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# A review on small scale combustor and power generator

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## ABSTRACT

**In recent decades the demand of small scale high energy density producing devices are increased too much. And these devices are should be compact, lightweight and highly powerful. Conventional chemical batteries or highly developed Li-Ion batteries are not able to complete the demand of electronic devices. And high energy requirement of electronic devices is increased day by day and gap between supply and requirement is widen. The hydrocarbon fuels having much more energy density than chemical composition used in the batteries, which is 50 to 100 times more. Therefore high energy density hydrocarbon fuels are good alternatives for the batteries and which are best in technologically also. Because of growing demand for smaller scale and higher energy density power sources, various combustion-based micro power generators are being developed around the world. The main application involves generation of electricity via the heat released by the combustor by using the Seebeck and Peltier effect. This review paper provides update on recent progress and development in small scale combustion and small power generator. Also this paper focus on the experimental work that has been conducted on small scale heat recirculating swiss roll combustor and effect of geometry, material and scale of the combustor. This paper also works on thermal performance, extinction limit and flame dynamics.**

***Keywords—*** **Combustion Chamber, Extinction limit**

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## I. INTRODUCTION

There has been increase in interest in MEMS based micro system because of rapid development in MEMS. This system converts chemical energy directly or indirectly into the thermal or electrical energy by using the thermo photovoltaic material to convert radiant energy. But the convection efficiency of this material is very low and which is not useful in case of micro combustor practical application. In such cases other type of converter is used called as piezo-electric type converter [16]. But which is having micro prime motor. The advantage of this system is the system is works on the hydrocarbon fuel of very high energy density. The micro-power generators show better performance than conventional batteries if only the efficiency is higher than 1% [3]

One of the key factors for micro combustors is stable and sustainable combustion. But with decrease in the size of geometry, the surface to volume ratio increases and due to this instability in the combustion chamber increases because of scale effect [3, 4]. Heat loss to the surrounding becomes relatively large as compared to relatively large as compared to a standard sized flame as the flame scale is reduced, then the flame gradually loses the stability and is eventually quenched. Different kinds of devices are developed to overcome the disadvantage of stability limit. And the example of such kind of device is swiss roll combustor which is having combustion space at the centre of combustor. And which works on the excess enthalpy concept shown in Fig. 1.

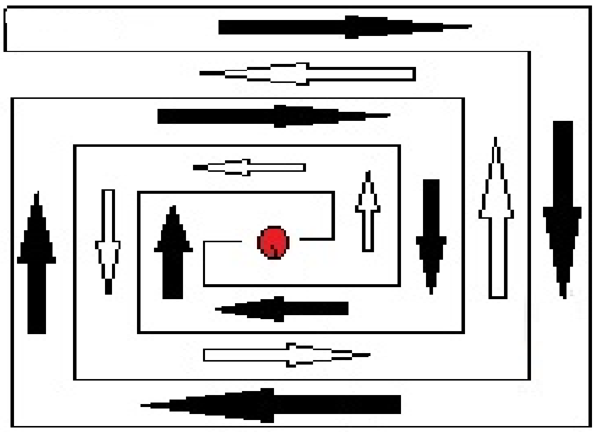

Fig. 01 Swiss Roll Combustor

For reducing this effect of excess enthalpy is proposed by Weinberg et al [17]. in excess enthalpy combustor combustion product and air flow mixture flows parallel but opposite in direction or in counter flow with each other because of that excess heat is supplied to air fuel mixture and increase the total enthalpy of combustion.

Extinction is caused by excessive heat loss to the inner wall and due to that the flame speed is increases and extends the flammability limit. Roney developed the simplest model of counter flow heat recirculating combustor model with operating limits and the effect of Reynolds number on performance of combustor. The propagation of flame possible only when the combustor size is larger than the quenching distance. And the quenching distance depends on rate of reaction and heat loss to the ambient. The quenching distance is also depends on the temperature and the pressure of operating system. Rate of reaction is and operating conditions are also controlled by catalytic surface.

Weinberg et al. reported steady combustion with swiss roll combustor with mixture well beyond normal flammability range. The channel size used for swiss roll is larger than the quenching distance. At an atmospheric temperature and pressure [9, 10] studied 3 combustor of different size and same geometry, the characteristic length are smaller than the quenching distance and achieved the stable combustion.

## II. MICRO COMBUSTOR

**Flame dynamics in micro swiss roll combustor-**

To study the flame phenomenon in micro swiss roll combustor, three micro swiss roll designs were designed using stainless steel [9], by EDM technique. The structure diagrams are shown in fig [2]. The locations of thermocouple of respective swiss roll combustor are also shown in figures.

All combustors are featured with double spiral channel the width of channel is 0.6 which is smaller than methane quenching distance [11] at normal state. The experiment shows the stable combustion of methane and air in three combustor. And the centre of the combustor is incandescent and because of that highest temperature attended at the centre and with the help of this we ensure that the combustion is happened at the centre. We also concluded that the only preheating is done in the combustor channel because the channel size is less than the minimum quenching distance of methane/air mixture. Because of only preheating in the channel the total enthalpy of premixed mixture is sufficiently increased.

For finding out methane air flammability range in the micro swiss roll combustors, stoichiometric air-fuel ratio is varied by varying the flow rate of whether varying flow rate of air or methane and keeping other constant. Figure shows the main structural parameters of three swiss roll combustors. These three models may have different numbers of turns. There are main three tasks of these study is to find out (a) air fuel rich and lean limits (b) temperature distribution along the combustor chamber and (c) extinction limits of methane/air mixture in swiss roll combustor for different Reynolds number. Equivalence ratio is defined as the ratio of air to fuel ratio to stoichiometric air-fuel ratio.

Fig. 3 shows the typical set of time history of temperatures and reactant ER, where panel

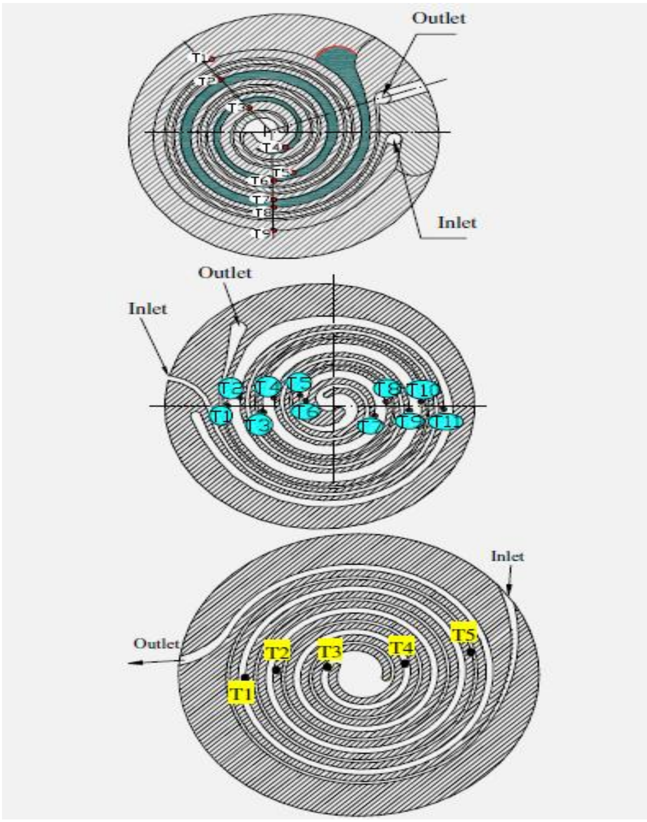


Fig. 2 Structural Diagram

| | Model I | Model II | Model III |
|---|---|---|---|
| Channel depth (mm) | 7 | 7 | 10 |
| Channel width (mm) | 0.6 | 1.0 (exhaust channel) 0.6 (premixture channel) | 0.6 |
| External diameter (mm) | 55 | 55 | 40 |
| Thermal insulation in gaps | With high-temperature adhesive | With alumina powder | Without |
| Thermal insulation in ends | With high-temperature adhesive | With alumina powder | Without |
| Channel turn | 3 | 2.5 | 4 |

Fig. 3 Main Structural Pentameters of Swiss Roll Combustor

(a) Shows the determination of fuel lean limit and panel (b) for the fuel rich limit. The highest temperature is attained at ER= 1.0. Later the air flow rate was increased and readings are taken for different ER and Reynolds number for different Swiss roll combustor. It can be seen that the flammable range for the combustor I is wide and methane can be burned stable for wide range of equivalence ratio. The fuel rich limit for combustor I is near ER=0.8 and fuel lean limit is 2.0 were observed at Re=410 the combustion heat release is estimated at a rate of 410 W [9].

The flammable range for model II combustor is significantly extended in comparison to that of 1 with combustion stability. The model II combustor can operate with greater Re and equivalence ratio. Fuel rich and lean limits are changes with Re in case of combustor II. The changes in the fuel lean limit is relatively significant and the flammable range changes rapidly with Re. the fuel rich limit near ER = 0.65-0.70, and fuel lean limit near ER = 2.35 were obtained at Re = 524. The estimated heat release rate is 112 W. The comparative study is shown in fig 4.

Figure 4 shows the flammable range for model 2 without recirculating and insulation. It is found that the flammable range is much narrowed compared to combustor 1. These suggest the effect of recirculation on combustion characteristics of Swiss roll combustor.

The flammable range for methane/air mixture in the model 3 were narrower than 2 combustor using both high and low Re. the fuel rich limit near ER = 0.73 at Re = 128 and the maximum lean limit was reached at Re = 318. The combustion stability is best in the methane flow condition. The estimated heat release rate is about 192W at Re = 430.

The comparison of flammable ranges of methane/air mixtures in the Swiss roll combustors are shown in figure 4. The model III combustor has the smallest flammable range although it has most efficient heat recirculation. The most stable combustion occurred in the combustor III at high methane flow rate or larger than 1.2 mg/s. in the micro swiss roll combustor loss of heat is most important factor that controls the combustion stability in micro scale combustor.

**Temperature distribution in the combustor [13]-**

In this study, methane air mixture of various equivalence ratios were achieved by changing the air flow rate while keeping the methane flow rate constant. Temperatures are recorded with the help of thermocouples for every equivalence ratio after attaining the stable combustion. For the model I gap

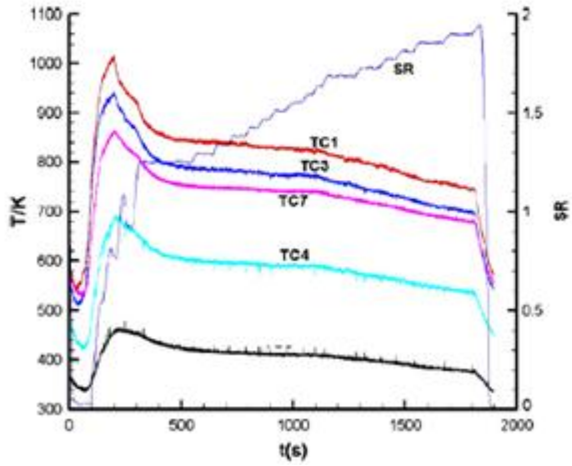

Fig. 4 (a) fuel lean limit

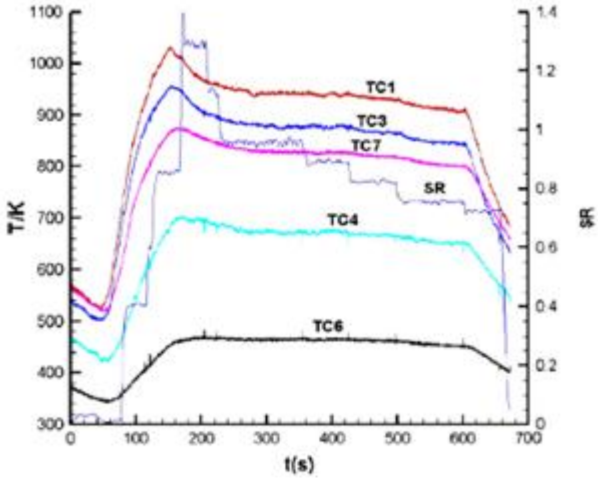

Fig. 4 (b) Fuel rich limit

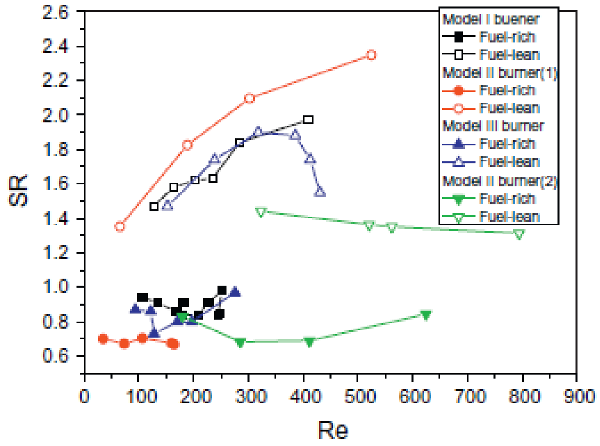

Fig. 5 Extinction limits of Methane/Air mixture in swiss roll combustor

Between inlet and outlet are filled with high temperature adhesive as thermal insulation and
External surfaces are also insulated by thermal insulator. And the series of readings are recorded for different flow rate of methane and equivalence ratios as shown in figure 5. From the figure it is clear that the temperature is highest at the centre of the combustor and gradually decreases along the radial direction. It indicates that methane air mixture can establish stable combustion at the centre. Wall temperature

curves as a function of ER in model I combustor, wall temperature having their maximum temperature at ER = 1. The wall temperature increase when larger methane flow rate were used, for example, the maximum wall temperature is 1200 K At methane flow rate is 2.27 mg/s while is 850 K at 1.04 mg/s at ER = 1.0.

Figure 7 shows the temperature profile measured in model II combustor over a range of different methane flow rate. Each temperature profile is at equivalence ratio. Temperature at the centre is increase with methane flow rate, the maximum temperature reached at the centre is 1250 at methane flow is 2.17 mg/s at about ER = 0.7 and the minimum temperature at the centre is reached is 750 K with methane flow rate is 0.43 mg/s. Temperature at the centre is much higher than the edge temperature. This indicates that the thermal insulation between exhaust and reactant channel suppress the heat transfer and heat loss to the ambient is reduced due to thermal insulation external side of combustor. Figure shows that the temperature profile of the combustor is function of Reynolds number also.

Figure 8 indicates that temperature distribution of model III combustor over a range of Re and ER values. Figure shows the temperatures are relatively uniform along the radial direction of combustor with small variation. Because there is no thermal insulation at the external side of the combustor. It has large heat loss to ambient and due to this narrow flammable range as compared with other two combustor. The largest temperature at the centre is low as compared to other two at high methane flow rate, due to combustion instability or even extinction when non stoichiometric mixture was used. The surface temperature profile is the function of Re at ER = 1.

## III. FLAME STABILIZATION AND COMBUSTOR TEMPERATURE

A Swiss-roll combustor consists of a combustion room at the center and a pair of long

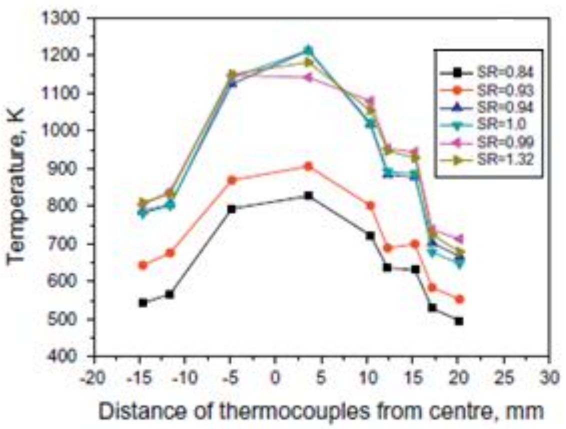


Fig. 6 Wall Temperature Distribution for model I

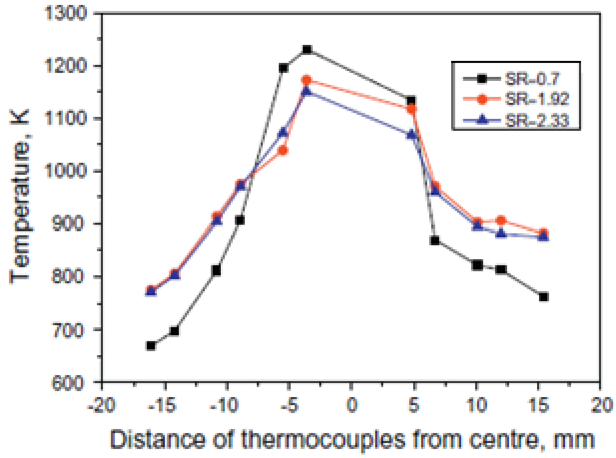


Fig. 7 Wall Temperature Distribution for model II

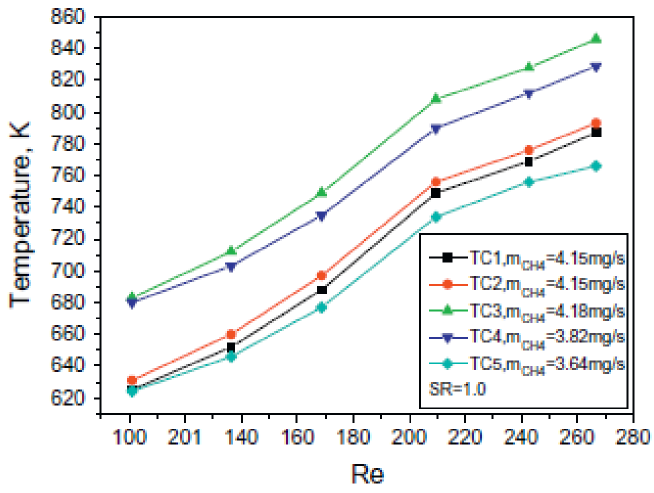


Fig.8 Variation of temperature with Re, Model III

Channels for heat recirculation from the burned gas to the unburned mixture. Figure 9 shows a Swiss-roll Combustor in which a flame was successfully stabilized. Three types of Swiss-roll combustors were precisely fabricated using the electro discharge machining (EDM) technique to the specifications shown in table below. Those three types of combustors are denoted as S, W, and D-combustors. The mean velocity was defined as the mass-flow rate divided by product of the density of the reactants and the cross sectional area of the channel. Flame position can be controlled easily by adjusting the mean velocity. This characteristic can be used to stabilize the flame at the center at the initial state. The flame speed is affected by pressure, temperature, and equivalence ratio. Thus, the flammable limits of various Swiss-roll combustors were investigated for various equivalence ratios and mean velocities. Results are shown in figure 10. A premixed flame in a channel can be stabilized when the mean velocity is similar to the laminar burning velocity.

Minimum velocities of each flammable regime of the experimental cases decreased in the order of W, Sq, S, Si, and D. Minimum mean velocities of W, S, and D-combustors were 3, 1.7, and 0.42 m/s, respectively.

In this experiment, the temperatures of the combustor having a similar trend and the deviations from the mean temperatures were small.

Therefore, the mean temperature of the combustor was considered to be a representative parameter for comparison of various experimental conditions. The dependency of the mean temperature on the mean velocity was investigated at stoichiometric for the five cases of this study. The results are shown in figure 10.

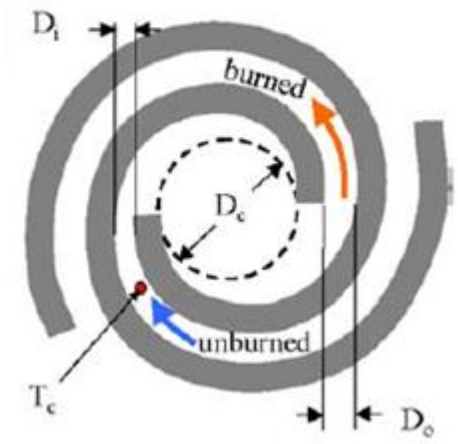


Fig. 9 Geometry of combustion Room

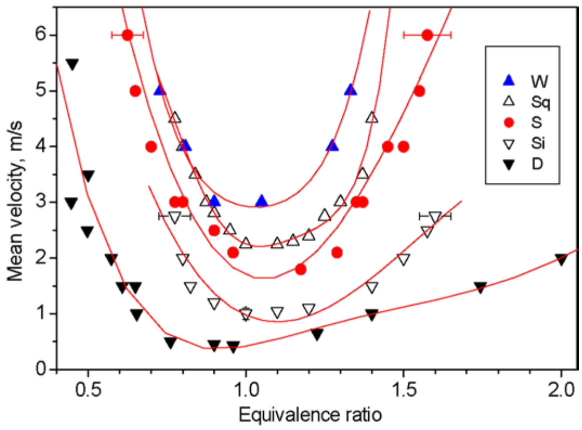


Fig. 10 Flame stabilization conditions for various combustors and different heat transfer conditions

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