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On the modeling of convective heat transfer coefficient of hydrogen fueled diesel engine as affected by combustion parameters using a coupled numerical-artificial neural network approach

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ABSTRACT

It has long been recognized that injector and combustion parameters are vital to the performance of hydrogen fueled diesel engine as well as thermal properties. However, until today, it has not been possible to assess the convective heat transfer coefficient of hydrogen fueled diesel engine for head, liner and piston walls as affected by equivalence ratio, liquid mass evaporated and temperature. This study has made a significant step in advancing the field through modeling the phenomena using the computational fluid dynamics code coupled with the predicting ability of artificial neural network approach. The results indicated that the heat transfer coefficient values of the walls are tangibly greater at 3500 rpm than those of 2500 rpm. The impact of the aforementioned parameters on heat transfer coefficient at diversified ranges was covered. The result of different modeling implementations using various training algorithms at diversified neurons revealed that a multilayer perceptron neural network with back propagation learning algorithm using 3-17-3 structure denotes the best model with root mean square error equal to 9.13. Coefficient of determination (R^2) for the three parts of liner, piston and head were obtained as 0.9870, 0.9975, and 0.9942, respectively in the training step.

Introduction

The continually increasing demand for energy supplies in addition to the termination of crude oil resources have sparked the context of alternative fuels as a dynamic studying filed of interest. The environmental problems occurred due to the adoption of petroleum products with diversified range of emissions are of drawbacks that encourage the researchers to center on cleaner fuels with equal or greater efficiency [1].

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Nomenclature

ANN	artificial neural network
ATDC	after top death center
BTDC	before top death center
CA	crank angle
CFD	computational fluid dynamics
EBU	Eddy break-up
GSTAB	gradient stabilized
HCCI	homogeneous charge compression ignition
HTC	heat transfer coefficient
KH-RT	Kelvin-Helmholtz Rayleigh-Taylor
MINMOD	minimal model
MLP	multilayer perceptron
R^2	coefficient of determination
RMSE	root mean square error
SIMPLE	semi implicit method for pressure linked equations
TDC	top death center
traingdx	gradient descent momentum and adaptive learning rate
trainlm	Levenberg–Marquardt training algorithm
trainrp	resilient back propagation
trainscg	scaled conjugate gradient

Hydrogen fuel is regarded as a zero-emission fuel that powers the vehicles during the combustion process in internal engines. Hydrogen serves a distinctive characteristic of carbon free fuel being environment-friendly alternative fuel. Hydrogen fuels regained the spotlight when the world was struck by the hydrocarbon fuel crisis and attention was paid to the environmentally destructive effects of hydrocarbon fuels [2]. Apart from its clean-burning and high energy efficiency characteristics, a significantly higher burning velocity associated with hydrogen fuel brings about little thermal efficiency in comparison with the other gaseous fuels owing to an increment in heat loss as a result of knock-like explosive combustion [3–5]. This is a major drawback of hydrogen being utilized as a fuel that requires further assessment to be solved during experimental, numerical and theoretical explorations. The literature is abundant with the investigations on the performance of hydrogen fuel engines indicating the promising performance in spark ignition engines [6–8]. A number of design and operational changes needed to affect the full potential of hydrogen as an engine fuel was investigated regarding SI engines [9]. Additionally, a numerical modeling of direct hydrogen injection and in-cylinder mixture formation [10], performance and combustion characteristics of a direct injection SI hydrogen engine were performed [11].

However, there are a few studies dedicated to the heat transfer phenomenon that need to be addressed [12–15]. The effect of injection timing under various equivalence ratios on energy and exergy terms based on the first and second laws of thermodynamics termsin a direct injection SI hydrogen fueled engine was investigated numerically using a Computational Fluid Dynamics (CFD) method [16]. Their results indicated that there is a good agreement with the experimental data while the exergy terms such as exergy transfer with work, exergy transfer with heat, exergy transfer with exhaust gas and fuel chemical exergy were computed based on principles of the second law. In another numerical study, the effect of the initial charge temperature on the second law terms under the various injection timings in a direct injection spark ignition hydrogen fueled engine was performed during compression, combustion and expansion processes of the engine cycle while the first law analysis was developed using the results of a three dimensional CFD code [17]. Their results showed that the indicated work availability is more affected by varying hydrogen injection timing in comparison with other second law terms. As well, there are other studies which address the application of hydrogen in direct injection compression ignition engines [18–20]. An experimental setup for the testing of a diesel engine in the direct injection hydrogen-fueled mode was developed [18]. Their experimental results showed that the use of hydrogen direct injection in a diesel engine gave a higher power to weight ratio when compared to conventional diesel-fueled operation, with the peak power being approximately 14% higher [18]. In Ref. [20], a turbulent transient 3D predictive computational model which was developed and applied to the HCCI engine combustion system, to assess the influence of changes in the swirl velocity of the intake mixture on the combustion processes within a homogeneous charge compression ignition (HCCI) engine fueled with hydrogen.

As far as our literature review is concerned, there is no study dedicated to the analysis of the convective heat transfer coefficient of hydrogen fueled diesel engine as affected by combustion parameters using a numerical based CFD (computational fluid dynamics) approach to derive the required data on the convective heat transfer coefficient of hydrogen fuel during combustion process. A code was written for the prediction of the convective heat transfer coefficients from the three walls of combustion chamber using the potential of artificial neural network.

Numerical CFD implementation

Fig. 1 demonstrates a schematic illustration of three external walls of the combustion chamber. A 3-D modeling representation of the combustion chamber is illustrated at TDC and

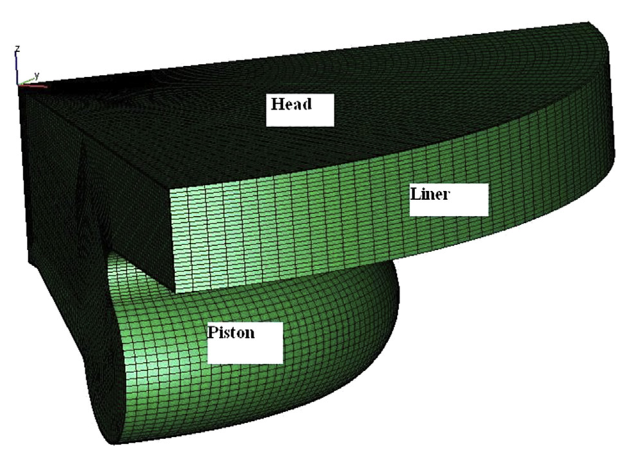

Fig. 1 – A schematic illustration of three external walls of the combustion chamber.