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One-dimensional Combustion Simulation for Different Hydrogen-enriched Natural Gas Blends

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ABSTRACT: Land-based gas turbines are one of the most practical turbines that use natural gas as the main fuel. Because of the variation of natural gas composition in different refineries and at different times, and also its variation in pipe lines into power plants, the combustion properties will vary widely and sometimes, it remains harmful effects. So, several ways are proposed to minimizing the negative effects of the undesirable combustion which is formed in hydrocarbon fuels. One of these ways is Hydrogen injection in the main fuel. Because Hydrogen has some desirable properties like low ignition energy, high reactivity, high diffusivity and high burning velocity, it has been considered as a good additive for the recovery of hydrocarbon fuels combustion. The objective of the present study is to clarify the effects of the natural gas composition variation and also the effects of Hydrogen addition in order to have a better combustion for different fuels compositions. It has seen that Hydrogen addition in a specific percentage, cause to a recovery in combustion properties, such as increase in flame stability limits. it's found that 10% Hydrogen injection can cause more uniform combustion for the investigated natural gas compositions. Moreover, the pressure increase has a significant effect on the increase of laminar burning velocity, temperature and flammability limits.

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1. INTRODUCTION

Nowadays, combustions with high efficiency and low harmful emissions have been the main purpose of industries and using lean premixed combustions creates this chance to achieve this goal [1]. Sustaining the flame in the close of lower flammability limits (i.e. in the lean mixture), especially for natural gas, can be hard and with considering some requirements [2]. So, wide variation in natural gas composition due to different condition such as refinery process, make it more difficult to reach stable combustion.

There are several methods to avoid the mentioned problem and consequently create sustained combustion with high combustion efficiency. One of these methods is using hydrogen and inject it into the main fuel (i.e. Natural gas) which has attracted significant interests recently [3, 4].

Based on the Author's researches [5, 6], suitable and good results have been extracted from using the hydrogen injection method. GRI3.0 kinetic has been used mostly in the recent studies [5, 6] and here, as for the initial conditions, GRI3.0 and AramcoMech1.3 kinetics have been compared to deduce which kinetic has better performance. Then, with the better kinetic, combustion characteristics like laminar burning velocity, temperature and NO_x emission have been investigated for different natural gas compositions with Hydrogen injection in different percentages. Finally, the effect of pressure is studied on the combustion characteristics.

2. NUMERICAL PROCEDURE

The calculations were performed using Ansys Chemkin 17.2. In the used solver (Flame_speed_freely_propagating solver), the combustion process is simulated in one dimension with thermal-diffusive equations. Fig. 1 shows a one-dimensional flow and properties are steady in the perpendicular direction to the flow and the corresponding equations are presented as follows. The Eqs. of 1, 2, 3 and 4 show respectively mass conservation, x-momentum conservation, energy conservation and species conservation equations.

$$\frac{d}{dx}(\rho v_x A) = 0 \tag{1}$$

$$\frac{dP}{dx} + \rho v_x \frac{dv_x}{dx} = 0 \tag{2}$$

$$\frac{d}{dx}\left(h + \frac{v_x^2}{2}\right) + \frac{\dot{Q}''P}{\dot{m}} = 0 \tag{3}$$

$$\frac{dY_i}{dx} - \frac{\dot{\omega}_i MW_i}{\rho v_x} = 0 \tag{4}$$

Considering the experimental study of Donohoe et al. [5], the simulation and experiment results are in good agreement and the maximum difference between them is 5.416%. The

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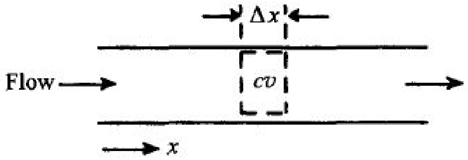

Fig. 1. Scheme of one-dimensional flow geometry in flame_ speed_freely_propagating solver

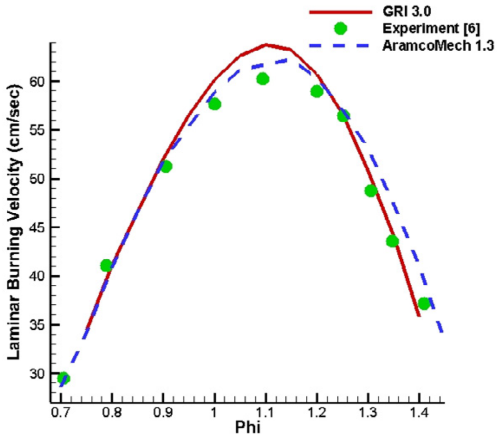

Fig. 2. One dimensional simulation validation with flame_ speed_freely_propagating solver

Table 1. Maximum absolute and relative errors for GRI3.0 and AramcoMech1.3 kinetics validation

Different Kinetics	Maximum Error	
	Absolute Error	Relative Error (%)
GRI3.0	3.47746	5.46
AramcoMech1.3	1.3936	2.26

validation results have been depicted in Fig. 2 and maximum absolute and relative errors for GRI3.0 and AramcoMech1.3 kinetics are presented as Table 1.

3. RESULTS AND DISCUSSION

The exact natural gas composition at any site will vary among the different regions and over time but for comparing GRI3.0 and AramcoMech1.3 kinetics performance, the chemical composition of natural gas which is announced by Union Gas, in comparison with pure methane, is assumed and Hydrogen as an additive, in amounts of 10, 20, 30 and 40 percent is added to natural gas components.

After that the better kinetic is defined, some fundamental combustion characteristics like laminar burning velocity, temperature, and NO_x emission have been analyzed for different natural gas compositions that are related to some Iranian refineries [7]. For evaluating the effect of Hydrogen addition, different percentages of adding Hydrogen is considered. Finally, the effect of pressure increase on the studied combustion characteristics has been analyzed. For brevity, the related results to laminar burning velocity are declared here. Also, any extra information about different natural gas chemical compositions or other combustion characteristics like temperature and NO_x emission is accessible in the Persian version of this article. The initial conditions are as follows. Initial mixture temperature is 600 K, the pressure is 1 atm, ambient temperature is 298 K and inlet velocity is 40 cm/s.

As for Fig. 3 and the results, it's deduced that with the considered initial conditions, GRI3.0 kinetic has a better performance than AramcoMech1.3 kinetic and GRI3.0 converged for all the considered states which Hydrogen is injected into natural gas.

Then, considered combustion characteristics have been analyzed for natural gas different compositions and different percentages of Hydrogen are added to their components. According to Table 2 and Fig. 4 and in comparison with the results of different percentages of Hydrogen injection, it's resulted that 10% Hydrogen injection can cause more uniform combustion.

According to Fig. 4, it's observed that with 10% Hydrogen injection, the laminar burning velocity magnitude increased and the maximum difference between two fuel compositions, decreases from 3.048% to 1.599% that is indicating more uniform combustion.

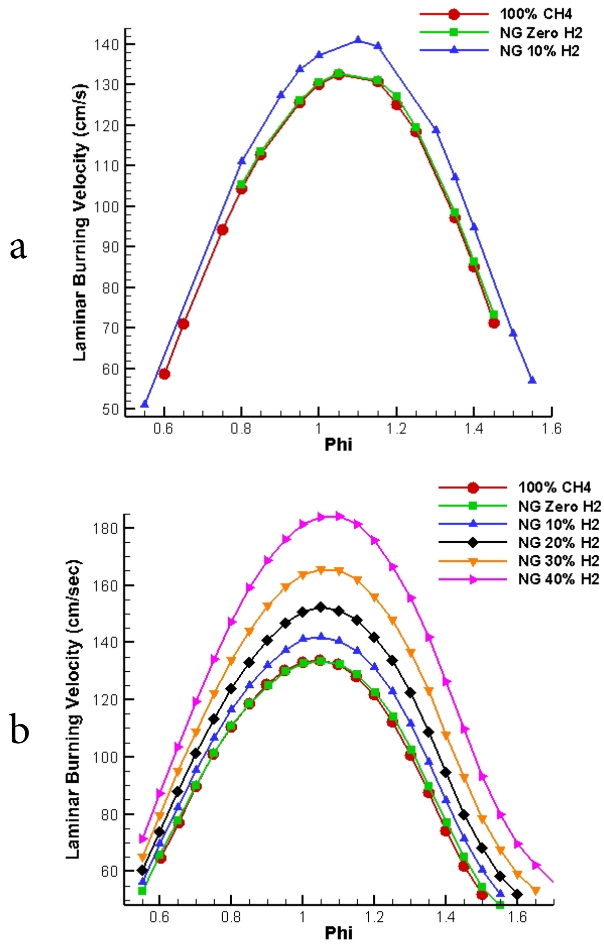

Fig. 3. Laminar burning velocity at various equivalence ratios for a) AramcoMech1.3 and b) GRI3.0 kinetics

Table 2. Converged equivalence ratio ranges for natural gas different compositions

Natural Gas Different Compositions	Converged Equivalence Ratio Range			
	Without Hydrogen Injection	10% Hydrogen Injection	20% Hydrogen Injection	30% Hydrogen Injection
Tehran	0.55-1.55	0.55-1.55	0.55-1.6	0.55-1.65
Sarkhoon	0.55-1.5	0.55-1.55	0.55-1.6	0.55-1.65
Khangiran	0.6-1.5	0.55-1.55	**0.55-1.55**	**0.55-1.6**
Bidboland	0.55-1.6	**0.55-1.6**	**0.55-1.65**	**0.55-1.7**
Kangan	0.55-1.55	0.55-1.55	0.55-1.6	0.55-1.65
Union Gas	0.55-1.55	0.55-1.55	0.55-1.6	0.55-1.65

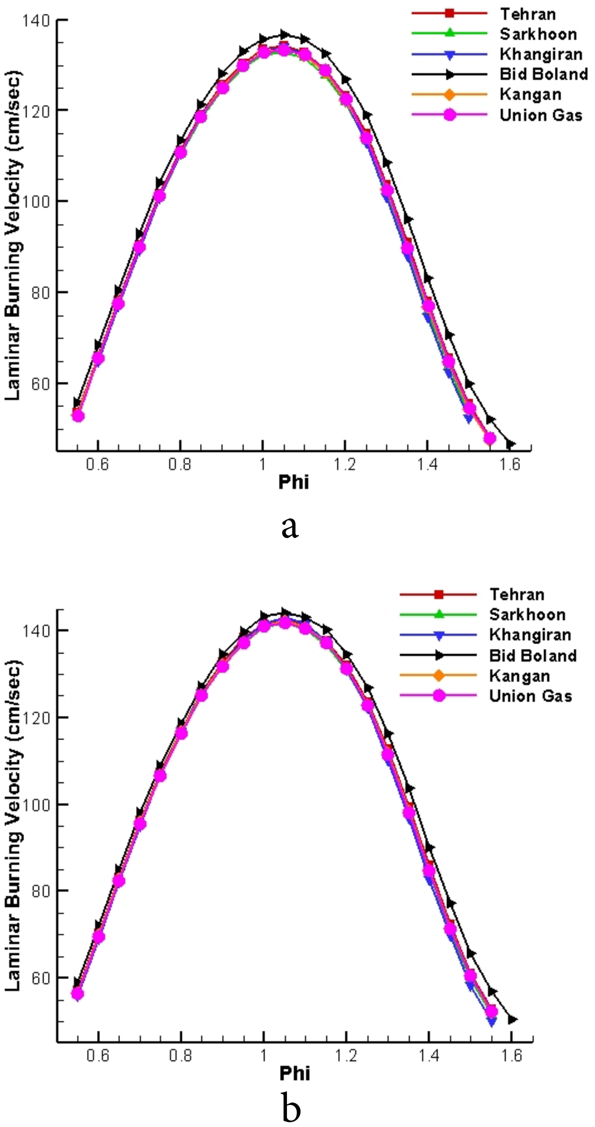

Fig. 4. Laminar burning velocity a) without Hydrogen injection and b) with 10% Hydrogen injection for natural gas different compositions

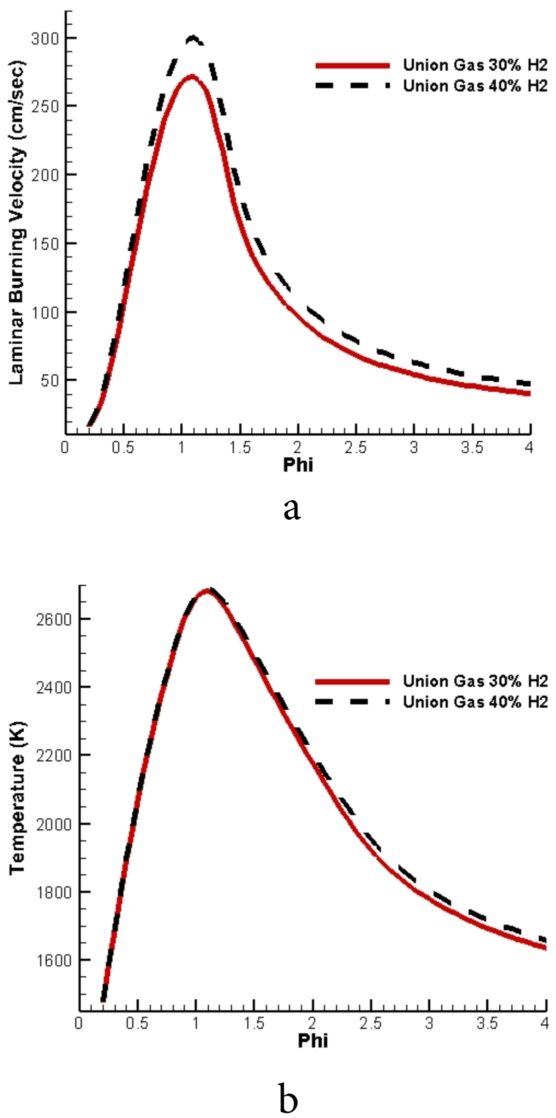

Fig. 5. The curves of a) laminar burning velocity and b) temperature at 10 atm

Finally, the effect of increasing pressure on the considered combustion characteristics is analyzed and it's assumed that the pressure is 10 atm. Considering the experimental studies, combustion in the equivalence ratio range of 0.2 to 4.0, is analyzed for 30% and 40% Hydrogen injection. The results show that increasing the pressure has a significant effect on the increase of laminar burning velocity, temperature, and flammability limits. Fig. 5 shows the laminar burning velocity and temperature curves at 10 atm.

4. CONCLUSIONS

One-dimensional combustion simulation for different Hydrogen-enriched natural gas blends was investigated using Ansys-Chemkin. It was found that GRI3.0 kinetic has a better performance than AramcoMech1.3 kinetic in the considered initial conditions.

Also, it's found that 10% Hydrogen injection can cause more uniform combustion for the investigated natural gas compositions. Moreover, the pressure increase has a significant effect on the increase of laminar burning velocity, temperature and flammability limits.

REFERENCES

[1] S.B. Shrestha, G.A. Karim, Hydrogen as an additive to methane for spark ignition engine applications, in: IECEC-97 Proceedings of the Thirty-Second Intersociety Energy Conversion Engineering Conference (Cat. No. 97CH6203), IEEE, 1997, pp. 910-915.

[2] J. Wang, Z. Huang, J. Zheng, H. Miao, Effect of partially premixed and hydrogen addition on natural gas direct-injection lean combustion, international journal of hydrogen energy, 34(22) (2009) 9239-9247.

[3] S.R. Bell, M. Gupta, Extension of the lean operating limit for natural gas fueling of a spark ignited engine using hydrogen blending, Combustion Science and Technology, 123(1-6) (1997) 23-48.

[4] G.A. Karim, Hydrogen as a spark ignition engine fuel, International Journal of Hydrogen Energy, 28(5) (2003) 569-577.

[5] N. Donohoe, A. Heufer, W.K. Metcalfe, H.J. Curran, M.L. Davis, O. Mathieu, D. Plichta, A. Morones, E.L. Petersen, F. Güthe, Ignition delay times, laminar flame speeds, and mechanism validation for natural gas/hydrogen blends at elevated pressures, Combustion and Flame, 161(6) (2014) 1432-1443.

[6] J. Wang, Z. Huang, C. Tang, J. Zheng, Effect of hydrogen addition on early flame growth of lean burn natural gas–air mixtures, international journal of hydrogen energy, 35(13) (2010) 7246-7252.

[7] PackmanCompany, Iranian refineries different natural gas compositions in, Packman company official website, 2018.

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