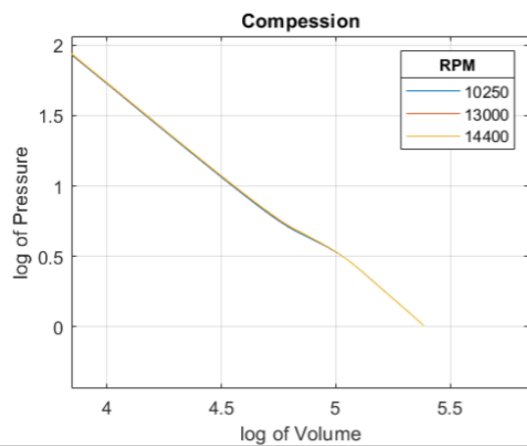
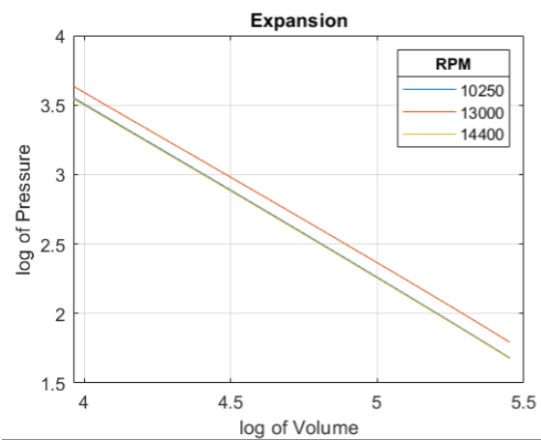
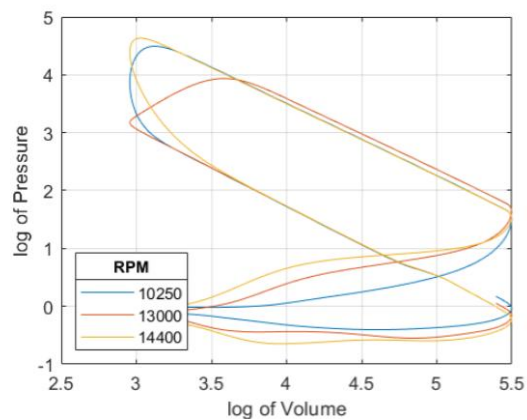
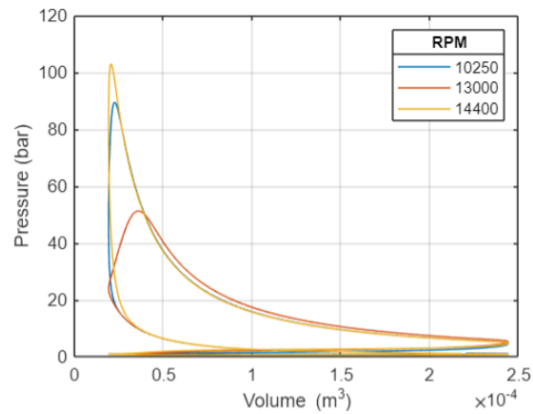
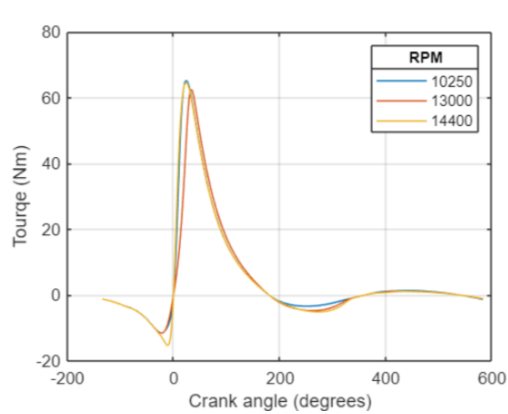
nExpMin = 1x3
-1.3262 -1.3234 -1.3208

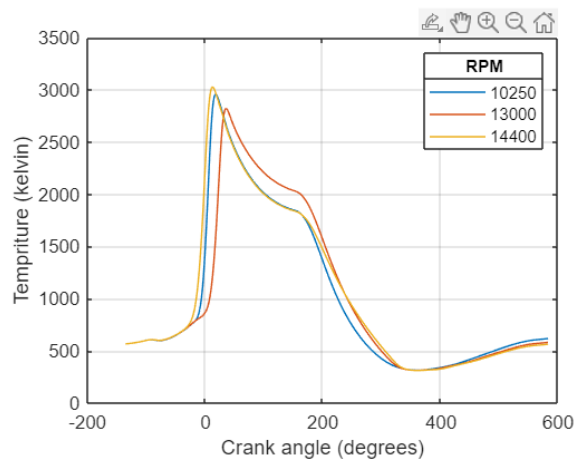
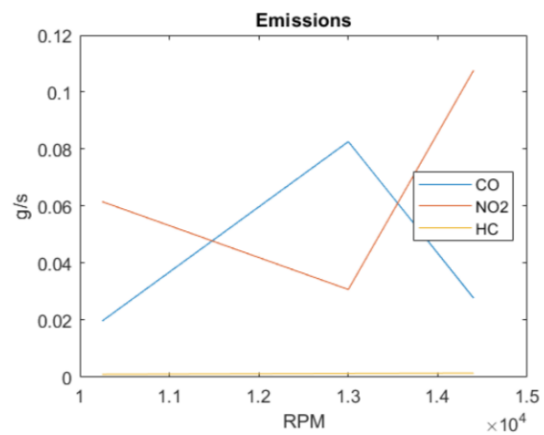
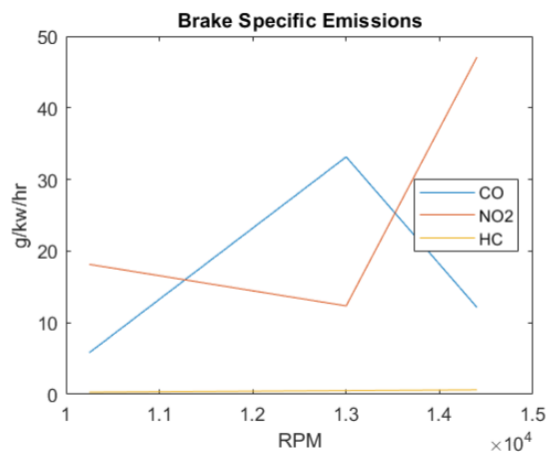
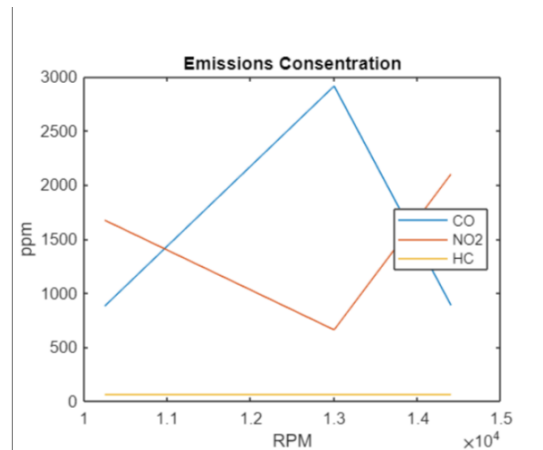
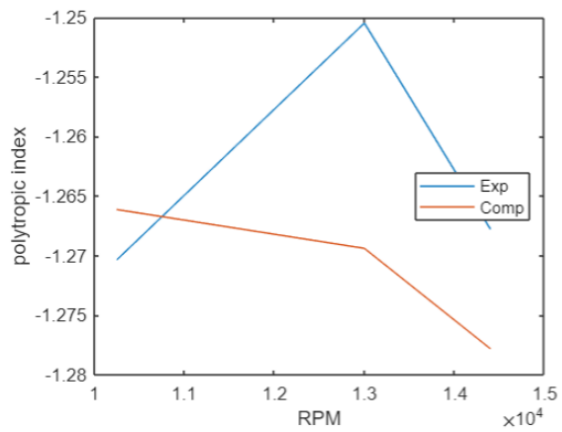
nExpMean = 1x3
-1.2672 -1.2592 -1.2615

```

3.3. E85 Simulation







nCompMax = 1×3
-0.8099 -0.8325 -0.8445

nCompMin = 1×3
-1.4337 -1.4298 -1.4894

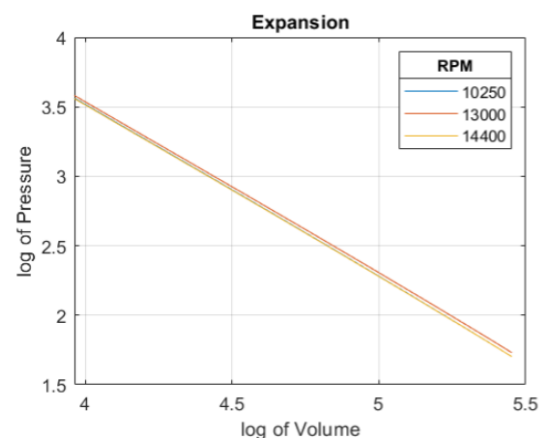
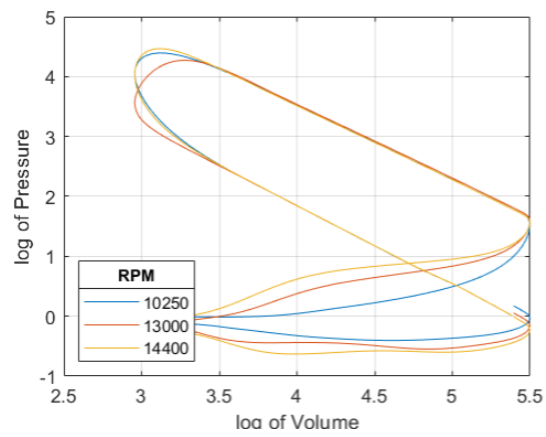
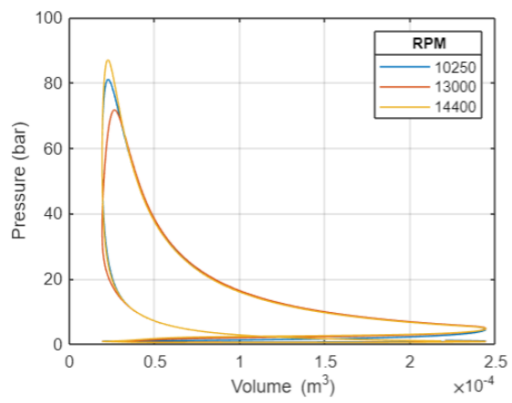
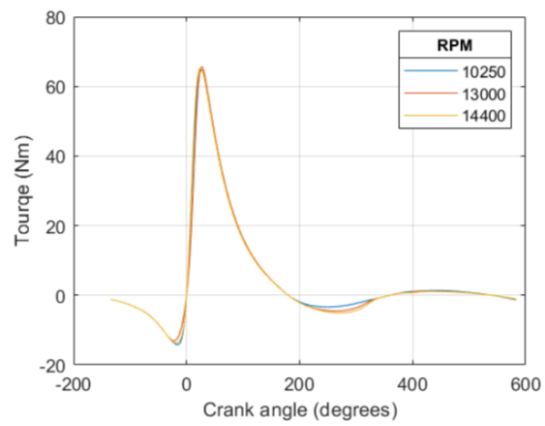
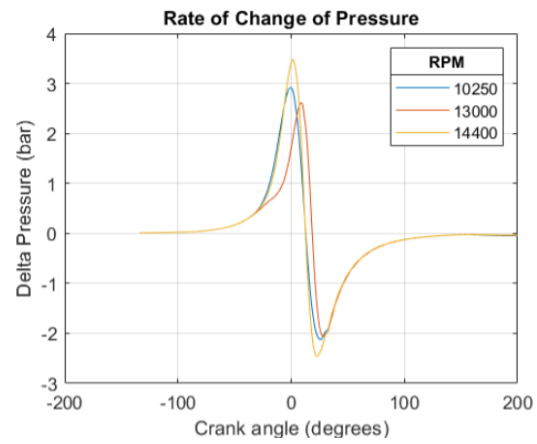
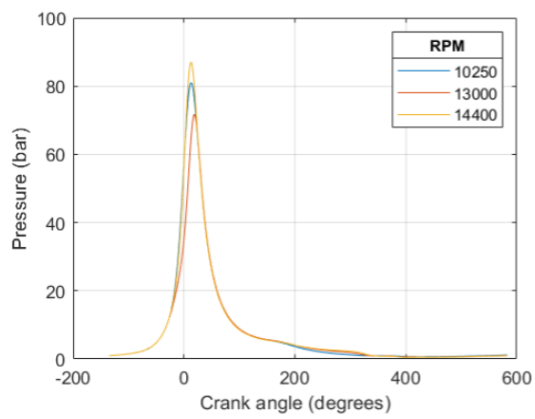
nCompMean = 1×3
-1.2661 -1.2694 -1.2778

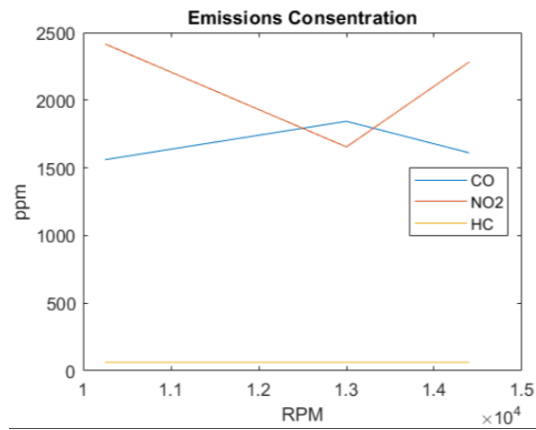
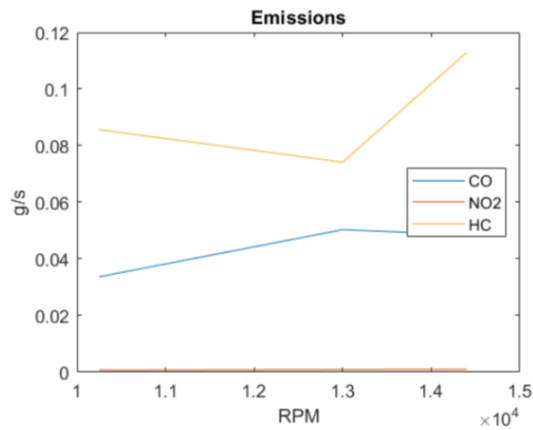
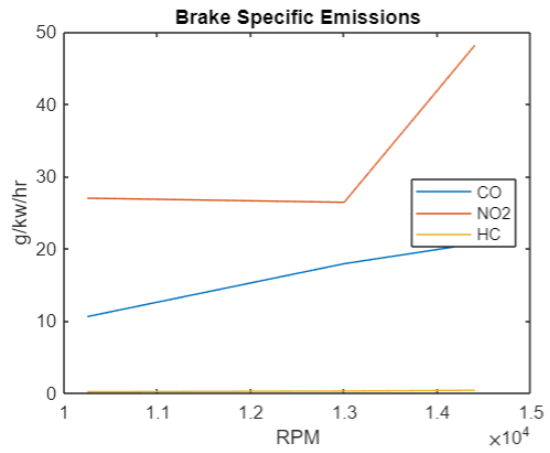
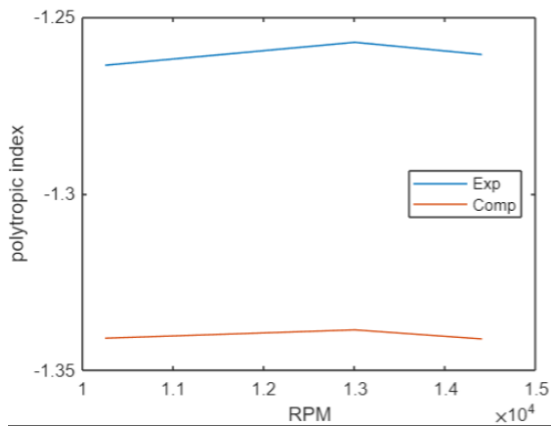
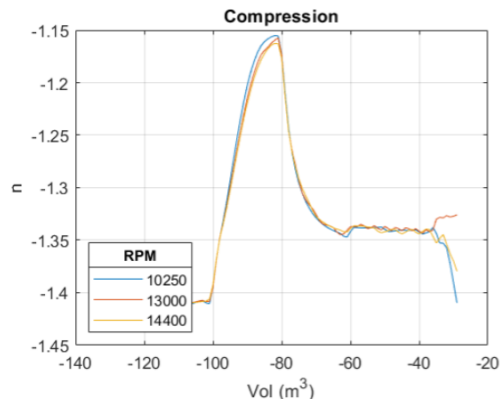
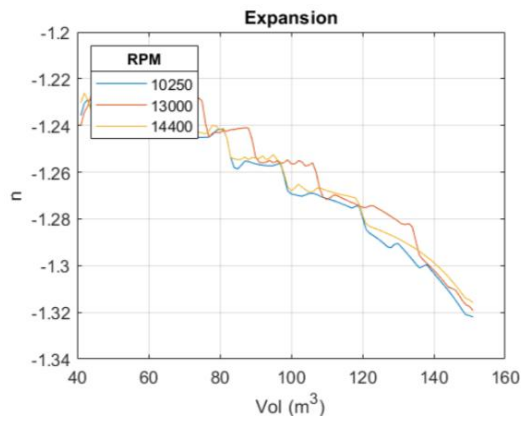
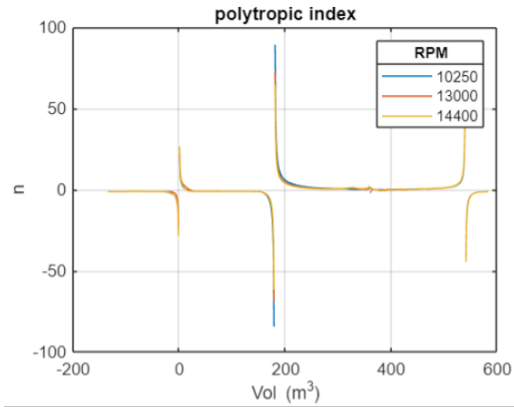
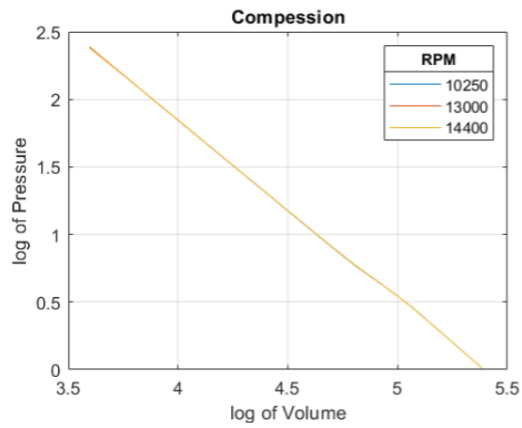
nExpMax = 1×3
-1.2310 -1.1995 -1.2275

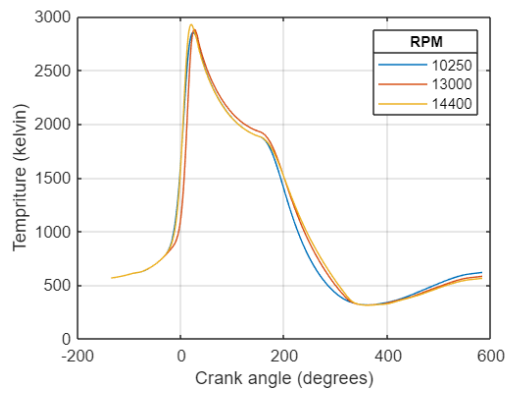
nExpMin = 1×3
-1.3238 -1.3058 -1.3176

nExpMean = 1×3
-1.2704 -1.2505 -1.2678

3.4. MTBE 25 Simulation







```

nCompMax = 1x3
    -1.1551    -1.1572    -1.1625

nCompMin = 1x3
    -1.4337    -1.4298    -1.4297

nCompMean = 1x3
    -1.3409    -1.3386    -1.3411

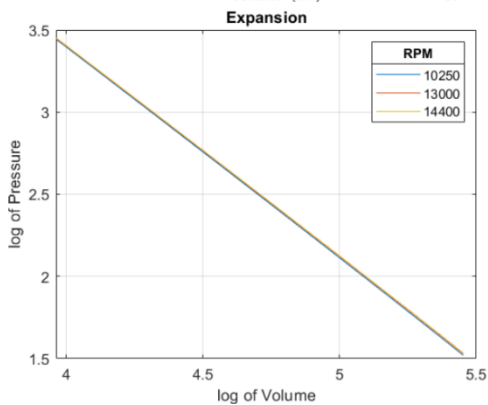
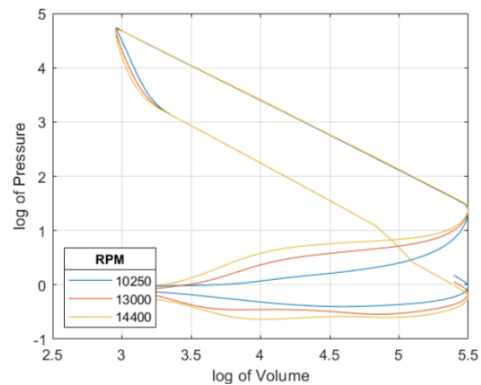
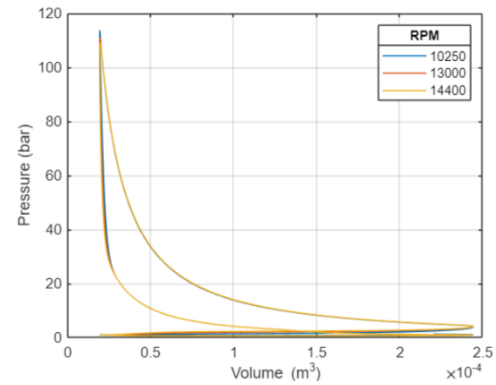
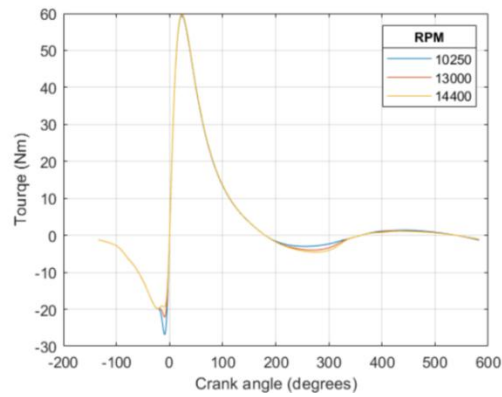
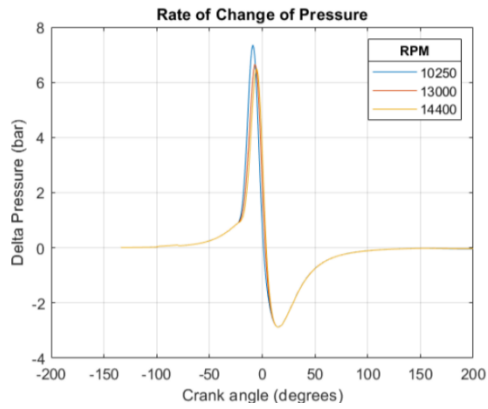
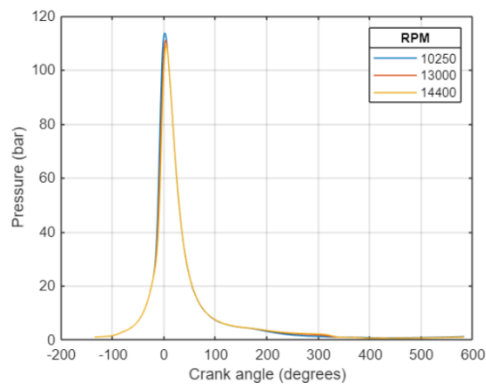
nExpMax = 1x3
    -1.2216    -1.2139    -1.2179

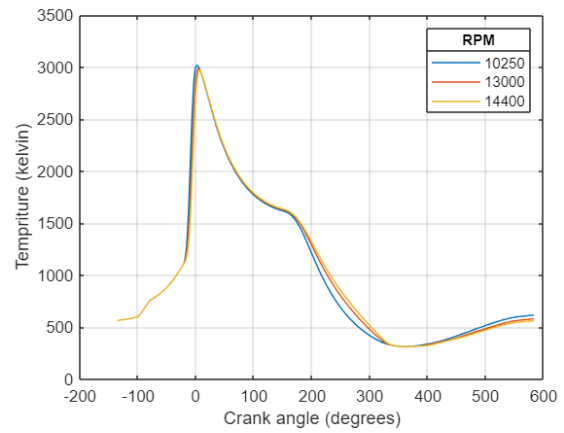
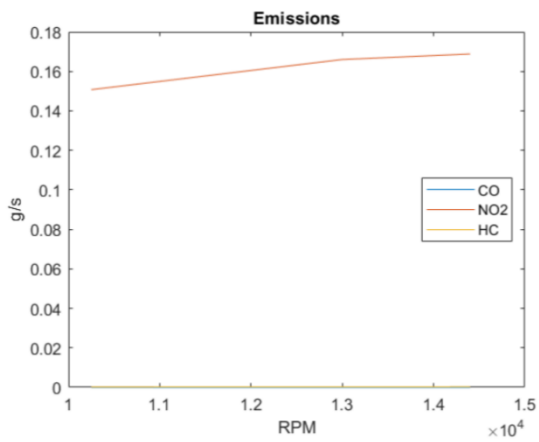
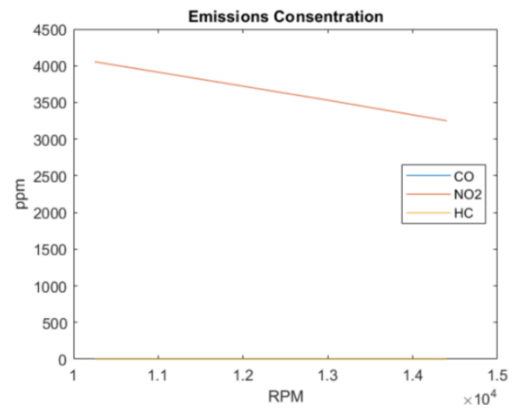
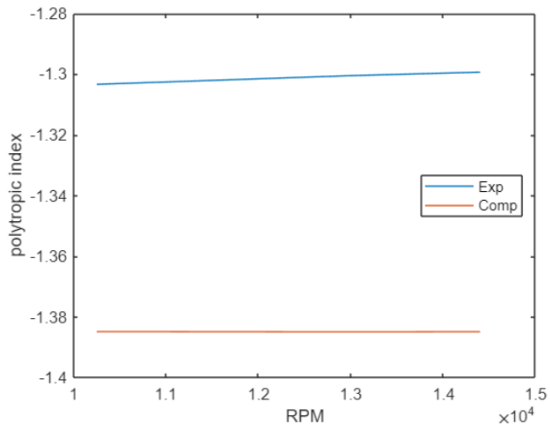
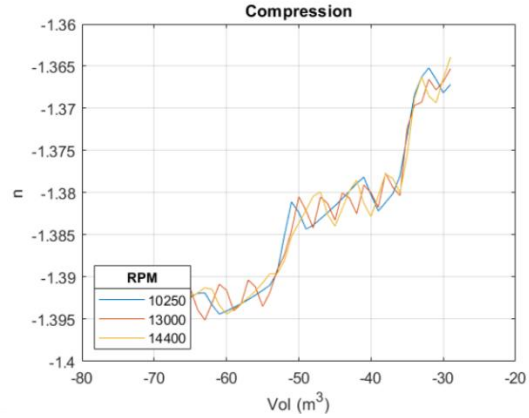
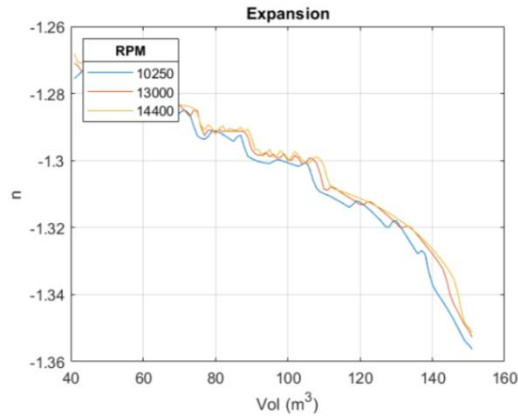
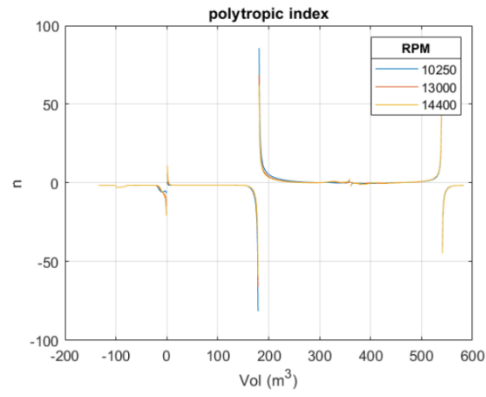
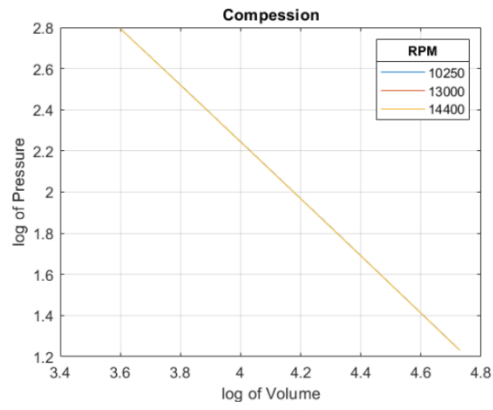
nExpMin = 1x3
    -1.3220    -1.3193    -1.3158

nExpMean = 1x3
    -1.2637    -1.2572    -1.2607

```

3.5. Hydrogen Simulation





```

nCompMax = 1×3
    -1.3652    -1.3653    -1.3639

nCompMin = 1×3
    -1.3949    -1.3969    -1.3958

nCompMean = 1×3
    -1.3849    -1.3850    -1.3849

nExpMax = 1×3
    -1.2720    -1.2684    -1.2683

nExpMin = 1×3
    -1.3563    -1.3527    -1.3513

nExpMean = 1×3
    -1.3034    -1.3005    -1.2994

```

