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Techno-economic performance analysis and environmental impact assessment of small to medium scale SRF combustion plants for energy production in the UK

C. Patel[a], P. Lettieri[a,*], A. Germanà[b]

[a] Department of Chemical Engineering, University College London, Torrington Place, London WC1E 7JE, UK
[b] Germanà & Partners Consultant Engineers, Via Badoero 67, Roma, Italy

ABSTRACT

This paper investigates a techno-economic analysis on small and medium scales: 50 kilo tonnes per annum (ktpa) and 100 ktpa combustion plants with steam turbine technology utilising solid recovered fuel (SRF). Energy and efficiency calculations for the technical assessment are performed. The economic viability of the two processes is investigated through a discounted cash flow analysis. The levelised cost is used to calculate the cost of production of one unit of electricity. A life cycle assessment (LCA) of the 100 ktpa scale SRF plant is performed, where the foundations of LCA calculations reside in energy calculations carried out for the technical analysis. Life cycle inventories were developed using inventory analysis and impact assessment. The results of the LCA are compared with those from equivalent scale coal, natural gas and electricity-mix plants. The LCA is also compared with a landfill reference system. Both scales are economically and technically viable. The SRF plant has a lower global warming potential emission (E_{GWP}) compared with the coal, natural gas and electricity-mix plants and the reference landfill system.

Keywords: Solid recovered fuel; Combustion; Life cycle assessment; Techno-economic analysis

1. Introduction

The major challenge facing the power generation industry over the coming decades will be to decrease the use of fossil fuels in order to meet stringent environmental goals. Especially, there is a need to reduce greenhouse gas (GHG) emissions to the atmosphere, with near-to-zero carbon dioxide (CO_2) emissions being the ultimate goal (Yang et al., 2000).

Rather than using fossil fuels for energy production, municipal solid waste (MSW) can be used to reduce greenhouse gas output. The UK produces around 29 Mt per annum of MSW, the majority of which is currently sent to landfill. Other means of waste management is necessary because our current reliance on landfill is the least desirable option for waste management (Kkvall and Finnveden, 2000). MSW can be processed into solid recovered fuel (SRF). This is a fuel produced from non hazardous MSW and is intended for use in an energy recovery facility (Defra, 2009a). The MSW undergoes mechanical heat treatment (MHT). A conventional MHT process is the Fairport process, which dries the waste to enable it to be more efficiently separated on the basis of size and density. The Fairport processor is a large rotating drum of approximately 13 m in length and 3 m in diameter. The waste material is fed into one end of the drum and air is heated by a gas burner counter currently. This creates a saturated steam environment inside the drum. This environment further breaks down the matter and cleans and sanitises other materials such as glass, cans and plastic bottles. As the material progresses along the drum moisture is driven off with the increasing temperature. The fractions are blend together and pelletised to produce a fuel meeting a predefined specification (Defra, 2005).

Various technologies exist for the production of electricity such as combustion, gasification, pyrolysis (so called advanced thermal treatments), wind, solar, and wave (ProEnviro, 2009). Combustion however is an old established technology, used to produce about 90% of our worldwide energy resources

* Corresponding author. Tel.: +44 020 7679 7867; fax: +44 020 7383 2348.
E-mail address: p.lettieri@ucl.ac.uk (P. Lettieri).
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Table 1 – Proximate and ultimate analysis of the SRF.

	Proximate analysis				Ultimate analysis					
	Moisture (%) (based on wt%)	Combustibles (%)	Inerts (%)	LHV (kJ/kg) (based on wt%)	C (%)	H (%)	O (%)	N (%)	S (%)	Cl (%)
SRF	15.8	64.20	20	16,701	69.63	5.75	22.25	0.88	0.62	0.87

(electricity, heating and fuel production) (Broek et al., 1996). Combustion technology can be used to produce energy from SRF (Cooke et al., 2003).

This present work investigates the environmental performance of an energy from SRF plant using the life cycle analysis approach.

Life cycle assessment (LCA) is a tool used to help identifying and quantifying the impacts of human interactions with the environment. LCA studies encompass all stages in the life cycle from extraction of raw materials ("cradle") to final disposal ("grave"), this is known as 'cradle to grave'. However, in some cases, the scope of the study will demand a different approach, where it is not possible to follow their numerous life cycles after the production stage. The scope of such studies is from 'cradle to gate', as they follow a product from the extraction of raw material to the factory gate (Azapagic et al., 2004). The approach used is better defined with a 'system boundary', which identifies all the stages from extraction of raw materials to the final disposal (De et al., 2009). Within the system boundary lies a detailed system characterisation where a number of interlinked subsystems are shown, these are represented by flow diagrams. The subsystems can represent a unit operation or a group of units (Papageorgiou et al., 2009).

A functional unit is a fundamental element in an LCA study because it represents a quantitative measure of the output of products or services which the system delivers. A functional unit enables comparisons of different systems (Clift et al., 2000).

This paper investigates from "cradle to gate" the LCA of energy production from SRF using fluidised bed combustion with steam turbine technology. This work stems from a previous investigation on the techno-economic performance analysis of producing energy from combustion and gasification of municipal solid waste plants by Yassin et al. (2008) subsequently extended by Patel et al. (2011) to consider also energy from forestry wood waste and rapeseed oil production. The work presented here investigates a real life plant for the medium scale at 100 ktpa. This plant was then scaled down to investigate whether it was technically and economically viable at a smaller scale of 50 ktpa. Hot spot analysis is used to define the unit operations within the plant that contribute to high emissions. The environmental burdens are calculated and compared with energy from coal, natural gas or electricity mix at similar scales. A landfill reference system is also compared against the proposed SRF combustion plant. This will allow determining if the proposed system is a better option environmentally than the traditional method of SRF disposal such as landfill (Whittaker et al., 2009).

2. Initial data

A flow chart for the fluidised bed combustion plants is shown in Fig. 1. The SRF characteristics used for developing the technical model for this work were provided by Germanà & Partners Consulting Engineers (2007) and these are summarised in Table 1.

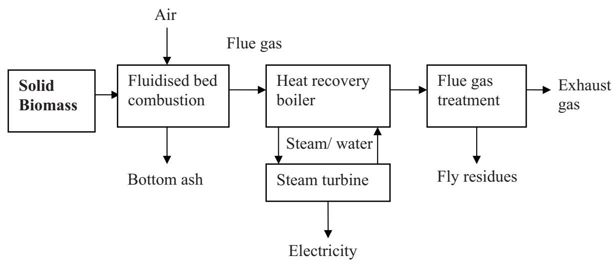

Fig. 1 – Energy recovery from SRF utilising fluidised bed combustion technology.

3. Techno-economic assessment

Performing energy calculations enable the assessment of the technical performance by determining the overall system efficiency. This is defined as the ratio of the net electricity generated to the energy input to the system, see Eq. (1):

$$\text{Overall efficiency} = \frac{Net\ power\ output\ [\text{MW}]}{Energy\ input\ to\ the\ system\ [\text{MW}]} \times 100 \quad (1)$$

The energy input to the system is given by the thermal capacity of the SRF, E_{th}, as expressed in Eq. (2):

$$E_{th}[\text{MW}_{th}] = LHV[\text{kJ/kg}] \times m[\text{kg/h}] \quad (2)$$

where *LHV* is the calorific value of the SRF and *m* is the SRF feed rate.

The net power output is the net electricity generated $E_{electricity,net}$ which is given by:

$$E_{electricity,net}[\text{MWe}] = E_{electricity,gross} - E_{auxiliary} \quad (3)$$

$$\text{Gross electricity generated} = E_{electricity,gross}[\text{MWe}] = \eta_{steam\,turbine} \times E_{th} \quad (4)$$

where the gross electrical generation efficiency of the steam turbine $\eta_{steam\ turbine}$ is 30% (see Table 2); the auxiliary consump-

Table 2 – Plants' overall electrical efficiencies and heat and power results.

Plant scale (ktpa)	SRF 50 Steam turbine	SRF 100 Steam turbine
Electricity produced (MWe)	5	13
Steam turbine electrical efficiency (%)	30	30
Overall system efficiency (%)	26	28