

# A Temperature-dependent Model of Ratio of Specific Heats applying in Diesel Engine

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## Abstract

Rate of heat release is a standard tool when engineers tune and develop new engines. The ratio of specific heats  $\gamma$  is considered an essential parameter for an accurate rate of heat release calculation as it couples the engine system energy and other thermodynamic properties. The  $\gamma$  model is a function of various factors, such as temperature, air-fuel-ratio, pressure, etc. To improve the accuracy of ROHR calculation in the Scania diesel engine in NTNU machinery laboratory since constant-value  $\gamma$  model is applied there, three existing temperature-dependent  $\gamma$  model are investigated in this work. Some other more complex model considering other factors are not discussed here as real-time computation is required. An engine experiment comprising of constant speed and propeller curve test cycle is carried out for supplying the raw data.

A reference model based on the theory of Zacharias's formulas is established to evaluate the accuracy of three candidate models. The models are evaluated in both  $\gamma$  domain and ROHR computed by corresponding candidate model. Three evaluating criteria including MRE, RMSE and NRMSE are carried out to analysis the error of models. A retrofit  $\gamma$  model is proposed by applying  $\gamma$  offset value to further improve accuracy in the end.

## Introduction

The more stringent exhaust emission regulations and stronger competition between engine manufactures has driven development of engine technology forward. More complex engine system and advanced engine technologies rely on more accurate in-cylinder data during tuning and optimizing. An Accurate Rate of heat release curve requires a accurate model of ratio of specific heats. The ratio of specific heat is the ratio of heat capacity at constant pressure ( $C_p$ ) to heat capacity at constant volume ( $C_v$ ).

The ratio of specific heat couples the system energy to other thermodynamic quantities. In many cases, the working medium is considered as ideal gas, therefore the ratio of specific heat ( $\gamma$ ) is set to constant value for the convenience of calculation. However, this is not accurate as specific heat influenced by factors like temperature, air fuel ratio and so on. Consequently, a more accurate model of specific heat ratio is desired for calculating accurate ROHR curves. Among mentioned factors, in-cylinder temperature is considered as dominant one. In this work, three temperature-dependent models are evaluated and retrofitted to applying in computing ROHR of Scania diesel engine in NTNU machinery laboratory.

## Main Objectives

NTNU machinery laboratory offers real-time ROHR computation While working medium are considered as ideal gas for the convenience of calculation. Correspondingly, the ratio of specific heat is set to constant value, which leads to inaccurate absolute value of rate of heat release. To improve the computing accuracy, the investigation on existing  $\gamma$  models is carried out. A reference model shall built up for evaluating the candidate models. The candidate model which fit better with results from reference model is going to be implemented in ROHR computation module in lab.

## Materials and Methods

For offering the real-time ROHR computation service, close-system method is applied: ROHR computing equation:

$$\frac{dQ_n}{d\phi} = \frac{\gamma}{\gamma-1} p \frac{dV}{d\phi} + \frac{1}{\gamma-1} V \frac{dp}{d\phi}$$

As temperature is considered as dominating factor that affect ratio of specific heats, three existing temperature-dependent  $\gamma$  models are chosen as candidate models:

- a simple linear model given by [3]:

$$\gamma_{lin}(T) = 1.375 - 6.99 * 10^{-5} * T \quad (1)$$

- a higher order polynomial model proposed by [1]:

$$\gamma = 1.338 - 6.0 * 10^{-5} * T + 1.0 * 10^{-8} * T^2 \quad (2)$$

- an exponential model presented by [2]:

$$\gamma = 1.38 - 0.2 * \exp(-900/T) \quad (3)$$

A reference model is required for evaluating the performance of the candidate models, by applying Zacharias's formulas and ordinary differential equations, the reference model is built up. The building process is shown in figure [1]

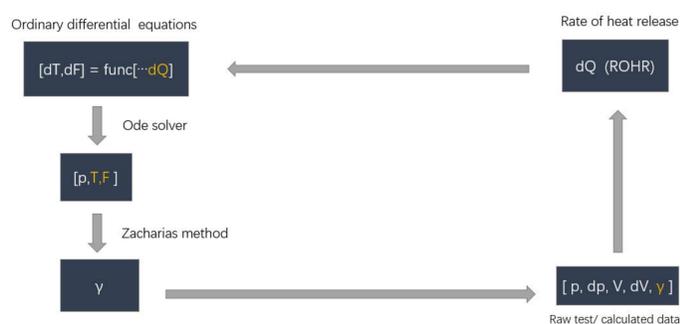
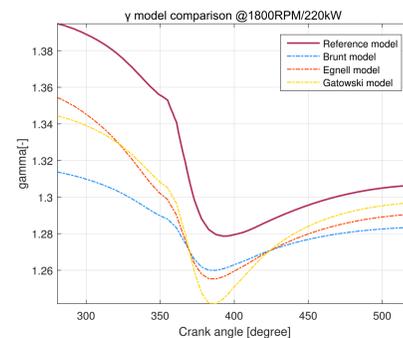


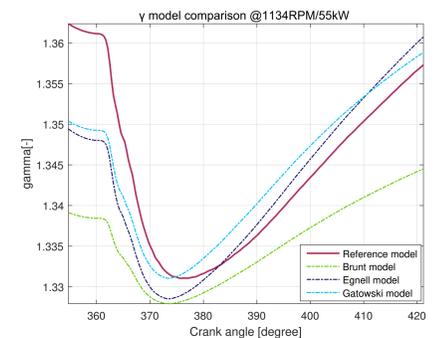
Figure 1: Reference model iterating process

## Results demonstration

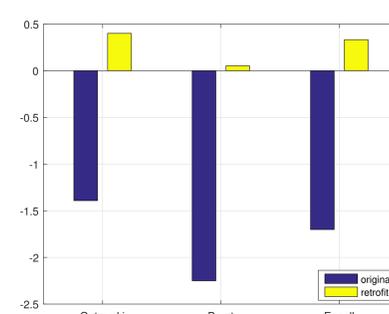
Comparison of  $\gamma$  models @220kW/1800RPM



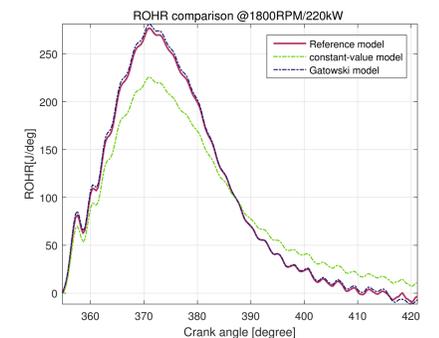
Comparison between ROHR computing @55kW/1134RPM



Mean value of NRMSE among all test points



Comparison of ROHR @220kW/1800RPM



The first figure demonstrates the comparison of candidates  $\gamma$  models and reference model. To compensate the absolute value error, the mean error between candidate models and reference model are taken as offset value applying to the candidate models, the comparison is shown in second figure. The normalized root mean square error of candidate models are improved significantly shown in third figure. The last figure shows the ROHR computed by retrofit model is much closer to the reference model than the original curves.

## Conclusions

In  $\gamma$ -domain, the Gatowski's model achieves the closest results with reference model in both maximum relative error and normalized root mean square error among most of test points. The Egnell's model perform nearly same good as Gatowski's model while Brunt's model seems to have a much significant error. In ROHR domain, the ROHR applying Gatowski's model gains the least RMSE level at 5.48[J/deg], the Brunt's model and Egnell's model give 31.5% and 10.1% higher RMSE respectively.

It is observed that the candidate  $\gamma$  models having a high level of similarity with reference model in trace, while there is error in absolute value. To maximally eliminate the effect of this absolute error, a set of  $\gamma$  value offset are applying in the candidate models. The mean error between candidates model and reference model among all 7 test points are used as the offset value. The candidate model with applying  $\gamma$ -offset is called retrofit model. In  $\gamma$  domain, the retrofit Gatowski's model yields better results in both RME and NMRSE criteria. By comparing the ROHR results calculated by retrofit gatowski's model and original constant-value  $\gamma$  model, the accuracy is improved by average 60% in all the test points.

## Forthcoming Research

Other factors like air-fuel ratio, pressure, etc. also have impact on ratio of specific heats. Some higher order polynomial  $\gamma$  model which considers the effect of those factors can be also worked out. More effort could emphasize in the influence of those factors individually.

## References

- [1] Michael FJ Brunt, Harjit Rai, and Andrew L Emtage. The calculation of heat release energy from engine cylinder pressure data. Technical report, SAE Technical Paper, 1998.
- [2] Rolf Egnell. Combustion diagnostics by means of multizone heat release analysis and no calculation. Technical report, SAE Technical Paper, 1998.
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