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A Simulation Study of Methanol Fuel in Alcoholic Cooking Stove

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Abstract: It is very difficult to study the burning behavior of liquid fuels in real condition according to fuel's operating conditions. Also, the chemical kinetics of a fuel changes the dynamics of combustion. There are many residue products like soot, NOx to be considered in fuel combustion efficiency. The purpose of enhancing efficiency can be solved by two methods either by improving design specification of stove or improving the flame efficiency. This study reports the CFD simulation and experimental verification methanol & Ethanol combustion in a stove using temperature profile of a flame. Using computational fluid dynamics has been a useful tool for optimizing the efficiency of burners in the last two decades. However, its relative precision has not yet been sufficiently refined. Also, the chemical kinetics of a fuel changes the dynamics of combustion. There are many residue products like soot, NOx to be considered in fuel combustion efficiency. Various studies have been done on spray combustion simulation. One of the important parameters, which has received little attention in the past, is a detailed knowledge of the interaction between the evaporating droplets and the surrounding chemically reacting flow field. The simulation study has shown the range of methanol flame propagation and combustion products to be compared with other fuels.

***Index Terms* - CFD, Methanol, Ethanol, Combustion, Flame Diagnostics**

I. INTRODUCTION

Cooking energy accounts for a large share of total energy use in developing countries. Given the vast size of use, even a slight increase in efficiency will have a significant overall influence on fuel economy. 2.5 billion people worldwide use fuel wood, charcoal and dung for cooking and heating, which has been linked to respiratory infections, stunting growth, pneumonia and diarrhoea .The importance of this problem has also been addressed in recent literature reviews. In addition, the emissions of these fuels contribute to climate change, which has severe consequences for human health and the environment*[1]*. This has led to the development of a new generation of cookstoves and fuels. This study aims to study & evaluate the performance of a canister-based methanol stove for cooking purposes. The performance of the stove under different operating conditions such as flow rate and pressure of methanol, has been investigated. The results of previous study have helped in the selection of the cooking stove for the use of methanol. Methanol emits less CO and NOx compared to other cooking fuels. The NOx emission of methanol stove has been found to be less than 1 ppm *[2]*. For using methanol as a cooking fuel, the currently available favorable technology is the canister-based stove. This technology handles methanol in a very safe manner and does not require a regulator or piping system. The canister-based methanol stove, also known as an evaporative stove, is a stove that produces heat by evaporating methanol vapors from a canister. *[3-5]* The methanol stove is made consisting of a stainless-steel construction (stove body) with a pot support at the top and facilities on the sides to help with canister insertion and removal. Mineral wool is used to retain the methanol in the canister, which is made of stainless steel. The fuel supply is controlled by a power control lever on the stove. Inside the canister, the fuel is adsorbed by firmly packed mineral wool. Capillary motion transports liquid methanol from the mineral wool to the evaporative surface at the top, i.e., the canister top opening. The canister hole fits beneath the combustion chimney, while the side vents allow air into the chimney. In the chimney, methanol vapour and air combine to generate a flammable mixture, which ignites above the surface of the canister opening. The FP levels are determined by fuel burning rates. As a result, the fuel burning rates were carefully monitored throughout the studies. The ratio of energy consumed during water heating and evaporation to energy provided by burning the fuel is known as the stove's thermal efficiency. A circular array of laminar jet flames impinges on the vessel in a traditional household burner. While some research has been done on heat transmission from a single or multiple jet flames impinging on a flat plate, knowledge of real flame behavior for a burner assembly is still lacking. Accordingly, there are two regions of peak temperature along a radial line from the center burner to outside. Heat transfer from a laminar jet flame hitting a flat plate is very sensitive to the ratio of the height of the plate to the height of the flame *[6-7]*. The efficiency seems to be maximum when the height of the plate is slightly less than the height of the flame.

Figure 1 : Canister based Alcoholic Cooking Stove

II. Numerical Modelling

Controlling the efficiency of numerous industrial processes, such as combustion, is virtually always a hot topic. It is based on a prior input stream characterization, needed stoichiometric conditions, and measurements of the main species in the exhaust. Computational models and simulations are beginning to play an increasingly essential role in optimising the performance of combustion systems. CFD models are useful for determining how potential improvements affect overall performance in a reasonably cost-effective way. Computational fluid dynamics (CFD) algorithms have complimented traditional techniques based on expensive experimental tests in the last two decades as a predictive and design technique for improving energy system efficiency*[8]*. Despite the relative precision that a CFD simulation can provide in describing the complicated fluid dynamics that occur in burners , where specific combustion performance is of relevance & more research is required. It is extremely difficult to examine the burning of liquid fuels directly in real boilers in engineering practise. The fuel's burning behaviour should be considered during burner design, and the operating parameters should be determined by a preliminary examination of the fuel *[9]*.A schematic test section has been shown in Fig 1. The main objective of this model is to get a flame temperature profile. This profile could help in getting optimal loading height that would enhance burner efficiency. The numerical modelling of flow and combustion is done using CFD software like Ansys Fluent & Chemkin. It consists of a rectangular test section 0.25 x 0.5 m^2.

Figure 2: Geometry of test section for combustion

Volumes, surface, edges, and vertices have all been aspects of the model's geometry. For meshing technique, any of these items can be employed. Model meshing is the most essential part of the CFD procedure. The meshing technique will determine the quality of the meshing. Mesh will produce a grid of cells or elements that will answer all of the desired fluid flow equations. For this simple geometry Quadrilateral/hexahedral meshing is used, which is smoothen by face meshing.

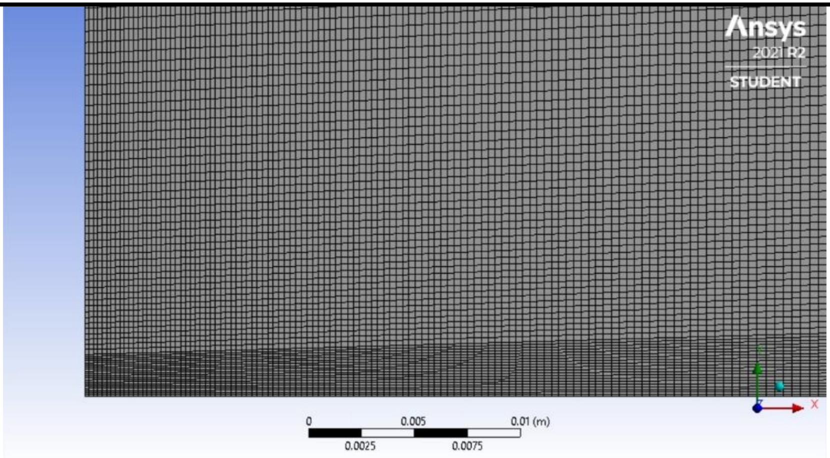

Figure 3: Quadrilateral Meshing of geometry, upper part showing air inlet & lower part fuel inlet.

CHEMKIN was used to conduct a chemical examination of the combustion process. The chemical mechanism that was used was CRECK *[10]*, which is believed to be the most thorough mechanism in the public literature. Unlike other mechanisms, this one contains choices for determining the concentration of CO, NOx & Soot in combustion products as well as the most recent chemical kinetics reaction data for Premixed Stabilization Flame simulation.

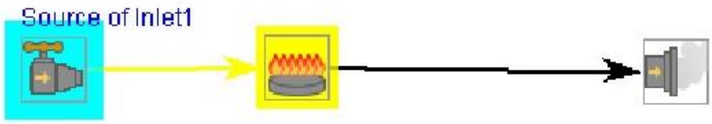

Figure 4: Chemkin project flow diagram for premixed flame

- Solver Type was selected as Pressure based, Absolute Velocity Formulation; Steady Time & Axisymmetric 2D space.
- Energy & Wall Prandtl number is kept 0.85.
- Boundary conditions: mass flow at the entrance to the burner; pressure at the outlet.
- Turbulence Model: Standard k-ε turbulence model, standard wall function.
- Flow entry parameters: air mass flow rate 5.41 g/s, inlet temperature - 300K, reference pressure - 101325 Pa. Methanol mass flow rate – 0.833 g/s.(AFR for methanol/air is maintained at 6.5:1)
- Solution method – Steady state, pressure velocity coupling; solver - pressure-based, SIMPLE scheme, method of a discretization – second order upwind.
- Combustion model: Premixed steady diffusion flamelet. CRECK detailed chemical kinetic mechanism used for laminar flamelet calculations.
- NOx & Soot emissions were evaluated using the FLUENT postprocessing. Absolute convergence criterion for flow simulations

IV. RESULTS AND DISCUSSION

Temperature distribution along the combustor is shown in Fig. 3 . One can see a gradual increase in temperature towards the exit with a non-smooth profile. This shape of temperature distribution is due to the simulation of methanol combustion in a constrained environment. The adiabatic flame temperature for methanol is around 2100 ˚C but the result shows slightly higher temperature due to lack of air inlet from the walls. It has been discovered that the heat transmission potential of these gases is underutilized. Thus, a mechanism that improves heat transfer by efficiently circulating gas around the vessel, increasing the time of hot gas contact with the vessel, or raising the temperature gradient between the flue gases and the vessel will improve the thermal efficiency of the system

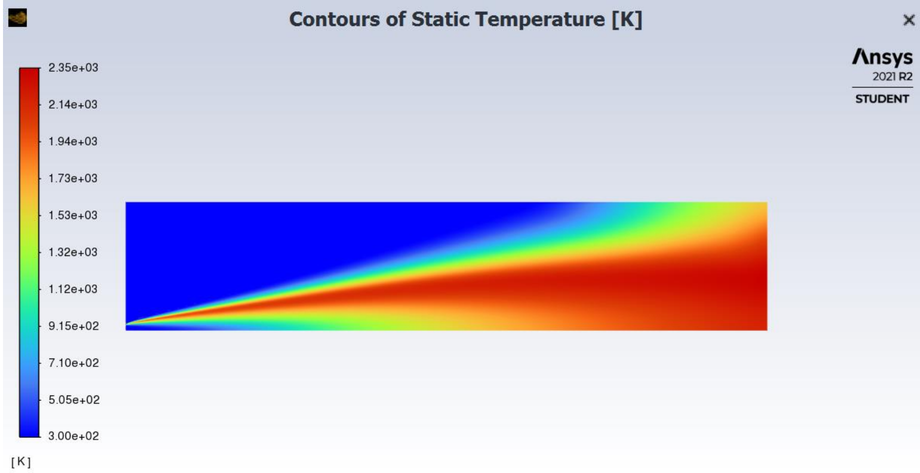

Figure 5: Temperature Profile for methanol combustion

The adiabatic flame temperature for methanol is nearly 20% less than LPG (2673 ˚C) so we can conclude that the methanol can be suitable for cooking application with suitable design changes for flame spreader.

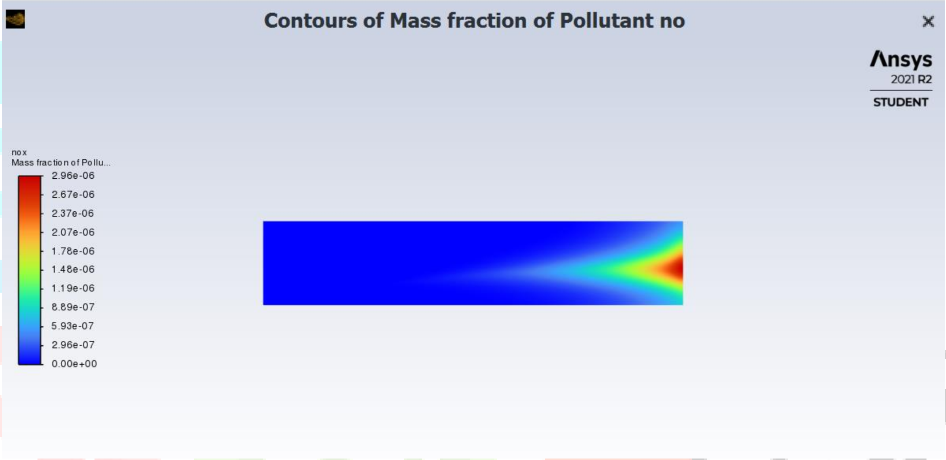

Figure 6: Mass fraction of NOx in Methanol

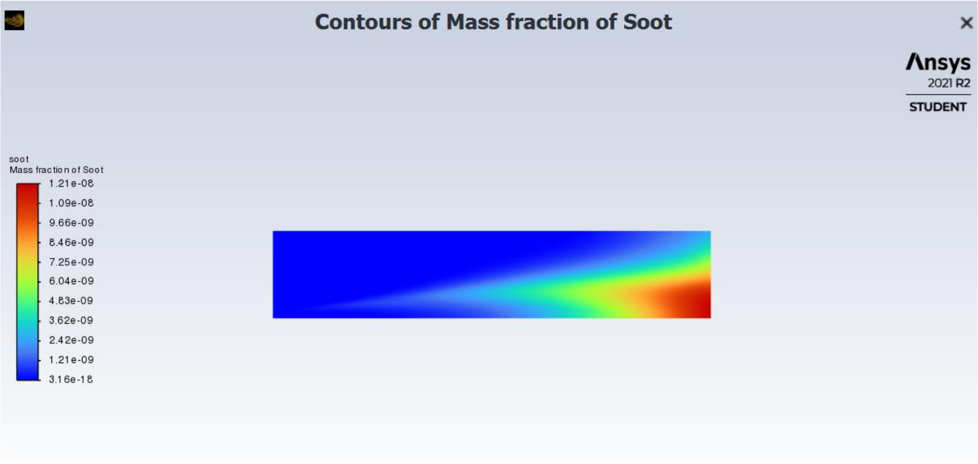

Figure 7: Mass fraction of Soot in Methnaol

The results above show that the Soot & NOx formation in methanol combustion is very less, when compared to Ethanol . Also, NOx formation takes place at high temperature so distribution indicates the flame height at which maximum temperature is available. It will be useful to decide the optimum loading height of the stove. This also suggest that Methanol is very clean and hazard free fuel it is suitable for cooking purpose despite of having lower calorific value.

III. CONCLUSION & FUTURE SCOPE

The purpose of this study is to see if methanol can be used as a domestic cooking fuel in India. To emphasise the benefits of the methanol stove, the performance of several household stoves was compared to the methanol stove. The improved thermal efficiency of the methanol stove is an advantage from the user's perspective. Methanol stoves produce cleaner combustion and fewer CO emissions. The methanol stove's overall thermal and emission characteristics, as well as its economic availability, makes it a viable choice for household cooking. The output has setup a visionary scope for improving the efficiency of methanol cooking stove , but the experimental data is necessary to verify the observed simulation data. Also, Methanol has shown a slight increase in burning rate after adding water. This could be optimised and studied using similar experimental setup. Fire Power is a very underrated aspect in this study which has a great potential in improving combustion efficiency.

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