A NUMERICAL MODEL TO PREDICT THE PERFORMANCE OF A CI ENGINE ENRICHED BY HYDROGEN FUEL AND FLOW VISUALISATION IN THE INTAKE MANIFOLD FOR HYDROGEN INJECTION USING CFD

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Abstract
The present investigation includes two stages. One is numerical modeling of diesel engine enriched by hydrogen fuel and later, using CFD analysis, the investigation carried on so as to predicting the position of hydrogen gas injector and injection angle for manifold injection of dual fuel diesel engine. In the first stage, thermodynamic analysis was done using double weibe heat release equation during the combustion period. A MATLAB code has been written for the thermodynamic model, which takes input as engine parameters, fuel data and gives the Pressure-Crank angle, Temperature-Crank angle and Rate of heat release-Crank angle plots. These plots were used to analyze the performance of engine. Further study has been done on effect of intake air temperature on ignition delay period, when the diesel engine enriched by hydrogen gas fuel.

Keywords: CFD analysis, manifold injection, Weibe heat release equation, performance, ignition delay period.

Introduction
The recent most concerning problems of dwindling resources of petroleum fuels and the ever growing menace of air pollution because of vehicular emissions revitalized the interest in hydrogen as engine fuel. Hydrogen’s renewable nature and clean burning traits make it the best suitable future fuel. Hydrogen was widely and extensively tried as engine fuel all over the world by a number of experimentalists and researchers.

The initiative for using hydrogen fuel in CI engine came much recently. Despite the facts that hydrogen, as energy carrier possess attractive energy and ecological characteristics, whereas the reserves of raw materials for hydrogen production are practically unlimited and relatively high cost of hydrogen and complexity of its storage systems hamper its uses as a motor fuel.

The properties of hydrogen that contribute to its use as a combustible fuel are:
- Wide range of flammability
- Low ignition energy
- Small quenching distance
- High autoignition temperature
- High flame speed at stoichiometric ratios
- High diffusivity
- Very low density

Hydrogen can be used in various systems such as in neat mode in a spark ignition (SI) engine system, in dual-fuel mode in SI and compression ignition (CI) engine systems, in fuel cells In, hybrid electric vehicle systems.

Literature Survey
The work has been carried out by researchers on the thermodynamic modelling of compression ignition engine fuelled with hydrogen were discussed here.

Abdel Aal H K. [1] and Ali Sanli et al. [2] approached a new theoretical model which the hydrogen is mixed with predetermined amounts of methane gas called as “hydrothane”. The most important properties studied were flame speed, lower explosion limit (LEL) and upper explosion limit (UEL) and functions were developed for the ratio of the hydrogen–methylene.

Karim G A [3] given a brief about the various gaseous fuels in conventional compression ignition engines of the dual fuel type. This paper includes, how to convert diesel engine to dual-fuel engine, what are the factors affecting, cost effective and performance of combustion characteristics and emission levels.
Rajendra Prasath B [4], Chow A et al[5] developed a mathematical model for analyzing the combustion and performance characteristics of the compression ignition engine and LHR engine. The predicted results are compared with the experimental results of the engine fueled by diesel and B20 in STD and LHR engine.

Sebastian Verhelst et al. [6] discussed fundamentals of the combustion of hydrogen, details on the different mixture formation strategies and their emissions characteristics, measures to convert existing vehicles, dedicated hydrogen engine features, a state of the art on increasing power output and efficiency while controlling emissions and modeling.

Andras Horvath et al. [7], Ali Hocine et al. [8] studied simulated the air flow characteristics of the intake port of a Diesel engine by numerical simulation, which is based on a self-developed code and numerical results were compared to experimental results and found both were valid. Swirling ratio also one of parameter that effected by the intake port flow.

Ervin Adorean [9], effort was to give support to experimental research by providing some insight into the complex phenomena that occur in the cylinder and the combustion chamber of diesel engines, using Computational Fluid Dynamics (CFD) modeling. The first task was to calculate the air flow through the inlet ports and cylinder of a diesel engine and the second one was to calculate combustion in a diesel engine. A steady flow test rig setup for diesel engine ports development has been successfully simulated with Open FOAM. The flow through the inlet ports was simulated at different valve lifts. The CFD calculated values of flow coefficients and swirl ratios agree fairly well with the experimental result.

Objectives of the present work:
On the basis of the survey the thermodynamic model was developed to determine the combustion parameters of the compression ignition engine enriched by hydrogen fuel and CFD analysis carried out by considering intake manifold injection system for predicting the optimum location of the fuel injector. The main objectives of the present work are

• To study the Combustion parameters in compression ignition engine enriched by hydrogen fuel using thermodynamic analysis.
• Developing the software program for Compression Ignition engine in MATLAB environment.
• To study the effect of intake air temperature on ignition delay period, when the CI engine enriched by hydrogen fuel.
• Prediction of optimum position and angle of hydrogen gas injector mounting in a manifold using CFD

CI engine simulation:
Engine simulation refers to the simulation of different processes involved in engine operation and these processes occur cyclically shown in Figure 1

Computational procedure:
The simulation of compression ignition engine enriched by hydrogen fuel was developed using MATLAB version 7.0 software and the various equations of the thermodynamic model were solved numerically. The fuel parameters such as mass of air, mass of hydrogen, heating value, molecular weight of the fuel, and the various constants used in the model are defined in the Data Subroutine. Bore, stroke length, connecting rod length, Compression ratio, relative equivalence ratio, engine speed, inlet conditions, and atmospheric conditions are given as input.

Results and discussions:
The comparison of theoretical results of hydrogen enriched diesel fuel with pure diesel and results obtained from CFD analysis on intake manifold injection are discussed.

Thermodynamic analysis of CI engine enriched by hydrogen fuel:
When a small amount of hydrogen is added to the intake air, the combustion process of the internal combustion engines could be considerably enhanced. The thermodynamic analysis performed under the following two conditions.

(i) Case I: engine runs on diesel only.
(ii) Case II: engine runs on diesel as primary fuel and hydrogen as secondary fuel.

Table 1: Mass of fuels

<table>
<thead>
<tr>
<th>Case no.</th>
<th>Mass of diesel (kg/min)</th>
<th>Mass of hydrogen (kg/min)</th>
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Comparison of Theoretical Results of Case I and Case II:

Cylinder Pressure and temperature:

with the addition of hydrogen fuel to the diesel, the pressure rises suddenly with in small crank angle duration compared to the pure diesel. The peak pressure of hydrogen operated engine is found to be 91.7 bar, compared with 87.1 bar for the diesel operated engine at 1500 rpm.

Results obtained from CFD analysis:

Velocity contours of 4, 6, 8, 10 mm of valve lift for 30° injector angle placed at 70 mm from cylinder axis:
The concentration of hydrogen was found to be unevenly distributed in the combustion chamber at 4 and 6 mm valve lift compared to the 8 and 10 mm valve lift positions. The results obtained from the CFD analysis of 4, 6, 8, 10 mm of valve lift for 30° injector angle placed at 70 mm from the cylinder axis were shown in Figure 2.

Temperature rise with addition of hydrogen fuel. With the addition of hydrogen fuel to diesel the rise in temperature observed. Because of hydrogen has high calorific value when compared to diesel fuel and high flammability limits. The combustion duration reduction is due to reduced mixing controlled combustion phase invoking higher net heat release rate. The reduction of mixing controlled combustion phase is due to the flame propagation of homogenous hydrogen-air mixture through the combustion chamber. The flame propagation improves the diffusion process between the hot air and diesel vapours causing its faster completing. The diffusion process improvement causes higher heat utilization and higher net heat release respectively.
angle, 45° injector angle gives better swirling action inside the combustion chamber.

![Fig3](image)

**Fig3:** Contours of velocity magnitudes at 45° injector angle, 70mm from cylinder axis at (a) 4, (b) 6, (c) 8 and (d) 10 mm valve lift

**Velocity contours of 4, 6, 8, 10 mm of valve lift for 60° injector angle placed at 70 mm from cylinder axis:**

Compared to 30° and 45° injector angles, 60° gives better swirling action inside the combustion chamber.

By comparing the above three cases, 60° angle found to be best for injecting hydrogen.

![Fig4](image)

**Fig4:** Contours of velocity magnitudes at 60° injector angle, 70mm from cylinder axis at (a) 4, (b) 6, (c) 8 and (d) 10 mm valve lift

**CONCLUSIONS:**

On the basis of observations and the theoretical analysis obtained during the modeling of the CI engine enriched by hydrogen fuel on a single cylinder compression ignition engine, the following conclusions are drawn from the present study

- The peak cylinder pressure of hydrogen enriched CI engine and diesel operated engine are found to be 91.7 bar and 87.1 bar at 1500 rpm respectively.
- The cylinder temperature of hydrogen enriched CI engine is found to be 1997 K and for diesel operated engine, it was found to be 1898 K at 1500 rpm.
- The rate of heat release of hydrogen enriched CI engine is found to be 88.2 J/deg, compared with 86.9 J/deg for the diesel engine at 1500 rpm. The maximum heat release occurs at nearer to the TDC for hydrogen operation, which makes the cycle efficiency, improves.
- For enriched diesel engine, 0.76 ms ignition delay was found for intake temperature of 30°C. While in case of intake temperature of 40°C, ignition delay was found to be 0.7 ms. With shorter ignition delay, premixed combustion stage decreases due to which efficiency engine will increase.

**Scope for future work:**

- This thermodynamic model can be extended to calculate NOx emissions.
- Experiments can be conducted on real time model for varying injector position and angles.

**References**


