Small Scale Biomass Incinerator with a Bubbling Fluidised Bed. II. Combustion of Feathers and MBM

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SMALL SCALE BIOMASS INCINERATOR WITH A BUBBLING FLUIDISED BED. II. COMBUSTION OF FEATHERS AND MBM

The paper presents the results from a study of the combustion of wastes of animal origin - feathers and meat and bone meal in a 1.5 MW bubbling fluidised bed reactor. The process of thermal utilisation is stable and short-term fluctuations on the composition of the wastes are not a problem, since the operational parameters of the combustor are constantly monitored and controlled. The process does not require conventional supporting fuel and the level of CO in the flue gases is comparable to that observed with some low quality coals, but NOx and SO2 emissions are present, because of relatively high content of combined N and S in animal wastes. With proper selection of the operational parameters, to take into account the character of the wastes to be treated, the use of fluidised bed reactors for the thermal utilisation of such wastes should be the preferred practical proposition.

INTRODUCTION

The incidence of BSE (bovine spongiform encephalopathy) in cattle and scrapie in sheep rose rapidly in the 1990-ties. Because of this threat, the members of the EU and many other countries banned the use of products derived from fallen of culled animals as additives to animal feed. In Great Britain alone, between 1987 and 2004 there were 180 thousand cases of BSE in cattle [1]. Since BSE is incurable, difficult to detect in the early stages and the incubation period is at least 5 years, the decision to cull all animals in herds where the disease was detected was a drastic but inevitable measure to curb its further spread. As a result, it became necessary to dispose of hundreds of thousands of animal carcasses. The method used was burning them, on crude grates or piled up, with inter-layers of wood or old tyres and drenched with crude oil (Fig.1). At the same time, MBM piled up, since its production had not been stopped. For example, in Poland about half a million tons of animal wastes are processed annually to give 200 thousand tons of MBM [2]. Incineration could be the
best method to get rid of animal wastes and MBM already produced. This removes the risk of any transfer of the disease, via the biological material present in the wastes, to any substances that could be used in the production of human food or animal feeds. Also, the environment is not burdened with hazardous wastes, which could not be excluded if the wastes passed into compost, to be used in agriculture.

In thermal utilisation, the key factor is ensuring sufficient rate of supply of oxygen. This can be achieved through proper organisation of the combustion process. Our own work on laboratory and semi-technical scales [3-6] as well as that of others [7-11] suggests that the fluidised bed technology, with either a bubbling or a circulating fluidised bed can provide the required conditions. An examination of the elemental composition of animal waste, biomal, indicates that dried animal waste could be an effective fuel. In Table 1 the composition of biomal is compared with that of wood chips. The high content of C and H and relatively low of O points to high fuel values. However, in comparison with wood, N, Cl and S are at a much higher level. This might cause practical problems, particularly because of the Cl.

Table 1. Elemental analysis for biomal and wood chips, dry and ash free, mass %.

<table>
<thead>
<tr>
<th></th>
<th>Carbon</th>
<th>Oxygen</th>
<th>Hydrogen</th>
<th>Nitrogen</th>
<th>Chlorine</th>
<th>Sulfur</th>
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<tbody>
<tr>
<td>biomal</td>
<td>65.5 - 67.1</td>
<td>17.0 - 15.2</td>
<td>9.7 - 10.6</td>
<td>7.1 - 6.5</td>
<td>0.30 - 0.31</td>
<td>0.40 - 0.37</td>
</tr>
<tr>
<td>wood chips</td>
<td>53.1</td>
<td>40.6</td>
<td>6.0</td>
<td>0.31</td>
<td>0.03</td>
<td>0.04</td>
</tr>
</tbody>
</table>

The process should be conducted so as to minimise the formation of PAH, PCB, PCDF and PCDD. This requires that the gas residence times in the high temperature zone should be sufficiently long [12]. If raw meat wastes, containing about 60% water, were to be burned, a supporting fuel, such as e.g. wood chips, would have to be
Fig. 2. Technological scheme of the thermal utilisation of biomal, MBM and feathers.

employed. The technological scheme for burning animal wastes, including raw wastes and feathers, is given in Fig. 2.

The construction and mode of operation of a bubbling fluidised bed reactor is conducive to maintaining high and relatively high temperature over the whole volume of the bed. Intensive mixing helps to supply oxygen to the surface of the burning material and provides good heat exchange conditions. This leads to efficient combustion with excess oxygen, but should pyrolysis products escape from the bed, their oxidation can be completed in the freeboard.

THE EXPERIMENTAL INSTALLATION AND TEST PROCEDURES

The tests were carried out in an installation that had been described in detail before [13], designed for burning sewage sludge. It consists of a 1.5 MW\textsubscript{th} fluidised bed combustor, a gas-gas heat exchanger for preheating the fluidising air, a gas-liquid exchanger for recovering heat from the flue gases to produce hot water and a scrubber for cleaning the flue gases.

At the start of a run, the combustor, with a distributor area of 0.49 m\textsuperscript{2}, is filled with 50 kg of sand. When MBM is burned, the sand is gradually replaced by mineralised bone fragments, usually a few mm in diameter. When feathers are burned, it is necessary to add inert bed material to maintain the bed inventory. The preheated
air fluidises the bed material and provides oxygen for the combustion process. The air supply rate was 2520 m$^3$/h, giving an air excess factor of 5 for the combustion of feathers and about 3.4 for that of MBM. Elutriated particulates carried with the flue gases are partly removed in the suitably designed heat recuperator. The flue gases are then directed to a scrubber, which removes the remaining particulates and captures most of the SO$_2$.

During the operation of the combustor, the temperatures of the bed, of the flue gases entering and leaving the recuperator and of the gases at the exit from the scrubber were monitored continuously. The flue gases were analysed before and after the scrubber, also on a continuous basis. The results after the scrubber came from a MRU VarioPlus$^\text{TM}$ instrument. The concentrations of O$_2$, NO, NO$_2$ and CO were determined using electrochemical sensors, to the nearest 0.1% for O$_2$ and 1 ppm (vol.) for the others. For the concentrations of CO$_2$ and of organics IR absorption was used and the measurements were to the nearest 0.1% and 1 ppm respectively. The concentrations of polyaromatic hydrocarbons (PAH) in an aqueous extract of MBM, samples of water from the scrubber, ash from the ash trap and flue dust collected from the chimney duct were determined chromatographically.

RESULTS AND DISCUSSION

Three sets of tests on the thermal utilisation of wastes were carried out, burning wood chips, meat and bone meal and turkey feathers. The wood chips were used to assess the quality combustion in the newly constructed fluidised bed installation for the utilisation of sewage sludge. The wood chips were not subjected to any initial conditioning, by drying or segregation for wood type or size of the fragments. After ignition, it took 30 min. for the combustor to attain steady operation at the required temperature. Fig. 3 shows records of the temperature of the bed and of the flue gases entering the chimney and of the concentrations of selected components of the flue gases, measured after the scrubber. In Fig. 3 (as well as in Figs. 4 and 5) the NO$_x$ concentration is the sum of NO an NO$_2$, expressed as NO$_2$. Except for O$_2$ and CO$_2$, all concentrations are normalised to 11% of O$_2$ in the flue gases. Clearly, any fluctuations in the stoichiometry as a result of changes in the stream of fuel or in the air supply are quickly reflected in the CO concentration records. Frequent and appreciable changes in the air excess coefficient lead to higher CO levels.

Table 2 gives the mean values and standard deviation of the bed temperature and of the concentrations of the important constituents of the flame gases recorded when wood chips, MBM and turkey feathers were burned (converted to 11% O$_2$). With wood chips the mean concentrations of CO and NO$_x$ (in terms of NO$_2$) were 568 and 226 mg/m$^3$ respectively. The very low level of SO$_2$ was a result of the very low S content of wood and not of any desulphurisation process. On comparing the standard deviations from the mean for the quantities collected in Table 2 it can be seen that
wood chips gave a more stable process than the other materials burned, even with wider variation in the value of the air excess coefficient. This can be ascribed to the more uniform character of the wood and good control of the feed delivery rate. The combustion of MBM was attempted without any modifications in the feed system, but it was noted that the sloping duct through which the fuel feed enters the combustor became strongly heated. This made the MBM stick to the bottom of the duct, causing disturbances in the feed rate. However, lack of uniformity in the feed rate was not really reflected in the composition of the flue gases, illustrated in Fig. 4. After about 10 min. the operation of the installation stabilised and the CO concentration fluctuated around 280 mg/m$^3$. This level was due mainly to the presence of volatile constituents in the MBM or the evolution of volatile pyrolysis products. Because of the presence of proteins, MBM contains about 10 - 20 times more N and S than wood chips (Table 1)
and the observed mean concentration levels were 1507 and 250 mg/m³ respectively. For an assessment of the quality of the combustion process the presence of volatile organic compounds, VOC, in the flue gases is important and such substances can pass into the water discharged from the scrubber. Samples of this water and of water condensed out of the flue gases were collected and analysed by GC/MS, to determine the concentrations of the PAH present. It must, however, be stressed that the combustion of MBM in a 1.5 MW fluidised bed is not a source of any noxious odours, so the operation of such an installation is not "objectionable", even with the utilisation of about 50 kg of MBM/h.

Feathers contain cystine (an amino acid containing S), at a level of 700-900 µmol/g (dry mass) [14]. The S content in dry feathers can be even as high
as 3%. With feathers alone a sharp increase in the SO$_2$ concentration was therefore expected, and for this reason feathers were burned together with wood chips, in a 1:2 proportion (by mass). Use was made here of the two fuel feeders provided and one of them was used for the wood and the other for feathers. It was noted that with the feathers there were some problems with maintaining a constant feed rate, since the feeder had not been designed to work with such materials and had not been suitably adapted. The records temperature records given in Fig. 5 show that during the co-combustion of feathers with fast burning wood chips, the automatic control system sent the bed temperature into oscillations, which could not be damped. Similar oscillations were also observed with wood chips alone, Fig. 3. The oscillations led to
effects on the concentrations of the temperature – dependent species NO$_x$, CO. However, the mean concentrations quoted in Table 2, together with the corresponding standard deviations indicate that overall, the co-combustion of wood chips and feathers was reasonably stable and gave lower NO$_x$ and SO$_2$ concentrations than the combustion of MBM. It is also worth noting that with the co-combustion the degree of conversion of NO to NO$_2$ appears to be appreciably higher, by a factor of about 5 than with MBM alone and near to that observed with wood chips, though it must be borne in mind that with MBM the air excess coefficient $\lambda$ was appreciably lower than with the other fuels (Table 2).

Table 2. The mean values and standard deviation for the bed temperature, the air excess coefficient $\lambda$ and the concentrations of selected constituents of the flue gases

<table>
<thead>
<tr>
<th></th>
<th>Wood chips</th>
<th>MBM</th>
<th>Feathers+wood chips</th>
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<tbody>
<tr>
<td>CO</td>
<td>568.31 ± 112.3</td>
<td>282 ± 143.6</td>
<td>550.1 ± 201.9</td>
</tr>
<tr>
<td>NO</td>
<td>204.4 ± 9.1</td>
<td>1476.8 ± 225.2</td>
<td>636.2 ± 328.2</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>21.72 ± 10.3</td>
<td>30.2 ± 8.2</td>
<td>61.9 ± 21.5</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>00.0</td>
<td>263.2 ± 66.4</td>
<td>117.0 ± 73.8</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>4.7 ± 1.2</td>
<td>3.5 ± 0.4</td>
<td>4.9 ± 0.8</td>
</tr>
<tr>
<td>$T_{\text{bed}}$</td>
<td>930.2 ± 13.9</td>
<td>929.4 ± 16.1</td>
<td>926.9 ± 16.6</td>
</tr>
<tr>
<td>$C_{xH_y}$</td>
<td>78.9 ± 31.1</td>
<td>246.8 ± 23.3</td>
<td>-</td>
</tr>
</tbody>
</table>

In earlier publications [3,5] it had been shown that because of the variability of the composition of the waste (mainly the proportions of fat and bones), the combustion of meat waste can lead to appreciable concentrations of VOC in the flue gases. To test the effect of the scrubber on the concentration of VOC in the flue gases entering the chimney, a series of analyses were carried out to determine the concentrations of polyaromatic hydrocarbons in the water used in the scrubber and in the condensate obtained on cooling the gases during the final stage of the removal of particulates. The PAHs selected were those that are mentioned in the US EPA Method 610 [15]. It has been found that the presence and concentrations of individual polyaromatics in the scrubber water depended on the fuel burned. Figure 6 gives the total detector current.
due to ions characteristically derived from PAHs, for which the M/e\(^{-}\) had one of the following values: 128, 152, 153, 166, 178, 202, 228, 252, 276 and 278.

It has been found that in comparison with the situation during the burning of MBM, during the combustion of wood chips the scrubber water contained far fewer ions of elected masses. Since after the scrubber the concentrations of organic substances were comparable, it was possible that the scrubber captured an appreciable proportion of the PAHs. The results of detailed analysis of the scrubber water and condensate during combustion of wood chips are shown in Fig. 7.

When MBM was burned, the water contained relatively high concentrations of naphthalene,acenaphthene,acenaphthylene,anthracene,fluoranthene and pyrene. After the combustion of MBM, the total concentration of PAHs in the water was often two orders of magnitude higher than with wood chips. It must be stressed that the PAH concentrations found in the scrubber water and the condensate depend strongly on the operational parameters of the combustor. The measurements were made with the installation working below full load. Such conditions optimum oxidation conditions in the freeboard for material elutriated from the bed.

![Fig. 6. The total ion current obtained for samples of water from the scrubber when the fuel was a) wood chips, b) meat and bone meal.](image1)

![Fig. 7. The PAHs present in the scrubber water and in the condensate obtained from the flue gases when wood chips were burned.](image2)
Fig. 8. The total ion current, due to selected ions, measured for condensate samples obtained during the combustion of a) wood chips, b) meat and bone meal.

The determination of the total emissions of PAHs would require separate measurements of the amounts associated with fine flue dust and those emitted independently of any particulates. In this work, measurements were limited to the condensate obtained on cooling the flue gases to 15 °C when they pass through a quartz filter. Fig. 8 represents the total detector ion current due only to ions that could result from the fragmentation of PAH molecules, measured for the condensate obtained during the co-combustion of wood chips (a) and of MBM (b).

On the basis of a detailed analysis of the chromatograms the content of individual PAH compounds in the condensate was determined. The results are shown in Fig. 9. It can be seen that for MBM, in comparison with water from the scrubber, the concentrations of some compounds, particularly most of those that in the scrubber water were present in the highest concentrations, i.e. naphthalene, acenaphthene, acenaphthylene, anthracene, fluoranthene and pyrene, can be lower, even by over an order of magnitude. Thus the scrubber was at least in part effective in capturing organic pollutants, including PAHs.

The results obtained indicate that the combustion of MBM can lead to the formation of a wide variety of organic compounds, in various concentrations. If the
freeboard temperature is too low, preventing oxidation reactions from going to completion above the bed, organic pollutants can accumulate in the water circulating in the scrubber. Since, however, not all of them are captured in the water, some of them can pass through the gas cleaning system. With wood chips, the concentrations of PAHs in the scrubber water and in the condensate are similar. With MBM these concentrations are higher by up to 2 orders of magnitude, particularly so in the scrubber. The situation described is exaggerated, but the problem of PAH emissions deserves attention. In further work, it is planned to extend the analysis to the fine fly dust escaping the scrubber and to attempt to assess the effect the different operational conditions on the qualitative and quantitative characteristics of the PAHs formed.

CONCLUSIONS

1. Under favourable conditions, meat wastes can be utilised in a suitably designed bubbling fluidised bed combustor, with partial energy recovery. High enough temperatures of the bed and the freeboard and sufficiently long residence time of the gases in the reactor are particularly important.
2. The utilisation process can be fully controlled and can be made very stable.
3. The concentration of CO in the flue gases depends on the air excess coefficient and the temperature. If the temperature is too low, it can rise very rapidly. In this work, with air in excess, the average CO concentration (normalised to 11% of O₂ in the flue gases) during the combustion of MBM and feathers was 196 ± 51 and 551 ± 205 mg/m³_N respectively.
4. In wastes of animal origin, the content of combined N is higher than in conventional fuels and that of S is usually comparable to that in low sulphur coals. With MBM and feathers, the measured NOₓ (as NO₂) concentrations were 1625 ± 222 and 680 ± 284 mg/m³_N respectively. The corresponding SO₂ concentrations were 263 ± 50 and 115 ± 70 mg/m³_N.
5. This work has demonstrated the feasibility of thermal utilisation of meat wastes in a bubbling fluidised bed combustor, on a small but realistic scale, but for practical applications of the process full optimisation of the process is necessary.

ACKNOWLEDGEMENTS

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LITERATURE


