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EE11704009-Experimental investigations into the effect of depths oncircular swiss roll combustor on its thermal performance.

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Abstract

Higher energy density of hydrocarbon fuels compared to commercially available batteries provides an opportunity to generate power at small scale. So to develop mechanical systems running on the electrical energy (i.e. in few watts), which is produced from heat generated by burning hydrocarbon fuels in the small scale combustors. It is well known that the use of combustion processes for electrical power generation provides enormous advantages over batteries in terms of energy storage per unit mass even when the conversion efficiency in the combustion process from thermal energy to electrical energy is taken into account. Hence present work deals with implementing the idea of heat recirculation used with one turn circular swiss roll combustor to generate electricity. Main aim of the study was to get stable flame in the combustor and to check its heat producing capacity by varying depths of the combustors. Depths of the swiss roll combustors varied were such as 20mm, 15mm. During test LPG (mixture of propane and butane) quantity was kept constant and air quantity was varied to check effect of an equivalence ratio on the channel temperatures and heat loss to surrounding. Parameters varied during test were equivalence ratio, flow velocity. Heat loss and temperature were measured subsequently.

Keywords: *Swiss Roll combustor, Flame stability, Different depths.*

1. Introduction

Recently interest in heat-recirculating "excess enthalpy" burners, first studied over 30 years ago, has been renewed due to efforts in microscale combustion and power generation. Such work is motivated by the fact that hydrocarbon fuels contain 100 times more energy per unit mass than lithium-ion batteries, thus devices converting of fuel to electricity at better than 1% efficiency represent improvements in portable electronic devices and other battery-powered equipment. Consequently, many groups have considered heat recirculation using a counter-current heat exchanger for thermal management. By transferring thermal energy from the combustion products to the reactants without mass transfer (thus dilution of reactants), the total reactant enthalpy (sum of thermal and chemical enthalpy) is higher than in the incoming cold reactants and therefore can sustain combustion under conditions (lean mixtures, small heating value fuels, large heat losses, *etc.*)

Hydrocarbon fuels provide an energy storage density of typically 45 MJ/kg, whereas even modern lithium ion batteries commonly used in laptop computers provide only about 0.50 MJ/kg(P.D.Ronney, C.Hsienkuo, 2007).Thus, even at only 10% conversion efficiency from thermal to electrical energy, hydrocarbon fuels provide 10 times higher energy storage density than batteries. Still, these advantages of combustion processes have not yet been exploited for the generation of electrical power in small-scale systems.Applications like small space heating, small thrusters, fuel reformers (Lee et al., 2010) Small capacity fans, small propellants, sensors (Jejurkar and Mishra, 2009), run on few watts of power. The basic idea is to produce heat in small scale devices and then it can be converted into electricity by thermoelectric devices (Jejurkar and Mishra, 2009). But heat at small scale of combustor creates problems more which are because of limitation on quenching dimension for a particular fuel and issue with flame stability (Kim et al.,2005). Main problems are the amount of heat loss to atmosphere is higher, with reduction in the ratio of volume of combustion space to surface area of combustion space (Chen et al.,2009), flash back and blow out of flame (Lee et al., 2010), difficulties in manufacturing, friction(Sitzki et al., 2001) and assembling the power generating devices with minimum losses. To eliminate such problem following a attempts are made to increase flame stability: using proper thermal management systems (Kim et al., 2005), by supplying external heat (Wang et al.,2011), pressurizing incoming mixture of fuel and air, and by lower Reynolds number (Chen et al.,2009). In previous experiments performed on swiss roll combustors by using fuels like hydrogen, methane etc. To improve flame stability, it requires less mixture velocity, less heat loss to atmosphere, more residence time, more heat recirculation (Bei-Jing and Jian-Hua, 2010), less conductive materials for combustors (Lee et al., 2010).

In the present experimented study was conducted by using LPG (which mixture of propane and butane). Stainless steel combustor manufactured by EDM (Electro discharge machining). Inlet channel dimension was below quenching limit of LPG flame to avoid flash back and higher dimension of outlet channel to take advantage of heat from discharge which are let out to atmosphere.

2. Concept of heat recirculation

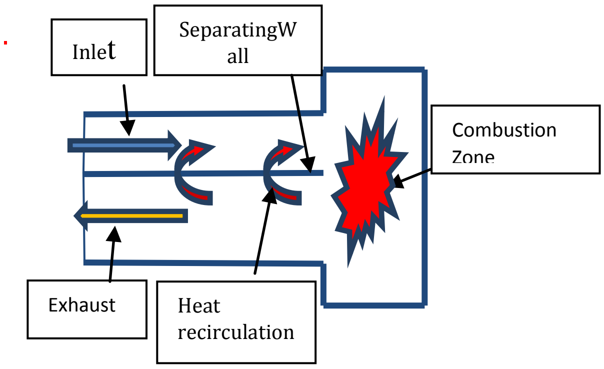

Fig.1 Heat Recirculation

On combustion of the fuel, heat is released and is distributed into:

i) Conversion of useful work

ii) Lost to the surrounding

iii) Carried along the products of combustion

The heat carried away by these products of combustion can be utilized in order to increase the enthalpy of the incoming fresh charge with the help of heat recirculation.

3. Experimental Methodology

3.1*Experimental set up*

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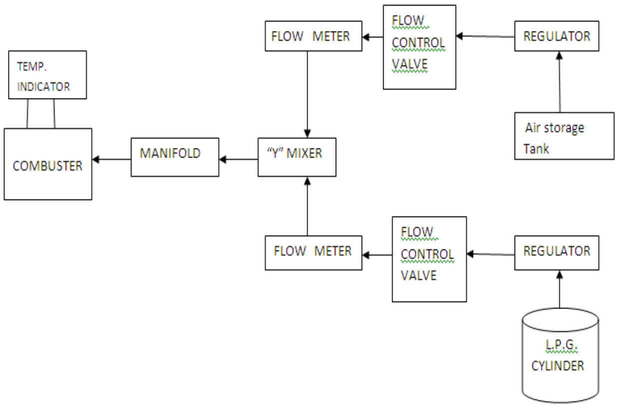


Fig.2 Layout of experiment

Figure.2 shows an experimental set up. Air storage tank, LPG tank, Y mixer to mix LPG and air, LPG flow meter (0.23 – 2.3 LPM) and air flow meter (0–20LPM), controlling valves were used in the set up. Experiment was conducted at atmospheric conditions. Initial combustion was established with rich mixture and later mass flow rate of air was increase to check flash back and

blow out conditions at same quantity of LPG. Five thermocouples are placed in the combustor; two in the inlet channel to measure the temperature of incoming air-LPG mixture, one in the combustion chamber to measure temperature of combustion and two in the exhaust channel to measure the exhaust flue gases temperature. Thermocouples were placed in the channels are shown in the Fig.5 and recorded by K type thermocouples. The surface temperatures were recorded by thermal gun.

Fig.3 Photo of an experimental set up

3.2*One turns small scale circular Swiss roll combustor*

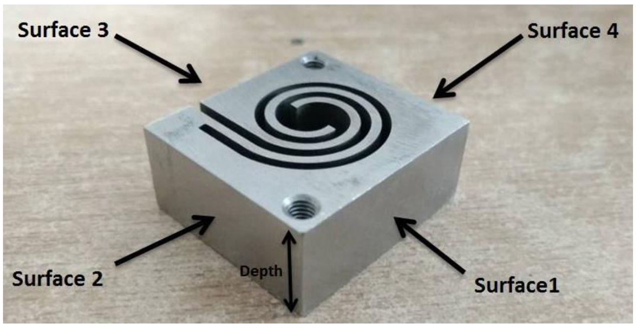


Fig.4 Combustor shows surfaces exposed to atmosphere with thermocouple locations.

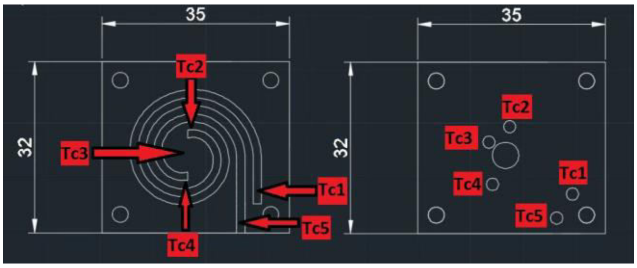
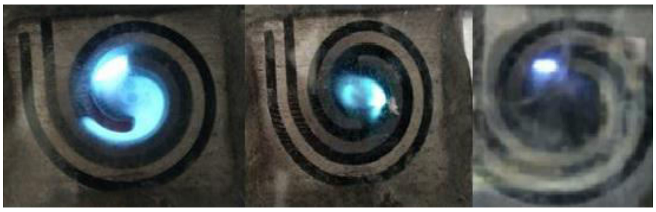


Fig.5 Combustor showing all channel & thermocouple locations.

4. Experimental results and discussions

4.1 Flammability limits

To determine LPG flammable limit in Swiss roll combustors, actual air-fuel ratio were varied by adjusting air flow rate while keeping LPG flow rate constant which varies equivalence ratio. Equivalence ratio (ϕ) is defined as actual air-fuel ratio to the stoichiometric air-fuel ratio. Continuous heat generation is a requirement of thermoelectric device to generate electricity at constant rate (Jejurkar and Mishra, 2009).At the beginning of an experiment LPG flow rate was fixed and air flow rate was gradually increased or decreased to get varying equivalence ratio between which stable flame observed at center. Blowout was observed for all the models and at a particular flow rate more than beginning speed of flame, because of exhaust channel dimension which was more than quenching dimension shown in Fig6(c). .Flash back was occurred when equivalence ratio (ϕ=1.124) shown in Fig.6(a).Stable flame was observed when equivalence ratio (ϕ)=1.0125 as shown in Fig.6(b)



(a) **(b)** **(c)**

Fig.6 Flame conditions: (a) Flash back (b) Flame stable at center(c) Blow out

4.2 Optimized conditions of maximum total heat loss (Q_{total})

Heat loss is varying from surface to surface which calculated by using surface temperature measured. Method used by(Kim et al.2005) was implanted for heat loss calculations. For 20 mm and 15 mm depth as an equivalence ratio increases heat loss increased up to a particular limit and beyond that it decreases because mixture become leaner resulting in less combustion temperature and less thus heat loss shown in Fig.7 and 8. At richer side greenish color of flame is observed due to incomplete combustion, while at leaner side as more air was present resulted in proper combustion with blue flame.

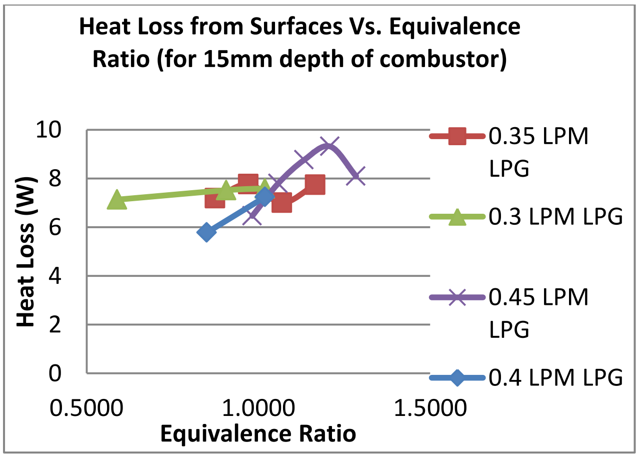


Fig.7 Variation of maximum heat loss vs equivalence ratio (15 mm depth)

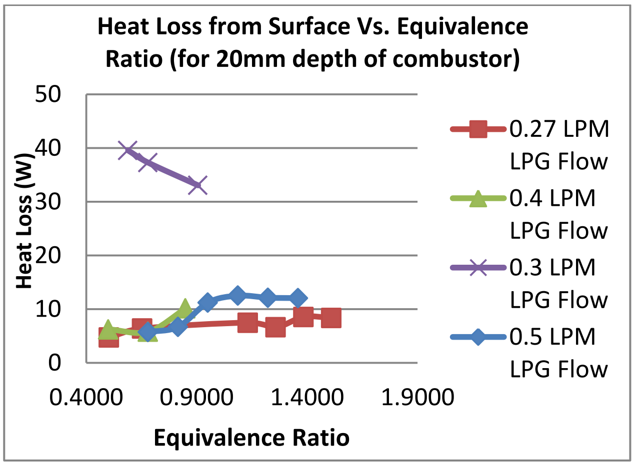


Fig.8 Variation of maximum heat loss vs equivalence ratio (20 mm depth)

4.3 Temperature profile

To find out heat sharing between the channels wall, thermocouples were inserted into channels through bottom plate and temperatures were recorded. Fig.9 shows for the depth of combustor was 15mm, variation of temperature in the channels with equivalence ratio, at different locations of thermocouples.

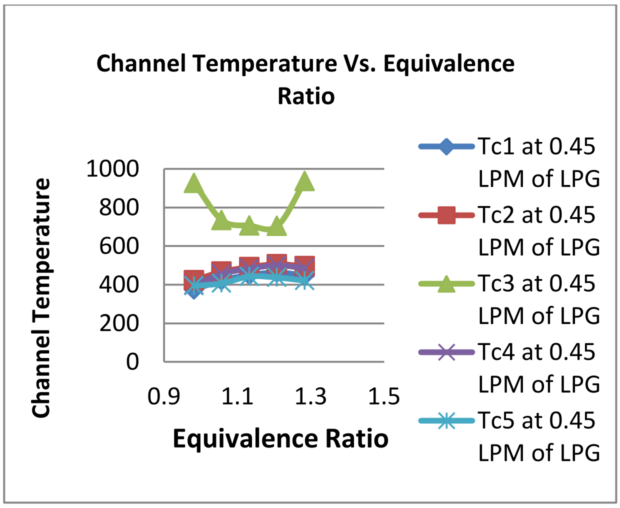


Fig.9 Variation of temperature vs equivalence ratio for 15mm depth

The thermocouple Tc3 was placed in actual combustor space measured highest temperature of 936 K when equivalence ratio was 1.2841. It was also observed that thermocouples located at far distance from center region measured lower temperatures because of heat conduction through walls and convection through gaps. The thermocouple Tc1 measure lowest temperature of 375 K at equivalence ratio was 0.9820 as shown in Fig.9.

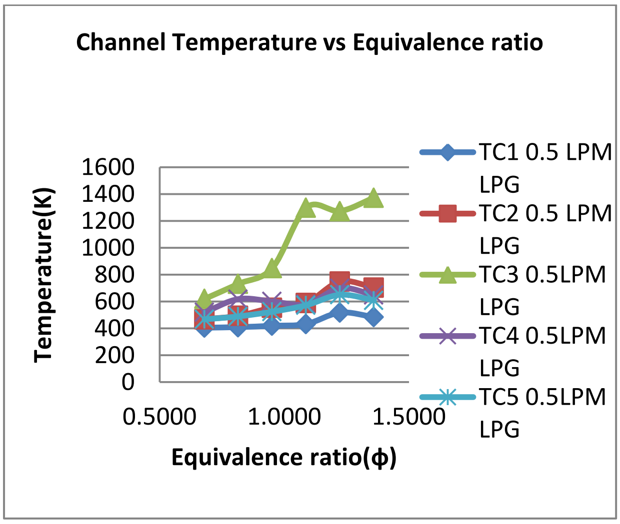


Fig.10 Variation of temperature vs equivalence ratio for 20mm depth

Fig.10 shows for the depth of 20mm, variation of temperature in the channels with equivalence ratio, at different locations of thermocouples. It shows for 20 mm depth, the temperature in combustion space is higher than the 15mm depth. The thermocouple Tc3 measured highest temperature of 1373 K when equivalence ratio was 1.3597. The thermocouple Tc1 measure lowest temperature of 406 K at equivalence ratio was 0.6798 shown in Fig.10.

5. Conclusion

Stainless steel combustors were tested for different depths at Meso scale. With decrease in the depth of combustor heat exchange area between inlet charge and exhaust gases decreased resulted in to less combustion temperature. During experiments combustion temperature observed for 20mm depth is higher than 15mm depth, because of uniform distribution of mixture along the depth i.e. fully develop flow through inlet channel of combustor and efficient combustion. Temperatures are higher close to equivalence ratio equal to. Stable flame was observed for all the experiments conducted. Heat loss was higher in case of higher depth (20mm), because of more area were available for heat transfer. There is more scope in future to develop a model with more number of turn and provide insulation to improve flame stability.

6. References:

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