Numerical Analysis of Syngas Premixed Flame in Counter-flow Arrangement

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Abstract

The purpose of this analysis is to find out the effect of stretch on syngas premixed flame with air. The analysis is done at ambient condition of temperature 300 K and 1 atm pressure. The fuel is syngas which is also known as synthetic gas or producer gas. This is mixture of gases like hydrogen, carbon monoxide, methane, carbon dioxide and nitrogen. Out of which carbon dioxide and nitrogen act as inert while burning and heat energy is produced from hydrogen, carbon monoxide and methane. This syngas is mixed with air which acts as an oxidizer. The mixing is done before burning, therefore the flame front formed is called as premixed. The present analysis is done with very rich condition of syngas in air with equivalence ratio of 1.8 in counter-flow arrangement with increasing velocity of premixed syngas and air from both the nozzles. As the velocity increases the stretch in flame also increases. The temperature, velocity and species distribution of hydrogen, carbon monoxide and methane are analysed in current study.

Keywords: Counter-flow, Flame, Numerical Analysis, Premixed, Stretch Rate, Syngas

I. INTRODUCTION

Syngas or synthetic gas is a mixture of hydrogen, carbon monoxide, methane, carbon dioxide and nitrogen. This can be produced with gasification of coal, organic matter or plant residues. This can be source of renewable energy if produced from biomass i.e., plant residues like rice straws, wooden pieces through gasification process. The syngas is mixed with air prior to burning therefore the flame is called premixed flame. This can be studied in counter-flow arrangement [1] as shown in fig. 1.

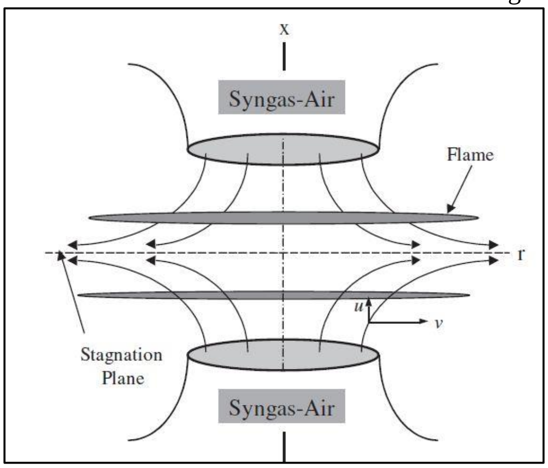

Fig. 1: Schematic of Counter-flow Arrangement

Counter-flow configuration can be formed with two axisymmetric nozzles placed opposite to each other forming a stagnation plane where momentum balance of combustible gas flows is achieved. When these opposed combustible gas flows are ignited, two stable planar flame fronts form on the either side of stagnation plane and away from the nozzle exit planes.

II. NUMERICAL STRATEGY

Stagnation flames are formulated with OPPDIF code of CHEMKIN package [2]. The reaction mechanism used is GRI-Mech 3.0 [3]. It consists of 53 species and 325 elementary chemical reactions. The distance between two opposite facing nozzles is set to 2 cm. The syngas components hydrogen, carbon monoxide, methane, carbon dioxide are premixed with air in rich quantity so as to get equivalence ratio of 1.8 through species input. The inlet velocity of both the nozzles is increased in from 20 cm/s to 100 cm/s

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in the steps of 20. With increase in inlet velocity the flame stretch also increases. As stretch or strain rate is function of inlet velocity of premixed syngas-air flow [14].

III. RESULTS AND DISCUSSIONS

A. Variation of Stretch with Increase in Inlet Velocity:

From fig. 2, the axial velocity increases with as flame initiates at both inlets rapidly. This sudden increase in axial velocity is due to addition of thermal energy from flame. The flame is initiating very near to the nozzle inlet due to richness of fuel i.e., syngas content is high. Most of the thermal energy flame is dissipated to ambient and the flow approaches towards the stagnation zone the axial velocity shows considerable decrement and approaches to zero at 1 cm which stagnation point. With increase in axial velocities from 20 cm/s to 80 cm/s, the stretch in flame and its burning velocities show higher values proportional to inlet velocities. The velocity gradients approaching become steeper as the inlet velocities are increased. The highest flame stretch can be seen with highest inlet velocity.

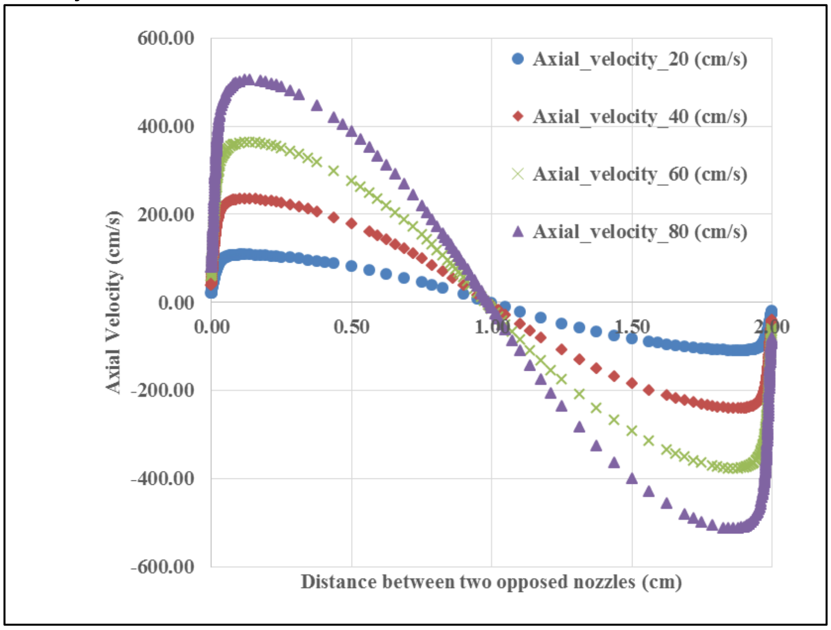

Fig. 2: Variation of Stretch with Increase in Inlet Velocity from Both Opposed Inlets

B. Variation of Temperature with Highest Inlet Velocity of 100 cm/s from Both Nozzles:

The highest stretch employed with inlet velocity of 100 cm/s from both counter-flow nozzles. The temperature distribution along the distance between two opposed nozzles is shown in fig. 3. The rapid increment in temperature i.e., gradient of temperature shows the premixed flame location. As there are two gradients of temperature, the two flame fronts can be located easily on the either side of stagnation plane. The temperature is close to adiabatic flame temperature of typical syngas-air premixed flame.

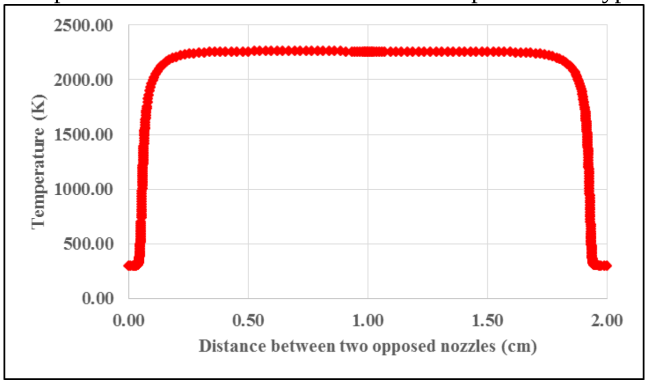

Fig. 3: Variation Temperature with Highest Inlet Velocity of 100 cm/s from Both Nozzles

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C. Variation of Axial Velocity with Highest Inlet Velocity of 100 Cm/S from Both Nozzles:

The high stretch rate can be obtained with high inlet velocity of 100 cm/s from both opposed nozzles. The axial velocity does not start rapid increase like the previous cases of 20 cm/s to 80 cm/s. The thermal energy from flame plays a crucial role with high inlet velocity. The axial velocity starts increasing after few millimeters from nozzle inlet as shown in fig. 4. This behavior is different from earlier cases where the flame initiates as early as possible with lower stretch rate.

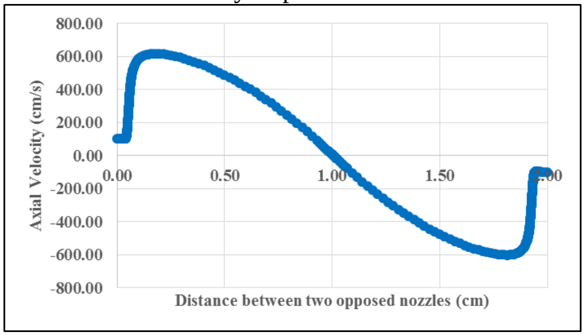

Fig. 4: Variation of Axial Velocity with Highest Inlet Velocity of 100 cm/s from Both Nozzles

D. Variation of Density with Highest Inlet Velocity of 100 cm/s from Both Nozzles:

The law of mass conservation plays an important role here, as velocity increases density of flow should decrease so as to conserve mass. This can be seen in fig. 5. The location where the rapid increase in velocity is observable from fig. 4, the same location shows gradient in density in fig. 5. As the thermal energy is released, the temperature is very high and density is inversely proportional to temperature. Therefore, the vicinity of flame shows increment in axial flow velocity, decrement in density of the flow.

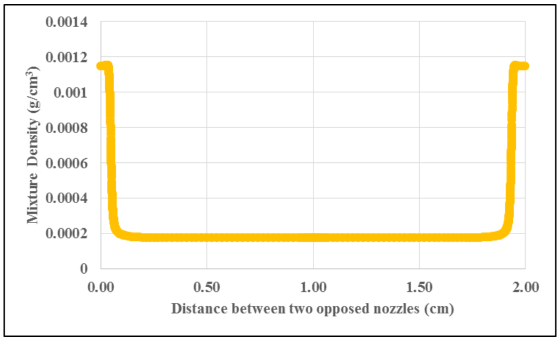

Fig. 5: Variation of Mixture Density with Highest Inlet Velocity of 100 cm/s from Both Nozzles

E. Variation of Species with Highest Inlet Velocity of 100 cm/s from Both Nozzles:

The species distribution also shows gradients in flame region. The reactants have steep gradients in decreasing nature.

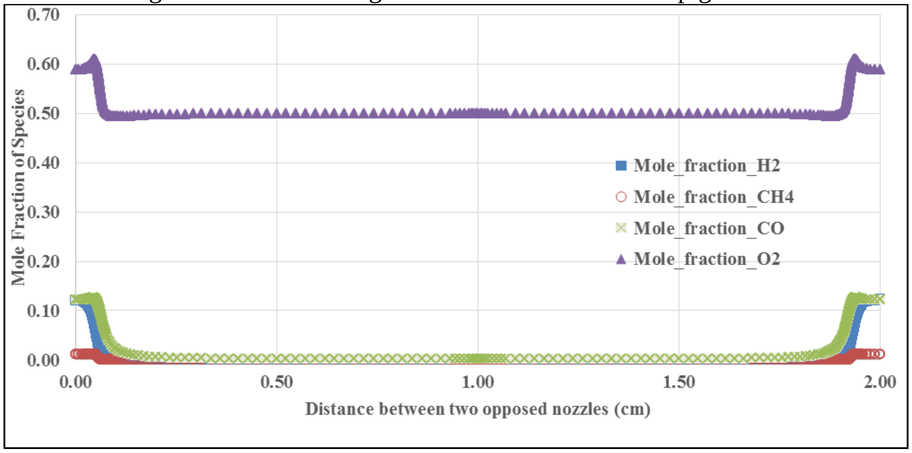

Fig. 6: Variation of Species with Highest Inlet Velocity of 100 Cm/S from Both Nozzles

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IV. CONCLUSION

The following conclusions can be drawn from the behavior of syngas in rich condition of premixed with air:

1) The axial velocity of flow in flame region is increasing with increasing inlet velocity of flow.
2) The axial velocity is higher with higher stretch rate i.e., with higher inlet velocity.
3) With higher stretch rate the axial velocity of flow do not show rapid increment like in lower stretch rate cases. It remains constant over few distance and then shows rapid increment due to thermal energy input.

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