AIR POLLUTION FROM BIOMASS COMBUSTION IN DOMESTIC COOKSTOVE

J. B. KANDPAL*, R. C. MAHESHWARI* and TARA CHANDRA KANDPAL†
*Centre for Rural Development and Technology and †Centre for Energy Studies, Indian Institute of Technology, Delhi Hauz Khas, New Delhi 110016 India

(Received 7 December 1993; accepted 24 January 1994)

Abstract—The concentration of three air pollutants in indoor air during a one hour combustion period of three biofuels, i.e. fuelwood, dung-cakes and agri-residue, was monitored. A mixture of fuelwood and dung-cake (1:1) was also used in the study. The concentration of all three pollutants was measured at three monitoring positions. The concentration of air pollutants was found to be maximum in the kitchen at the breathing level height of a standing person.

I. INTRODUCTION

Biomass fuels meet a major fraction of domestic cooking energy demand in most developing countries [1]. In India 66.5% of the total domestic energy requirement is met by these fuels [2]. Normally, combustion of these biomass fuels is carried out in primitive devices which have low thermal efficiencies and release a large amount of pollutants. Therefore, the use of biofuels in energy inefficient devices, particularly in poorly ventilated houses, leads to a high degree of indoor pollution [3–5]. Global efforts to develop and disseminate improved biofuel combustion devices have been undertaken in the past decade or so [6]. In the case of domestic cookstoves, both fixed mud and portable metallic cookstoves [7, 8] have been developed which can use fuelwood, agri-residue and dung-cakes. Sugam-II, developed at Centre for Rural Development and Technology, IIT Delhi, is one such cookstove which has been successfully disseminated in several villages [7]. While a detailed thermal performance evaluation of this cookstove has already been undertaken, the emission of air pollutants from the combustion of different biofuels in such a cookstove has not yet been studied. This paper reports on the results of an investigation undertaken to study the emission of CO, NOx, and HCHO during the combustion of four biofuels in an improved mud cookstove (Sugam-II), along with analysis of the flue gases for the CO/CO2 ratio.

2. COOKSTOVE, BIOFUELS AND MONITORING POSITIONS

The specifications of the cookstove used in the present investigation (Fig. 1) are shown in Table 1. Sugam-II, used in the present work, is a two-pot cookstove which can use fuelwood, dung-cakes and agri-residue. The indoor concentration of three pollutants was monitored at three different positions (Table 2). Three biofuels, fuelwood (Acacia nilotica), dung-cake and agri-residue (mustard stalks) were used in the study. During the field work in the rural areas near Delhi it was found that a combination of fuelwood pieces and dung-cakes are used together for certain
Table 1. Specifications of improved mud cookstove (Sugam-II)

<table>
<thead>
<tr>
<th>Property</th>
<th>Type</th>
<th>Fixed mud stove</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>80 × 36 × 24 cm</td>
<td></td>
</tr>
<tr>
<td>Number of pot holes</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Diameter of pot holes</td>
<td>24 cm each</td>
<td></td>
</tr>
<tr>
<td>Size of fire box</td>
<td>17 × 19 cm</td>
<td></td>
</tr>
</tbody>
</table>

end-uses. Therefore a 1:1 combination of fuelwood and dung-cakes was used as the fourth biofuel in the present work. Small pieces of fuelwood, (length 30–40 cm; diameter 4–5 cm) were used while the length of agri-residue was kept between 30 and 40 cm. The average length of dung-cake pieces was 20 cm.

3. EXPERIMENTAL PROCEDURE

The cookstove was installed in a kitchen of size 2.6 × 2.8 × 2.3 m which opens into a living room of size 6.6 × 2.8 × 2.3 m. The kitchen itself has no other arrangement for ventilation. The living room, however, has a window which was kept open during the experimentation. The cookstove was ignited with the biofuels for determining the thermal performance as well as its emission characteristics. The thermal performance was determined by a Water Boiling and Evaporation Test [9]. A flat bottomed aluminum pot of 24 cm diameter and mass 0.800 kg was used for the thermal performance evaluation. The flue gas samples were collected in the glass sampling bottles by water displacement from the chimney at a height of 0.5 m from the cookstove. For each experiment four to five flue gases samples were collected. The analysis of CO and CO₂ from the flue gases was carried out in a molecular sieve column and Porapak-Q column [10]. The injector and detector temperatures were maintained at 90°C and the oven temperature was kept at 40°C for the above purpose.

The indoor concentration of CO was determined with a battery operated CO Personal Sampler (Model Ecolyser-2000) regularly at an interval of 10 min during the 1 h cookstove operation period. Even after extinguishing the cookstove the CO concentration at position B was further monitored until it came down to the prescribed safe values of air standards [11].

The concentration of NO₂ and HCHO were monitored by employing wet scrubbing techniques. A set of two sampling trains, one each for NO₂ and HCHO, consisting of a midget glass impinger, filled with 25 ml of absorbing solution and a rotameter connected to a vacuum pump, were employed. The Katz method [12] was used for NO₂ and the Sawicki method [13] was used for HCHO determination.

4. RESULTS AND DISCUSSION

The thermal performance of the cookstove is presented in Fig. 2. The maximum thermal efficiency of the present improved mud cookstove (Sugam-II) was observed with the fuelwood while it was found to be minimum with the dung-cakes. The best thermal performance was observed at a burning rate of 16.7 g min⁻¹ (i.e. 1 kg h⁻¹).

The concentration of CO and CO₂ in the flue gases during the combustion of four biofuels in the Sugam-II stove is presented in Fig. 3. The combustion of dung-cake releases maximum CO in the flue gases while its release is minimum for fuelwood combustion.

Table 2. Characteristics of the biofuels and details of monitoring positions

<table>
<thead>
<tr>
<th>Property</th>
<th>Fuelwood (Acacia nilotica)</th>
<th>Dung-cake</th>
<th>Agri-residue (mustard stalks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content(%)</td>
<td>10.0</td>
<td>9.4</td>
<td>14.5</td>
</tr>
<tr>
<td>Fixed carbon (%)</td>
<td>18.0</td>
<td>14.4</td>
<td>16.8</td>
</tr>
<tr>
<td>Volatile matter(%)</td>
<td>70.0</td>
<td>60.9</td>
<td>65.2</td>
</tr>
<tr>
<td>Ash content (%)</td>
<td>2.0</td>
<td>15.3</td>
<td>3.5</td>
</tr>
<tr>
<td>Calorific value (kJ kg⁻¹)</td>
<td>16,100</td>
<td>10,920</td>
<td>13,800</td>
</tr>
</tbody>
</table>

Monitoring positions

Position A: In the kitchen at a distance of 30 cm from the cookstove at a vertical height of 30 cm from the floor level (breathing level in squatting posture).

Position B: In the kitchen at a distance of 30 cm and at a vertical height of 150 cm from the cookstove (breathing level of a person standing in the kitchen).

Position C: In the centre of the living room at a vertical height of 150 cm from the floor (breathing level of a standing person).
at all burning rates. It may be noted that the increase in the biofuel burning rate (i.e. increasing fire power) increases the emission of CO for all the four biofuels. The CO₂ concentration in the flue gas decreases with an increase in the biofuel burning rate. This is as expected since for a given air (oxygen) intake an increase in the fuel burning rate would result in incomplete combustion leading to higher CO concentration. For the two other biofuels, i.e. agri-residue and fuel-wood and dung-cake mixture, the CO concentration lies in between the two extremes. However, these values are closer to the concentration observed for the combustion of dung-cakes. It may also be noted from the results presented in Fig. 3 that the incremental change in the CO concentration with increase in the fire power (burning rate) is much higher at higher burning rates. This is explicit from the slope of the curves in Fig. 3. As regards the emission of CO₂ in the flue gases, it is lowest for dung-cakes and highest for the fuelwood. This may be attributed to the fact that the dung-cakes have the lowest fixed carbon content as compared to the other biofuels considered in the present study and also that its incomplete combustion releases the highest CO in the flue gases. As the CO concentration in the flue gases increases with an increase in the fuel burning rate accompanied by a decrease in the CO₂ concentration, the CO/CO₂ ratio increases much more more rapidly as the fuel burning rate is increased. The emission of CO during the 1h biofuel combustion period at the three monitoring positions is shown in Figs 4–6. While analysis of the flue gases was undertaken for different fuel burning rates, Figs 4–6 have been plotted for a single value of fuel burning rate broadly corresponding to the best thermal performance of the cookstove, i.e. at a burning rate of 16.7 g min⁻¹. Figure 4 shows the CO concentration at position A in the indoor air during the combustion of four biofuels in the Sugam-II cookstove. Similar to the results obtained for the CO concentration in the flue gases, the maximum release of CO concentration in the indoor environment at position A was caused by the combustion of dung-cakes. The fuelwood combustion releases minimum CO. The
time at position B is shown in Fig. 5, whereas the same variation for position C is shown in Fig. 6. At these two positions maximum CO concentration is also caused by the combustion of dung-cakes. A comparison of the CO concentration in Figs 4-6 at any time during the 1 h cookstove operation period shows the maximum concentration of CO is observed at position B, whereas position A has its minimum concentration during the entire test duration and for all biofuels. The CO concentration in the living room is also very high which may be attributed to the dispersion of CO to the living room as the kitchen door opens into it. The increase in the CO concentration with time during the 1 h combustion period effectively shows the accumulation of CO released during the combustion since igniting the fire in the cookstove.

It is worth pointing out that the values of CO concentration observed for the case of fuelwood combustion in Sugam-II are more or less similar to those reported in reference [14]. The disappearance of indoor CO (as monitored at position B) for all four biofuels is shown in Fig. 7. It may be seen from the results presented in this figure that it takes more than 30 min for CO concentration in the kitchen to come down to acceptable limits.

The concentrations of NO₂ and HCHO in the indoor environment for the 1 h cookstove operation period (operating at a fire power of maximum thermal efficiency) are presented in Table 3. Similar to the case of CO, the maximum concentration of both air pollutants was observed at position B with all the four biofuels, whereas it was minimum at position A. The concentration of NO₂ as well as HCHO in the living

CO release for two other biofuels is in between the values for fuelwood and dung-cakes. The increase in CO concentration in the indoor environment with
room (position C) was found to lie in between the concentrations observed at positions A and B.

During the 1 h test period the CO concentration was also measured in the outdoor environment at two locations: at horizontal distances of 50 and 150 cm, respectively, from the chimney outlet. While the CO concentration at a distance of 150 cm from the chimney outlet was less than 1 mg m⁻³ (minimum detection limit of the instrument), its values at a distance of 50 cm are presented in Table 4. It is obvious from the values presented in this table that although the combustion of biofuels increases the indoor air concentration of CO beyond the safe limits, its impact on the quality of the outdoor environment may not be significant. However, further studies will have to be undertaken to arrive at any definitive conclusions.

5. CONCLUDING REMARKS

Results of a preliminary investigation on the air pollutant emission characteristics of an improved mud cookstove (Sugam-II) with the four biofuels is presented in this paper. Though it is difficult to arrive at any major conclusion on the basis of this preliminary study, which is a part of the on-going efforts at IIT Delhi to study the thermal and environmental performance characteristics of biomass cookstoves, the results obtained indicate that the combustion of dung-cakes may lead to considerably higher concentrations of CO in the indoor environment. For other biofuels as well, the indoor air concentration of CO is significantly higher than the prescribed safe limits. Further work both on the monitoring of air pollutants from the operation of the cookstoves in a variety of design and operational conditions, as well as on the development of less pollutant-releasing cookstoves, is necessary for improvement of the indoor air quality in rural areas.

REFERENCES