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AN EXPERIMENTAL STUDY OF POROUS MEDIUM IN BIOMASS STOVE

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Abstract

The use of biomass stove is widespread in the rural communities of developing countries. It is important to improve the efficiency of this stove in order to reduce the global warming contribution. Although combustion offers many benefits to the human, it also has a downside which is producing pollutants such as nitrogen oxides (NO_x) and carbon monoxide (CO). The use of metal foam made from aluminium and cast iron in combustion has proved that the reduction of NO_x and CO emissions can be achieved through its thermal and physical properties. The complex metal foam can also distribute heat of combustion into large area in combustion chamber and enhance the temperature at its region. Generally, the porous medium (PM) configurations used have created the phenomenon of radiative energy feed-back and species backflow which influence the NO_x and CO emissions and temperature profiles. From the comparison analysis of combustor without porous medium and with porous medium, it is found that the NO_x and CO emissions can be reduced approximately 59% and 21% respectively with the presence of porous medium.

Keywords: composite metal foam, biomass, particulate matter, combustion.

Nomenclature

η_{th}	Thermal efficiency	-
Qg	Heat gained	*W*
Q_s	Heat supplied	*W*
ρ	Density of metal	*kg/m^3*
c_p	Specific heat capacity	J/kgK
u	Free stream velocity	*m/s*
k	Thermal conductivity	*w/mK*

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1. INTRODUCTION

In developing countries like India about 90% of rural people depend on biomass sources for heating needs. Although combustion offers many benefits to the human, it also has a downside which is producing pollutants such as nitrogen oxides (NO_x) and carbon monoxide (CO). The use of porous medium in combustion has proved that the reduction of NOx and CO emissions can be achieved through its thermal and physical properties. However, these combustion systems which h use porous medium in premixed combustion are complicated system, high risk and the porous medium used is too complex to be manufactured. The investigation was focused on the NOx and CO emissions and temperature contours and profiles. From the comparison analysis of combustor without porous medium and with porous medium, it is found that the NOx and CO emissions canbe reduced approximately 59% and 21% respectively with the presence of porous medium. The porous medium can also distribute heat of combustion into large area in combustion chamber and enhance the temperature at its region. Generally, the porous medium (PM) configurations used have created the phenomenon of radiative energy feed-back and species backflow which influence the NOx and CO emissions and temperature profiles. Comparison of NOx trends and temperature profiles results between simulation and experiment showed a good agreement.

1.1 THE COMBUSTION OF SOLID BIOMASS AND THE FORMATION OF THE MAJOR POLLUTANTS

Biomass combustion consists of the steps: heating-up; drying; devolatilisation to produce char and volatiles, where the volatiles consist of tars and gases; combustion of the volatiles; Early predictions of biomass combustion used simplified rate expressions for each of these steps models include more detailed, biomass specific chemistry to better predict burn-out and pollution formation indicated Modeling of each of these steps is discussed in the following sections. Pollutants are formed alongside the main combustion reactions from the N, S, Cl, K as well as other trace elements contained in the volatiles and char. CO, PAH and soot, together with characteristic smoke markers of biomass combustion such as levoglucosan, guaiacols, phytosterols and substituted syringols [20] are released if the combustion is incomplete, due to factors such as local stoichiometry (mixing), temperature, residence time etc. Thus, the atmospheric emissions can contain tar aerosols and soot, which together with fi ne char particles and metal-based aerosols such as KCl, form smoke. The nitrogen compounds are partially released with the volatiles, whilst some forms a C-N matrix in the char and is then released during the char combustion stage forming NOx and the NOx precursors, HCN and HNCO. Sulphur is released as SO_2 during both volatile and char combustion. KCl, KOH and other metal containing compounds together the sulphur compounds form a range of gas phase species, which can be released as aerosols, but importantly also deposit in combustion chambers.

1.2 COMPOSITE METAL FOAM

Aluminium (75%) and mildsteel(25%) scrap are mixed together and compressed using a hammer into a thin plate. The thin plate is enclosed on both sides by mild steel mesh. The use of porous medium in combustion also gives an advantage which is the ability to maintain stable combustion during any minor fluctuations of the flame temperature or even to restart the combustion immediately by simply restoring the flow of the fuel and oxidant after flame extinction caused by momentary interruption of the fuel, or oxidant flow or others. The reason for this advantage is that the specific heat of most porous material is sufficient to maintain its temperature above the ignition temperature for some time after the flame has been extinguished.

In the past, many works of using porous medium in combustion have been investigated and the successful results were achieved. However, mostly the works are regarding to the premixed combustion system with so many limitations. Since porous medium has been shown to enhance the heat transfer, it has also been used in liquid and gaseous fuel combustion to improve the combustion process. Babkin et al. (1991) were the first to do the experimental study of the porous medium usage in combustion. In their study, the combustion flame was directed to go through the porous medium in order to study the level of porosity that flame can pass through.

Fig. 1 composite metal foam

1.3 PECLET NUMBER

Peclet number is defined as the thermal energy convected to the fluid to thermal energy conducted within the fluid. If peclet number is small conduction is very important. It is equal to the product of Reynolds number and Prandtl number.

$$Pe = \frac{\text{Heat transfer by convection}}{\text{Heat transfer by conduction}}$$

$$Pe = \frac{uL\rho C_p}{k}$$

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2. EXPERIMENTAL STUDY

The comparative combustion efficiency of both biomass stove with and without porous medium has been experimentally determine by using the following equation.

$$\eta_{th} = \frac{Q_g}{Q_S} \qquad (1)$$

2.1. BIOMASS STOVE WITHOUT POROUS MEDIUM

In cooking, a cook stove is heated by burning wood, charcoal, animal dung or crop residue. Cook stove are the most common way of cooking and heating food in developing countries. Fig.2 shows the biomass stove without porous medium.

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Fig. 2 Biomass stove without porous medium

2.2. BIOMASS STOVE WITH POROUS MEDIUM

Aluminium (75%) and mildsteel (25%) scrap are mixed together and compressed using a hammer into a thin plate. The thin plate is enclosed on both sides by mild steel mesh.In domestic cooking, a layer of above said metal foam is placed over the cook stove to increase the combustion rate and to arrest the particulate matter coming from the combustion process. Fig. 3 shows the biomass stove with porous medium.

Fig. 3 shows the biomass stove with porous medium.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1. BIOMASS STOVE WITHOUT POROUS MEDIUM

Fig .1 shows the time taken for the combustion process when the biomass stove is in normal condition. Boiling process has been conducted for the following conditions: T =26˚C; heat is supplied continuously for 20min

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by using biomass (Calorific value=6850KJ/Kg.) as the heat source. The time period for the above said process was obtained after the boiling process is 18.22 min.

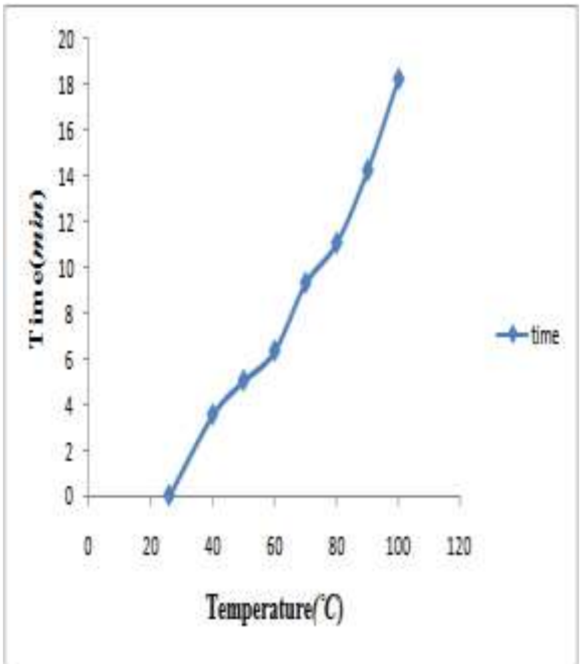

Fig. 1 shows the time taken for the combustion process when the biomass stove is in normal condition

The combustion efficiency obtained for the biomass stove without porous medium is 31%.

3.2 BIOMASS STOVE WITH POROUS MEDIUM

Fig .3 shows the time taken for the combustion process when the composite metal foam layer of thickness 10*mm* is placed above the biomass stove. Boiling process has been conducted for the following conditions: T =26˚*C*; heat is supplied continuously for 20*min* by using biomass (Calorific value=6850*KJ/Kg*.) as the heat source. The time period for the above said process was obtained after the boiling process is 16.56 min.

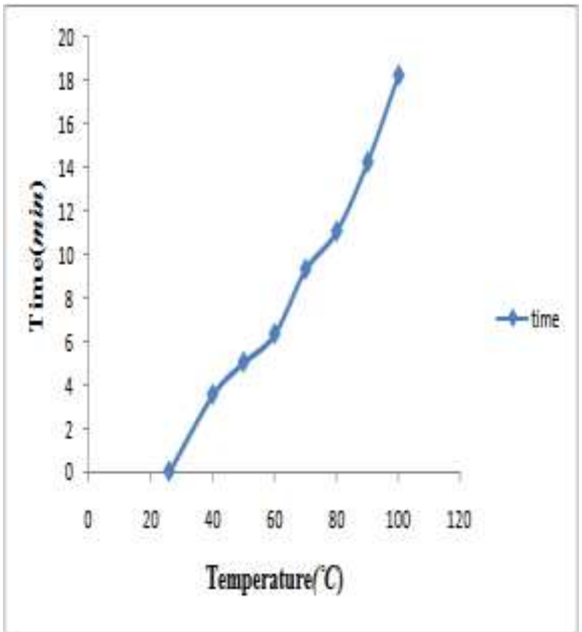

Fig. 2 shows the time taken for the combustion process when the composite metal foam is placed above the biomass stove.

The combustion efficiency obtained for the biomass stove with porous medium is 34%.

3.3 COMPARATIVE ANALYSIS

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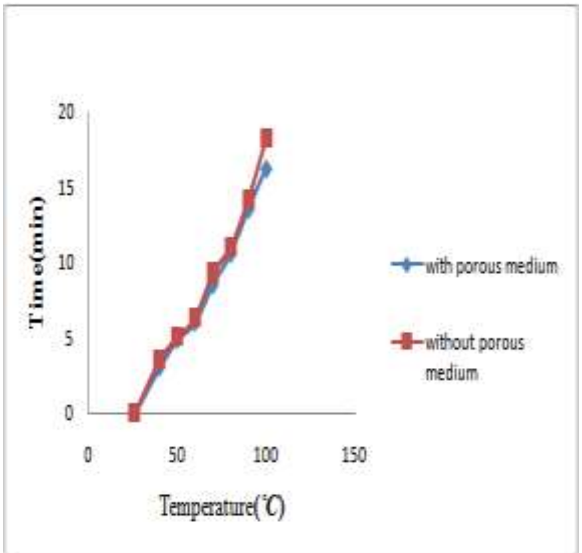

Fig. 3 shows the comparative analysis of with and without porous medium

While comparing the combustion efficiencies for both conditions, it is obvious that the efficiency of biomass stove with porous medium ($\eta_{th} = 34\%$) is greater than the efficiency of stove without porous medium ($\eta_{th} = 31\%$).

4. CONCLUSIONS

Performance of the biomass stove with porous medium layer was tested. For the layer, the investigation was model. For those cases combustion efficiency were obtained. The maximum combustion efficiency obtained for the biomass stove with composite metal foam layer. These results will be useful in future to increase the combustion rate and to arrest particulate matter coming from biomass.

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