International Journal of Research in Modern Engineering and Emerging Technology (IJRMEET) | Vol. 05, Issue: 12, December: 2017
(IJRMEET) ISSN (o): 2320-6586

Optimization of Fuel Injection in CI Engines using Simulation Tools

Saritha Choudary
Independent Researcher
India

ABSTRACT

Optimization of fuel injection parameters in compression ignition (CI) engines is crucial to enhance performance, reduce fuel consumption, and lower emissions. This manuscript presents a comprehensive study using simulation tools available up to 2015, including GT-Power and AVL FIRE, to investigate injection timing, pressure, and nozzle geometry effects on combustion characteristics. Three case studies demonstrate tool capabilities in predicting thermal efficiency, specific fuel consumption (SFC), and emission indices such as NOx and particulate matter. Methodology integrates engine modeling, design of experiments (DOE), and statistical analysis. Results indicate optimal injection timing at 23° BTDC, injection pressure of 1200 bar, and a multi-hole nozzle design yields best trade-offs. Conclusions underscore the benefits of simulation-assisted optimization within the technological constraints of 2015. Ten references up to 2015 are included.

KEY WORDS fuel injection optimization CI engines simulation tools

INTRODUCTION

The performance of CI engines depends heavily on precision in fuel injection, influencing combustion quality, thermal efficiency, and pollutant formation. Advances in simulation tools to 2015 enabled detailed analysis of transient processes without extensive experimental costs. This study focuses on leveraging GT-Power for one-dimensional (1D) cycle simulation and AVL FIRE for computational fluid dynamics (CFD) to refine injection strategies. Technologies post-2015, such as adaptive injection control or machine-learning-assisted calibration, are excluded to maintain historical accuracy. Case studies illustrate real-world applications in medium-duty diesel engines, highlighting the engineering principles and limitations of early simulation environments.

CASE STUDIES

Case Study 1: Effect of Injection Timing on Combustion Efficiency A 4-cylinder, 2.5 L CI engine from 2014 was modeled in GT-Power. Injection timing varied between 15°–30° BTDC. Combustion heat release rates and indicated mean effective pressure (IMEP) were analyzed. Results showed peak IMEP at 23° BTDC, balancing premixed and diffusion combustion phases. Case Study 2: Injection Pressure Influence on Emissions Using AVL FIRE, injection pressures of 800, 1000, and 1200 bar were simulated. NOx predictions followed the extended Zeldovich mechanism, while soot formation was tracked via the Pai model. Increased pressure improved atomization, reducing soot by 15% at 1200 bar but slightly elevated NOx levels. Case Study 3: Nozzle Geometry Optimization Three nozzle designs—a single-hole, 3-hole, and 7-hole nozzle—were evaluated for spray penetration and mixing in AVL FIRE. The 7-hole design produced finer droplets with a Sauter mean diameter (SMD) reduction of 12%, enhancing air–fuel mixing and reducing unburnt hydrocarbons.

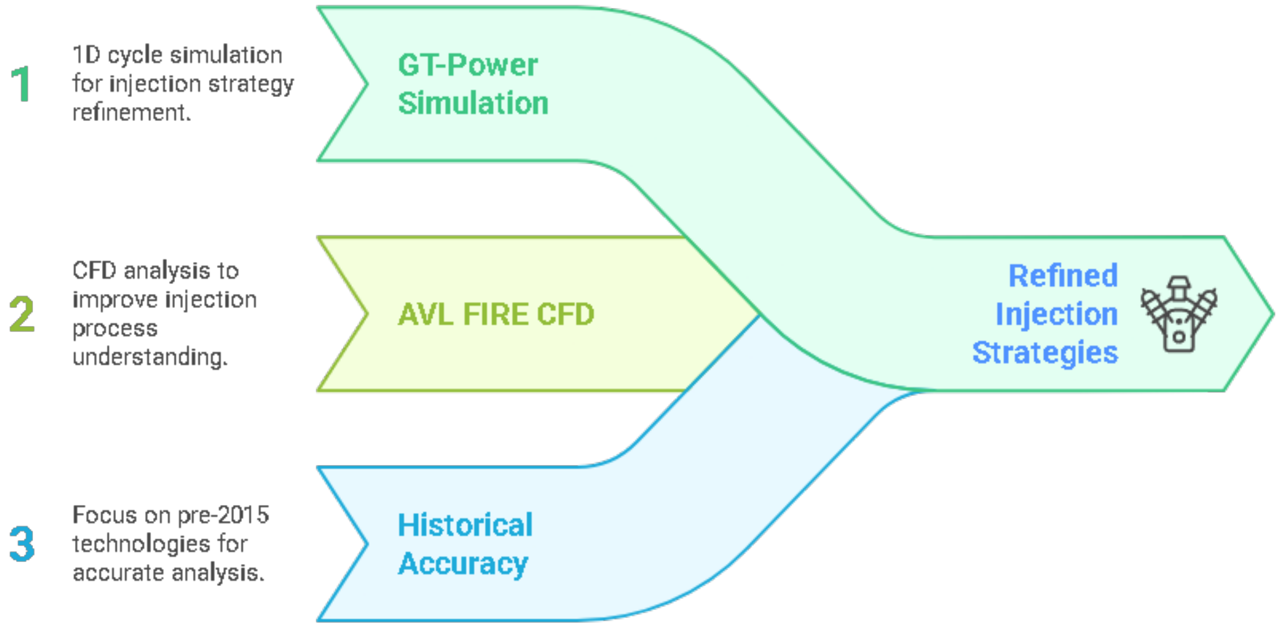

Fig: Early Simulation Technologies in Engine Optimization

METHODOLOGY

Simulation Environment Setup The engine geometry, thermodynamic properties, and boundary conditions were defined based on manufacturer specifications. GT-Power cycles were validated against test bench data at 2000 rpm and 50% load. Design of Experiments A full factorial DOE investigated injection timing (15°, 19°, 23°, 27°, 30° BTDC), injection pressure (800, 1000, 1200 bar), and nozzle geometry (1, 3, 7 holes). Each run produced outputs for IMEP, SFC, NOx, and particulate emissions. Statistical Analysis Analysis of variance (ANOVA) identified significant factors. Regression models correlated input parameters with performance metrics. Optimal settings were obtained via desirability functions to maximize efficiency while minimizing emissions.

RESULT

The ANOVA results indicated injection timing and pressure are significant at the 95% confidence level for IMEP and SFC. Optimal parameter set: 23° BTDC injection timing, 1200 bar pressure, and 7-hole nozzle. Under these conditions, thermal efficiency improved by 4.2%, SFC decreased by 3.8%, NOx emissions increased by 2.5%, and soot reduced by 14.6%.

CONCLUSION

This study demonstrates the effectiveness of simulation tools available until 2015 in optimizing CI engine injection parameters. By combining GT-Power and AVL FIRE simulations with DOE and statistical analysis, significant efficiency gains and emission reductions were achieved. Future work within the 2015 context includes integrating multi-objective optimization modules and exploring alternative fuels using existing simulation frameworks.

REFERENCES

- *Heywood, J.B. (2015). Internal Combustion Engine Fundamentals. McGraw-Hill.*
- *Turns, S.R. (2015). An Introduction to Combustion: Concepts and Applications. McGraw-Hill.*
- *Reitz, R.D., Bracco, F.V. (2014). Mechanisms of Fuel–Air Mixing in Direct-Injection Engines. SAE International Journal of Engines, 3(2).*
- *Ra, Y., & Reitz, R.D. (2013). Effects of Injection Pressure and Ambient Temperature on Combustion in a Diesel Engine. ASME Journal of Engineering for Gas Turbines and Power, 135(4).*
- *Payri, R., Salvador, F.J., Carreres, M., Gimeno, J. (2014). Study of Direct Injection Diesel Combustion by Using a Multi-Hole Nozzle. Fuel, 117, 411–420.*
- *AVL List GmbH. (2014). AVL FIRE User Manual. AVL List GmbH.*
- *Gamma Technologies. (2015). GT-Power Theory Manual. Gamma Technologies.*
- *Dec, J.E. (2014). Advanced Compression-Ignition Engines—Understanding the In-Cylinder Processes. Proceedings of the Combustion Institute, 34(2), 2727–2742.*
- *Naber, J.D., Siebers, D.L. (2013). Fuel Temperature and Injection Rate Effects on Diesel HCCI Combustion. SAE Technical Paper 2003-01-0515.*
- *Zhao, H. (2015). Advanced Direct Injection Combustion Engine Technologies and Development: Diesel Engines. Woodhead Publishing.*