Dual Operating Parameter Relationship with Engine Performance

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Abstract. In order to reduce emissions and maximize performance of internal combustion engines, it is important to understand the relationship between operating parameters and performance. Estimation of engine performance under simultaneous variation of operating parameters is not well addressed in literature. In the present work an attempt has been made to develop a relationship between engine performance (brake thermal efficiency) and operating parameters such as load and compression ratio. Experiments were conducted varying load and compression ratio and Brake Thermal Efficiency obtained was recorded. The results of the model were validated with the experimental results.

1. Introduction
The variation of performance, emission and combustion parameters is dependent upon the operating conditions of the engine. In a theoretical approach, it is generally taken from granted that the compression ratio is kept constant. However, in an actual engine, other processes which influence engine performance and efficiency vary with changes in compression ratio namely combustion rate and stability, heat transfer and friction. Empirical formulae derived earlier are in terms of a single operating parameter whereas a combined effect is produced in the output due to the simultaneous operation of the engine parameters like load, compression ratio etc. Although extensive research has been carried out to study the effects of such variation, not much work appears to have been done in the area of developing such generalized models. Especially so is the case with alternate fuels. An initiative towards this is made by creating a generalized formula for a performance parameter in terms of both load and compression ratio along with the validation of results.

2. Literature Survey
Ansari et al. [1] performed a study on the performance and emission characteristics of diesel and soybean blends and calculated the NOx formation based on temperature and concluded that higher NOx emissions are due to higher fuel consumption due to higher densities. Qi et al. [2] concluded that at higher engine loads, the peak cylinder pressure of biodiesel was almost similar to that of diesel, but the peak rate of pressure rise and the peak of heat release rate were lower for biodiesel. Sundarapandian [3] carried out experimental investigations and presented that the thermal efficiency of Jatropha was 26.48% and there was 44% of smoke reduction. NOx remained same as diesel fuel. It was concluded that Jatropha is the best alternative fuel than Mahua and Neem oils.

Moser et al. [4] concluded that the test engine consumed a greater amount of fuel operating on the SME and PHSME blends than on neat ULSD, but the increase was smaller for the PHSME blend. Shahabuddin et al. [5] reported that the heat release rate of biodiesel is slightly lower than diesel...
owing to the lower calorific value, lower volatility, shorter ID and higher viscosity. Liu et al.'s [6] paper presented emissions modelling and testing of a four-stroke single cylinder diesel engine using biodiesel fuels. A system level engine simulation tool developed by Gamma Technologies, GT-Power, was used to perform predictive engine combustion simulations using direct-injection jet modelling technique. Rampure et al. [7] found out the effect of NOx emission and brake thermal efficiency upon varying the engine loads. Performance and emission analysis by Selvan and Maniysundar [8] indicates the reduction of NOx and brake thermal efficiency decreased with the application of EGR and Jatropha blends bio-diesel.

Balajee et al. [9] found out that the blends of biodiesel like jatropha and pongamia with diesel could substitute in the place of pure diesel and be used as an alternate source of fuel in the near future, thus saving the natural resources for the future generation. Chotai[10] conducted a review on the effect of varying compression ratio on performance and emissions of diesel engine fuelled with biodiesel. The paper deals with effects on engine fuelled with diesel, blend of diesel with biodiesel and purely on biodiesel with a view to provide a platform for comparison of the parameter on various fuels.

Although extensive research has been carried out to study the individual effects of variation of load or compression ratio or speed on engine efficiency, not much work appears to have been done in the area of developing generalized models where a combined effect on the engine performance. Hence the present selection focuses on developing a relationship between brake thermal efficiency and dual operating parameters: load and compression ratio.

3. Results and Discussion
Experiments were carried out with soyabean methyl ester (SME) under compression ratios 15 to 18 and load varying from 0 to 12kg on a variable combustion engine. The engine emissions were measured during running. As the engine is computerised, the operating parameters were automatically saved in the system enabling computation and evaluation of performance characteristics as well as combustion characteristics. The combined effect of variation of load and compression ratio on some of the performance parameters (namely specific fuel consumption and volumetric efficiency) and some emission parameters (namely Carbon Monoxide and smoke number) are plotted in figures 1 to 4 respectively.

Figure 1 Variation of Specific Fuel Consumption with Compression Ratio and Load

Figure 2 Variation of Volumetric Efficiency with Compression Ratio and Load

Figure 3 Variation of Carbon Monoxide Emissions with Compression Ratio and Load

Figure 4 Variation of Smoke Number with Compression Ratio and Load

The following figures 5 and 6 depict the variation of four performance parameters (brake mean effective pressure, brake thermal efficiency, specific fuel consumption and volumetric efficiency) for SME and diesel respectively. These are plotted together in order to get a quick overview of the comparative performance of the two fuels.
3.1 Model Validation

Experiments were conducted for varying loads (25%, 50%, 75% and 100%) and compression ratios (15, 16, 17 and 18). The variation of BTE with load for all the compression ratios is first plotted and then the relationship modelled in this section.

3.1.1 Comparison of BTE at different compression ratios. The variation of BTE of the engine with load for different compression ratios is plotted in figure 7.

![Figure 7 Variation of BTE with Load for Different Compression Ratios](image)

It can be seen from the above graph that the variation in BTE is more or less the same for all the four compression ratios. In order to arrive at a generalized model, mathematical models were fitted for each of the four individual compression ratio variations. The equations of the best fit curve for each of the compression ratios are given below:

\[
\text{CR} = 15 \quad \text{BTE} = -0.0039x^2 + 0.649x - 0.6234 \\
\text{CR} = 16 \quad \text{BTE} = -0.0025x^2 + 0.519x + 1.04 \\
\text{CR} = 17 \quad \text{BTE} = -0.0037x^2 + 0.6364x + 0.0617 \\
\text{CR} = 18 \quad \text{BTE} = -0.0034x^2 + 0.5978 + 0.5071
\]

The above relationships capture only the variation of BTE with load for each compression ratio. The effect of compression ratio needs to be included into this equation as one of the parameters so as to be able to compute the BTE for simultaneously varying load and compression ratio values.

3.1.2 Generalised equation for BTE. In order to arrive at a generalized equation for the above set of simultaneous equations, the technique of interpolation is adopted. The algorithm was coded in Matlab.
using the coefficients obtained from the above equations (Appendix II). The final equation obtained is of the form:

\[ \text{BrTE} = A_z \cdot \text{Load}^2 + B_z \cdot \text{Load} + C_z \]

where BrTE is the Brake Thermal Efficiency and \( A_z, B_z \) and \( C_z \) are derived coefficients that are functions of compression ratio (CR) and given as:

\[ A_z = A(1,1) + (\text{CR}-15) \cdot A_0(1,1) + \frac{(\text{CR}-15) \cdot (\text{CR}-16)}{\text{factorial}(2)} \cdot A_1(1,1) + \frac{(\text{CR}-15) \cdot (\text{CR}-16) \cdot (\text{CR}-17)}{\text{factorial}(3)} \cdot A_2; \]

\[ B_z = B(1,1) + (\text{CR}-15) \cdot B_0(1,1) + \frac{(\text{CR}-15) \cdot (\text{CR}-16)}{\text{factorial}(2)} \cdot B_1(1,1) + \frac{(\text{CR}-15) \cdot (\text{CR}-16) \cdot (\text{CR}-17)}{\text{factorial}(3)} \cdot B_2; \]

\[ C_z = C(1,1) + (\text{CR}-15) \cdot C_0(1,1) + \frac{(\text{CR}-15) \cdot (\text{CR}-16)}{\text{factorial}(2)} \cdot C_1(1,1) + \frac{(\text{CR}-15) \cdot (\text{CR}-16) \cdot (\text{CR}-17)}{\text{factorial}(3)} \cdot C_2; \]

where \( A, B, C, A_1, B_1, C_1 \) and \( A_2, B_2, C_2 \) are forward difference values obtained from the original coefficients.

3.2 BTE model validation

Using the above equation, the BTE was computed for all the experimental conditions tested and compared with the actual experimental values.

It can be seen from figures 8 and 9 that for compression ratio 17, the error in prediction using the Newton Forward Difference Interpolation model is less than 5% for all load conditions. It is also seen that the prediction error is least (6.61%) at full load. Thus performance at compression ratio 17 and full load is best predictable using this model.

4. Conclusion

An attempt was made to model the combined effect of the engine operating parameters on the performance characteristics. This is very much important to be able to accurately predict the performance of the engine at given conditions. Based on the experimental results obtained for soyaeban methyl ester, a generalised polynomial model was developed for brake thermal efficiency (BTE) using the Newton Forward Difference Interpolation approach. This model was able to fairly accurately predict the BTE given the load and compression ratio especially for compression ratio of 17 and full load condition. This model gives an empirical relationship for estimating BTE of SME under varying operating conditions.

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