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# EXPERIMENTAL STUDIES FOR CNG-$H_2$ FUEL BASED TURBULENT JET DIFFUSION FLAME

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## ABSTRACT

Combustion characteristics of H2 gas, CNG gas and CNG-H2 hybrid fuel were investigated experimentally in turbulent diffusion flame with co-flowing air stream with swirler. The air velocity changes from slow to high flow rate. Reynolds number is varying throughout the process from laminar to turbulent region. Results showed that the non dimensional flame length decreases with increase the air flow rate and also Non dimensional flame length decreases as decrease in M.F.R. and equivalence ratio. Flame stability increases with increasing the hydrogen content in the hybrid fuel mixture. Flame's colour for H2, CNG and CNG-H2 were also discussed in the entire experimental work.

## 1. INTRODUCTION

Now a day's pure CNG is using transportation sector and other industrial sector. The problem of atmospheric pollution is increasing day by day by using pure CNG as a fuel. The level of $CO_2$, CO and other oxide of carbon and nitrogen is increasing in the atmosphere. So hydrogen CNG (Compressed natural gas) hybrid fuel is attractive energy option for solving the problem of that type of environmental pollution.

The burning of pure CNG fuel is increasing the carbon and its oxide level in atmosphere while Burning of CNG-$H_2$ mixture produces low pollutant emissions and better combustion characteristics. This is proved that Hydrogen hydrocarbon hybrid fuel is better option in spite of pure hydrocarbon fuel (4-7). However the pure hydrogen has several problems like flashback, difficult storage problems due to its low volumetric density and high combustibility.

Pure CNG has also created several problems like high emission of $CO_2$, CO and other exhaust gasses which damage our eco-system. So hydrogen hybrid fuel is an attractive solution. It is proved that addition of hydrogen to CNG the pollutant gasses i.e. $CO_2$, CO etc. reduces.

Increasing the percentage of hydrogen in hydrogen-natural gas hybrid fuel mixture, the flame thickness reduces and rate of heat release increases. Flame adiabatic temperature and flame stability increase with increasing the percentage of hydrogen in hybrid fuel mixture. (1-3)

Flame characteristics mainly flame length, flame stability and flame colour of $H_2$ fuel, CNG fuel and hybrid fuel CNG-$H_2$ on turbulent diffusion flame are also discussed in the progress report.

## 2. EXPERIMENTAL SETUP AND PROCEDURE

A schematic experimental setup was developed for the of study of flame length, flame stability and flame colour of $H_2$ air flame, CNG air flame and CNG-$H_2$ air hybrid fuel flame of jet diffusion flame. The various inputs of the set-up were air and fuel (CNG and $H_2$). The various parts of the experimental set-up were burner, burner enclosure chamber, flow meters, fuel regulating valves, digital camera, compressor and mixer.

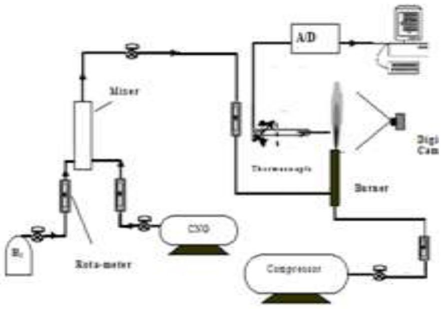


**Fig.2.1** Experimental setup

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Hydrogen and compressed natural gas mixture was supplied from hydrogen and CNG cylinder respectively to the mixing section through calibrated rotameter where proper mixing was achieved. Combustion air was supplied from the single stage reciprocating compressor through calibrated rotameter to the settling chamber where three meshes were available so the flow rate of air was become consistent. The velocity of air was increased by swirler due to its vane angle. The fuel (i.e. $H_2$, CNG or Hybrid fuel CNG-$H_2$) was being supplied through a central tube which was made up of stainless steel while the swirling air flow was provided by a coaxial annulus. The calibrated hydrogen rotameters 10-100 LPM and 20-200 LPM and calibrated air rotameters 20-200 LPM and 100-1000 LPM were used. The 2-20 LPM and 10-100 CNG rotameters were also used for measuring the flow rate of natural gas. The main component of natural gas was methane (about 95%). All tests were performed at ambient pressure and ambient temperature. In our study, the data have taken at $45^0$ vanes swirler. The fuel outlet diameter was 4 mm and the swirler diameter was 30 mm.

The flow rates of hydrogen were taken as 30.6 LPM, 48.29 LPM and 122.45 LPM corresponds to 5 kW, 10 kW and 20 kW of power level at 98 % efficiency. Air flow rates were varied from 20 LPM to 250 LPM. The stoichiometric proportion of hydrogen and air flow rates is 1: 2.373 as LPM unit.

The flow rates of CNG were taken as 8 LPM, 16 LPM, 32 LPM and 48 LPM corresponds to 5 kW, 10 kW, 15 kW and 20 kW of power level at 98% efficiency. Air flow rates were varied from 20 LPM to 200 LPM. The flow rates of hybrid fuel, the mixture of $H_2$-CNG, were taken for 10 kW power level. The hydrogen flow rate was varied from 8 to 32 LPM while the CNG flow rate varies from 5 to 12 LPM. The air flow rate was varied from 20 to 200 LPM. The Reynolds number was varied from laminar to turbulent region.

The Sony handy cam has used for flame video-grapy. This video has converted to flame photograph by using softwares i.e. Irfan-view and M.T.S. converter. The flame length has calculated by image-J software.

## 3. RESULTS AND DISCUSSION

### 3.1 Hydrogen-air

### 3.1.1 Flame length

Fig. 3.1 shows the variation of M.F.R. with N.F.L. It is noted that increase the M.F.R., increases the N.F.L. for both the power levels of 5 kW and 10 kW. It is also noted that in fig.3.1 the non dimensional flame length (L/D) of 5 kW power level is less than the 10 kW power level due to the velocity of hydrogen is greater at 10 kW power level in spite of 5 kW power level.

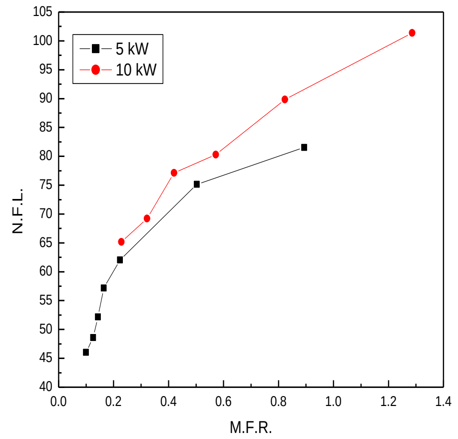



**Fig.3.1 The N.F.L. variation with M.F.R. for 5 kW and 10 kW power level for hydrogen**

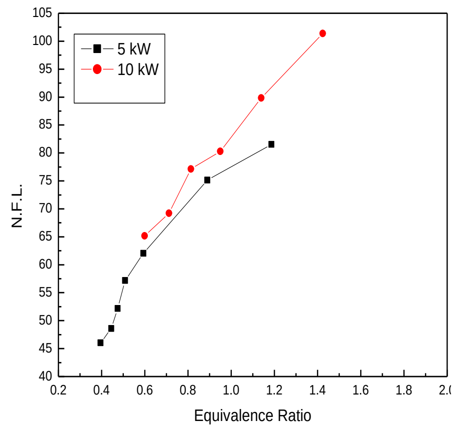



**Fig.3.2 The N.F.L. variation with equivalence ratio for 5 kW and 10 kW power for hydrogen**

Figure 3.2 shows that increase in equivalence ratio, the value of non dimensional flame length (N.F.L.) increases. The reason is the air flow rate is increasing in the case of 5 kW power level and 10 kW power level. It can be noted that decrease in the air flow rate, the value of equivalence ratio increases so N.F.L. also increases.

### 3.1.2 Flame Colour

Fig. 3.3 shows that the base of flame is light blue and the colour of mid flame and top flame is pale yellow and reddish red for pure hydrogen air flame. The blue colour in base of flame increases with increase the oxygen. The pale yellow colour goes to reddish colour with increase the oxygen.

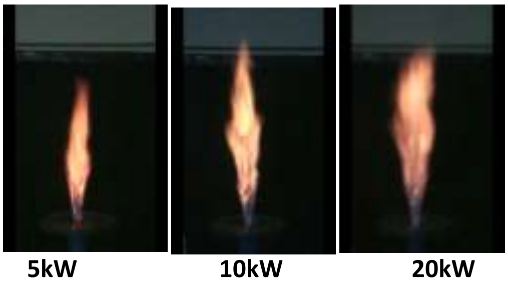



**Fig.3.3 Pure hydrogen flame of 30 LPM $H_2$-100LPM air, 48 LPM $H_2$-100 LPM air and122 LPM $H_2$-150 LPM air.**

The nature hydrogen flame at 5 kW, 10 kW and 20 kW for given conditions was attached and stable.

## 3.2 CNG-Air

### 3.2.1 Flame length

Fig.3.4 shows that non-dimensional flame length increases with increase the Momentum Flux Ratio. The value of NFL is constant after achieving a maximum value.

Fig.3.5 explains that the value of flame length increases (approximately linearly) with increasing the CNG fuel velocity for different flow rate of air. It is clear that the flame length increases with increase the fuel content hence more fuel is

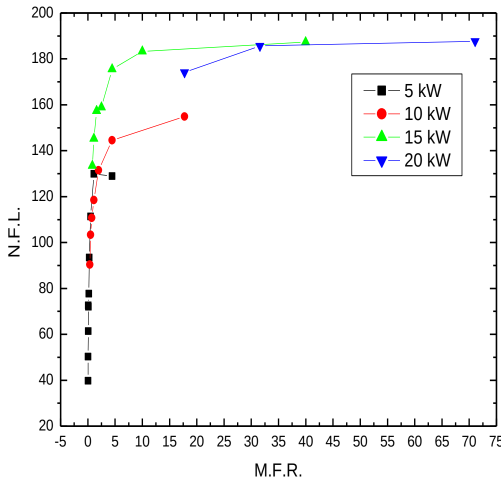



**Fig.3.4 The N.F.L. variation with MFR 5 kW, 10 kW, 20 kW and 20 kW power level for CNG**

available for combustion.

### 3.2.2 Flame colour

It is clear from fig. 3.7 the base of flame and mid flame is light blue and the colour of top flame is pale yellow for pure CNG air flame at 5kW and 10kW power level. The blue colour in base of flame increases with increase the oxygen. The pale yellow colour goes to reddish colour with

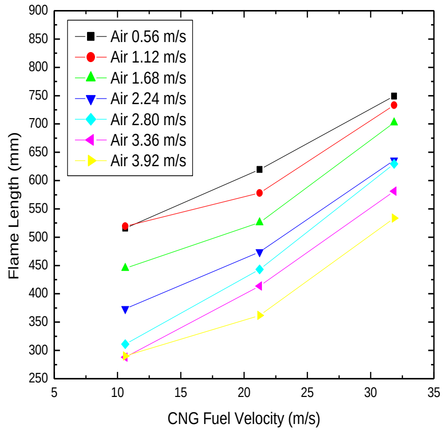



**Fig.3.5 The flame length variation with jet fuel (CNG) velocity at various air velocities**

increase the oxygen. The colour of 20 kW flame is reddish red at mid region and top region. The nature hydrogen flame at 5 kW, 10 kW, 15kW and 20 kW for given condition is lifted flame. The blow off height increases with increasing the air as well as natural gas. The blow-off height increases with increase the power level.

## 3.3 CNG-$H_2$ hybrid fuel

### 3.3.1 Flame length

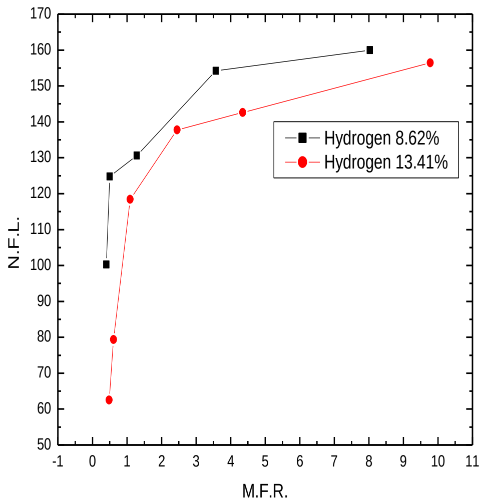
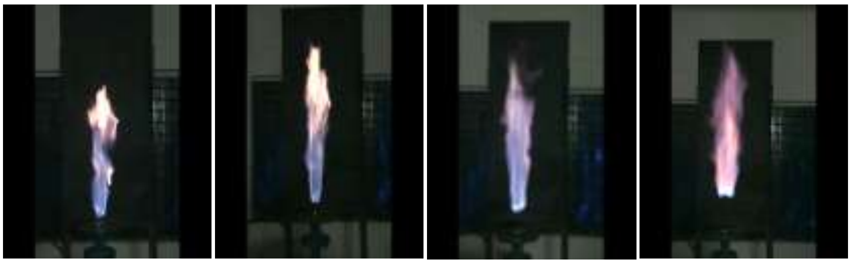



**Fig.3.8 the N.F.L. variation with M.F.R. for $H_2$ CNG fuel of 8.62% hydrogen and 13.41% hydrogen**

Fig. 3.8 shows that In $H_2$-CNG mixture NFL increases with increase of MFR. Increasing the hydrogen content NFL decreases. So hydrogen content increases 8.62% to 13.41%, the flame length decreases about 8-10% approximately.



5kW 10kW 15kW 20kW

**Fig.3.7 Pure CNG flame of flow rates of 8 LPM, 16 LPM, 24 LPM and 32 LPM with slow co-flowing swirling air (20 LPM air)**

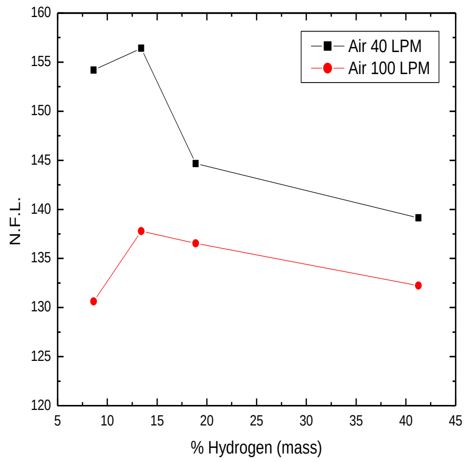



**Fig.3.9 the N.F.L. variation with % hydrogen by mass for various hydrogen concentrations with 40 LPM air and 100 LPM air**

Fig. 3.9 shows that the flame length decreases as the hydrogen concentration increases in $H_2$-CNG hybrid fuel and also that the flame length decreases with increase the swirling air content in the CNG -$H_2$ hybrid fuel. The radicals are increasing with increasing the $H_2$ addition. So increasing the $H_2$ in CNG-$H_2$ hybrid fuel, the radicals of H and OH also increases. This is the reason the combustion rate increases and then flame length decreases.

Hence if the hydrogen flow rate is increasing then more fuel is available for burning so value of NFL firstly increases and then decreases due to higher diffusivity of hydrogen in air.

### 3.3.2 Flame Colour

Fig. 3.10 shows that the base of flame is light blue and the colour of mid flame and top flame is luminous pale yellow for CNG-$H_2$ hybrid fuel flame 10 kW power level. The blue colour in base of flame increases with increase the air. Increasing the concentration of hydrogen, the flame thickness decreases. The nature hydrogen CNG flame of 10 kW power level for given condition is attached flame. It is clear that the increase the hydrogen content in the hybrid flame the flame

13.41% H2 18.88% H2 41.27% H2

**Fig.3.10 CNG-$H_2$ flame with flow rate of 11.46 LPM CNG-13.8 LPM $H_2$, 10.02 LPM CNG-18.13 LPM $H_2$ and 5.7LPM CNG-31.13 LPM $H_2$. The CNG flame firstly blue in colour with small yellow luminous at the flame tip. This yellow colour changes in blue colour after increasing the percentage hydrogen fraction. Higher diffusion of hydrogen in CNG and air appears an increase n visible blue zone width for near burner region, when hydrogen addition from 20% on wards. Non dimensional flame length increases about 5% at 5-12% hydrogen content but after 12% non-dimensional flame length decreases continuously. This results is the good agreement of existing literature (1-4)**

become to stable.

The stability limit of hydrogen is very much higher than CNG. The higher co-flowing swirling air velocity provides a lot of stability of flame. The blow out limit of the attached hydrogen flame was greater than the 161.89 m/s while the blow out limit of CNG flame was 42.46 m/s for 4 mm diameter of burner. So stability of flame was improved by addition of hydrogen gas to CNG. So the blow out limits of all CNG-$H_2$ hybrid flame lifted of attached, were much higher than the pure CNG flames. The blow out limit was observed about double by mixing about 25% of hydrogen to CNG. So addition of hydrogen is increasing not only burning velocity but also density difference between the gasses fuels. Similar observation is made by several researches [1-5]

## 4 ERROR ANALYSIS

The 10-100 LPM hydrogen rotameter and 20-200 LPM hydrogen rotameter were calibrated with soap bubble method due to less flow rate of air in hydrogen rotameter. The density ratio of air and hydrogen is about 14.74. So air is denser than hydrogen. The error for hydrogen Rota meter was about ± 2-3 %

The 20-200 Air rotameter and 10-100 CNG rotamater were calibrated with pitot tube method. The error for air Rota meter was about ± 4-5 %. The 10-100 LPM CNG rotameter was also calibrated. The error for the rotameter was measured about ± 4-5 %.

The uncertainties of flame length, blow off and lift off measurement were estimated to be about ± 2-5%. Each test was carried out three times and the average data were reported.

## 5 CONCLUSIONS

The effect of hydrogen addition on CNG in turbulent diffusion flame was investigated and the property of flame in lean hydrogen and lean CNG was also investigated.

As hydrogen content increases the visible flame size decreases and flame stability increases. For 5-20 kW the lean CNG flame was lifted flame, but mixing the hydrogen in CNG flame for 10 kW the flame was stable. It was also observed that the flame thickness decreases with increases the hydrogen percentage.

Non dimensional flame length decreases as increase in air flow rate and also non dimensional flame length decreases as decrease in M.F.R. and equivalence ratio for pure $H_2$, pure CNG and hybrid fuel of CNG-$H_2$. The flame length increases with increases the hydrogen percentage for 0-20% by mass and then flame length decreases with increases the hydrogen percentage for 20-40% by mass.

So increasing the $H_2$ in CNG-$H_2$ hybrid fuel, the radicals of H and OH also increases. This is the reason the combustion rate increases and then flame length decreases.

It was also observed that the stability limit of hydrogen is very much higher than CNG. The higher co-flowing swirling air velocity provides a lot of stability of flame. The blow out limit of the attached hydrogen flame was greater than the 161.89 m/s while the blow out limit of CNG flame was 42.46 m/s for 4 mm diameter of burner. The blow out limit was observed about double by mixing about 25% of hydrogen to CNG. So addition of hydrogen is increasing not only burning velocity but also density difference between the gasses fuels.

## 6. NOMENCLATURE

N.F.L.: Non dimensional flame length, M.F.R.: Momentum flux ratio, C.N.G.: Compressed natural gas

L.P.M.: Liter per minute, L: Flame length, D: Diameter of burner, $\rho_F$, $\rho_A$: Fuel and air density,

$A_F$, $A_A$ : Outlet fuel and air area, $V_F$, $V_A$: Outlet fuel and air velocity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