Performance Analysis of Swiss Roll Combustor by Varying its Dimensions using CFD

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ABSTRACT

Within recent years, there has been increase in amount of interest in utilizing high energy densities of hydrocarbon fuels at small scale. The reason behind this is primarily, generation of electrical and mechanical energy through the heat released by combustion process. Taking this into consideration, many schemes regarding thermal challenges associated with small scale combustion have been studied and relevant suggestions are proposed to solve problems. The main motivation behind Micro-combustion research is the development of portable, autonomous power generators like, micro TPV (thermo-photovoltaic) with improvement in energy density over batteries. 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. Heat recuperation is a technique which contributes to better energy efficiency performance by recovering heat from the exhaust gas. Among different heat-recirculating combustors, the Swiss-roll combustor which recirculates the heat via a counter-flow heat exchanger is considered thermally very efficient due to the large ratio of heat exchange to heat loss area. However, due to complexity of the interaction between heat transfer and chemical reaction, the design of the combustor especially for small scale application is not straightforward. Therefore, to properly apply Swiss-roll combustors, it is necessary to obtain further understanding of its performance at different scales by using CFD. The CFD analysis has been used to identify important thermal pathways within the system.
To find the optimum parameters for the combustor, a study of the effects of dimensions on a SS 304 single turn Swiss-roll heat recirculating combustor was conducted. The difference between flow recirculation between two different chamber dimensions has also been done in order to find out the most optimum dimension. Methane gas is used as a fuel. The simulation via ANSYS FLUENT has been carried out for two depths- 10mm, 20mm at different flow velocities. The experimental results that were obtained were validated by using CFD software.

Keywords: Micro-Combustion, Swiss-Roll Combustor, Counter-Flow Heat Exchanger, CFD analysis.

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1. INTRODUCTION

Hydrocarbon fuels contain about 50 times more energy per unit mass than state-of-the-art batteries, thus devices converting fuel-to-electricity at greater than 2% efficiency represent improvements over batteries for portable electronics [1]. At small scales, however, heat and friction losses become more significant, thus fuel-to-electricity conversion devices based on existing macro-scale systems such as internal combustion engines may be impractical. Consequently, many groups have considered heat-recirculating or “excess enthalpy” combustors for thermal management and thermoelectric, piezoelectric or pyroelectric devices, having no moving parts, for power generation. In heat-recirculating combustors, by transferring thermal energy from combustion products to reactants
without mass transfer (thus reactant dilution), the total reactant enthalpy (sum of thermal and chemical enthalpy) can be higher than in the incoming cold reactants and therefore can sustain combustion under conditions (lean mixtures, low heating value fuels, large heat losses, high flow rates) that would extinguish without recirculation.

One popular type of excess-enthalpy combustor is the double-spiral counter-current Swiss roll heat recirculating combustor [2,3] which provides large ratios of (internal) heat exchange area to (external)heat loss area and thus broad extinction limits. Besides application to small-scale portable power, at larger scales Swiss roll combustors have shown promise for portable air purification devices [4]; because of high combustion temperatures any toxic chemical or biological agent can be destroyed, while the very lean mixtures yield exhaust products with sufficiently high O2 levels and low CO2 levels such that the exhaust is breathable.

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Moreover, stable combustion has been demonstrated over more than a 1000-fold range of flow rates and 100-fold range of equivalence ratio in a single device [5], thus Swiss roll and similar combustors are potentially useful in many applications where the reactant flow and/or mixture strength may vary substantially.

2. CFD RESULTS AND DISCUSSION

2.1 Flow Recirculation

Flow recirculation was checked for the two models shown in the figure 1 out of which model 2 showed better recirculation characteristics. This model was then further checked for recirculation characteristics at two different depths of 10 mm and 20mm.

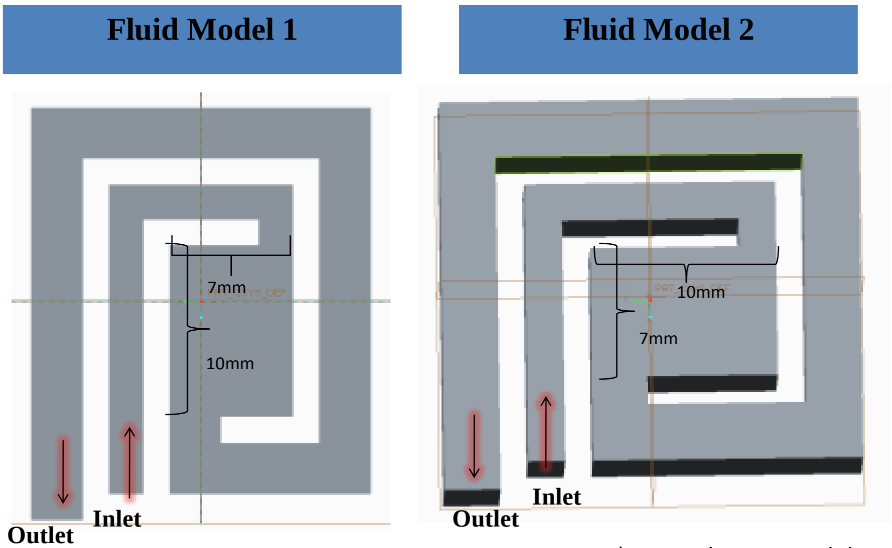


Figure 1: CAD MODELS

The **Damkohler number** is used in turbulent **combustion** and corresponds to the ratio of chemical time scale and turbulent time scale. This turbulent scale is usually taken as the integral scale. **Damkohler number** measures how important is the interaction between chemistry and turbulence.

$$Da = \frac{\text{Residence time}}{\text{Chemical reaction time}}$$

Damkoher Number gives us the ratio of the residence time of the mixture in the combustor to the chemical reaction time. The value should be greater than 1 in order to have a stable flame. Thus the increased recirculation in the chamber causes a longer residence time and thus helps in attaining a stable flame. This also increases the chances of complete combustion of the incoming air-fuel mixture, thus increasing the thermal efficiency. The analysis of the recirculation of the air fuel mixture is shown as follows.

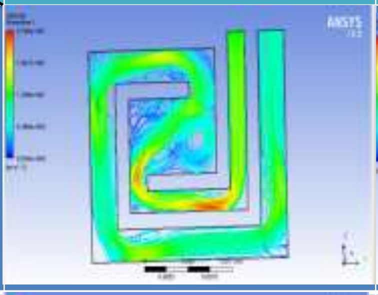
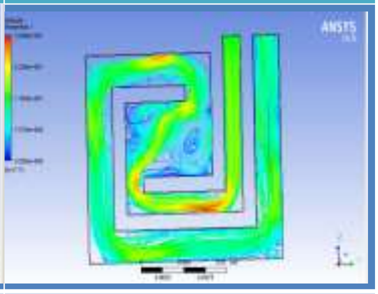
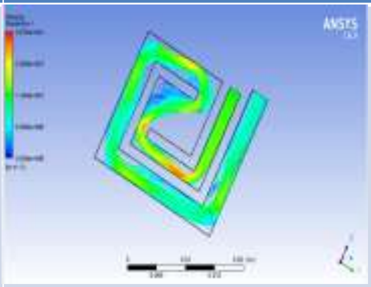
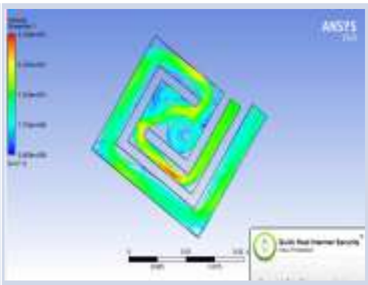
VELOCITY / DEPTH	13 m/s	15 m/s
10 mm		
20 mm		

Fig 2: Flow recirculation comparison

The general observation from figure 2 and 3 is that the recirculation inside the chamber is directly proportional to the inlet velocity. The higher the inlet velocity, higher will be the recirculation. This large recirculation leads to higher stability of the flame.

The figures also show the difference between recirculation patterns obtained for 10mm and 20mm depth. It can be seen that the recirculation for 20mm depth is not throughout the depth but instead is near the surface, whereas incase of 10mm depth chamber the flow is throughout the depth, thus optimizing the size of the chamber and reducing the cost of the otherwise extra material needed.

2.2 Combustion Analysis:

The combustion analysis was carried out in Ansys Fluent 16. The geometry was taken only of the central combustion space. The meshing was also carried out in fluent. The number of nodes in the mesh were 31400 and the number of elements were 31000. The meshing done was a structured mesh in order to have maximum accuracy and minimum aspect ratio. A uniform structured mesh gives the best results for symmetrical geometry.

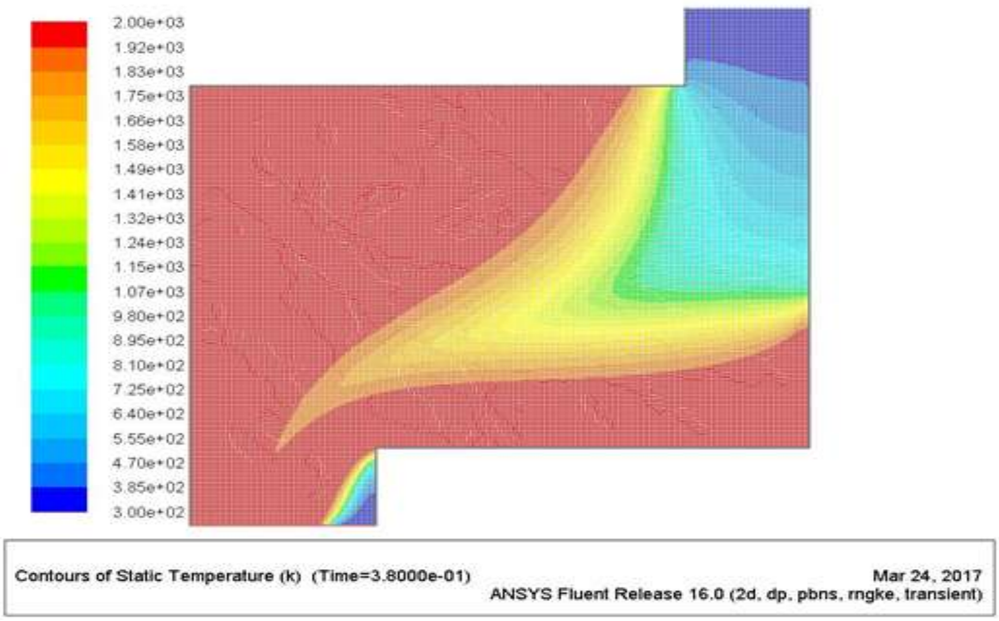


Fig 4: Main chamber with flame front.

While doing the combustion analysis, only the central part of the chamber was considered due to the meshing and time consideration. The flame was initiated with the help of a spark, located at the centre of the chamber. The different contours of various colours indicate various temperatures which have been described alongside the simulation. The conditions that were simulated were adiabatic and thus only the flame front is clearly visible. The flame front is the region where the actual product formation takes place. The maximum adiabatic temperature that was attained during the combustion is 2000K.

3. CONCLUSION

Higher flow speeds result in better recirculation.The decrease in depth of the chamber results in better recirculation. Flow recirculation in the combustion chamber leads to a better flame stability.

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