Proceedings of the Eleventh International Waste Management and Landfill Symposium. S. Margherita di Pula, Cagliari, Italy. 1-5 October 2007. Paper 411.

COMPARATIVE EVALUATION OF SRF AND RDF CO-COMBUSTION WITH COAL IN A FLUIDISED BED COMBUSTOR

A. GARG*, R. SMITH*, P.J. LONGHURST*, S.J.T. POLLARD*, N. SIMMS† and D. HILL *

** Centre for Resource Management and Efficiency, Sustainable Systems Department, School of Applied Sciences, Cranfield University, Building 40, Cranfield, MK43 0AL, UK r.smith1@cranfield.ac.uk*
† Energy Technology Centre, Sustainable Systems Department, School of Applied Sciences, Cranfield University, Building 61, Cranfield, MK43 0AL, UK
‡ DPH Environment and Energy Ltd, Rutland House, 30 Greencroft Gardens, London, NW6 3LT, UK

SUMMARY: The experimental study reported here was carried out to assess the feasibility of municipal solid waste (MSW) derived solid recovered fuel (SRF) in energy recovery applications. SRF was prepared by grinding and blending the major MSW constituents such as paper, plastics, wood and textile. The percentage of various constituents was the same as from the Ecodeco process employing bio-drying followed by mechanical treatment. The heating value of synthetic SRF was *ca.* 21 MJ/kg (as received basis). The metal emission results from the SRF co-combustion with coal were compared with that obtained from coal mono-combustion and refuse derived fuel (RDF) co-combustion with coal. RDF was also derived from MSW and was obtained from a local mechanical treatment waste facility. Use of SRF as co-fuel does not increase the emissions of metals to the environment in the flue gas stream when compared to coal mono-combustion. In addition, use of MSW derived fuel reduces the arsenic release to the atmosphere. The results showed that most of the metals are retained in the ash components (except mercury). The mobility of metals depends on the volatility and type of feedstock.

1. INTRODUCTION

Increasing fossil fuel prices and greenhouse gas (GHG) reduction requirements compels energy users to utilise cost effective materials that also have a significant biomass fraction. The biomass fraction is considered 'carbon neutral' and does not contribute towards GHG emissions. The UK, like many Member States, is facing challenging landfill diversion targets for BMW (biodegradable municipal waste) to fulfil the Landfill Directive (Council Directive, 1999) requirements (Garg *et al*., 2007). According to the latest data, the UK landfilled *ca.* 62% of total MSW in 2005-06 (Defra, 2006).

Use of waste derived fuels as co-fuel is receiving attention due to the availability of such fuels at low cost. However, the quality of such fuels to meet a required specification remains a

concern for fuel users. The fuel requirements for different facilities may vary widely in terms of heating value, biomass fraction, sulphur, chlorine and metals. To mitigate the ambiguity regarding the fuel quality, CEN Technical Committee CEN/TC 343 "Solid Recovered Fuels" has been mandated by the European Commission to prepare a document classifying solid recovered fuels (SRF) produced from non-hazardous wastes (CEN).

Mechanical-biological treatment (MBT) of MSW can produce a fuel complying with CEN standards. MBT is a combination of mechanical and biological unit operations that produce a high heating value stream, suitable for energy recovery processes. MSW derived fuel is characterised as SRF or RDF depending upon the composition and characteristics of fuel. SRF is considered to be a market driven product whereas RDF is input driven (Juniper, 2005). There is a considerable amount of evidence to suggest that source segregated materials tend to have a lower content of trace elements, including metals, then mechanically segregated materials (Bardos, 2004). Recently, a SRF co-combustion study was carried out in a pulverised fuel-fired combustor to study the fate of mercury and chlorine (Hilber *et al*, 2007). Two different qualities of SRF were used: (a) high heating value fractions of MSW and (b) SRF obtained from (a) plus commercial waste (25%). Commercial waste was added to reduce chlorine content in SRF. No significant change in the mercury emissions was observed. However, chlorine concentrations in the flue gas stream increased with a higher SRF proportion. The present experimental study determines the effect of using SRF and RDF as co-fuel with coal on metal emissions.

In order to achieve the targets, synthetic SRF was prepared in the laboratory using various MSW constituents and co-combustion studies with coal were performed in a fluidised bed combustor located at Cranfield University. The waste derived fuel proportion in the fuel mixtures was kept at 10% (by weight). Metal content in ash and flue gas stream was measured and the results were compared for SRF and RDF co-combustion with coal. Coal mono-combustion was also performed as reference run.

2. EXPERIMENTAL STUDY

2.1 Preparation of fuel samples

Bituminous coal used for the present study was obtained from Daw Mill mine, UK. Synthetic SRF was prepared by shredding and grinding paper, saw dust, polypropylene, polyethylene, PVC, and textiles in the same proportion as that obtained from the Ecodeco process (Cozens, 2004). The synthetic fuel comprised 58% paper, 22% plastic, 15% textile and 5% wood by weight (w/w). Polypropylene polyethylene and PVC were used as representative of plastics, whereas conifer saw dust was used for wood (See Table 1). MSW derived RDF was obtained from a local mechanical treatment plant located in the UK. For experimental purposes, the coal was sieved to provide a particle size between 5 and 13 mm whereas SRF and RDF (diameter = 18 mm) were used in the form of pellets.

2.2 Fluidised bed combustion test facility

Mono- and co-combustion studies were carried out in a 50 kW capacity pilot scale fluidised bed combustion plant at Cranfield University, UK (Figure 1).

Table 1. Composition of synthetic SRF

Material	Percent weight	Source
Paper	58	Royal mail
Polypropylene	8	Sigma Aldrich Chemical Company, Limited, UK
Polyethylene	12	Sainsbury, UK
PVC	2	Sigma Aldrich Chemical Company, Limited, UK
Sawdust	5	Conifer
Textile	15	Household sheets, Ikea, UK

The fluidised bed combustion test facility consists of a fluidised bed made of clean silica sand, a gas cooling system and cyclone assembly. The fuel was introduced into the combustor via a drop tube above the surface of the fluidised bed. The fluidised bed temperature was maintained by adjusting the fuel feed rate and flow of preheated air. Preheated air was supplied to the chamber from the bottom. As a result of combustion, a combusted gas stream was formed that entered into a second (refractory lined) chamber before passing through a water cooled heat exchanger assembly. Prior to release to atmosphere, the flue gas stream passed through a cyclone assembly. The combustor was operated at below atmospheric pressure in order to prevent gaseous release into the combustion hall. The combustor was equipped with a number of thermocouples to measure the temperatures of fluidised bed, secondary chamber and preheater along with bottom and fly ash removal devices. Fly ash samples were collected from the fly ash silo located under the cyclone assembly. In order to achieve complete combustion, the CO concentration was kept as low as possible (near to zero).

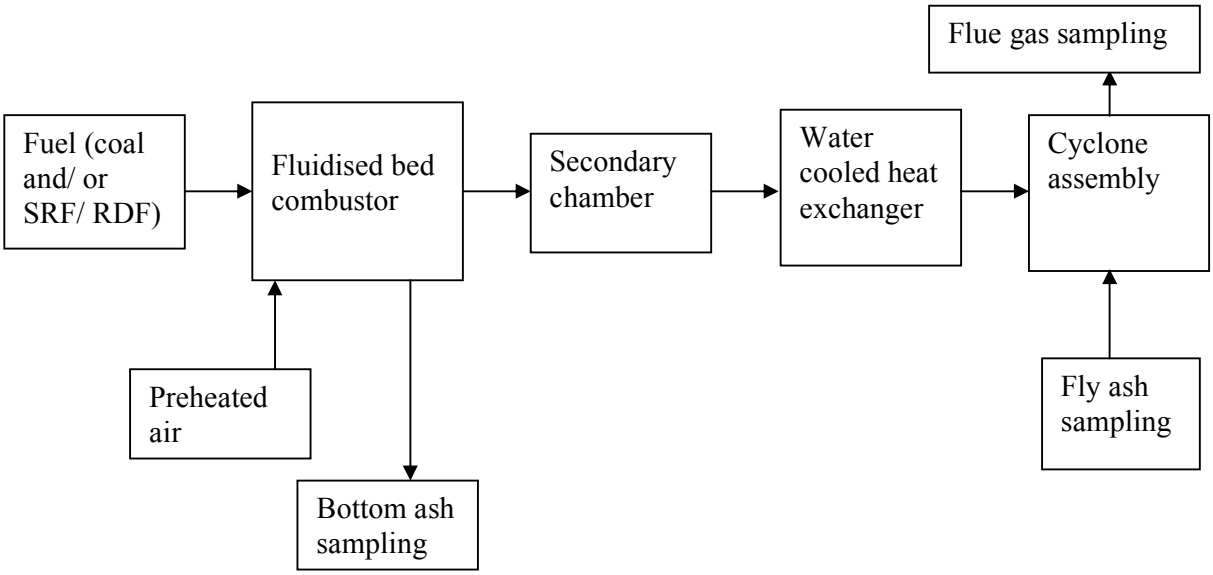

Figure 1. Flow diagram of fluidised bed combustor system

As the test facility was used for relatively short periods with solid fuels, the bed material was not extracted during its operation. For each experimental run, used bed material was replaced with clean silica sand.

2.3 Sampling and analytical methods

Fuel samples (coal, SRF and RDF) were sent to a commercial laboratory in the UK for the determination of elemental composition and proximate analysis. Bottom and fly ash samples along with clean silica sand were also sent to the same laboratory for measurement of metal content (including Hg) and elemental oxide analysis.

The flue gas samples of metal analysis were collected with three bubbling traps (two containing 10% nitric acid to dissolve metals and the third one was a guard of water to protect the pump from acid) immersed in a cold bath. Different metals such as Cr, Zn, Cu, Ni, Pb, Fe, Ca, Mg, Na, K, Al, Mn, Cd and Co in the flue gas samples were measured using Atomic Absorption Spectrophotometer (AAS) (Hitachi Z8100 Polarized Zeeman Spectrophotometer) at Cranfield University.

3. RESULTS AND DISCUSSION

3.1 Fuel characterisation

Elemental and proximate analyses show that synthetic SRF has a much higher heating value (21.4 MJ/kg, as received) in comparison to real RDF (13.15 MJ/kg, as received). However, the heating value of bituminous coal was found to be much higher, that is, 26.75 MJ/kg (as received). Ash content in RDF was the highest (ca.16% in comparison to ca. 11% in other two fuels) (Table 2). Elemental analysis of the fuels reveals that in SRF, sulphur and chlorine are present in lesser amounts than in RDF (S and Cl in SRF were 0.1% and 0.14% in comparison to 0.32% and 0.25%, respectively in RDF). Table 2 makes reference to RDF in 1993 and waste in 1972 to provide an indication of data variability and changing waste streams.

Table 2. Elemental and proximate analyses of fuel samples

Fuel	Coal	SRF	RDF
Proximate analysis			
Moisture (%)	6.2	3.0	30.4
Ash (%)	11.4	10.57	16.2
Volatile Matter (%)	33	79.63	46.1
Fixed carbon (%)	49.4	6.8	7.3
Gross Calorific Value (MJ/kg)	27.56	22.72	14.75
Net Calorific Value (MJ/kg)	26.45	21.4	13.15
Ultimate analysis			
C (%)	66.28	46.31	28.1
H (%)	4.19	5.90	3.36
N (%)	1.2	0.16	0.98
S (%)	1.71	0.10	0.32
Cl (%)	0.28	0.14	0.25

The presence of a high metal content (e.g. Hg, Zn, Cr, Pb and Cd) in RDF indicates that this may be contaminated with hazardous materials such as batteries, cosmetics and paint (Sharma *et al*, 1997). Heavy metals like Pb, Cu, Zn and Cd are also found in paper and plastic fractions. Presence of high concentrations of Na and K in RDF may be due to the presence of salt in food waste thus contaminating RDF and reducing its heating value (See Figure 2). SRF used in this study contained a biomass fraction of around 70%.

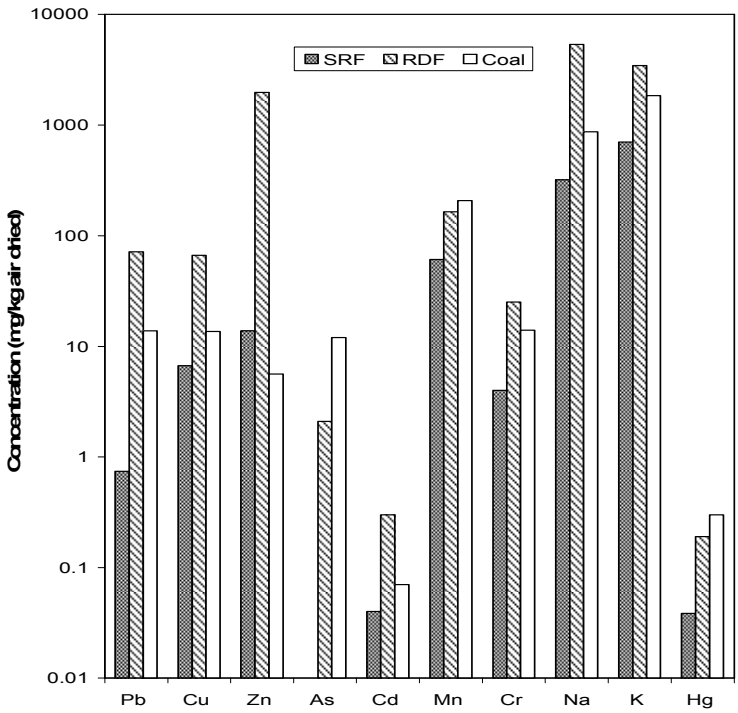

Figure 2. Concentrations of metals in fuel samples

3.2 Combustion performance

Fuel/ fuel blends examined in the present study include coal, (coal + 10% SRF) and (coal + 10% RDF). The feed rate for fuels varied from 6 – 9 kg/h and the fluidised bed temperature was maintained between 750 – 950 °C. The coal and RDF mixture could hardly reach 900 °C, most likely due to the high moisture content in RDF. The coal and SRF mixture attained a maximum temperature of 950 °C. SRF contains high volatile matter (~ 79%) and low moisture content (~ 3%); therefore there is lesser amount of heat loss in removing moisture from the fuel mixture. Another reason may be the need for an increase in feed rate for the coal and RDF mixture.

3.3 Metal emissions in flue gas samples

Metal emissions from flue gas as a result of combustion trials were measured (Table 3). There was little difference in the metal emissions in flue gas samples from the combustion of the two

fuel mixtures, that is, (coal + 10% SRF) and (coal + 10% RDF). Only the Pb emission was considerably higher for the coal and RDF mixture. For co-combustion, cement kilns require other metal emissions (e.g. Cr, Cu, Ni, Pb, Co, Mn) below 1000 $\mu g/m^3$ (EA, 2001). In our experimental study, the sum of these metals was 660 $\mu g/m^3$ for coal and (coal + 10% SRF) fuels and 830 $\mu g/m^3$ for (coal + 10% RDF). The results are within the limits; however the coal and RDF mixture showed slightly higher emissions.

3.4 Metals in ash samples

Metal concentrations were measured in the bottom and fly ash samples obtained after combustion (Table 4). It is clear that the larger fraction of metals remains in the fly ash. The release of metals is a function of their volatility. Highly volatile specific components such as Hg escape in the flue gas stream, whereas most of the metals remain in ash components. The containment of a specific metal in bottom ash or fly ash also depends on the composition of fuel/ fuel mixture, its handling and combustion history (Chang *et al*, 1998). Another factor affecting the mobility may be the weight and particle size. Metals having a lower weight and smaller particle size are usually found in fly ash. However, the metal release/accumulation process is quite complex.

Our fractionation data shows that the major proportion of the metals remains in ash rather than in the flue gas stream (except mercury). Generally, mercury is found in three forms, viz. particle-bound, gaseous elementary mercury and an oxidized form. With a decrease in temperature, Hg is oxidized to $HgCl_2$ and HgO. The temperature drop may also result in deposition of mercury on ash particles. It was found that a significant amount of arsenic escapes with the flue gas stream. During coal mono-combustion, around 50% of arsenic was released to atmosphere, whereas this value was around 30% for the other two fuel mixtures. It was also observed that for the fuel mixture (coal + 10% SRF) less than 10% quantity of Pb, Cu and Cd was accumulated in the bottom ash and most of these metals were contained in fly ash. On the other hand, these figures were quite different for the other two fuel/ fuel mixtures. Even for (coal + 10% RDF) mixture, accumulation of Cu and Cr in bottom ash was greater than 50%.

Table 3. Metal concentrations in flue gas streams

Trace elements	Concentration ($\mu g/m^3$) in flue gas samples		
	Coal only	(Coal + 10% SRF)	(Coal + 10% RDF)
Cr	114	70	95
Zn	890	160	250
Cu	60	122	116
Ni	330	92	90
Pb	120	120	255
Cd	1.2	3.6	2.8
Na	1450	3800	2650
K	12450	26500	44300
Co	6.4	15	13.4
Mn	30	300	265
Fe	1140	10550	10600
Al	690	27350	28000

Table 4. Heavy metal concentrations in fly ash and bottom ash samples

Elements	Coal bottom ash	Coal fly ash	SRF bottom ash	SRF fly ash	RDF bottom ash	RDF fly ash
Pb	21	260	5	254	21	243
Cu	10	199	1.5	176	157.3	184
Zn	91	831	35	328	55	562
As	4	36	7	58	8.7	36
Cd	0.2	11.9	<0.1	7.8	0.4	10.9
Mn	105	881	349	925	101	877
Cr	9	265	27	194	86.7	319
Na	560	38900	579	39700	686.7	40500
K	2030	15900	1920	14800	8929.7	16000
Tl	<1	<1	<1	<1	<1	<1
Hg	0.05	<0.13	0.02	0.31	0.03	0.16

4. CONCLUSIONS

Use of MSW derived SRF in energy intensive industries as an alternative fuel can assist in reducing reliance on fossil fuel. In addition to this, operators can earn Renewable Obligation Certificates (ROCs) from the biomass fraction of fuel and revenues in the form of gate fees.

Several conclusions are drawn from our study:

- SRF prepared from the Ecodeco MBT process contains ~ 70% biogenic fraction.
- MSW derived SRF contains a lesser amount of S, Cl and heavy metal content than RDF with coal.
- Characteristics of SRF reveal that this kind of fuel can be suitable for power plant operators and cement producers as an alternative non-fossil fuel.
- A lower moisture content and higher amount of volatile material reduces the loss of heat in removing moisture and raises the fluidised bed temperature at comparatively lower feed rates.
- Combustion results show that a large fraction of mercury (*ca.* 90%) releases to the atmosphere due to high volatility.
- Heavy metal emissions in the flue gas stream from coal mono-combustion and (coal + 10% SRF) combustion were similar and were lower than that obtained from (coal + 10% RDF) combustion.
- Distribution of the trace elements in ash and the flue gas stream shows the containment of most of the metals (except mercury and arsenic) in ash samples (up to 98%).
- Addition of waste derived fuel reduces the amount of arsenic released to the atmosphere thus reducing potential health impacts on local receptors.
- Behaviour of different metals in terms of mobility depends on the fuel mixture, its combustion history and handling.

Overall, SRF has the potential of being used as an alternative co-fuel in energy intensive industries. Future studies should be aimed at measuring gaseous emissions. Behaviour of heavy metals at a higher SRF proportion with other fuels should also be studied. Thermodynamic modelling can be carried out in order to assess the technical feasibility of different co-

combustion scenarios. There is a need to assess risks associated with a number of options on a comparative basis.

ACKNOWLEDGEMENTS

This research is sponsored by a consortium of organisations and Grantscape under the Landfill Tax Credit Scheme (Project No. 158/169). The authors express their thanks to the project steering group members for their contributions. Views expressed are those of the authors' alone.

REFERENCES

Bardos, P. (2004). Composting of mechanically segregated fractions of municipal solid waste - a review. SITA Environmental Trust report. http://www.compostinfo.info/

CEN/TC 343/WG 2 Solid recovered fuels – specifications and classes. Draft European Standard. European Committee for Standardisation. http://www.erfo.info/CEN_TC_343.18.0.html

Chang, Y., Chen, W.C. and Chang, N. (1998). Comparative evaluation of RDF and MSW incineration. *J. Hazard. Mat.*, 58, 33-45.

Council of the European Union (1999). Directive 1999/31/EC on the landfilling of wastes. Official Journal of the European Communities, L182, 1-19.

Cozens, P. (2004). EfW - An alternative vision. *Proceedings of the Ist UK Conference and Exhibition on "Biodegradable and Residual Waste Management"*, Eds. E. K. Papadimitriou and E. I. Stentiford, Harrogate, UK.

Department for Environment, Food & Rural Affairs (Defra) (2006). Key facts about: Waste and recycling, Municipal waste management, 2005/06. http://www.defra.gov.uk/environment/statistics/waste/kf/wrkf06.htm

Environment Agency (2001). Solid recovered fuels in cement and lime kilns - an international perspective. R&D Technical Report P4-087/TR/1. Environment Agency, Bristol.

Garg, A., Smith, R., Hill, D., Simms, N. and Pollard, S. (2007). Wastes as co-fuels - the policy framework for solid recovered fuel (SRF) in Europe, with UK implications. *Environ. Sci. Technol.*, In press.

Hilber, T., Thorwarth, H., Stack-Lara, V., Schneider, M., Maier, J. and Scheffknecht, G. (2007). Fate of mercury and chlorine during SRF co-combustion. *Fuel*. (In press).

Juniper (2005) MBT: A guide for decision makers - processes, policies and markets. http://www.assurre.org/downloads/archive/5c29aa6e-0470-4375-a2ad-fab143a06d14.pdf

Kelsey, G.D. (1972). Incineration of municipal waste. *The Certificated Engineer*, August.

Porteous, A. (1981) Refuse derived fuels. Applied Science Publishers. ISBN 0853349371.

Sharma, V.K., Canditelli, M., Fortuna, F. and Cornacchia, G. (1997). Processing of urban and agro-industrial residues by aerobic composting: review. *Energy Convers. Mgmt.*, 38, (5), 453-478.