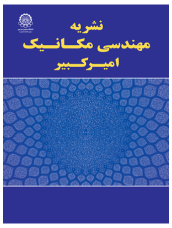

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Investigation on Effects of Water Addition on Performance and Emissions of an n-heptane Fueled Homogeneous Charge Compression Ignition Engine

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ABSTRACT: The main purpose of current study is investigation on the effect of water addition on n-heptane homogenous charge compression ignition combustion. A multi zone model coupled to the semi-detailed chemical kinetics mechanism is used for simulation of n-heptane homogenous charge compression ignition combustion. First, the accuracy of the model was estimated for two different operating modes, and then seven different amounts of water were added to the fuel and its effects on n-heptane combustion were investigated. Thermal, chemical and dilution effects of water are studied using artificial inert species method. The results show that the start of combustion was retarded by water addition due to the thermal effect of water. Peak values of in-cylinder pressure and heat release rate decreases by water addition. Water addition has caused the maximum amount of radicals in the combustion chamber to be reduced and the time of their formation is delayed. Water addition increases the amount of unburned hydrocarbons at exhaust. Thermal effect of water on start of combustion and emissions formation is more significant than its dilution and chemical effects. Using small quantities of water will increase the thermal efficiency of the engine and reduce emissions from it.

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1. Introduction

The Homogeneous Charge Compression Ignition (HCCI) engines have low exhaust NOx and fuel consumption and significant power. Of course, these engines also have disadvantages that have prevented their commercialization for dynamic applications. The main disadvantages of these engines is the lack of a means for direct control of them [1-3]. One of the ways to control combustion in HCCI engines is to use additives. Additives are combinations that combine fuel and air inside the combustion chamber, and control the combustion with a change in mass percentages [4,5]. There are several other add-ons that have been frequently studied in literature [6-8]. Water vapor is one of the additives that can be used by internal combustion engines. With the idea of HCCI engines, the idea of adding water to combustion components in these engines has also been considered.

2-Methodology

In this study, a multi-zone model is used to simulate the engine closed cycle. The combustion chamber is divided into four general types: the core zone, the middle zones, the boundary layer zone, and the crevice zone. The boundary layer zone is the nearest zone to the wall and is exchanging heat with the wall. The equations of the first law of thermodynamics and chemical kinetics are solved simultaneously for each zone at each time step. Eqs. (1) to (5) show the governing equations.

$$\frac{dU_i}{dt} = -\frac{dW_i}{dt} + \frac{dQ_i}{dt} \tag{1}$$

$$\frac{dU_i}{dt} = c_v^i m_i \frac{dT_i}{dt} + m_i \sum_{j=1}^{n_s} u_j \frac{dY_j}{dt} + \sum_{j=1}^{n_s} u_j Y_j \frac{dm_i}{dt} \tag{2}$$

$$\frac{dW_i}{dt} = P \frac{dV_i}{dt} \tag{3}$$

$$\frac{dQ_i}{dt} = \frac{dQ_{i,cond}}{dt} + \frac{dQ_{i,conv}}{dt} + \frac{dQ_{i,mtran}}{dt} \tag{4}$$

$$\frac{dY_{k,i}}{dt} = \frac{\dot{\omega}_{k,i} Mw_k}{\rho_i} \tag{5}$$

Further details of the model and are available in previously published studies [9,10]. The combustion process of n-heptane is simulated utilizing a chemical kinetics mechanism containing 57 species and 290 reactions [11]. Seven different amounts of water are added to the fuel and effects of water on n-heptane HCCI combustion are focused.

3-Discussion and Results

Two different operating modes have been selected and the effects of water addition on them have been investigated. Table 1 shows the characteristics of the two cases.

For validation of the model, experimental data of the Cooperative Fuel Research (CFR) engine available at the University of Alberta has been used. Experimental and

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Table 1. Engine operating conditions

Case number	*Rc*	*λ*	Exhaust gas recirculation (%)	Engine speed (rpm)
1	12.7	3.87	0	700
2	12.7	2.46	40	700

Table 2. Numerical (Num.) and Experimental (Exp.) values of engine exhaust emissions

Case number	Exp. CO_2	Num. CO_2	Exp. CO	Num. CO	Exp. UHC	Num. UHC
A	3.71	3.71	0.073	0.073	995	867
B	6.33	6.32	0.149	0.148	1705	1573

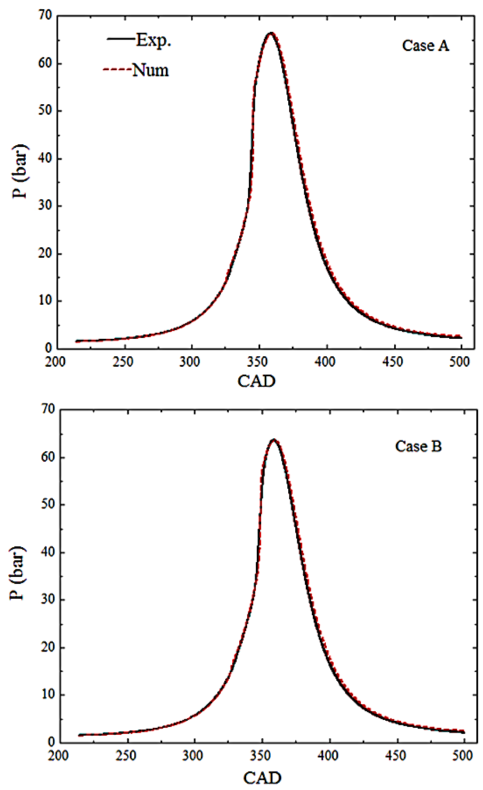

Fig. 1. Experimental and numerical curves for the in-cylinder pressure

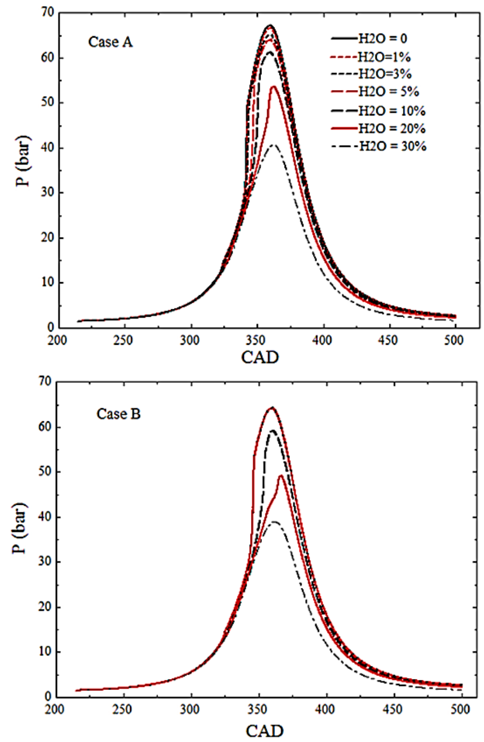

Fig. 2. Effect of water on in-cylinder pressure and temperature of core zone

numerical in-cylinder pressure curves are indicated in Fig. 1. Table 2 also shows the data on engine emissions for both of the cases. As the figure and table show, the model has a good accuracy in prediction of the in-cylinder pressure and exhaust emissions.

After verifying the model, seven different amounts of water are added to the in-cylinder mixture and its effects on n-heptane combustion are studied. Fig. 2 shows the effects of the water addition on the in-cylinder pressure. As shown in this figure, with the addition of water, the peak pressure decreases and its position is delayed. This is because water is a tri-atom molecule with a high specific heat capacity, so it absorbs the heat of the combustion chamber and reduces the in-cylinder temperature and causes delayed chemical reactions. With the delay in the initiation of reactions, the main stage of heat release is transferred to the expansion process, which prevents significant pressure increase and reduces the peak pressure.

4-Conclusion

In the present study, water has been added to the HCCI engine –n-cylinder mixture and its effects on the performance and pollutants of engine have been investigated. HCCI engine is simulated utilizing a thermodynamic multi zone model. A semi-detailed chemical kinetics mechanism is applied for combustion process modelling. Seven different values of water are added to in-cylinder mixture and its various effects are studied. The most important results are:

- Use of water delays the start of combustion.
- Water addition reduces in-cylinder pressure and temperature.
- Using small quantities of water will increase the thermal efficiency of the engine and reduce exhaust emissions.

References

[1] F. Agrell, H.-E. Ångström, B. Eriksson, J. Wikander, J. Linderyd, Control of HCCI During Engine Transients by Aid of Variable Valve Timings Through the Use of Model Based Non-Linear Compensation, in, SAE International, 2005.

[2] F. Zhao, D.N. Assanis, T.N. Asmus, J.E. Dec, J.A. Eng, P.M. Najt, Homogeneous Charge Compression Ignition (HCCI) Engines, SAE, USA, 2003.

[3] A.K. Amjad, R.K. Saray, S.M.S. Mahmoudi, A. Rahimi, Availability analysis of nheptane and natural gas blends combustion in HCCI engines, Energy, 36(12) (2011) 6900-6909.

[4] H. Guo, W.S. Neill, The effect of hydrogen addition on combustion and emission characteristics of an n-heptane fuelled HCCI engine, International Journal of Hydrogen Energy, 38 (2013) 11429-11437.

[5] M.T. García, Francisco José Jiménez-Espadafor Aguilar, T.S. Lencero, Experimental study of the performances of a modified diesel engine operating in homogeneous charge compression ignition (HCCI) combustion mode versus the original diesel combustion mode, Energy, 34(2) (2009) 159-171.

[6] S. Voshtani, M. Reyhanian, M. Ehteram, V. Hosseini, Investigating various effects of reformer gas enrichment on a natural gas-fueled HCCI combustion engine, International Journal of Hydrogen Energy, 39 (2014) 19799-19809.

[7] P. Das, P. Subbarao, J. Subrahmanyam, Control of combustion process in an HCCI-DI combustion engine using dual injection strategy with EGR, Fuel, 159 (2015) 580-589.

[8] K. Leea, S. Chob, N. Kimb, K. Minb, A study on combustion control and operating range expansion of gasoline HCCI, Energy, 91 (2015) 1038–1048.

[9] E. Neshat, R.K. Saray, Development of a new multi zone model for prediction of HCCI (homogenous charge compression ignition) engine combustion, performance and emission characteristics, Energy, 73 (2014) 325-339.

[10] E. Neshat, R.K. Saray, Effect of different heat transfer models on HCCI engine simulation, Energy Conversion and Management, 88 (2014) 1-14.

[11] V.I. Golovitchev, K. Atarashiya, K. Tanaka, S. Yamada, Towards universal EDC-based combustion model for compression ignited engine simulation, in: SAE, 2003.

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