

# Energy from waste – POWERING YOUR FUTURE

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*The energy from waste (EFW) industry in the United Kingdom has experienced significant growth over the last decade. It has been driven by the desire to reduce landfill and mitigate harmful greenhouse gas emissions. Part one of this paper evaluates the typical challenges faced by refractories in EFW, including oxidation and slag corrosion. These challenges require innovative solutions to extend performance and reduce downtime.*

## LOW CARBON FUTURE

At first glance, the incineration of municipal waste as a low carbon solution may seem counterintuitive. The burning of hydrocarbons to produce electricity is facing strong push back from the public, but the energy from waste industry has grown significantly in the last ten years. In five years the number of energy from waste facilities in the UK has increased from 38 to 52, and the Department for Environment, Food and Rural Affairs notes 66 EFW facilities are under development<sup>(1-3)</sup>.

The EU and UK, encourages waste prevention as its first priority as stated in article 4 of the *EU Waste Framework Directive (2008/98/EC)*<sup>(4)</sup>, with disposal as the least favourable option (fig.1). With best intentions, landfilling remains the method most commonly used for managing waste in many European countries, which is up to eighty per cent in some cases<sup>(2)</sup>. Considering the present impact of waste disposal and subsequent methane formation, recovering energy from unrecyclable waste allows us a more efficient usage of resource without resorting to landfill.

This desire for efficiency ultimately means higher combustion temperatures in the furnaces from calorific pre-sorting<sup>(5)</sup>. With elevated combustion temperatures, refractories witness significant levels of ashes and corrosive flue gases, which in turn leads to limited refractory performance<sup>(6)</sup>. In addition to the challenging environment, plant operators require greater value in use, either by reducing down-time or extending campaign lengths between major outages. As with other high temperature industries, a trend in the energy from waste market has been the introduction of rapid turnaround products<sup>(7)</sup>, which offer immediate savings to the end user by speedily returning their process back to service following an outage. Several rapid turnaround technologies exist from low chemically combined water options to permeability enhancing solutions<sup>(8-11)</sup>.

## Application and Products

In Europe and the USA, combustion chambers of municipal solid waste EFW facilities are typically grate or stoker type (fig.3), where primary air is introduced below the waste to allow for efficient combustion<sup>(2)</sup>. Refractories in the combustion chamber sidewalls are



### What is Energy from Waste?

- Energy from Waste Controversy
- Typical WTE layout
- Reduced downtime and Energy Saving



### Typical refractory concerns

- Alkali Resistance
- Slag and Residue
- Oxidation

Part two of this study (to be published in the next issue of *The Refractories Engineer*) reviews the advancements such as rapid turnaround technologies, improved alkali and slag resistant monolithics, and next generation oxide-bonded silicon carbide tiles. Case studies demonstrate the effectiveness of new refractory materials, including fused mullite monolithics and innovative bonding systems, in extending service life and improving operational efficiency. By addressing value in use – through cost, longer life, and reduced refractory waste – this paper highlights how refractory innovations contribute to the EFW industry's future and will help evolve the industry towards a more sustainable future.



Fig.1 Waste hierarchy

	Bottom Ash		Slag	Surface Slag	
	Biomass Inc.	Medical Inc.	Gassifier	Biomass Inc.	MSW
Na <sub>2</sub> O	1.89	6.99	0.38	2.20	1.18
MgO	2.42	1.32	3.95	3.46	3.17
Al <sub>2</sub> O <sub>3</sub>	12.90	10.81	12.77	14.56	8.68
SiO <sub>2</sub>	39.60	50.46	29.14	36.34	39.40
P <sub>2</sub> O <sub>5</sub>	0.49	0.60	2.76	2.46	2.62
K <sub>2</sub> O	1.37	0.64	<0.05	<0.10	0.14
CaO	19.59	9.16	42.42	32.58	36.79
TiO <sub>2</sub>	3.22	1.58	3.96	3.24	3.49
Mn <sub>2</sub> O <sub>4</sub>	0.25	0.14	0.18	0.16	0.13
Cr <sub>2</sub> O <sub>3</sub>	0.32	0.87	0.09	<0.10	0.05
Fe <sub>2</sub> O <sub>3</sub>	14.84	9.57	3.93	4.34	3.70
Others	3.11	7.86	0.42	0.66	0.65

Table 1 Typical bottom ash and surface slag chemistries from various EFW sites

typically high alumina low cement monolithics with enhanced alkali resistance. Gunning is often a preference for ease of installation, with high alumina gunning used for the combustion roof and zones up to the lower first pass.

Secondary air is introduced at the lower first pass or roof to allow for any volatile combustion. Silicon carbide tiles are often present in the first pass area to promote thermal transfer from flue gas and to protect the waterwall boiler tubes, which contain the high pressure water that is heated to produce steam then electricity by means of turbines<sup>(6)</sup>.

**TYPICAL CONCERNS**

Refractory maintenance is critical to continued operation of an EFW boiler and plant operators are looking to high thermal conductivity solutions for heat flow efficiency, along with rapid turnaround solutions. However, the

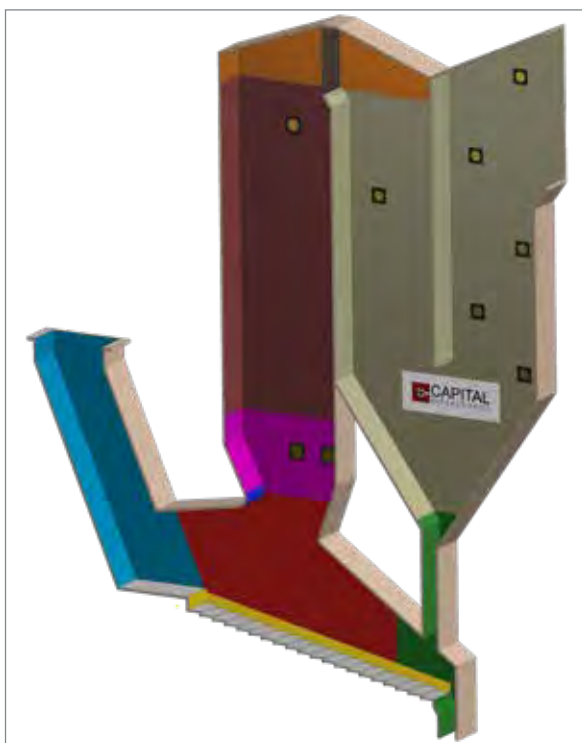


Fig.3 Typical schematic of a grate fired boiler, showing the fuel chute in blue, with the combustion chamber in red, and the first pass directly above in pink and burgundy

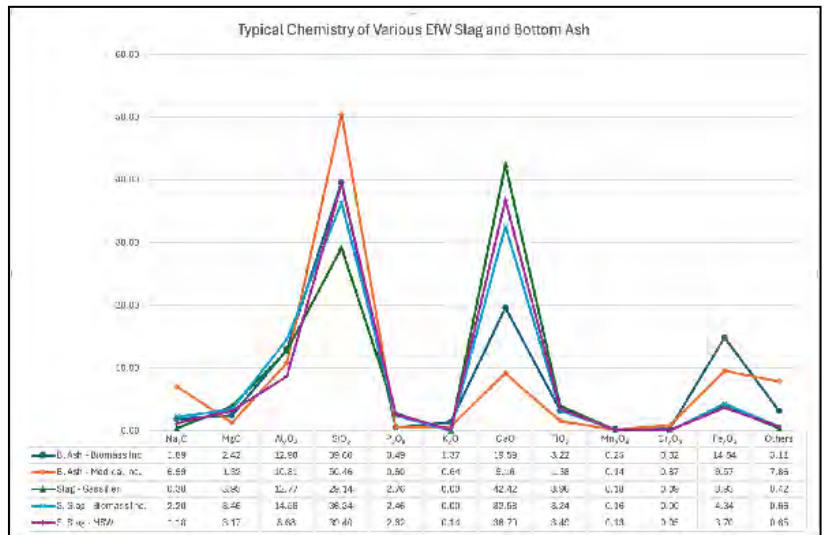


Fig.2 Typical chemistry of various EFW slag and bottom ash

refractory engineer must contend with significant alkali attack, potential chlorides and sulphides, ash and slag fouling, oxidation, and abrasion or erosion (Table 1, fig.2).

**Alkali Attack**

Alkali attack from corrosive vapour is a key concern for refractories in EFW, where volatilised soda and potash penetrate and condense below the surface, potentially forming low melting point eutectics upon reaction with silica, and in turn, corroding the refractory matrix. The resulting precipitated phases promote volume changes that cause cracking or 'bursting' of the refractory<sup>(12)</sup>. At temperatures below 1100°C, when burning feedstock high in soda, it is believed that the amorphous silicate is corroded to precipitate thenardite (Na<sub>2</sub>SO<sub>4</sub>), with mullite (3Al<sub>2</sub>O<sub>3</sub>·2SiO<sub>2</sub>) being corroded to form albite (Na(AlSi<sub>3</sub>O<sub>8</sub>)) and secondary alumina<sup>(13,14)</sup>. Similarly, fuels which contain high levels of potash, such as waste wood, can attack silicates to precipitate kaliophilite (KAlSiO<sub>4</sub>) amongst other phases<sup>(15)</sup>. Corrosion of alumina to form β-Alumina (Na<sub>2</sub>O·11Al<sub>2</sub>O<sub>3</sub>) is more favourable when the temperature is above 1100°C. Prigent et al. considers the temperature gradient key to inhibiting corrosion and, by modification of the isotherm inside the refractory, they suggest that condensation of alkali sulphates in the porosity of the refractory could be prevented<sup>(6)</sup>.

**Ash, Slag, Residue Corrosion**

Surface fouling followed by corrosion can occur due to the high levels of calcia in typical fly ash. Reviews on the fouling tendency of biomass fuels indicate that no universal relationship exists between the operating environment and the level of fouling. However, a positive correlation has been observed between high alkaline ash content and increased fouling<sup>(16)</sup>. The slag deposits can form in layers, and comprise of akermanite (Ca<sub>2</sub>Mg(Si<sub>2</sub>O<sub>7</sub>)), gehlenite (Ca<sub>2</sub>Al<sub>2</sub>SiO<sub>7</sub>) and wollastonite (CaSiO<sub>3</sub>), which precipitate out of an alkaline enriched phase. The slag reacts with matrix products in high alumina monolithics to precipitate anorthite (CaAl<sub>2</sub>Si<sub>2</sub>O<sub>8</sub>) and melilite (Ca<sub>2</sub>(Al,Mg,Fe)((Al,Si)SiO<sub>7</sub>)) along grain boundaries<sup>(14)</sup>. Gas vesicles forming on silicon carbide products, where slag adheres to the surface, indicate oxidation during service<sup>(17)</sup>.

**Oxidation**

Process operators require high thermal conductivity to transfer heat from flue gases to the waterwall boiler tubes. Silicon carbide (SiC) tiles therefore are used to protect the high pressure tubes and conduct heat. At temperatures exceeding 1000°C, the oxidation kinetics of SiC are generally favourable. However, in high temperature steam environments, the oxidation rate increases significantly<sup>(17)</sup>. As steam is a combustion product of burning hydrocarbons, SiC tiles are exposed to very difficult conditions, especially when burning high moisture waste such as biomass fuel or wood. Active oxidation of SiC can occur depending on the oxygen potential, forming

volatile silica species and weakening the tile structure. Typically, passive oxidation occurs during in service<sup>(18)</sup>, particularly in the middle to upper sections of the first pass where tiles swell and expansion joints disappear. The reaction product from passive oxidation could be in the form of amorphous silica, leading to attack by slag, forming para-wollastonite ( $\text{CaSiO}_3$ ), and alkalis that form sanidine ( $\text{K(AlSi}_3\text{O}_8)$ ) or microcline ( $\text{K(AlSi}_3\text{O}_8)$ ). Otherwise, dependant on conditions, cristobalite can form and has been found in forensic post service analysis<sup>(17)</sup>. Both the formation of cristobalite, and precipitation of plagioclase feldspar reaction products lead to significant expansion, disturbing and cracking the glaze and allowing corrosive gas deeper into the tile<sup>(6)</sup>. Once silica has formed from passive or active oxidation, it can become dissolved in the surface slag. Forensic samples show that macropores and permeability is often left around the SiC grain, beginning a cyclic wear pattern<sup>(17)</sup>.

To be continued in Part 2...

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Technical papers are required to be in a Microsoft Word format with any supporting imagery supplied as separate, high resolution jpeg files.

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