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HEAT TRANSFER OF INTAKE PORT FOR HYDROGEN FUELED PORT

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ABSTRACT

The steady state heat transfer analysis of intake port for port injection engine is investigated. One dimensional gas dynamics was described the flow and heat transfer in the components of the engine model. The differences in characteristics between hydrogen and methane fuels are led to the difference in the behavior of physical processes during engine cycle. One of these processes is the heat transfer inside intake port. The engine model is simulated with variable engine speed and equivalence ratio (φ). Engine speed varied from 2000 rpm to 5000 rpm with increment of 1000 rpm, while equivalence ratio changed from stoichiometric to lean limit. The effects of equivalence ratio and engine speed on heat transfer characteristics for the intake port are presented in this paper. The baseline engine model is verified with existing previous published results. Comparison between hydrogen and methane fuel was made. The obtained results are shown that the engine speed has the same effect on the heat transfer coefficient for hydrogen and methane fuel; while equivalence ratio is effect on heat transfer coefficient in case of hydrogen fuel only. Rate of increase in heat transfer coefficient comparison with stoichiometric case for hydrogen fuel are: 4% for ($\varphi=0.6$) and 8% for ($\varphi=0.2$). While negligible effect was found in case of methane fuel with change of equivalence ratio. But methane is given greater values about 11% for all engine speed values compare with hydrogen fuel under stoichiometric condition. The blockage phenomenon was affecting the heat transfer process dominantly in case of hydrogen fuel; however the forced convection was influencing the heat transfer process for hydrogen and methane cases.

Keywords: Heat transfer, Hydrogen, Methane, Intake port, Port injection.

INTRODUCTION

One of the alternative fuels is hydrogen. Hydrogen is a very efficient and clean fuel. Its combustion will produce no greenhouse gases, no ozone layer depleting chemicals, and little or no acid rain ingredients and pollution (Kahraman, 2005). Hydrogen, produced from renewable energy (solar, wind, biomass, tidal etc.) sources, would result in a permanent energy system which would never have to be changed (Kahraman et al., 2007). Hydrogen Internal Combustion Engines (H2ICE) is a technology available today and economically viable in the near-term. This technology demonstrated efficiencies in excess of today's gasoline engines and operate relatively cleanly (NOx is the only emission pollutant) (Boretti et al., 2007). Increases efficiencies, high power density and reduce emissions are the main objectives for internal combustion engines (ICE) development (White et al., 2006). One of the major parameter that effective in the improvement of performance and emission regulation in the ICE is the amount of heat loss from the total heat release during combustion process. So, the accurate model that describes the heat transfer phenomena for H2ICE will give important information that required for improving the simulation of these engines on digital computers.

The heat is convected from the intake port wall to the mixture charge. Heat transfer in this part mainly caused by forced convection, which is controlled by turbulent charge movement and the temperature gradient of the mixture charge to the wall. Whilst surveying the correlations for use in modeling the quasi-steady heat transfer in the piping system of internal combustion engine, the authors noticed that these correlations mostly are based on the similarity theory developed by Nuβelt (Schubert et al., 2005).

$$\alpha = \frac{d}{k_f} . C . \mathrm{Re}^m \tag{1}$$

where α, d and kf are heat transfer coefficient, cylinder diameter and fluid thermal conductivity respectively.

Because a correlation type, easy-to-use unsteady heat transfer model is not available, classical, steady correlations in the form of Nu = C Rem or Nu = C RemPrn are widely used for estimating convective heat transfer coefficient in the intake manifolds of engines (Dittus and Boelter, 1930; Bauer et al., 1998; Depcik and Assanis, 2002; Shayler et al., 1996). No two engines will have the same flow patterns. Since flow is the gesture to heat transfer, the same magnitude of flow in two different engines can give two different heat transfer values. In addition, frequencies based on valve events, as well as pipe lengths, drastically alter the flow patterns and change the heat transfer relationship (Depcik and Assanis, 2002). Besides all of these reasons, type of the working gas another parameter will give a significant effect on the heat transfer process. These correlations provide reasonable agreement with experimental data in fully-developed steady pipe flows and acceptable agreement with time-resolved experimental data in unsteady flows with slow velocity variation under the quasi-steady assumption. However, for highly unsteady flows with rapid velocity variation, such as engine flows, these correlations can produce large errors in both phase and magnitude (Zeng and Assanis, 2004).

The physical properties of hydrogen fuel differ significantly from those fossil fuels (Li et al., 2006; Verhelst and Sierens, 2001). This provides the impetus for the authors to check up heat transfer process inside intake port for hydrogen fueled engine and specify the differences with fossil fuel (methane). So, heat transfer process will be under taken for the present study to show the ability of the heat transfer correlations which basically found for intake port with hydrocarbons fueled engine to represent heat transfer process inside intake port with hydrogen fueled engine, as well as, features detection of heat transfer phenomenon for the intake port with the new alternative fuel. (Vasanthy and Jeganathan 2007, Vasanthy et.al., 2008, Raajasubramanian et.al., 2011, Jeganathan et.al., 2012, 2014, Sridhar et.al., 2012, Gunaselvi et.al., 2014 & 2020, Premalatha et.al., 2015, Seshadri et.al., 2015, Shakila et.al., 2015, Ashok et.al., 2016, Satheesh Kumar et.al., 2016).

MATERIALS AND METHODS

Engine Model

The internal combustion (IC) engine simulation is one of the most interesting topics in the field of computational fluid dynamics. The modeled engine is supposed to have single cylinder, four stroke, spark ignition, port injection, hydrogen fuel and two valves (one inlet and one exhaust). Above mentioned engine was modeled exploiting the GT- Power software. The injection of hydrogen was located in the midway of the intake port. The model of the hydrogen fueled, single cylinder, four stroke, port injection engine is shown in Figure 1. The schematic diagram for the model is demonstrated in Figure 2. The specific engine characteristics are used to make the model (A) which is listed in Table 2. It is important to indicate that the intake and exhaust ports of the engine cylinder are modeled geometrically with pipes. The characteristics of the intake port of engine are listed in Table 3. The air mass flow rate in intake port was used for hydrogen flow rate based on the imposed equivalence ratio (φ). The specific values of input parameters including the equivalence ratio and engine speed were specified in the model. The boundary condition of the intake air was defined first in the entrance of the engine. This object describes end environment boundary conditions of pressure, temperature, and composition. The air enters through this object to the pipes. This object describes an orifice placed between any two flow components and its parts represent the plane connecting two flow components. The orifice diameter is set equal to the smaller of the adjacent component diameter on the either side of the orifice.While the orifice forward and reverse discharge coefficients are automatically calculated using the geometry of the mating flow components and orifice diameter, assuming that all transitions are sharp-edged.Several considerations for heat transfer and pressure losses calculations were made the model more realistic. Firstly, the heat transfer multiplier is used to account for bends, additional surface area and turbulence caused by the valve and stem. Secondly, the pressure losses in these ports are included in the discharge coefficients calculated for the valves. No additional pressure losses due to wall roughness were used (pressure losses were computed using dependency on Reynolds number only). (Manikandan et.al., 2016, Sethuraman et.al., 2016, Senthil Thambi et.al., 2016, Ashok et.al., 2018, Senthilkumar et.al., 2018.

Model Governing Equations

One dimensional gas dynamics model is used for representation the flow and heat transfer in the components of the engine model. Engine performance can be studied by analyzing the mass, momentum and energy flows between individual engine components and the heat and work transfers within each component. To complete the simulation model other additional formulas beside of the main governing equations are used for calculations of the pressure loss coefficient, heat transfer, and friction coefficient. The heat transfer from the internal fluids to the pipe and flow split walls is dependent on the heat transfer coefficient, the predicted fluid temperature and the internal wall temperature.

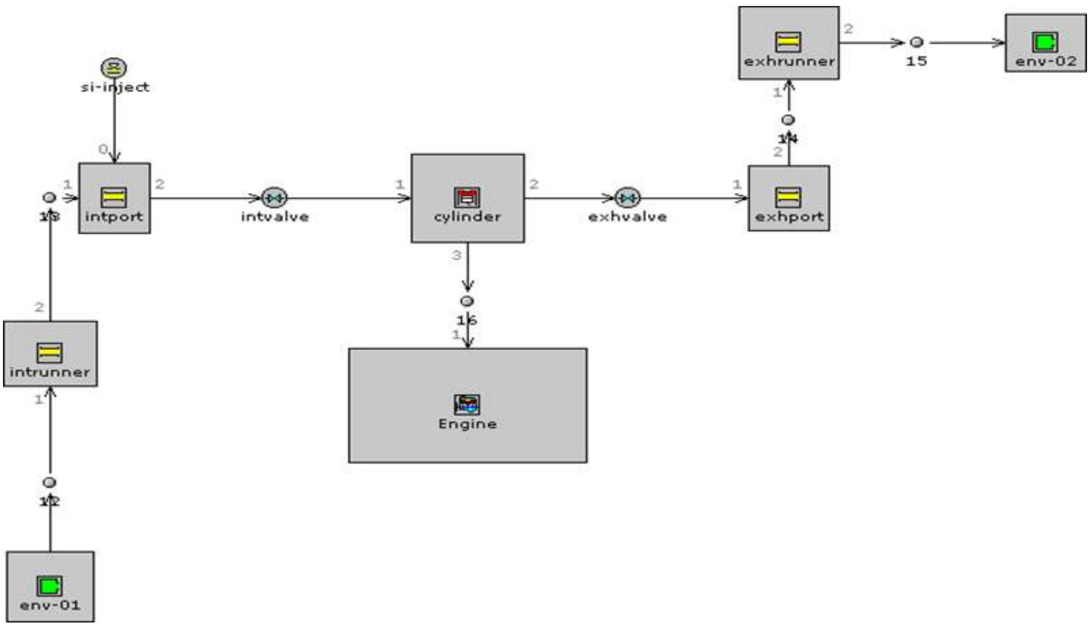

Figure 1: Model of single cylinder four stroke,port injection hydrogen fueled engine

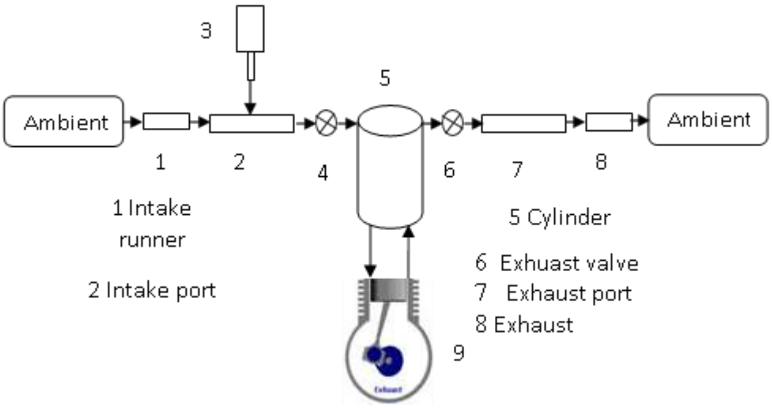

Figure 2: Schematic diagram for the model

RESULTS AND DISCUSSION

Steady state gas flow and heat transfer simulations for the in-cylinder of four stroke port injection spark ignition hydrogen fueled engine model is running for two operation parameters namely equivalence ratio (φ) and engine speed. The equivalence ratio was varied from stoichiometric limit (φ = 1.0) to a very lean limit where (φ = 0.2) with change step for the equivalence ratio equal to 0.2 and engine speed varied from 2000 rpm to 5000 rpm with change step equal to 1000 rpm.

Model Validation

In the present study were approved by adopting experimental results from two previous works. General assessment for the model performance is dedicated in the first validation while the second validation is devoted for revealing the extent and reliability of model results compared with previous existing correlation for intake port heat transfer. The experimental results obtained from (Lee et al., 1995) were used for purpose of first validation in this study. Engine specifications of (Lee et al., 1995) and present single cylinder port injection engine model (B) are listed in Table 4. The same engine model which described in Figure 1 was used for the purpose of first validation (taking into account the difference in the engines dimensions). Engine speed and equivalence ratio were fixed at 1500 rpm and (φ=0.5) respectively in this comparison to be coincident with (Lee et al., 1995) results. The in-cylinder pressure traces for the baseline model (B) and experimental previous published results (Lee et al., 1995) are shown in Figure 3. It can be seen that in-cylinder pressure trace are very good match for compression stoke and acceptable trends for expansion strokes while large deviation was obtained for combustion period due to the delay in the combustion for experimental as in claim's of (Lee et al., 1995), beside the difference between the some engine configuration conditions that is not mentioned in (Lee et al., 1995). However, considerable coincident between the present model (B) and experimental results can be recognized in spite of the mentioned model differences. To demonstrate the effectiveness of the adopted model for the present study model (A), direct comparison with model (B) in term of in-cylinder pressure traces was done as shown in Figure 4. The difference between two models is due to the difference in dimensions and compression ratio between of two models. Correlation which introduced by (Depcik and Assanis, 2002) is used for the purpose of model verification specifically for the intake port heat transfer in present study. This correlation was proposed by using a least square curve-fit of all available experimental data to get a general relationship which describe a dimensionless heat transfer coefficient Nu with Reynolds number expressed as Eq. (7).

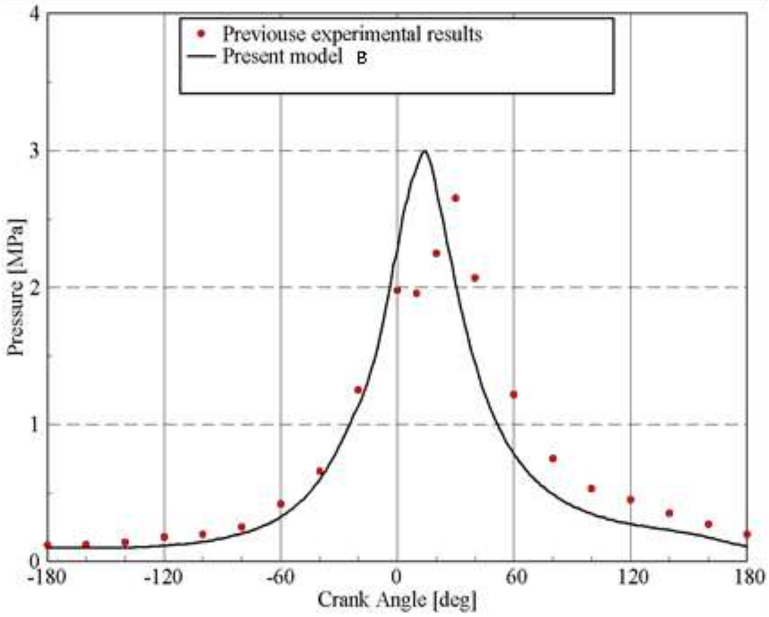

Figure 3: Comparison between published experimental results (Lee et al., 1995) and present single cylinder port injection engine model (B) based on in-cylinder pressure

Direct comparison between the acquired results from the engine model (A) and the getting results from empirical correlation for hydrogen and methane fuel is represented. Variation of heat transfer coefficient with engine speed for hydrogen and methane with stoichiometric mixture is revealed in Figure 5. It’s clear that the correlation performance for describing of methane fuel give a good agreement with engine model results, where the deviation is 11% within correlation limit and 16% outside this limit, if taking into consideration both of the deviation and limitation for the original correlation compared with the original experimental results which used for fitting. Where correlation have an r-value (deviation factor) of 0.846, and applicable with range.

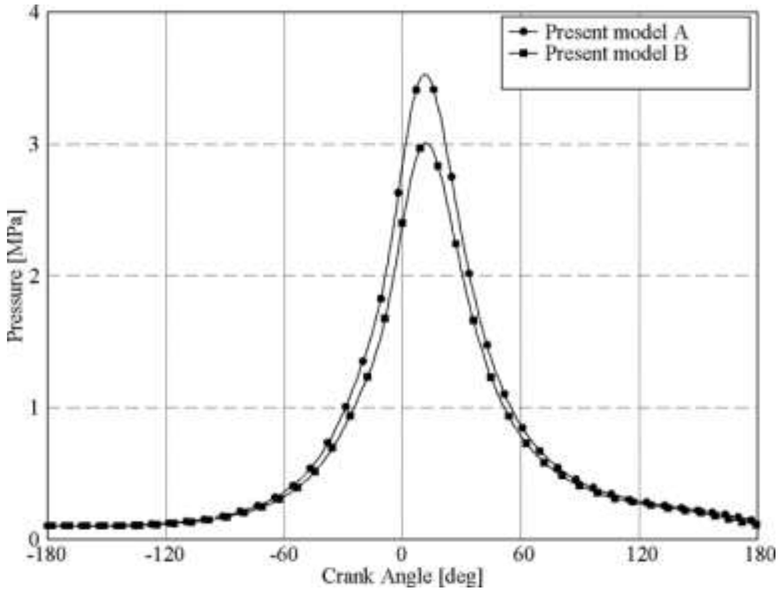

Figure 4: Comparison between models (A and B) based on in-cylinder pressure traces.

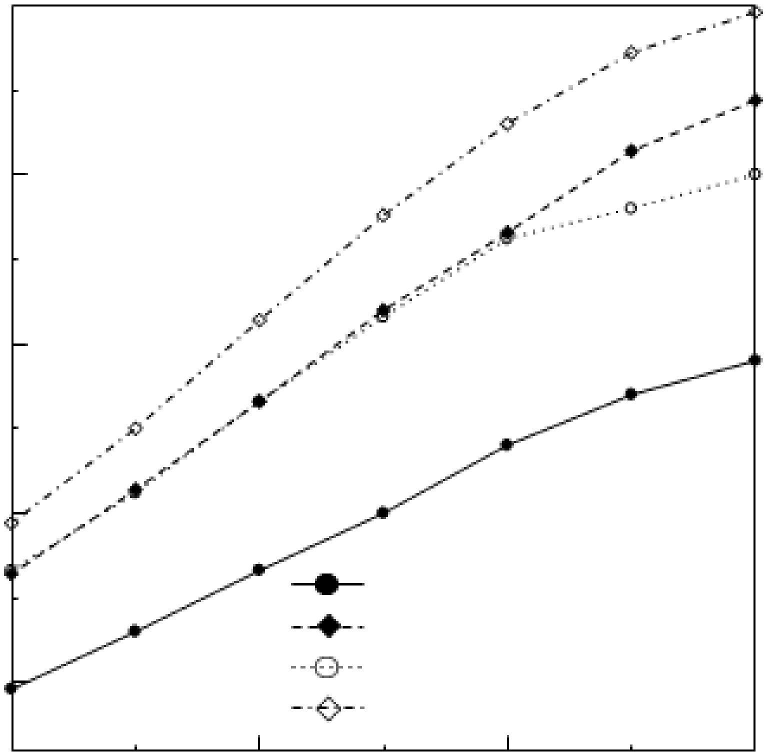

Figure 5: Comparison between previous (Depcik and Assanis, 2002) and model

(A) in present study for heat transfer coefficient.

Heat Transfer Coefficient for Intake Port

Comparison between hydrogen and methane in term of heat transfer coefficient and their behavior with changes of engine speed and equivalence ratio (φ) represents as indicator used to reveal the characteristics of steady state heat transfer inside the intake port for port injection H2ICE. Direct comparison between hydrogen and methane in term the variation of heat transfer coefficient with engine speed is described in Figure 6. The heat transfer coefficient is increasing as engine speed increase for methane and hydrogen fuels with keeping the highest values for methane fuel.

Effect of equivalence ratio (φ) on heat transfer coefficient with variation of engine speed is shown in Figures 7 and 8 for methane and hydrogen respectively. The difference between methane and hydrogen behavior is very clear in term of equivalence ratio (φ). In case of methane there are no effect (or negligible) for equivalence ratio (φ) on the values and behavior of heat transfer coefficient. As a result, it is expected that there will be no any impact for this variable on the overall process of heat transfer. On the contrary, it can be seen the impact of this factor in case of hydrogen. It decreases the equivalence ratio (φ) values heat transfer increase due to disappear of the blockage phenomenon.

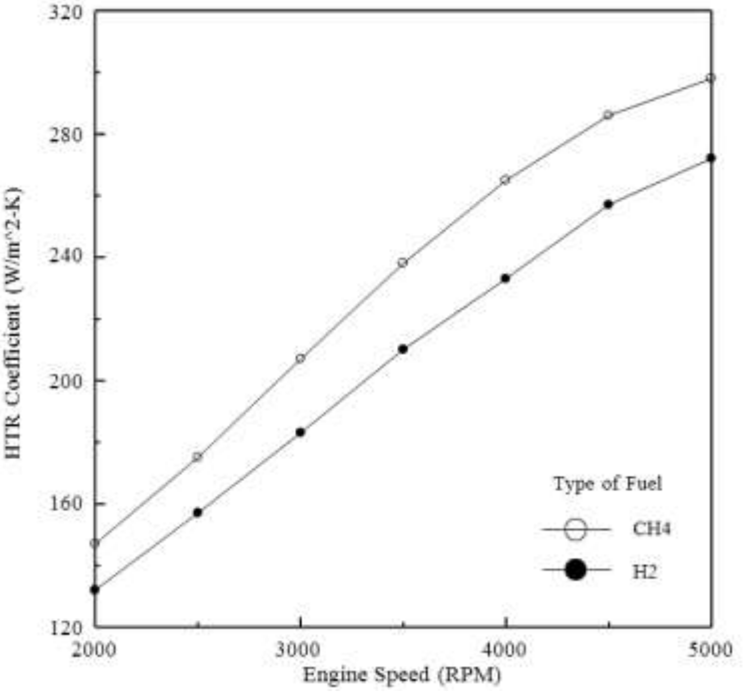

Figure 6: Comparison between hydrogen and methane in term of variation of heat transfer coefficient with engine speed for equivalence ratio φ=1.0.

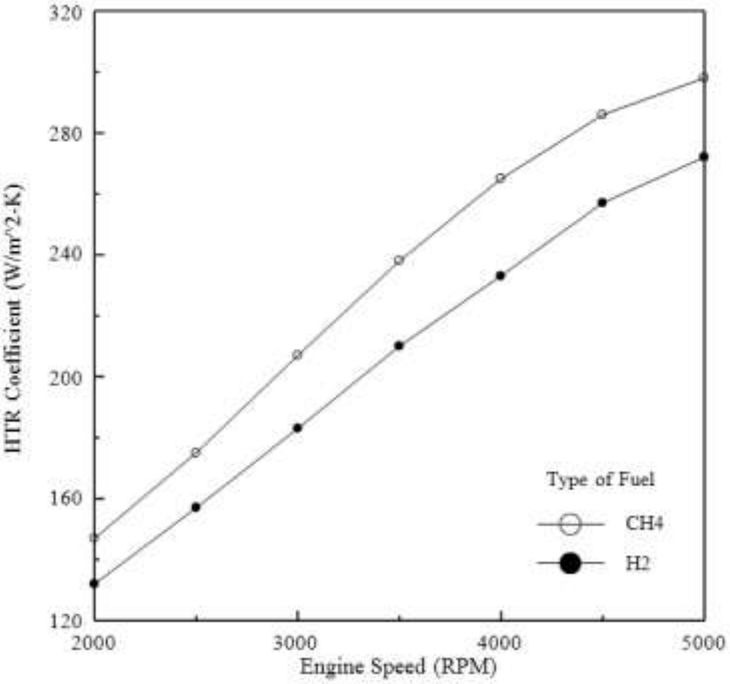

Figure 7: Variation of heat transfer coefficient for methane fuel with engine speed and equivalence ratio.

From the previous sections the effect of engine speed and equivalence ratio on heat transfer coefficient are clarified in case of hydrogen and methane fuels. The behavior of heat transfer coefficient is found to be governed by the blockage and forced convection effects. Forced convection effect is related to engine speed variation, while the blockage effect is related to equivalence ratio variation.

In term of engine speed, both of them (hydrogen and methane fuel) they have the same trends which is increased the heat transfer coefficient as engine speed increased due to increasing the driving force for the heat transfer process (forced convection). But methane is given greater values about 11% for all engine speed values compare with hydrogen fuel. Density of methane fuel is greater than hydrogen as well as the diffusion coefficient for methane is lesser than hydrogen, hence the blockage effect for hydrogen fuel is greater than methane so that the present of forced convection with methane is more strength, due to the high restriction for the charge flow in case of hydrogen fuel; therefore, the heat transfer effect is more efficient in case methane fuel.

The effect of variation for the equivalence ratio (φ) in case of methane is negligible. On the other hand, the decreasing of the equivalence ratio (φ), in case of hydrogen fuel, lead to enhance of heat transfer process due to the limitation in the blockage phenomenon and on so on the gas flow become more fluently which means that effect of the forced convection is more strength. Rate of increase in heat transfer coefficient comparison with stoichiometric case for hydrogen fuel are: 4% for (φ=0.6) and 8% for (φ=0.2).

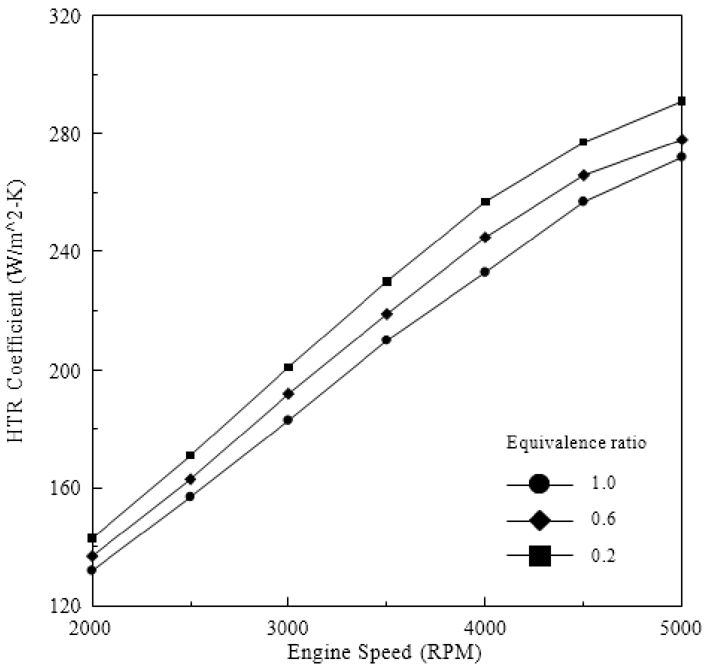

Figure 8: Variation of heat transfer coefficient for hydrogen fuel with engine speed and equivalence ratio.

CONCLUSION

The present study considered the comparison in heat transfer characteristics inside the intake port for port injection engine fueled with hydrogen and methane respectively. The foregoing results indicates that heat transfer coefficient in the intake port is changed with variation of engine speed and equivalence ratio due to effect of forced convection and blockage phenomena respectively. Comparison between hydrogen and methane in term of heat transfer coefficient and their behavior with change of engine speed and equivalence ratio are clarified that hydrogen is more dependable on equivalence ratio, whilst both of them have the same trend with engine speed variation. The blockage phenomenon was affecting the heat transfer process dominantly in case of hydrogen fuel, due to the low density and high diffusion velocity for hydrogen in comparison with methane.

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