CHAPTER 19 - THERMAL TREATMENT

Thermal processing of both bottom ash and APC residue streams has been considered to reduce leaching of residue constituents, to further reduce the volume of the residues requiring disposal, and produce a treated material suitable for utilisation. In order to make a technically sound decision on the applicability of thermal treatment processes for MSW incinerator residues, fundamental knowledge of the various processes, including the process chemistry, temperatures and properties of the product generated are required. As a result, this chapter seeks to build on the information provided in Chapter 8, by describing the fate of elements during thermal processing of ash, and the potential applicability of these processes as treatment options. The major categories of thermal treatment are (i) vitrification, (ii) fusion and (iii) sintering and/or thermal binding. The principal differences between these categories relate more to the characteristics of the treated material, rather than the process itself. Definitions and descriptions of each of these thermal treatment categories are provided as follows:

> **Vitrification** - a chemical process whereby a mixture of glass precursor materials and waste materials are melted or fused at high temperature to generate an amorphous, single phase glass product.
>
> **Fusion** - a chemical process whereby MWC residues are melted or fused at high temperature and form either a crystalline or heterogenous product.
>
> **Sintering** - a chemical process whereby MWC residues are heated to sufficient temperature to allow reconfiguration of chemical phases present in the solid materials (refer to Chapter 8 for a detailed discussion of sintering).

19.1 DEFINITIONS

19.1.1 Vitrification

In a vitrification process, a residue or waste stream is incorporated with glass forming materials and/or other appropriate waste solids, by melting the mixture at a sufficiently high temperature to form a homogeneous liquid phase. Typical vitrification temperatures are between 1,100 and 1,500°C. The molten material is cooled to form an amorphous, homogeneous, single phase solid. If cooling is not rapid enough, the molten material may crystallise or "devitrify." The generation of the monophased glass within a controlled composition range ensures consistent chemical and thermal stability of the glass product. The final glass product should not contain any undissolved refractory feed material or other crystals formed on cooling. Additionally, glass compositions should avoid the potential of liquid-liquid phase separation in the melting process which would result in a glass solid being formed with two or more intermingled glass compositions. In general, mixed phase glasses may contain one phase which is less durable in acid or alkaline environments, which may have a negative effect on the overall leaching characteristics of the glass.

Vitrification processes are distinguished by the physical configuration and operation of the melting furnace, and by the process chemistry. Typical vitrification furnaces or melters are refractory lined vessels heated by either fuel combustion (most frequently natural gas) or joule heating with submerged electrodes. Materials to be vitrified may be fed either batchwise or continuously. "Hot crown" or "hot top" melters function with the entire contents of the melting vessel in a molten state. "Cold crown" or "cold top" melters function with a continuous layer of unmelted feed material floating on top of the molten material being vitrified. Additional feed material is placed on top of the melter to maintain the unmelted layer as melting progresses. Size reduction or pre-treatment of the residues to allow efficient melting may be required.

The objectives of vitrification processes are generally to either separate specific elements from the melted material through volatilisation or retention of specific elements within the vitrified product. However, the ultimate fate of potentially toxic constituents must be considered in all cases. Fluxing agents and glass precursors typically are added to the material to be vitrified to control retention of volatile metals during the melting process, and to control the treated material's physical and leaching properties. Process additives may be either virgin materials (silica, calcium carbonate, etc.) or recycled glass cullet. The relative quantity of additives used may vary from approximately 20 to 70% (by weight) of the total feed. Removal of excess sulphur, carbon, chloride or organics may be facilitated by appropriate thermal or chemical oxidations, or by thermal desorption at temperatures <1,000°C. Vitrification units generally require an oxidising environment to cause combustion debris and contaminants to oxidise (ideally) to carbon dioxide and water, and to solubilise any trace metals present in the feed. This may also reduce the volatility of some metals during the melting process, depending on the speciation of the metals entering the melt and respeciation during the melting process.

Products from vitrification can either be aggregate formed by "drigaging" (immediate immersion of the molten glass in water to form fractured, granular material), or formed into products such as fibre glass or molded shaped. Vitrified granular material has been considered for use as fill and as an aggregate substitute in pavement applications. Typical product specific gravities are between 2.4 and 2.9. Volume reductions achieved are a function of both the resulting product density and the quantities of additives used during the process.

19.1.2 Fusion

Fusion processes are similar in operation to vitrification processes but do not result in a homogeneous, amorphous glass single-phase product. Considerably less emphasis is placed on process chemistry during fusion processes. Typical melting scenarios may include the formation of a separate molten metal phase within the melter. Fused materials may be crystalline ("de-vitrified") with multiple crystal phases, or contain inclusions of unmelted feed. Products from fusion processes typically are being evaluated as aggregate substitutes.

19.2 GLASS COMPOSITION AND METALS RETENTION IN GLASS MATRICES

In view of the inherent variability in the chemical composition of incinerator residues, the need to evaluate the chemical characteristics and control the vitrification chemistry is considered highly important (Rabiger, 1992). The following introduction to glass structure and retention of metal constituents is summarised primarily from McLellan and Shand (1984), Wicks et al (1985, 1986) and USEPA (1992).

19.2.1 Glass Structure

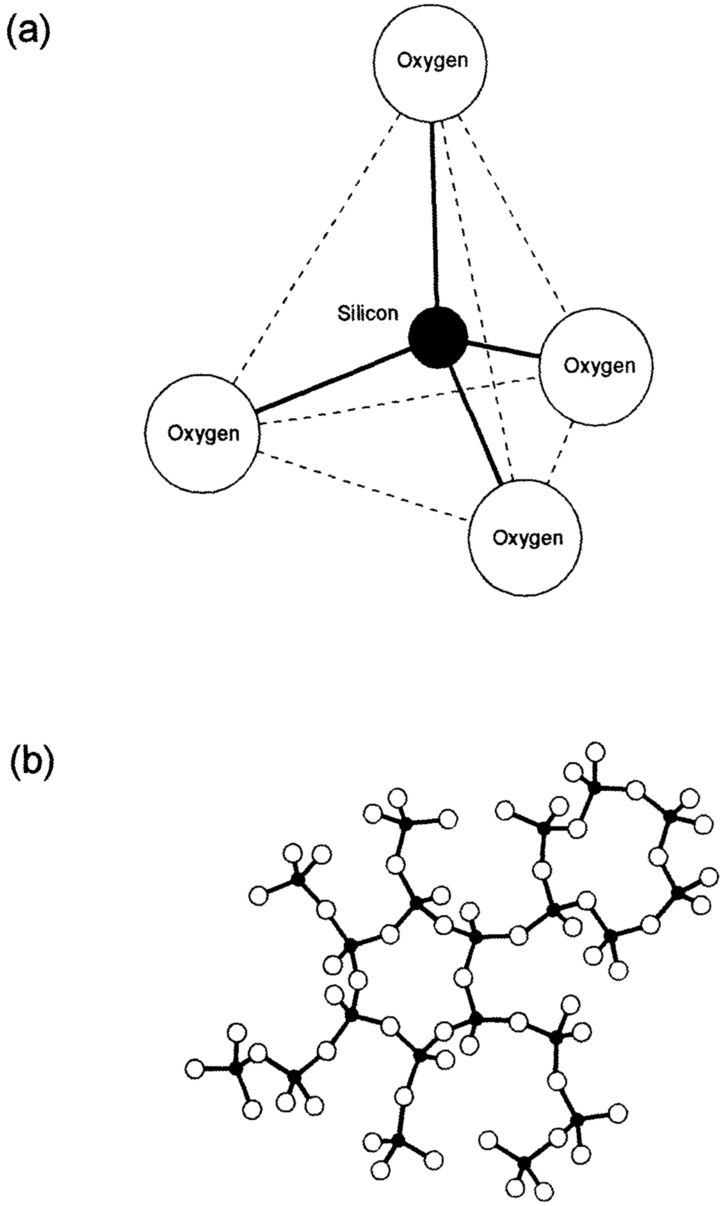
Glass is a rigid, non-crystalline material of relatively low porosity, often composed primarily of silica, alumina, and oxides of alkali and alkaline earth elements. Although phosphate, sulphide, and oxynitride glasses are also important glass types, most glasses produced during thermal treatment processes are silicate glasses. Thermally-formed glasses are produced by fusing or melting crystalline materials and/or amorphous materials (e.g., previously formed glasses) at elevated temperatures to produce liquids. These liquids are subsequently cooled to a rigid condition without crystallisation.

Silicate glasses are composed of three-dimensional networks. The basic structural unit of the silicate network is the silicon-oxygen tetrahedron in which a silicon atom is bonded to four oxygen atoms (Figure 19.1). The silicon tetrahedra are linked at the corners, where each shares one oxygen atom with another tetrahedron. Some, or all four, of the oxygen atoms from the tetrahedron can be shared with other tetrahedra to form a three-dimensional network. The extended 3-dimensional network is irregular and the Si-O-Si bonds randomly prevent tetrahedra from forming a crystalline network (McLellan and Shand, 1984).

The shared oxygen atoms are called "bridging" oxygens. In pure silica glass, the ratio of silicon to oxygen is ideally 1:2 with all oxygen atoms acting as "bridges". Some atoms, such as sodium, are ionically bonded to oxygen when present in glass, and thus interrupt tetrahedra linking and network continuity. An oxygen atom ionically bonded to another atom is called "nonbridging".

Appreciable amounts of most inorganic oxides can be incorporated into silicate glasses. Elements that can replace silicon are called "network formers". By replacing silicon in the glass network, some inorganic species (such as transition and other non-alkali metal elements) can be incorporated into a glass. Most monovalent and divalent cations (such as sodium, calcium and other alkali and alkaline earth [group 1a and 2a] elements) do not enter the network, but form ionic bonds with nonbridging oxygen atoms, and are termed network modifiers. Variation in the network integrity and the constituents of the glass are manifested in changes in glass properties such as softening point temperature and chemical durability (i.e., leachability and solubility) (McLellan and Shand, 1984).

Figure 19.1 The Basic Silicon-Oxygen Tetrahedron (a) and Linked Tetrahedron (b) Forming the Basic Structural Network in Silicate Glasses



McLellan, 1984

The role of certain elements in glass, termed intermediates, may vary with conditions. For example, aluminum may be a network former or a modifier depending on the ratio of aluminum to alkali and alkaline earth ions. The role of iron depends on redox state or oxygen availability in the molten material. For example, Fe^{+3} is a network former (McLellan and Shand, 1984) while Fe^{+2} is not.

The most common way of describing glass is to list relative amounts of oxides derived from the raw materials used in a glass formation, even though the oxides do not exist as such in the glass network. Many types of glass can be formed depending on the raw materials used. The glass industry prepares special formulations to obtain glasses with properties desirable for various uses. Important considerations for the thermal processing of incinerator residues include processing characteristics, such as melt viscosity and redox conditions, and product characteristics, such as physical and chemical durability.

In order to decrease the viscosity of molten glass and lower the melting point of the raw material mix, it is often necessary to add a flux, or network modifier, that will soften the glass by generating nonbridging oxygen atoms. Alkali metals, such as sodium, are often used as fluxes in their oxide forms. Alkalis can be incorporated into glass as carbonates, or other salts that react (at elevated temperatures) with silica to form a siliceous liquid. However, adding alkali to the glass generally decreases its chemical resistance. At high alkali concentrations, the glass may become water soluble. Alkaline earth fluxes, instead of or in combination with alkali fluxes, may be used to decrease the aqueous solubility of alkaline glasses while maintaining lower melting points. Oxides of calcium and magnesium are the most common alkaline earth or stabilising fluxes. However, adding too much calcium can cause calcium silicates and aluminates to form, resulting in crystallisation (devitrification) on cooling.

Soda ash (sodium carbonate) is commonly used in industry to supply alkali fluxes, while lime (calcium oxide) is commonly added to supply alkaline earth fluxes. Thus, glass made from silica, alkali and alkaline earth fluxes is commonly called soda-lime glass. Soda-lime glass is the most common type of glass, and is used in most container glass and window glass applications.

In addition to soda-lime glass, two other types of glasses are typically used to immobilise waste constituents. These are borosilicate glasses and aluminosilicate glasses. Borosilicate glasses are formed through the addition of boron oxide (B_2O_3) to silicate glasses. Boron oxide forms a network of planer boron-oxygen triangles upon cooling from temperatures above its melting point (460 °C). In low alkali silicate glasses, boron oxide maintains a triagonal planar coordination and serves as a fluxing agent by reducing the cohesiveness of the silicate glass structure. Aluminosilicate glasses are formed when alumina (aluminum oxide [Al_2O_3]) is added to silicate glasses. Alumina serves as a network former and forms a tetrahedral coordination similar to silica. However, since alumina is trivalent, it reduces the number of non-bridging oxygens resulting in increased glass cohesiveness.

The typical composition of soda-lime glass, borosilicate glass and aluminosilicate glass are compared with the composition of glasses formed from the vitrification of incinerator residues and other wastes in Table 19.1. Figure 19.2 presents the compositions for chemically durable glasses formed from incinerator APC residues reported by Wexell (1992). Waste glasses generally contain less silica and more aluminum and iron than soda-lime glasses. The "aluminum-bearing glasses" are generally more typical of glass compositions produced in waste vitrification.

The typical raw material used in industrial glass production consist of various formulations of the following main ingredients:

- Sand - SiO_2
- Feldspar - $KAlSi_3O_8$
- Dolomite - $CaMg(CO_3)_2$
- Limestone - $CaCO_3$
- Soda Ash - Na_2CO_3

In addition, different trace metal compounds can be incorporated into the glass mix to provide coloration. Table 19.2 contains a list of commonly used metal compounds along with the resulting colours.

Glasses typically can incorporate only small amounts (less than 1% by weight) of halogens, sulphur, nitrogen and carbon species, since a large proportion of these species are volatilised during melting. If large quantities are present in the mixture, they may form a separate phase in the melter. Elevated concentrations of these species in the product glass will result in decreased chemical durability of the material. In addition, carbon-based compounds can act as reducing agents and halogens can form more volatile metal complexes resulting in increased volatilisation of metal species during vitrification (also see chapter 8). Consequently, consideration of vitrification as a treatment technology for incinerator residues (especially APC residues) must include control of the off-gas emissions to minimise release of contaminants to the atmosphere.

19.2.2 Constituent Retention Mechanisms

Vitrification can incorporate incinerator ash constituents in a glass matrix via two main reactions - chemical bonding and encapsulation.

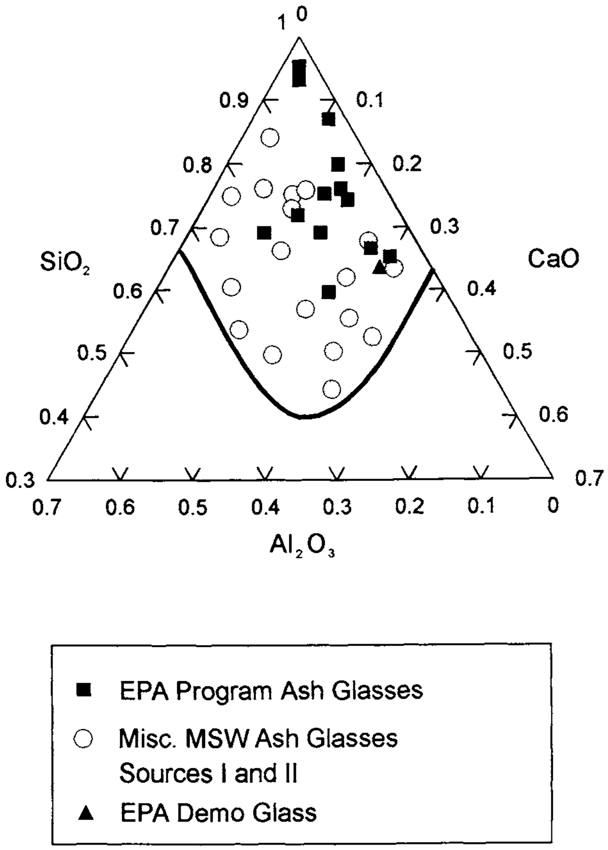
Certain inorganic species present in incinerator residues can be immobilised by chemical bonding with the glass-forming materials, particularly silica, present in the wastes to be vitrified. The most notable chemical bonding within a vitrified material occurs when certain metals or other inorganic elements bond covalently with the oxygen atoms in a silica network, becoming part of the network. Inorganic elements that interact in this way are considered network formers, since they essentially replace silicon in the glass network structure. Other inorganic species can behave as "network

Table 19.1
Typical Composition of Soda-Lime, Borosilicate and Aluminosilicate Glasses Compared to Glasses Formed from Vitrification of Incinerator Residues and other Wastes

Element	Typical Soda-Lime Glass[1]	Borosilicate Glass[2]	Aluminosilicate Glass[3]	Vitrified APC Residue (Corning)[4]	Vitrified MSWI flyash[5]	Vitrified MSWI ash (Kubota)[6]	Durable Glass Compositions for APC Residue Vitrification[4]	Whatcom County Ash Glass Sample
SiO_2	65 - 75	64 - 81	57 - 65	50	32	55	47 - 66	48.50
Al_2O_3	0.2 - 3	1 - 8	16 - 25	5.3	11	8	1 - 20	9.45
B_2O_3	nr	11 - 19	nr - 5	nr	nr	nr	0 - 6	0.37
Na_2O	12 - 15	2 - 9	0.5 - 1	7.7	1.5	5.5	1 - 15[a]	-
K_2O	0.1 - 3	1 - 7	nr	0.7	nr	1.5	a	-
MgO	0.1 - 5	nr	7 - 10	nr	2	1	nr	1.5
CaO	6 - 10	nr	8 - 10	17.2	24	16	9 - 31	11.30
BaO	nr - 0.5	2 - 3	0 - 6	0.04	nr	nr	nr	0.17
PbO	nr	0 - 6	nr	0.2	<0.005	0.03	nr	0.22
Fe_2O_3	nr	nr	nr	0.9	1.8	4	nr	20.10
TiO_2	nr	nr	nr	nr	nr	nr	0 - 7	1.10
ZnO_2	nr	nr	nr	nr	<0.1	nr	0 - 7	0.56

a = Includes Li, Na and/or K oxides
nr = not reported
1,2,3 = McLellan, 1984
4 = Vitrification of dechlorinated dry-scrubber residue with baghouse ash (Wexell, 1992)
5 = Sakai & Hiraoka, 1994
6 = Melting of bottom ash and ESP ash; mean values of 14 samples (Fujimoto, 1991)

Figure 19.2 Acid Durable Glass Compositions for APC Residues



Na_2O CONTENT

	Weight (%)
■ EPA Ash	2 - 14.8
○ Misc. MSW Ash	1.7 - 12.8
▲ EPA Demo	5 - 7

Wexell, 1992

Table 19.2
Inorganic Colorants used in Commercial Glasses

Material	Colour Produced	
	Under Oxidation	Under Reduction
Cadmium Sulphide	None	Yellow
Cadmium Sulphide, Selenium	None	Ruby
Cobalt Oxide	Blue-violet	Blue-violet
Copper (II) Oxide	Greenish blue	Greenish blue
Copper (II) Oxide	Greenish Blue	Ruby
Cerium Oxide	Titania Yellow	Yellow
Chromium (III) Oxide	Yellowish Green	Emerald Green
Gold	Ruby	
Iron (II) Oxide	Yellowish Green	Bluish Green
Manganese Dioxide	Amethyst to Purple	none
Neodymium Oxide	Violet	Violet
Nickel Oxide	Violet in K_2O glass	Violet in K_2O glass
Nickel Oxide	Brown in Na_2O glass	Brown in Na_2O glass
Selenium	Fugitive	Pink
Sulphur	none	Yellow to Amber
Uranium	Yellow with Green fluorescence	Green with fluorescence

Tooley, 1984

modifiers", forming ionic bonds with oxygen or other elements in the glass network. This ionic bonding incorporates the material into the glass, but disrupts the network continuity, thereby modifying the vitrified material's physical and chemical properties (see below).

Ash constituents also may be immobilised without direct chemical interaction with the glass network. Constituents that do not interact chemically or have not completely entered solution upon melting can be surrounded by a layer of molten material and encapsulated, as the melt cools. This layer of glassy material can protect the encapsulated constituents from chemical attack, and limit their ability to escape from the fused product (McLellan and Shand, 1984).

19.2.3 Chemical Attack and Leaching Mechanisms

Vitrified and fused materials are often thought of as being relatively "inert", because these materials exhibit high corrosion resistance compared with many other materials. However, all vitrified and fused products are chemically reactive to a limited degree.

There are two major forms of chemical attack on vitrified materials, namely, matrix dissolution and interdiffusion.

Matrix dissolution is characterised by alkali attack, typically at solution pHs greater than 9, which begins by hydration of the silica network and may proceed to product dissolution. In pure silica glass, the matrix dissolution process can be described by the following equation:

$$2\ NaOH + SiO_2 \rightarrow Na_2SiO_3 + H_2O$$

The resulting alkali silicate (Na_2SiO_3 in the above example) is usually water soluble, so as the silica network is attacked, the other constituents in the material are also released. Alkali attack is highly pH dependent. The rate of attack generally increases by a factor of 2 to 3 for each pH unit increase above 9. The influence of temperature on the rate of alkali attack follows an Arrhenius relationship with the rate of attack increasing by a factor of 2 to 2.5 for each 10°C temperature rise.

Interdiffusion is typified by acid attack, typically at solution pHs less than 5, on vitrified materials. While alkaline attack (matrix dissolution) leads to surface dissolution of the vitreous material, interdiffusion is an ion exchange process which preferentially extracts elements present as network modifiers, leaving the silica structure primarily intact. Generally, interdiffusion involves the exchange of hydronium ions in solution for ionically bonded elements in the vitreous network (McLellan and Shand, 1984). The rate of acid attack on glass is generally proportional to the square root of time. Since the process is controlled predominantly by diffusion, the rate of leaching decreases as the thickness of the leached layer near the glass surface increases. However, this effect can be limited if the layer dissolves or sloughs off. Although the rate of interdiffusion is influenced by temperature in a relationship similar to that for alkali attack, the interdiffusion rate increases only by a factor of 1.5 to 2 for each 10°C temperature rise.

While dissolution and interdiffusion describe leaching under many conditions, the leaching of many waste glasses appears to be modified by the formation of surface gel layers (Wicks et al, 1985). Layer formation is favoured in static or near-static solution conditions and where silica is present, as in many groundwaters. As matrix dissolution occurs, the surface layers, composed of insoluble glass components, arise. The formation of these layers proceeds in a three-stage process. Stage one is dominated by interdiffusion as network modifiers, such as sodium, diffuse out of the glass and into solution, and water diffuses in. The result is a modifier-deficient surface layer. During this stage, the pH of the leachant increases from the formation of alkali hydroxides in solution. Stage two is dominated by matrix dissolution. Stage three is characterised by the formation of surface layers from the precipitation and adsorption of insoluble compounds onto the surface of the glass. These compounds are the remaining more insoluble waste glass constituents. For example, these surface layers may contain substantial iron and manganese hydroxides. Where a surface layer forms, it can greatly reduce leaching of the waste glass underneath.

19.2.4 Factors Influencing Vitrified Ash Leaching

The use of vitrification to treat high level radioactive waste has resulted in considerable knowledge about waste glasses and their production, particularly in terms of chemical composition, waste loading, temperature, time and pH.

Chemical Composition

Chemical composition plays an important role in product durability (Wicks et al, 1985). In general, as the ratio of oxygen to network formers (such as silicon) decreases, more bridging oxygens are produced, resulting in a more durable product. Network modifiers such as alkalis and alkali earth oxides tend to decrease glass durability. This occurs because these oxides increase the oxygen-to-network former ratio and produce more singly-bonded oxygen, thus breaking up the glass network. However, these elements do decrease the melt viscosity and lower processing temperatures, and are used as fluxing agents. In general, oxides with valences greater than 1 may increase glass durability.

Composition of the waste feed can have enormous effects on product durability and processing parameters. Table 19.3 presents some of the effects of various inorganic oxides on processing and glass durability. Modification of the waste stream through additives and, or material removal can have dramatic impacts on processing and product characteristics. However, as Table 19.3 indicates, most additives have both desired and undesired effects.

Waste Loading

Increased incinerator residue loading does not necessarily increase product leachability (Wicks et al, 1985; Mendel, 1973). Research on borosilicate glass for the immobilisation of nuclear waste has indicated that glass leachability is reduced as the waste loading increases from 0 to 35% (by weight), with only small changes in leachability as the waste loading increases from 35 to 50% (Rankin and Wicks, 1983). In general, the incinerator residue loading in the product will be limited by the waste composition and the desired product physical and chemical properties. The amount of incinerator residue immobilised by borosilicate glass may not be limited by product durability, but by processing considerations. Some beneficial effects observed from increased waste loading on chemical durability results from the formation of surface layers during leaching that are made up of the major constituents found in the waste.

Temperature

Leachability of waste glass increases with temperature (Wicks et al, 1985). The mechanism of corrosion varies with temperature, i.e., at temperatures near ambient conditions, diffusion effects can dominate glass corrosion, but at temperatures near 100°C or higher, network dissolution can dominate. The exact temperature for the shift in mechanism varies with test conditions and glass composition.

Table 19.3

Effects of Waste Glass Components on Processing and Product Performance

Frit Components	Processing	Product Performance
SiO_2	Increases viscosity greatly; reduces waste solubility	increases durability
B_2O_3	Reduces viscosity; increases waste solubility	Increases durability in low amounts, reduces durability in large amounts
Na_2O	Reduces viscosity and resistivity; increases waste solubility	Reduces durability
Li_2O	Same as Na_2O, but greater effect on a unit mass basis; increases tendency to devitrify	Reduces durability, but less than Na_2O
K_2O	Same as Na_2O; decreases tendency to devitrify	Reduces durability, but more than Na_2O
CaO	Increases, then reduces viscosity and waste solubility	Increases then reduces durability
MgO	Compared to CaO has much greater effect in increasing viscosity and a smaller effect in reducing viscosity; reduces tendency to vitrify	Same as CaO, but more likely to decrease
TiO_2	Reduces viscosity slightly, increases, then reduces waste solubility; increases tendency to devitrify	Increases durability
ZrO_2, La_2O_3	Reduces waste solubility	Increases durability greatly
Waste Components	**Processing**	**Product Performance**
Al_2O_3	Increases viscosity and has tendency to devitrify	Increases durability
Fe_2O_3	Reduces viscosity; is harder to dissolve	Increases durability
U_3O_8	Reduces tendency to devitrify	Reduces durability
NiO	Is hard to dissolve; increases tendency to devitrify	Reduces durability
MnO	Is hard to dissolve	Increases durability
Zeolite	Is slow to dissolve; produces foam	Increases durability
Sulphate	Is an antifoam, melting aid; increases corrosion of processing equipment	Too much causes foam or formation of soluble second phase

US EPA, 1992; Adapted from Plodinec et al., 1982

Time

At a given temperature, the largest leach rates occur during the early stages of leaching (Wicks, 1985). Therefore, leach rates usually decrease over time. Two mechanisms appear to be involved in this leach rate decrease. First, under static or near static leachant conditions, the solution becomes saturated as elements are extracted from the glass and enter solution. Secondly, with time, the formation of surface layers can further inhibit leaching (Jantzen, 1988).

19.3 PROCESSING

19.3.1 Processing Equipment

A melting furnace or kiln is the central component for most treatment processes. Melter design is derived from either the glass manufacturing or smelting industries. Melters may be designed for operation either in a hot crown or cold crown mode. Energy required for melting can be supplied by electrical resistance (joule) heating, electric arcs or fossil fuel combustion. Use of fuels may be either through burners placed in the melting chamber or addition of fuel to the melter feed. Diagrams of three melter designs are provided in Figure 19.3.

Additional equipment required for thermal treatment processes included materials handling and air pollution control devices. Many processes propose recycling of the off-gases to the APC systems of the incinerator facility. In this case, a purge stream would be required to manage constituents (e.g., sulphates, halogens, etc.) that could not be incorporated into the fused or vitrified product.

19.3.2 Energy Requirements and Costs

Costs associated with vitrification of residues that have been estimated are widely variable (Edwards, 1994). Significant components of overall processing costs include capital investment, fuel or energy requirements, periodic refractory replacement, electrode consumption (when required) and management of process residues. Processing costs also can be estimated based on similar processing costs associated with glass production. Processing costs estimates for waste vitrification typically range between $150 and $750 per tonne of product produced. Capital investment, fuel and feed preparation typically represent 20, 50 and 10 percent of the total costs, respectively. A realistic first estimate of vitrification costs for incinerator residues is considered to be between $200 and $250 per tonne of product. These costs do not include cost recovery from sale of product or cost of product or residue disposal.

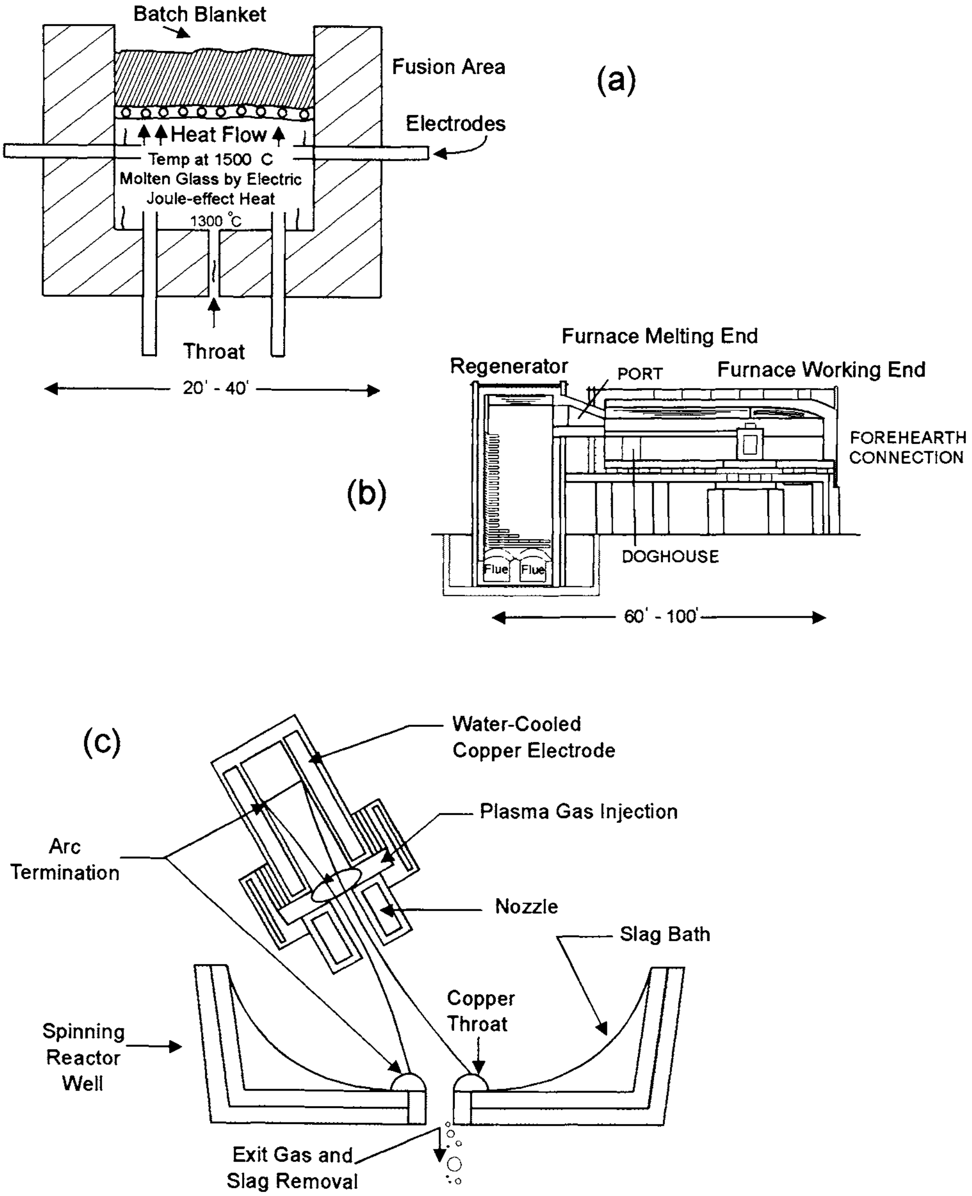
Thermal treatment of incinerator residues may not be economically attractive except under specific conditions. For example, if the residues are a substitute raw material for a glass in commercial production, processing costs associated with using incinerator residues may not be prohibitive. Other situations which may make it attractive are avoidance of extremely high disposal cost or use to meet specific regulatory requirements.

19.4 THERMAL TREATMENT PROCESSES UNDER DEVELOPMENT

19.4.1 Overview of Reported Processes

Several thermal treatment processes are under development by vendors. In general, each of the processes can be classified based on the characteristics of the product

Figure 19.3 Schematic Diagrams of Typical Melters; Submerged Electrode Melter (a), Fuel Fired Glass Melter (b), Centrifical Plasma Arc Melter (c)



Eschenbach et al., 1989

produced, the type of melter and the process chemistry involved. Table 19.4 provides an overview of the processes that have been reported. Most references contain a limited amount of technical details about the processing conditions and performance. Furthermore, most process demonstrations have been limited to batch (crucible) laboratory evaluations. In Japan, fusion/vitrification processes were originally developed for management of municipal sewage sludge and currently there are approximately ten full scale plants operating, some of which are processing bottom ash or bottom ash in combination with APC residues (Sakai & Hiraoka, 1994). Melting of APC residues only is under development but not in commercial application. A few processes (Kubota, Takuma, Corning, and ABB Deglor) have been demonstrated at pilot or commercial scale and are described in more detail in later Sections. A process that integrates RDF combustion with sintered aggregate production (Neutralysis Process) is also discussed later.

19.5 VITRIFICATION

Several vitrification processes have been reported in addition to those developed by Corning, Inc. The majority of these processes have been carried out in such a manner that results in the separation of volatile trace elements (eg., cadmium, lead, chloride, sulphur, etc.) from the incinerator residues. The off-gases from these systems are passed either through the existing incinerator APC system or through an independent APC system. When process off-gases are recycled to the incinerator, a purge stream is required to avoid infinite accumulation. Similarly, treatment and disposal of residues from independent APC systems must be considered. Although the applications for bottom ash appear to be more feasible, the only advantage to vitrifying APC residues is the reduction in the mass requiring further management. The requirement for off-gas treatment tends to defeat the purpose of treating the APC residues if the metals are not retained in the melt.

Combined ash from an incinerator was melted using joule heating and electric radiant heating in pilot unit being developed by Westinghouse Environmental Systems and Service Division (ESSD) (Westinghouse, 1990). The specific goals of these tests were to:

- Investigate the technical feasibility of combined ash vitrification
- Determine the emissions from the furnace while vitrifying combined ash
- Evaluate the vitrified ash material for leaching potential
- Determine the fate of the trace metals during vitrification

Combined ash was fed into the reaction chamber by means of a hopper and ram charger system. No glass forming additives were added to the combined ash prior to melting. The reaction chamber consisted of two sections, an upper dome with resistance heater, and a lower, water-cooled tub with submerged, water-cooled electrodes. The roof of the dome was cooled by forced-air convection. The reaction chamber off-gases passed through several treatment steps prior to being discharged

Table 19.4
Summary of Thermal Treatment Processes under Development or in Use

Process (Developer)	Short Description	Temp	Feed Stream (MSWI) Residue and Additives	Mass Balance Volume Reduction	Energy Needs	Developmental Status
Thermal Procedures SOLUR Procedure (developed by Sorg and Lurgi, marketed by Sorg, Germany)	glass melting kiln with directed heating by metal electrodes, unheated upper oven, glass byproducts are taken out cold crown oven	1300 - 1400°C	Filter ash and scrubber residue 32-36 M% SiO_2 10-14 M% Al_2O_3 22-24 M% CaO 2-5 M% Cl	adding 34 % glass waste 80% glass 10% gas 8.5% glass byproduct (melt crust) 1.5% Recycled volume of 50V % + 5V % remainder (byproduct)	0.8-1.8 kWh/kg	test installation 100 kg/h (up to max. 1 tonne/hour) (shutdown)
DEGLOR - Process = decontamination and glassification of residues (ABB + W + E Umwelttechnik)	continuous flow kiln with indirect electric heat by resister rods; hot crown oven, in larger plants additional bath electrodes	1300 - 1500°C	filter ash	75-80% glassified material 5-7% heavy metal salt concentrate volume reduced to 30%V	1-1.2 kWh/kg	experiment station Hinwil/Switz. 100kg/h since 1989
fully electric melting process (Melting technique Jodeit made in Jena, GmbH i, G)	glass melting kiln with direct heating by molybdenum electrodes, glass surface covered completely with feed (cold crown)	1400°C	residues from hazardous waste incineration from SAV "Schoneiche" (semi-dry)	79-82% solids 7-10 % glass byproduct (slag)/condensate 10 % vent produced gas	1.8-2.0 kWh/kg	experimental melting to form aggregate 1-2 tonnes/day test facility under construction

M = Mass, V = Volume, M % = wt %, DM = Deutsche Mark (1 DM = $0.6)

Table 19.4 Continued

Process (Developer)	Short Description	Temp	Feed Stream (MSWI) Residue and Additives	Mass Balance Volume Reduction	Energy Needs	Developmental Status
induction melting procedure DBA and Steinmüller	inductive (electrical) melting	1400°C	boiler and filter ashes	?	?	small scale test runs; data not available
CORMIN process = continuous residue mineralisation (KHD Humboldt Wedag AG)	staged combustion process with pulverised coal oxygen burners in melting cyclone melting film develops on the cyclone wall and drains off	1400 - 1600°C	boiler ash, fly ash, fine fraction (<1 mm) of bottom ash, also feed sewage sludge	10% lime 63-72% slag 10% dust 5-28% exhaust (vent gas) volume reduced to 25% of volume	--	(testing) station in Køln-Porz (FRG) test facility
burn-melting process (BABCOCK)	melting of bottom ash in gas fired kiln; produce mineral wool, condense some of heavy metals aggregate	1300 - 1400°C	bottom ash, boiler ash, filter ash	81% glass 3% glass byproducts, heavy metal concentrate	1.2 - 1.8 kWh/kg	experiments unknown
Flame chamber meltdown procedures (example: TAKUMA procedure (Kubota, Japan) offered in Germany by Lentjes/Mannes m ann)	twin cylinder melting process with 2 cylindrical surfaces, material added through a slot, heating oil or gas used as energy source	1300 - 1600°C	boiler and filter dust, i.e., slag	at the present: 55% slag 45% filter dust	2 kWh/kg	large scale plant process to 1 tonne/hour, 29 plants in Japan, different types of furnaces costs per plant approx. 10 million DM

M = Mass, V = Volume, M % = wt %, DM = Deutsche Mark (1 DM = $0.6)

Table 19.4 Continued

Process (Developer)	Short Description	Temp	Feed Stream (MSWI) Residue and Additives	Mass Balance Volume Reduction	Energy Needs	Developmental Status
Plasma melting process (Krupp-Mak)	Plasma reactor, heavy metals will be vaporised	1400 - 2000°C	filter ash	70% glassified granular substance 25% salt and heavy metal residues 5% dust	1.8 kWh/kg	Pilot Plant in Stapelfeld Maximum 1.3 tonne /hour, cost: 670 DM/tonne full-scale under planning, (Kiel, FDR) plant costs approx. 20 million DM
RedMelt process (BAM, TU Berlin)	arc type furnace with 3 graphite electrodes heating by means of electrical resistance of melted product under reducing atmosphere 2-phase, metal and slag	1250 - 1500°C	bottom ash filter ash ash from sewage sludge incinerator	89-95 M% Product with minimal heavy metal content 4-8 M% molten metal phase 1-5 M% Pb, Zn containing metal phase as exhaust gas condensate	0.8 kWh/kg	experimental plant batch type 100 kg/tonne Pilot plant is being planned in Berlin incineration costs: ~230 DM/tonne
HSR-Process "Holderbank" Smelting-Redox (Holderbank/ Switzerland)	1. slag will be melted and fuel oxidised with pure oxygen in a blast furnace 2. partial reduction of liquid slag with H_2/H_2O mixture	1300 - 1500°C	bottom ash filter ash ash from sewage sludge incinerator	80% M% granular Fine material 0.4 M% heavy metal condensate (Zn, Cd, Mg) 0.1 M% heavy metal precipitate	0.7 kWh/kg	Laboratory experiments pilot (plant) planned cost: 160-270 DM/t

M = Mass, V = Volume, M % = wt %, DM = Deutsche Mark (1 DM = $0.6)

Table 19.4 Continued

Process (Developer)	Short Description	Temp	Feed Stream (MSWI) Residue And Additives	Mass Balance Volume Reduction	Energy Needs	Developmental Status
FosMelt (L & C Steinmüller)	glass kiln fired with natural gas, combustion air enriched with O_2 (90% O_2)	1300 - 1500°C	slag filter dust sewage sludge incinerator ash	90 M% glassified product, contains heavy metals 2.5 M% condensate of exhaust gas (Hg, Cd, Zn) 7.5 M% exhaust	1.2 kWh/kg	experimental plant up to max of 100 kg/h Pilot plant being planned
as total process carbonising (distilling) - burning process Siemens-KWU	High temperature burning chamber with --- air supply fuel: gas and carbon from previous ----	1300°C	residues from the carbonising or distilling process up to 450°C. boiler and filter dust	---	---	Ulm, FRG, Test facility 200 kg/h Full-scale facility planned in Fürth, FRG

M = Mass, V = Volume, M % = wt %, DM = Deutsche Mark (1 DM = $0.6)

Courtesy of Umweltbundesamt, 1992

to the atmosphere. These treatment steps included particulate removal, cooling, and caustic scrubbing to neutralise acid gases produced during processing. An induced draft fan maintained a negative pressure throughout the reaction chamber and off-gas treatment system.

The principal conclusions from test operations were:

1. The majority of the trace metals found in the ash, specifically lead and cadmium, volatilised from the glass melt. The metals which remain in the glass were susceptible to leaching.

2. When furnace temperatures fell below 900°F, carbon monoxide emissions increase appreciably. A commercial system functioning in this capacity may require an afterburner.

3. Carbon accumulated on top of the glass melt during the testing of "cold top" operations. This indicated that continuous operation in this mode may not be practical unless a method can be found to burn the carbon more efficiently.

4. Pretest metal separation did not prevent molten metals from pooling on the bottom of the furnace. When designing a larger processing facility, the cost involved in improving the metal separation versus building a furnace with separate glass and metal discharges should be considered.

Champan (1989) has reported on laboratory studies involving vitrifying combined ash from the Whatcom County Incineration Facility, Washington, USA. This facility incorporates two Consumat CS-2000 incinerators with a nominal processing rate of 90 tonnes per day. The air pollution control system at the time of the laboratory research was a dry acid gas scrubber followed by a fabric filter unit.

Samples of the combined ash were oxidised by isothermal treatment at 750°C for up to 24 hours. Oxidation was assumed complete when no further weight loss was noted after 2 hours. Glass was made from 100 to 300 grams of oxidised ash by heating in a crucible at 1500°C for 1 to 2 hours. Molten iron typically collected at the bottom of the crucible. The bulk of the melt was a homogeneous glass up to the top surface, which was typically composed of an unmelted rim. This rim was enriched with oxides of aluminum. Apparently, aluminum metal in the ash melted, beaded to the surface, and slowly oxidised around the periphery. This portion of the heated mass typically did not melt into the molten glass and a sulphur odour was associated with the crusty layer. After melting from 6 to 14 hours at 1500°C, the rim of enriched aluminum reacted with the bulk to form a homogeneous melt. The glass was very lustrous, reflective, dark-black material with densities between 2.75 and slightly more than 3 g/cm^3. The highly lustrous surface may have resulted from reducing conditions during the melting process and the formation of metallic iron or hematite on the surface. The high density was attributed to the high concentration of iron in the glass. The 100 poise melting temperature of the resulting glass was about 1,325°C. The resistivity for this glass was 12 to 13 ohm/cm, at a viscosity of 100 poise. Table 19.1 includes the composition of the vitrified combined ash.

19.5.1 Vitrification of APC Residues by Corning, Inc.

The objectives of this vitrification process was to treat APC residue to form a homogeneous glass material as the principal product which was resistant to subsequent leaching and to retain potentially volatile metals in the glass (Wexel, 1992; Kosson, 1993). This process was one of several vendor processes evaluated under the USEPA program for evaluation of treatment and utilisation processes for incinerator residues.

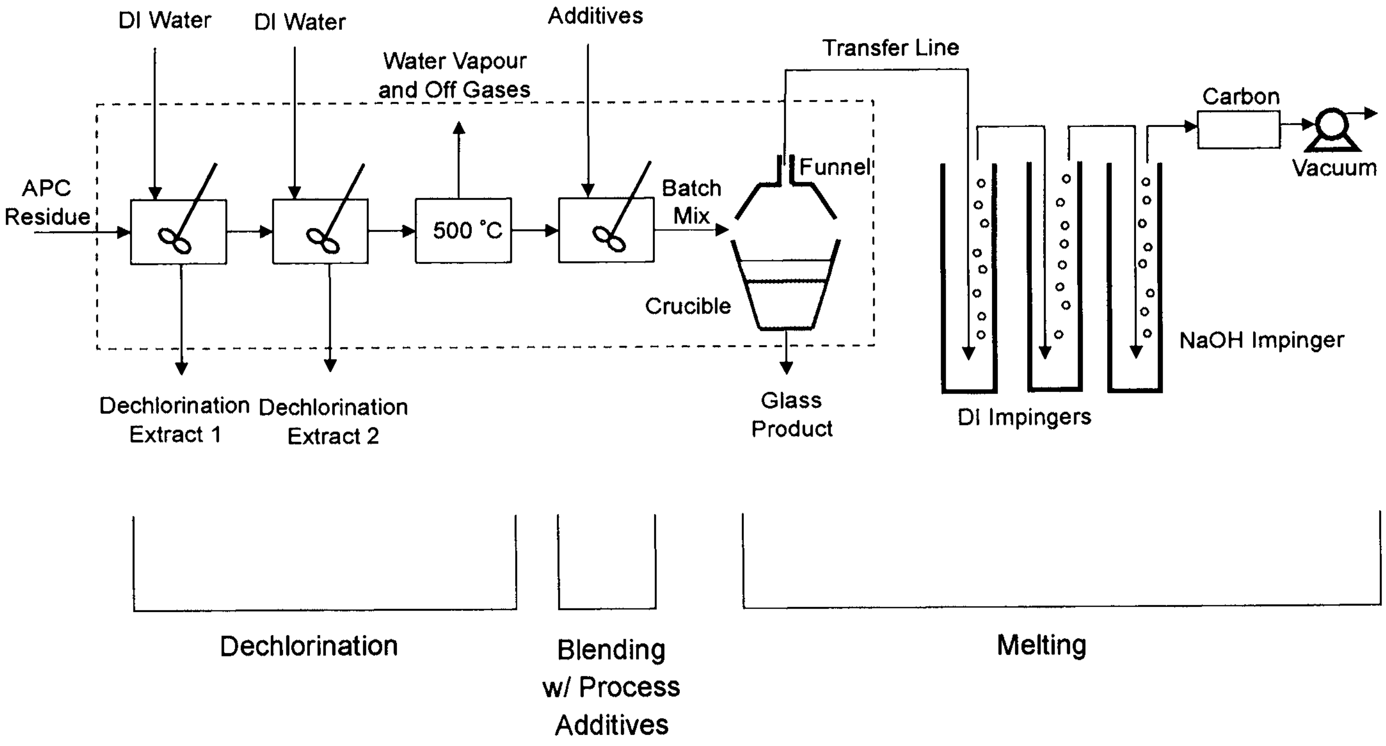
The APC residue used in this investigation was obtained from a mass burn incinerator incorporating a lime slurry spray drier (wet-dry) acid gas scrubber/fabric filter APC system. The bench-scale vitrification process consisted of three principal substituent processing steps (Figure 19.4), including:

1. Two serial aqueous extractions of the APC residue followed by suspended solids recovery and drying at 500°C to remove chlorides and carbon from the APC residue
2. Blending of the dechlorinated APC residue with glass forming additives, and
3. Melting of the blended dechlorinated APC residue and additives into a homogeneous glass in a cold crown melter, producing a glass product

The temperature of the molten glass is a function of the specific glass composition, but typically is between 1,100 and 1,500°C. The blanket of unmelted material served as a cooling layer for gases formed during the melting process and served to help reflux condensed volatile metals back into the reactor, however, the melting process step did result in the emission of off-gases. Glass products formed after the melting process were annealed to prevent stress fractures during cooling.

The APC residue dechlorination was accomplished by batch extraction with water and then filtered to recover the solids. The moist filter cake was dried at 500°C for approximately 16 hours (overnight) to remove water and residual organic carbon, leaving approximately 67% of the original dry weight of the APC residue. Approximately 30% of the calcium, 60% of the potassium, 17% of the sodium, 29% of the lead and 19% of the sulphur present in the untreated APC residue were removed from the system during the dechlorination process.

Figure 19.4 Process Flow Diagram of APC Residue Vitrification by Corning, Inc.



Kosson, 1993

16.7 kg of glass forming additives were blended with 18.0 kg of the dechlorinated APC residue and fed to the melter. The melter used to demonstrate the vitrification process consisted of a crucible placed in an electrical heating furnace. Feed was added to the top of the crucible as often as necessary to maintain a layer of unmelted material on top of the molten glass. Off-gases were collected from the melter and passed through a series of liquid-filled impingers and an activated carbon trap to collect volatilised metals and acid gases. The bottom of the crucible contained a reclosable orifice to allow semi-continuous collection of molten glass. Molten glass flowing from the melter was collected as patties in preheated graphite molds and then annealed at 575°C. The glass collected was olive green in colour.

Mass balances summaries for the dechlorination and blending steps of the process from both demonstrations are presented as oxide and elemental constituents in Table 19.5. The sum of the feeds includes the untreated APC residue and the vendor's additives. Using the sum of feeds and the removed material, the expected mass and composition were calculated based on the sum of the process feeds and the analysed extract composition. All water retained in the dechlorinated APC residue was assumed to be evaporated during the drying step. The calculated mass and composition were then compared to the measured mass and analysed composition.

The mass balance summaries for the melting step of the process are presented as oxide and elemental constituents in Table 19.6. The only feed stream was the batch mix as weighed and added during the melt. Material was removed from the system during the melting step through gaseous emissions. Dust collected from the funnel accounted for 2.19% (by weight) of the feed. Unmelted feed remaining in the crucible was assumed to have the same composition as the feed batch mix. The weight of the crucible with the remaining material minus the tare weight of the crucible was assumed to be vitrified material having the same composition as the glass product. An additional assumption was that the entire inventory of carbon and sulphur in the ash would be volatilised at the temperature of the melt. The expected mass and composition of the glass product were calculated by subtracting all removed material from the feed and compared with the measured mass of glass formed and the composition analysed. Relative error was calculated as the calculated glass quantity minus the measured glass quantity divided by the measured quantity.

Retention of cadmium, lead and zinc was calculated to be greater than 90% of the vitrified feed, although the >100% cadmium retention in glass was a result of cumulative analytical error. It should be noted that 29% of the lead originally present in the APC residue was removed with the dechlorination extracts. Corning, Inc. has indicated that subsequent process trials included precipitation of lead from the dechlorination extracts followed by addition of the lead precipitate to the melter feed (Wexel, 1992). Similar retention of lead in the glass product was claimed in this case.

Table 19.5
Mass Balance Summary for the Dechlorination and Blending Steps of the Corning, Inc. Process for Vitrification of APC Residue

Element	Sum of Feeds (g)	Dechlor Extract 1	Dechlor Extract 2	Sample	Batch Mix (g) calculated	Batch Mix (g) analysed	% recovered
Al	910	0.0 %	0.0 %	6.2 %	850	1,000	118 %
As	1.9	0.0 %	0.0 %	5.3 %	1.8	1.7	94 %
Ba	1.3	6.0 %	5.1 %	3.5 %	11	12	106 %
Ca	7,600	16.8 %	13.5 %	4.0 %	4,800	4,300	90 %
Cd	6.7	0.0 %	0.0 %	5.6 %	6.4	4.9	77 %
Cr	6.4	0.0 %	0.0 %	5.4 %	6.1	5.0	82 %
Cu	13	2.5 %	0.1 %	5.8 %	12	11	94 %
Fe	230	0.0 %	0.0 %	5.8 %	210	220	105 %
K	700	35.5 %	24.1 %	3.6 %	260	190	73 %
Mo	1.9	0.0 %	0.0 %	5.3 %	1.8	1.9	106 %
Na	2300	10.1 %	6.8 %	0.5 %	1,900	2,00	105 %
Ni	1.1	0.0 %	0.0 %	7.1 %	1.0	1.2	120 %
Pb	120	21.0 %	8.1 %	3.6 %	78	64	82 %
Si	7,300	0.0 %	0.0 %	1.2 %	7,200	8,100	113 %
Ti	200	0.0 %	0.0 %	5.8 %	190	200	105 %
Zn	430	0.3 %	0.1 %	5.7 %	100	3770	93 %
Cl	4,600	56.5 %	40.2 %	0.6 %	120	3880	317 %
S	860	7.3 %	12.1 %	6.7 %	630	890	141 %
Summary of elements	25,000	17.6 %	13.1 %	2.5 %	17,000	18,000	106 %

1. Number in boxes represent material removed from the system, expressed as percent of feed, due to the process indicated
2. Percent recovered is calculated as follows: % recovered = Analysed Batch/Calculate Batch

Table 19.5 Continued

Element	Dechlorination Extracts (1)	Emission Losses (2)		Vitrified Products (3)	
		% of Batch	% of APC	% of Batch	% of APC
Al	<0.1 %	0.03 %	0.03 %	89 %	94 %
As	<0.01 %	0.04 %	0.04 %	93 %	81 %
Ba	11 %	0.03 %	0.03 %	57 %	51 %
Ca	30 %	0.03 %	0.02 %	97 %	56 %
Cd	<0.1 %	0.84 %	0.60 %	138 %	98 %
Cr	<0.1 %	0.05 %	0.04 %	105 %	80 %
Cu	2.7 %	0.50 %	0.42 %	96 %	81 %
Fe	<0.1 %	0.03 %	0.03 %	87 %	85 %
K	60 %	0.10 %	0.03 %	107 %	29 %
Mo	<0.1 %	0.03 %	0.03 %	76 %	73 %
Na	64 %	0.85 %	2.72 %	56 %	178 %
Ni	<0.1 %	0.04 %	0.04 %	106 %	114 %
Pb	29 %	1.75 %	0.95 %	95 %	52 %
Si	<0.1 %	0.04 %	0.20 %	86 %	465
Ti	<0.1 %	0.03 %	0.03 %	93 %	89 %
Zn	0.5 %	0.15 %	0.13 %	107 %	91 %
Cl	97 %	0.86 %	0.07 %	38 %	3 %
S	19 %	0.13 %	0.13 %	19 %	20 %

1. Removal of APC residue by aqueous extraction for dechlorination
2. Losses from volatilisation during melting process
3. Retention of initial material in the final vitrification product

Kosson, 1993

Table 19.6

Mass Balance Summary for the Melting Step of the Corning, Inc. Process for Vitrification of APC Residue

Element	Feed (g)	Impinger 1 & 2	Impinger 3	Funnel Rinse	Transfer Line Rinse	Funnel Dust	Material Left in Crucible (g)	Glass Product Calculated (g)	Glass Products Analysed (g)	% recovered
Al_2O_3	1,900	NA	NA	NA	NA	0.03 %	730	1,200	950	79 %
As_2O_3	2.3	0.00 %	0.00 %	0.00 %	0.00 %	0.04 %	0.92	1.4	1.2	86 %
BaO	14	0.00 %	0.00 %	0.00 %	0.00 %	0.03 %	3.6	10	4.5	45 %
CaO	6100	NA	NA	NA	NA	0.03 %	2,600	3500	3,400	97 %
CdO	5.7	0.57 %	0.04 %	0.06 %	0.09 %	0.03 %	3.3	2.3	4.5	196 %
Cr_2O_3	7.4	0.00 %	0.01 %	0.00 %	0.00 %	0.04 %	3.4	4.1	4.5	110 %
CuO	14	0.21 %	0.00 %	0.04 %	0.04 %	0.19 %	5.7	8.0	7.5	94 %
Fe_2O_3	330	NA	NA	NA	NA	0.03 %	120	200	160	80 %
K_2O	240	NA	NA	NA	NA	0.10 %	110	130	140	108 %
MoO_3	2.8	0.00 %	0.00 %	0.00 %	0.00 %	0.03 %	1.0	1.9	1.2	63 %
Na_2O	2,700	NA	NA	NA	NA	0.82 %	690	2,000	860	43 %
NiO	1.5	0.00 %	0.00 %	0.00 %	0.00 %	0.04 %	0.69	0.83	0.92	111 %
PbO	71	0.81 %	0.04 %	0.17 %	0.17 %	0.50 %	29	41	38	93 %
SiO_2	18,000	NA	NA	NA	NA	0.04 %	6,700	11,000	8,700	79 %
TiO_2	330	0.00 %	0.00 %	0.00 %	0.00 %	0.03 %	130	200	180	90 %
ZnO	470	0.05 %	0.00 %	0.01 %	0.01 %	0.07 %	210	250	290	116 %
Ci	390	0.68 %	0.08 %	NA	NA	0.07 %	71	310	83	27 %
SO_3	2,300	0.06 %	0.00 %	NA	NA	0.07 %	250	0 [t]	250	[t]
C	[t]30	NA	NA	NA	NA	0.02 %	26	0 [t]	1.2	[t]
Sum of Elements	33,000	2.37 %	0.18 %	0.30 %	0.31 %	2.19 %	12,000	19,000	15,000	79 %

Notes: 1. Numbers in light box represent material removed from the system, expressed as percent of feed, due to process indicated.
2. Numbers in boldface and heavy box represent unmelted or uncollected glass, expressed in grams
3. Percent recovered is calculated as follows: % recovered = Analytical Batch / Calculated Batch

[t] Assumptions: C --> CO (g) and S --> SO_4 (g)

Kosson, 1993

Table 19.7 presents leaching test results from testing the vitrified APC residue produced by Corning, Inc. Leaching results indicated substantial reductions in leaching potential for all of the elements tested based on the availability leach test.

19.6 FUSION

There are several examples of fusion technology which have been demonstrated at different scales. The "VS reactor" has been suggested as a method to combust waste and thermally treat residues into a single process (Kunstler et al, 1992). In this configuration, grate ash from a mass burn facility passes directly into a rotary kiln. Grate siftings are recycled back into the waste feed to the primary combustion chamber just prior to the rotary kiln entrance. The flue gas is also partially recycled. Operating conditions in the rotary kiln are adjusted to provide either sintering or ash fusion prior to discharge. Initial testing was carried out at the KVA Basel facility, unfortunately no process mass balances or leaching test results are available. Pauli (1992) suggests the use of refuse derived fuel combustion with an integrated ash fusion section prior to discharge from the combustion chamber. Testing with fuels other than RDF have only been carried out at pilot scale.

The "FosMelt" process is designed for fusion of bottom ash with fly ash (Eisbein et al, 1992). The intent of the process is to separate volatile metals and inorganic constituents from the residue during fusion. Fossil fuels supply the energy necessary for fusion. The "RedMelt" process is similar in process objectives and design, but uses submerged electric arc heating rather than fossil fuel burners to achieve melting (Schumacher et al, 1992).

Several investigators have examined the use of plasma torches for fusion of bottom ash and fly ash (Jimbo, 1992; Klein, 1992). Pilot scale tests indicated that plasma torches may be used to carry out the fusion. The more volatile trace elements (Pb, Cd, Zn, etc.) and inorganic species (Cl, SO_4) are volatilised during the process and the trace elements remaining in the fused material are relatively non-leachable. Phase separation of the fused material into a fused heterogeneous semi-crystalline, semi-amorphous material and a metal phase has been observed.

MSW pyrolysis followed by combustion and residue fusion is carried out in the "Siemens Thermal Waste Recycling Plant." The process incorporates an initial pyrolysis of size reduced waste followed by high temperature combustion and fusion (approx. 1,300°C) of the pyrolysis products (Baumgärtel & Berwein, 1992). Metals and particles larger than 5mm are separated from the pyrolysis residues for recovery prior to introduction into the combustion chamber. ESP dust and boiler ash are recycled into the combustion chamber where they are fused with the other combustion residues. The fused ash is water quenched and forms a granular material. Pilot-scale (0.2 tph) testing of this process was carried out at the Ulm-Wiblingen facility. The elemental composition and leaching test results on the fused residue are provided in Table 19.8.

Table 19.7
Leaching Test Results for Testing of the Vitrified APC Residue Produced by Corning, Inc.

	TCLP (mg/l)					Availability Leach Test (release basis, mg/kg)				
	Vitrified APC Residue (2)					Vitrified APC Residue				
	Untreated APC Residue[1]	Demo 1	Demo 2	Detection Limit	Regulatory Limit	Untreated APC Residue	Demo 1	Demo 2	Detection Limit	% Reduction
Aluminum	0.04	0.20	0.19	0.02	-	2920	10	12	4	99.6
Arsenic	BDL	BDL	BDL	0.06	5.0	14.1	BDL	BDL	12	-
Barium	1.60	0.23	0.21	0.001	100	91.7	24	24	0.2	73.8
Cadmium	BDL	BDL	BDL	0.01	1.0	133	BDL	BDL	2	>98.5
Calcium	4,033	5.30	4.72	0.005	-	198,000	1,084	842	1	99.5
Chromium	0.22	BDL	BDL	0.001	5.0	6.4	BDL	BDL	2.0	>96.9
Copper	0.07	0.03	0.01	0.01	-	197	BDL	BDL	2.0	>99.0
Iron	0.06	0.17	0.17	0.01	-	30.1	BDL	BDL	2.0	>93.4
Lead	32.6	BDL	BDL	0.1	5.0	1,010	BDL	BDL	20	>98.0
Molybdenum	0.28	BDL	BDL	0.02	-	11.1	BDL	BDL	-	-
Nickel	BDL	BDL	BDL	0.005	-	4.4	BDL	BDL	2	<77.3
Potassium	712	1.6	1.50	0.01	-	13,800	38	44	2	99.7
Silicon	0.29	1.3	1.50	0.01	-	4,200	480	260	2	91.2
Sodium	-	-	-	-	-	14,000	600	460	0.2	96.2
Titanium	BDL	0.03	0.03	0.002	-	4.1	BDL	BDL	0.4	>90.2
Zinc	4.33	0.73	0.78	0.006	-	7,910	24	82	1.21	99.3
pH	11.9	5.9	5.9	-	-	-	-	-	-	-

(1) Extraction Fluid 2

(2) Extraction Fluid 1

Wexel, 1993

Relatively low total concentrations of trace metals (e.g. lead, cadmium) in the fused material compared to typical bottom ash values suggest that volatilisation of these elements may have occurred during fusion.

Table 19.8
Composition and Leaching Results for Granular Fused Ash from the Ulm-Wiblingen Facility

Element or Parameter	Total composition (wt%)	[1]Leachate concentration by DEV-S4 (mg/l)	[1]Leachate concentration by TVA (mg/l)
pH		8.9	9.54
Al	8.3	0.64	0.44
Pb	0.080	<0.05	<0.05
Cd	<0.0004	<0.002	<0.005
Cr	0.098	0.031	0.01
Fe	3.75	<0.63	2
Cu	0.19	0.08	0.14
Zn	0.2	<0.038	0.53
Cl	<0.08	1.3	0.5

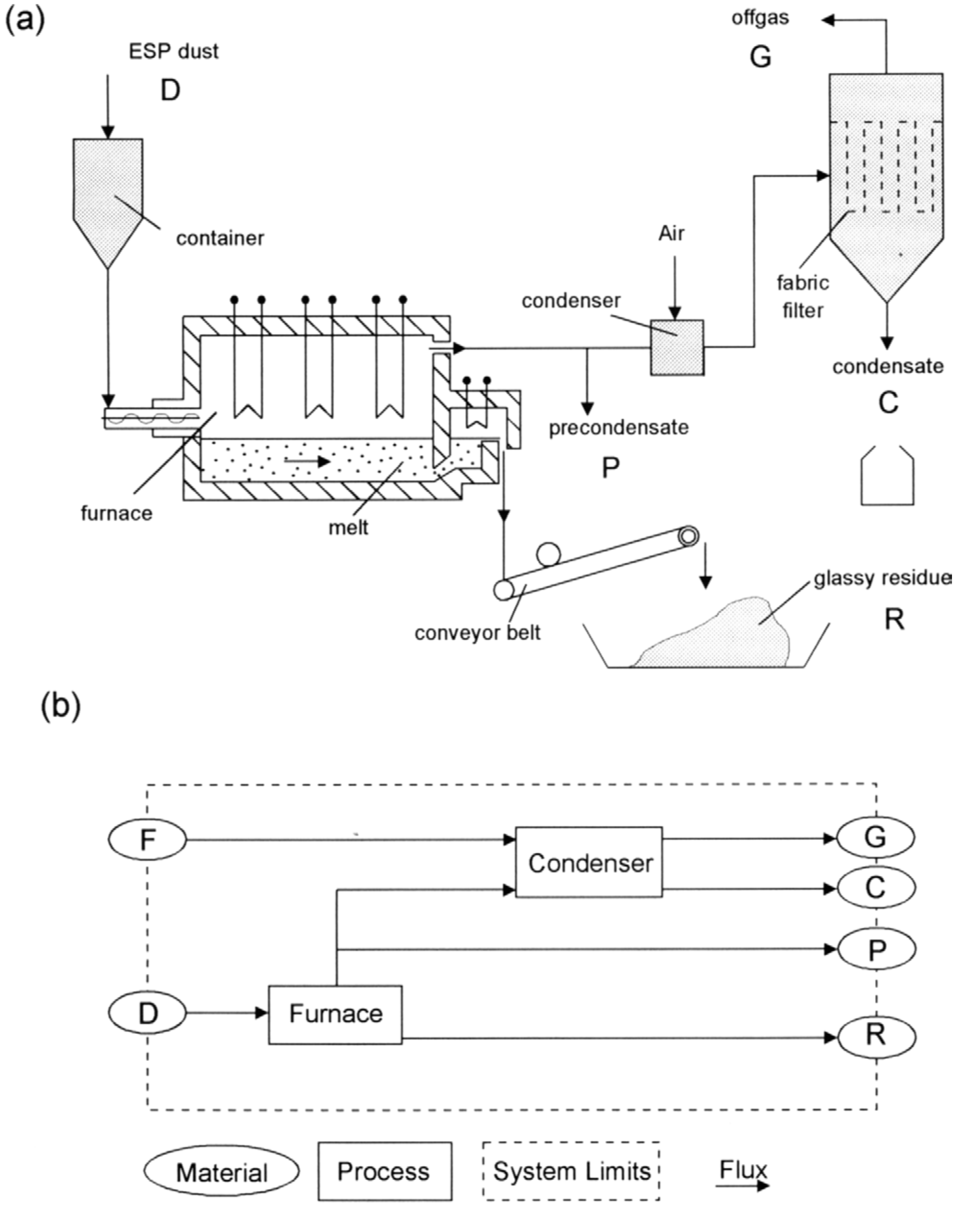
1 Fused residue was size reduced to less than 200 µm prior to testing
Baumgärtel and Berwein, 1992

19.6.1 Fusion of Filter Ash by ABB Deglor Process

The DEGLOR process has been developed by ABB (Baden-Dättwil, Switzerland) as a thermal process for treatment of ESP ash from waste incinerators (Hirth et al, 1990; Plumley & Boley, 1990). This glassification or fusion process splits the ash into two fractions, a major glass fraction, and a small fraction in which trace metals are condensed. The flue gases generated during the process are fed back into the incinerator. Laboratory furnaces with capacities of 1 and 3 kg/hour were utilised during the development of the program. A demonstration installation with a capacity of 100 kg/hour was operated processing an ESP ash slip stream at the Hinwil municipal waste incinerator near Zürich, Switzerland. A process schematic diagram and flow diagram are presented in Figure 19.5 (Stämpfli, 1992). The objective of the process is to separate specific metals through volatilisation and subsequent condensation to facilitate metals recycling. A black and green marbled, amorphous fused aggregate was the principal product. No additives were used in the melting process and the melting temperature was approximately 1350°C.

Composition of the ESP dust feed and process output streams are provided in Table 19.9, based on multiple analyses of samples obtained under nominal steady-state process conditions. Cd, Pb, Zn, Cl and S were substantially concentrated in the pre-

Figure 19.5 Process Flow Diagram (a) and Schematic Diagram for Mass Balances (b) for the DEGLOR Pilot Plant used to Fuse ESP Ash at the Hinwil MSWI, Switzerland



Stämpfli and Baccini, 1992

Table 19.9
ESP Dust Feed and Process Output Stream Compositions for the DEGLOR Plant Hinwil, Switzerland

Element		D	R	P	C	G - F
Carbon	C	1.6	n.d.	n.d.	n.d.	2700
Chlorine	Cl	1.2	0.27	7.9	10	220
Sulphur	S	1.1	0.090	2.4	1.0	1200
Zinc	Zn	0.33	0.13	0.62	0.88	0.28
Fluorine	F	0.18	0.18	<0.01	<0.005	2.3
Lead	Pb	0.030	0.0016	0.32	0.44	0.15
Copper	Cu	0.013	0.0020	0.036	0.040	0.015
Cadmium	Cd	0.0022	0.000056	0.032	0.033	0.0066
Mercury	Hg	5.5E-05	<5E-07	1.5E-06	3.7E-05	0.065
Silicon	Si	5.0	6.4	0.0025	0.0050	n.m
Calcium	Ca	3.7	4.2	0.0050	0.012	n.m
Aluminum	Al	3.3	3.9	0.0015	0.0011	n.m
Sodium	Na	1.0	0.74	3.7	3.3	n.m
Potassium	K	0.82	0.54	6.6	6.4	n.m
Magnesium	Mg	0.74	0.86	0.00082	0.0033	n.m
Iron	Fe	0.34	0.27	0.0068	0.029	n.m
Titanium	Ti	0.25	0.29	n.m.	n.m.	n.m
Phosphorus	P	0.18	0.20	n.m.	n.m.	n.m
Boron	B	0.023	0.024	<0.005	<0.005	n.m
Manganese	Mn	0.018	0.022	0.0011	0.0016	n.m
Tin	Sn	0.016	0.0025	0.0011	0.077	n.m
Chromium	Cr	0.010	0.015	<0.001	<0.001	n.m
Barium	Ba	0.0095	0.017	<0.0004	<0.0004	n.m
Antimony	Sb	0.0025	0.0039	0.0012	0.023	n.m
Nickel	Ni	0.0024	<0.0009	<0.0009	<0.0009	n.m
Molybdenum	Mo	0.0017	0.0027	0.0024	0.0029	n.m
Vanadium	V	<0.001	<0.001	<0.001	<0.001	n.m

n.m. = not measured n.d. = not detectable (<0.02 mol/kg)

Note: Element concentrations of the materials - mol/kg for D,R,P and C; mmol/m^3 for G-F

Stämpfli and Baccini, 1992

condensate stream, whereas concentrations of Pb and Cd in the fused residue were one and two orders of magnitude less than in the ESP dust. A process mass balance on a unit feed basis is provided in Table 19.10. Closure of the mass balance was within the analytical error for all elements presented, with the exception of Cu and Zn, which appeared to accumulate within the melter. Table 19.11 presents the results of the Swiss TVA leaching tests on the fused residues, which were significantly below the Swiss regulatory requirements (Plumley & Boley, 1990).

Table 19.10
Process Mass Balance for DEGLOR Pilot Plant, Hinwil, Switzerland (unit feed basis)

	D (input)	R	P	C	G-F	Output
Mass flux	47	33	0.26	2.6	9.6 (28)*	46
trans. coef.		0.70	0.0056	0.056	0.20	0.97

Elemental Transfer Coefficients - Average of Four Intervals

Element		R	P	C	G - F	Output**
Carbon	C	sm.	sm.	sm.	0.99	0.99
Chlorine	Cl	0.16	0.038	0.50	0.11	0.81
Sulphur	S	0.060	0.012	0.054	0.66	0.78
Zinc	Zn	0.26	0.010	0.15	0.0005	0.42
Fluorine	F	0.72	sm.	sm.	0.040	0.76
Lead	P	0.039	0.060	0.83	0.003	0.93
Copper	Cu	0.11	0.016	0.18	0.0007	0.30
Cadmium	Cd	0.017	0.080	0.82	0.002	0.92
Mercury	Hg	sm.	0.0002	0.038	0.67	0.70

* in parentheses the off-gas flux in m^3/h (standardised to 0°C, 1 atm and dry); typically F=120 m^3/h

** equal to 1 with complete transfer; sm. = smaller than 0.0001

Stämpfli and Baccini, 1992

19.6.2 Japanese Fusion Processes

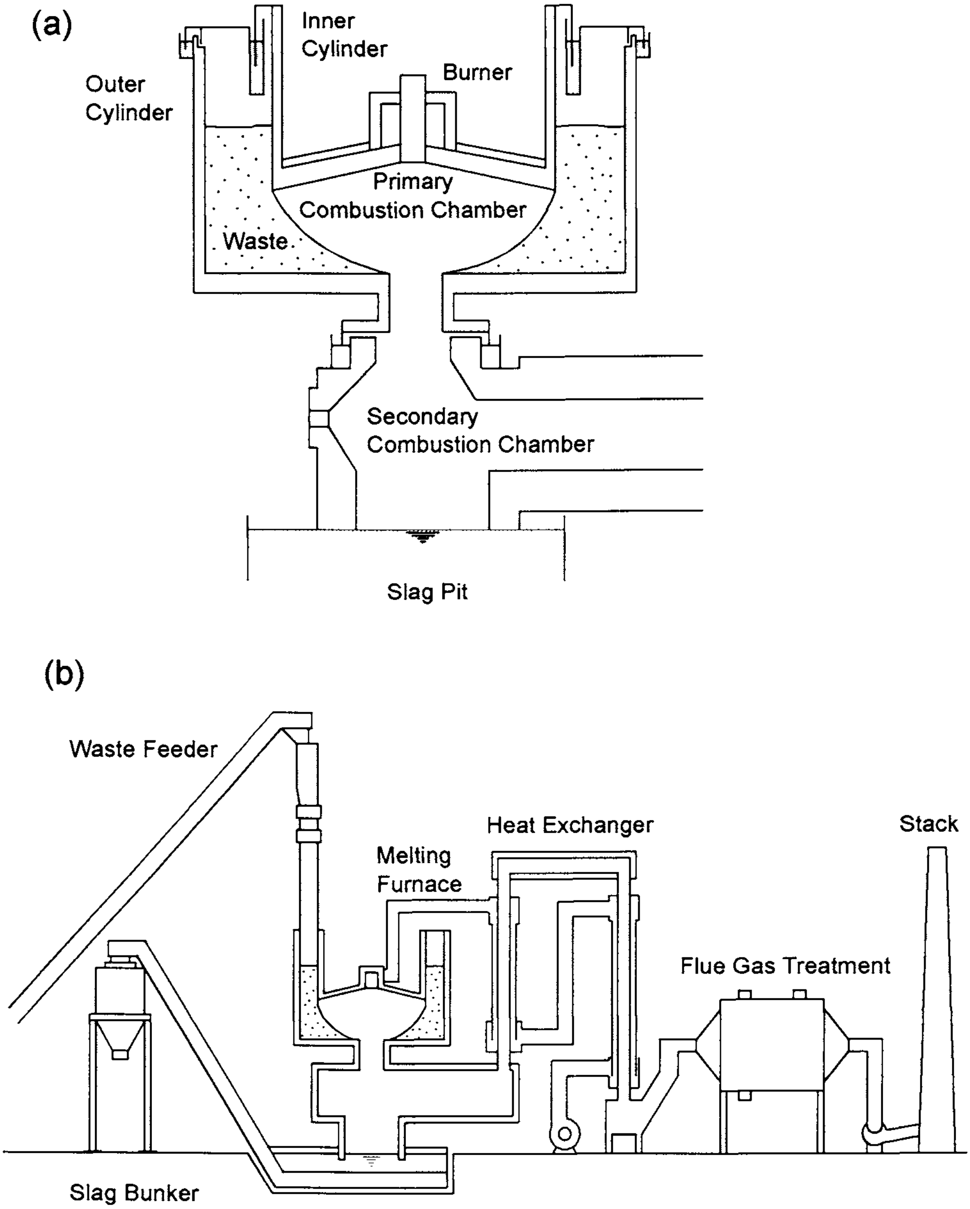
Kubota Corp. has seven full-scale melting furnaces in operation and three under construction as of 1992 (Fujimoto et al, 1991, 1992). Three of the facilities are for melting incinerator residues while the others are for sewage sludge or other waste types. A schematic diagram of a typical installation is provided in Figure 19.6. Melting, typically of combined bottom ash and fly ash, is accompanied in an annular melting

Table 19.11
Swiss TVA Leaching Test Results on Fused ESP Dust from the DEGLOR Process

		Leachate	Limit Established by Swiss TVA
Aluminum	mg/l	1.0	1
Arsenic	mg/l	<0.005	0.01
Barium	mg/l	<0.1	0.5
Cadmium	mg/l	<0.005	0.01
Chrome III	mg/l	<0.005	0.05
Chrome VI	mg/l	<0.005	0.01
Cobalt	mg/l	<0.01	0.005
Copper	mg/l	<0.01	0.2
Lead	mg/l	<0.05	0.1
Mercury	mg/l	<0.001	0.005
Nickel	mg/l	<0.01	0.2
Silver	mg/l	<0.005	0.01
Tin	mg/l	<0.1	0.2
Zinc	mg/l	0.2	0.5
Ammonium	mg/l	<0.05	0.5
pH Value	mg/l	6.0	6 - 11
Fluoride	mg/l	<0.1	1
Nitrate	mg/l	<0.01	0.1
Sulphite	mg/l	<0.05	0.1
Phosphates	mg/l	<0.01	1
DOC	mg/l	0.95	20
AOX	u/l	3.9	5 - 10

Plumbley and Boley, 1990

Figure 19.6 Schematic Diagram of Kubota Melting Furnace (a) and Fusion Facility Design (b)



Fujimoto et al., 1991

furnace. The target alkalinity for Kubota melter slags is 1.0, as calculated by dividing the percent weight ($CaO + MgO + Fe_2O_3$) by percent weight ($SiO_2 + Al_2O_3$), however, published average slag compositions from Kubota incinerators, are less basic. The melting point of the slag is 1,200 - 1,250°C and therefore the temperature in the combustion chamber is maintained at 1,300 - 1,400°C. Slag volume is typically about 45% of that of the ash feedstock volume. Approximate percentages of Cd, Cl, Pb, S, and Na_2O in the feedstock which are retained in the slag are 5, 5, 15, 30 and 70% respectively (Fujimoto et al, 1989).

Each plant generates a slag by-product (the largest plant has 5,850 tonnes/year slag output) that is approved by some of the municipal governments for use as substitute for landfill sand, pavement material for light-loaded roads, playgrounds and tennis courts, and bedding for pipes. Typical slag compositions appear in Table 19.1. Output from Kubota's Oyabe plant (1350 tonnes per year slag) is converted into decorative paving block.

Bottom ash and ESP ash from a mass burn facility in Numazu, Japan have been melted together with waste plastic in a demonstration plant annular film melting furnace (Kubota) which has been in operation since 1979 (Fujimoto et al, 1991). The melting furnace capacity is 18 tpd and operates at a melting temperature of 1300 to 1400°C.

Ferrous metal must be separated from the bottom ash prior to melting. Inclusion of crushed waste plastic (35% by weight) as fuel added to the incinerator ashes replaces the need for up to 200 litres of kerosene per tonne of ash melted. Fused ash is water quenched resulting in a residue weight and volume reduction of approximately 6 and 50 percent, respectively. Off gases from the melter are passed through an ESP. The resulting ESP ash is managed separately. The fused ash and ESP ash represent 73 and 16 percent, respectively, of the total mass of ash fed to the melter. Information on the composition and percent of mass for each element for each process stream is presented in Table 19.12.

A 48 hour trial of melting only fly ash was carried out to evaluate operating condition and process mass and energy balances. Approximately 28 tonnes of fly ash was melted during the trial at a temperature of 1,330°C. Utility consumptions reported were 260 litres kerosene, 235 kWh and 2 m^3 water per tonne of fly ash melted. Mass and composition was determined for the fused ash, particulate remaining in the transfer ducts (to APC system) and ESP dust. The fused ash, ESP ash, transfer duct particulate, and flue gas represented 88.5, 8.7, 3.8 and 0.025 percent, respectively, of the total mass of fly ash fed to the melter. Information on the composition and percent of mass for each element for each process stream is presented in Table 19.13. The more volatile elements (Na, Cd, Pb, Zn) were volatilised from the melter and concentrated in the ESP ash. The process also resulted in greater than 99.98% destruction of PCDD/PCDF toxicity equivalents.

Table 19.12
Composition and Relative Masses in Feed and Output Stream during Fusion of Bottom Ash and ESP Ash from an MSW Mass Burn Facility by the Kubota Process

Element	Bottom Ash and ESP ash	Fused ash		ESP ash (From melter)
	relative mass (%)	conc. (mg/kg)	relative mass (%)	relative mass (%)
S	100	2,900	-	-
Cl	100	1,400	10	90
SiO_2	100	330,000	100	0
CaO	100	260,000	90	10
Al_2O_3	100	115,000	90	10
Na	100	36,500	50	50
Fe	100	88,300	100	0
Cd	100	1.3	0	100
Pb	100	450	10	90
Zn	100	4,500	30	70
Cr	100	450	100	0

Fujimoto et al., 1991

Takuma Co., also has some experience with commercial scale fusion processes. The first facility began operation in 1981, and there are now four operating in Japan, with another under construction (Wakamura and Nakazato, 1994). These facilities only process bottom ash, however, some modifications are being developed to process combined bottom ash and APC residue. These four operating units are of the type known as "stationary single-slope surface-melting furnace." The bottom ash first undergoes a magnetic separation to remove ferrous material before it is charged into the furnace. In the furnace, a kerosene or fuel oil burner heats the ash and melts it from the top surface. The furnace temperature in the free standing units is approximately 1,300°C and their sizes range from 4.8 to 15 tonnes per day. After two-stage magnetic separation, the molten bottom ash will consist of 92% slag (fused ash), 4% gas and 4% fly ash. The volume of ash is generally reduced by 50%.

The 14.4 tpd unit built in 1985 is directly connected to the MSW furnace, and is designed to melt metals in the bottom ash. For this purpose, it is equipped with an oxygen generator (Pressure Swing Absorption) which produces 95% O_2. The oxygen is added to the combustion air to raise its oxygen levels to 28%, which increases the furnace temperature to approximately 1,400°C. A new 15 tpd facility currently under

Table 19.13
Composition and Relative Mass in Feed and Output Streams during Fusion of Fly Ash by the Kubota Process

Element	Fly Ash		Fused Ash		Duct Particulate		ESP ash	
	conc. (mg/kg)	[a]relative mass (%)	conc. (mg/kg)	[a]relative mass (%)	conc. (mg/kg)	[a]relative mass (%)	conc. (mg/kg)	[a]relative mass (%)
C	59,000		<1,000		26,000		18,000	
S	5,600	100	3,300	46	33,000	20	18,000	24
Cl	103,000	100	3,200	2.5	305,000	10	405,000	29
Si	113,000	100	142,000	100	1,000	0.03	<100	0.00
Ca	137,000	100	192,000	110	13,000	0.33	2,000	0.11
Al	54,000	100	75,000	110	1,000	0.06	<100	0.00
Na	21,000	[b]87	7,000	21	202,000	29	178,000	55
Fe	15,000	100	21,000	110	2,200	0.09	3,800	0.05
Cd	46	100	3.0	5.2	270	20	420	68
Pb	1,600	100	110	5.4	8,000	17	15,000	70
Zn	4,900	100	1,200	19	14,000	9.7	25,000	38
Cu	440	100	1,300	230	2,200	17	2,500	42
Cr	400	100	1,000	200	35	0.3	42	0.78

a = Relative mass (%) is equal to the percentage of the total mass of the element fed to the melter.
b = 13% of the sodium fed to the melter was in the form of NaOH used as a process additive

Fujimoto et al., 1992

construction will be equipped with opposed dual melting slopes for larger capacity and better melting efficiency. Figure 19.7 shows its structure and process flow. This design is based on a 5 tpd pilot plant which was used to study the melting characteristics of bottom ash only, combined bottom and fly ash, and bottom ash with crushed incombustibles. These incombustibles are the materials remaining from a bulky-waste crushing plant, where combustibles, ferrous and aluminum metals were removed from the waste stream. Certain portions of the material are combustibles (Nishigaki & Shibata, 1994). Table 19.14 provides some operating data.

Table 19.14
Operating Data from Takuma Surface Melting Plant

		Unit	Run A	Run B	Run C
Test Material	Test Material	-	Bottom Ash	Bottom Ash + incombustibles (10:6)	Bottom Ash + Fly Ash (10:6)
	Treated Quantity	kg/h	252	354	248
Gas-Air Temp.	Furnace Temperature	°C	1432	1394	1385
	Air Preheater Entrance	°C	699	732	726
	Air Preheater Exit	°C	533	572	534
	Bag Filter Entrance	°C	166	162	173
	Combustion Air	°C	378	389	385
Others	Kerosene Used	l/h	71	55	81
	Dust Produced	kg/h	1.5	2.0	8.3
	Slag Produced	kg/h	222	247	214
	Slag/Ash Ratio	l/tonne	282	155	327

When 6 parts fly ash were mixed with 10 parts bottom ash, the alkalinity of the molten slag increased to 0.6 from 0.3 for bottom ash alone. The kerosene consumption per tonne of ash also increased by 15%, but the slag production rate decreased from 94.5% to 86.4% due to the higher concentration of volatile matter in the fly ash.

When 6 parts of "incombustibles" were mixed with 10 parts of bottom ash, the remnant combustibles within the crushed "incombustibles" worked as an auxiliary fuel, and the kerosene consumption went down by 45%. Conversely, although the high concentration of soil, sand and glass in the crushed incombustibles reduced the alkalinity to 0.25, the slag production rate also decreased to 77.4% as the volatile matter was driven off in the exhaust gas.

Figure 19.7 Flow Diagram of Takuma's Surface Melting Process

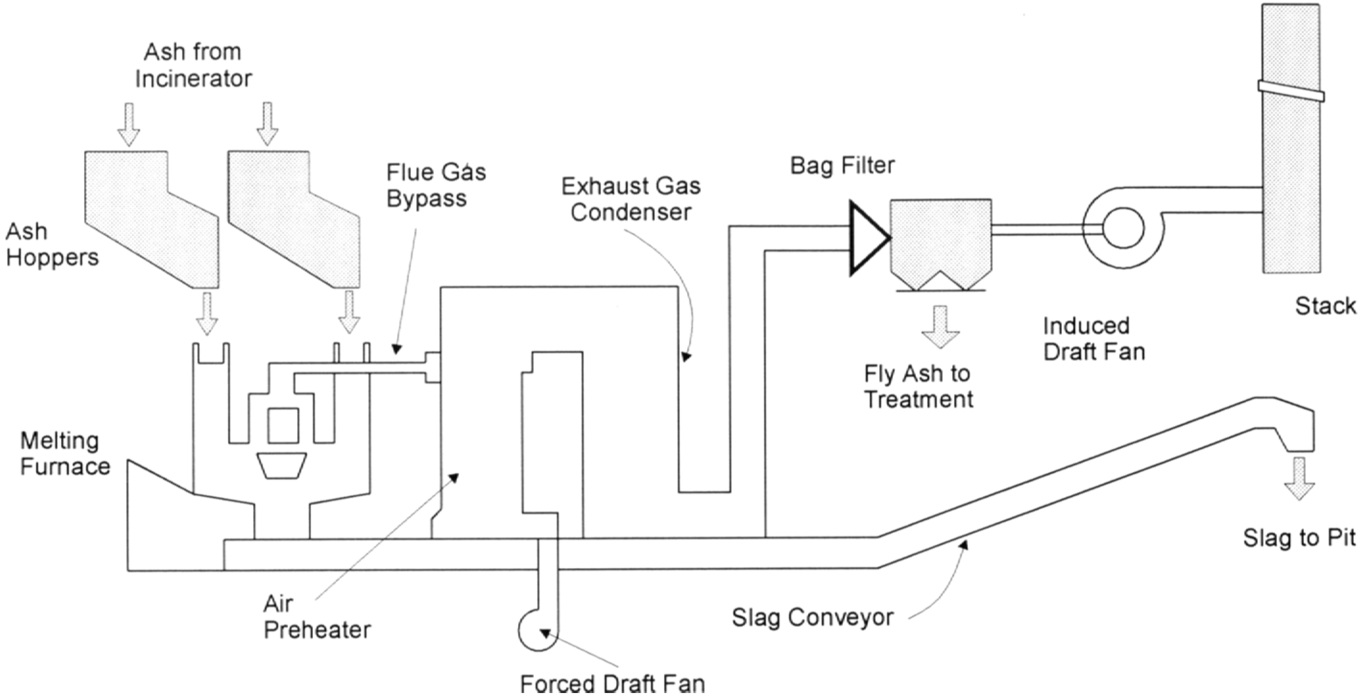


Table 19.15 shows the leaching test results of slag and bag filter dust from the test plant. There was no leaching of metals from the slag, but there was some leaching of Cd and Pb from the bag filter dust.

Table 19.15
Leaching Test Results of Slag and Bag Filter Dust from Takuma Surface Melting Furnace

Element	Unit	Run A		Run B		Run C	
		Slag	Fly Ash	Slag	Fly Ash	Slag	Fly Ash
Cd	mg/l	<0.01	17	<0.01	26	<0.01	39
Pb	mg/l	<0.05	16	<0.05	12	<0.05	170
As	mg/l	<0.02	0.02	<0.02	<0.02	<0.02	<0.02
T-Hg	mg/l	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.27
Cr	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

19.7 SINTERING

Wainwright and Robery (1991) have reported on a pilot-scale process for the sintering of residues obtained from incinerator facilities in Rotterdam, The Netherlands and several facilities in the United Kingdom. The process involved removal of the ferrous and nonferrous metals followed by crushing the material to pass a 300 mm sieve and blending the material with clay. The pelletised material was then fired in a rotary kiln to produce a spherical aggregate. Tests were performed to obtain the optimum firing time, temperature and the percentage clay to give the strongest aggregate as determined by a splitting tensile strength test. A 15/85% blend of clay/incinerator residue fired at 975°C for 13½ minutes was reported to be the best combination. The major oxide composition of the treated residues (before blending and firing) and of the aggregate, and some of the physical properties of the aggregate are shown in Table 19.16. It was indicated that sintering at 850°C for 3 minutes may not result in complete conversion of aluminum to alumina. Aggregate produced under these conditions resulted in hydrogen evolution during use in concrete, whereas aggregates produced at higher temperatures and longer sintering intervals showed no detrimental interferences when used in concrete.

Sintering and fusion pilot tests have also been carried out in an oil fired rocking kiln with bottom ash (Ruegg, 1992). Kiln temperature, solids residence time and kiln atmosphere (oxidising or reducing) were the experimental variables. Table 19.17 presents treated ash (sintered or fused) compositions as a function of trial conditions. Other results indicated that the kiln atmosphere has a negligible effect of fused ash composition.

Table 19.16
Major Oxide Composition and Physical Properties of Pretreated Residues (Before Blending and Sintering) and the Resulting Aggregates

Oxide %	Composition (%)			
	Edmonton		Rotterdam	
	Residue	Aggregate	Residue	Aggregate
SiO_2	50.23	54.14	57.50	63.42
Fe_2O_3	15.18	10.20	10.17	8.01
CaO	9.77	12.88	9.43	10.32
Al_2O_3	6.75	8.90	6.55	7.36
Na_2O	5.67	5.04	5.32	4.26
SO_3	1.14	1.52	0.88	0.76
K_2O	1.04	1.47	1.19	1.56

		Physical Properties			
		Edmonton		Rotterdam	
		Residue	Aggregate	Residue	Aggregate
Bulk Density	Loose		909	1059	
(kg/m^3)	Compacted		955	1121	
Relative Density			2.18	2.29	
Water adsorption (% SSD)			15.10	10.11	
Porosity (%)			38.04	24.96	

Wainwright, 1991

Table 19.17
Effects of Thermal Treatment on Bottom Ash Composition

Element (mg/kg) or test condition	Untreated Bottom Ash	Sintering with oxidising atmospheres	Sintering with reducing atmospheres	Fused Residue
Temp (°C)		950	900	>1200
Residence Time (min)		30	32	22.5
Cd	26.4	8.0	4.2	1.9
Pb	2100	1700	1667	1200
Zn	3700	4600	3767	5200
Cr	680	1633	1467	1800
Cl	640		520	
C	1.4	0.4	0.3	0.2

Ruegg, 1992

19.7.1 Integrated RDF Combustion with Sintered Aggregate Production (Neutralysis Process)

The Neutralysis process involves firing a pelletised mix of refuse derived fuel, liquid waste and clay in a rotating kiln to produce a lightweight aggregate for use in the construction industry (Krol et al, 1991). In August 1988, a pilot plant capable of processing 25 tpd of MSW was completed in Brisbane, Australia. This facility has been used to demonstrate the process, and to provide aggregate for a testing program designed to assess its environmental acceptability and marketability.

The major unit operations and process streams along with a solid's mass balance for a "typical" Neutralysis plant rated at 500 ton (RDF)/day are shown schematically in Figure 19.8. There are three main sections, including physical processing, kiln firing and gas cleaning. The actual mass balance will depend on factors such as the ultimate and proximate analyses of the MSW, and the desired RDF to clay ratio.

The MSW is pulverised prior to removing the ferrous/nonferrous metals and some glass, to produce a "fluff" RDF. This RDF is mixed with a similar weight of milled clay and liquid waste, and the mixture is extruded to produce pellets of a size suitable for the required aggregate application. The rate of nonhazardous liquid waste (and/or water) addition is controlled to produce cohesive pellets. The pellets are passed through a rotary drum tumbler which, in conjunction with a trommel screen, removes fines which are recycled back to the mixer. A dryer using hot air from the product aggregate cooler is used to reduce the moisture content of the pellets.

The partially dried pellets are passed through a series of rotary kilns. In the pyrolysis kiln, the pellets are heated to approximately 500°C under starved air conditions, producing porous pellets containing unburned carbon. In the oxidation kilns, air is added to burn off the carbon in the pores and raise the pellet temperature to approximately 900°C. The porous pellets then pass into a sintering kiln where the temperature is raised to approximately 1100°C. The off-gases from all three kilns are passed through an afterburner prior to entering the APC system.

Aggregate discharge from the sintering kiln is air-cooled, providing heated air for the pellet dryer and combustion. The resulting aggregate is typically a matrix of SiO_2 and Al_2O_3 with lower concentrations of other metal oxides such as Fe_2O_3, CaO and Na_2O. The total concentration of uncombusted carbon (as measured by the loss on ignition at 550°C) is less than 1%. In addition, APC residues, including fly ash and spent/excess lime are produced which require further treatment prior to disposal.

Table 19.18 presents total heavy metal concentrations and leaching test results for Neutralysis aggregate produced during a trial run and the range of values measured for other runs. Also shown are the concentrations of Cd, Cr, Pb and Hg in aggregate produced before and after the addition of metals into the kiln feed during one pilot plant run. The metals were added as an acetate salt solution and were equivalent to

Figure 19.8 Major Unit Operations and Process Streams Along with a Solids Mass Balance for a Typical Neutralysis Plant

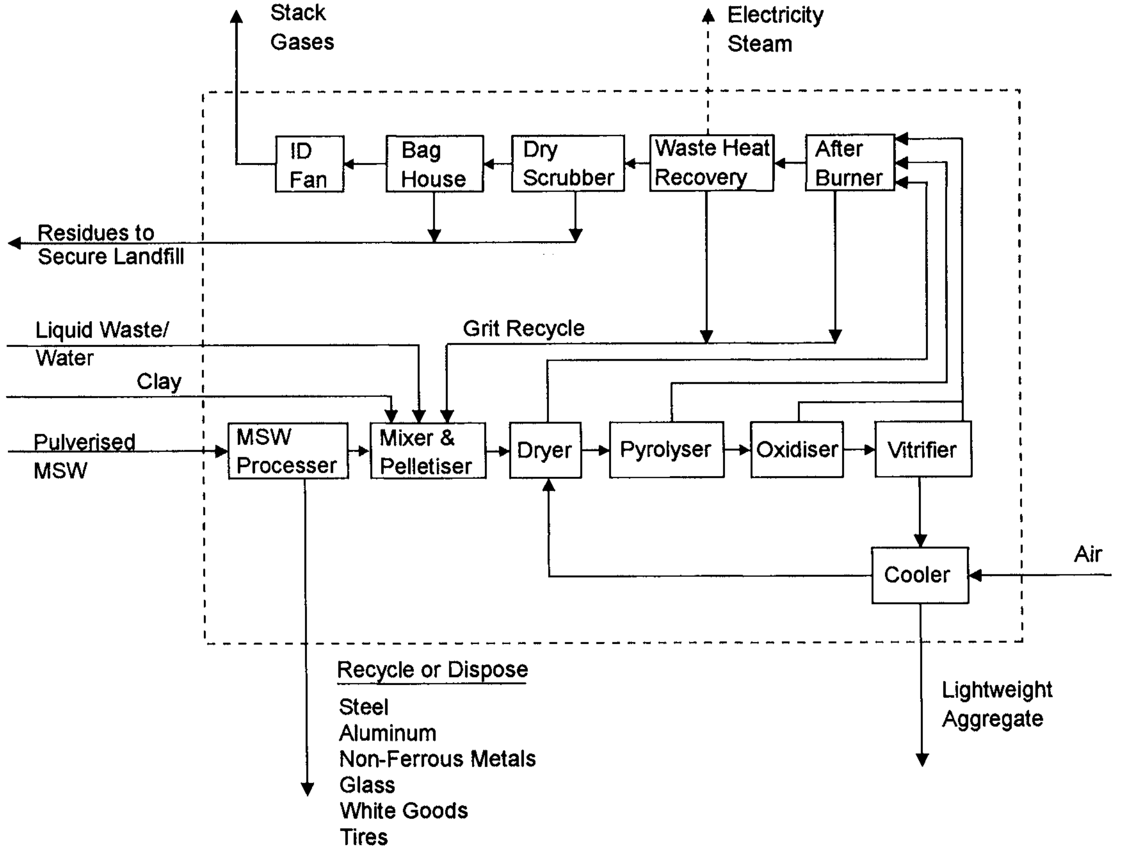


Table 19.18
Compositional Analysis and Leaching Test Results for the Neutralysis Aggregate

Element	Total Concentration in Aggregate				Leaching Test Results					
	Audit run (mg/kg)	Range in other runs* (mg/kg)	Spiking run (before addition) (mg/kg)	Spiking run (after addition) (mg/kg)	USEPA TCLP criteria (mg/l)	TCLP (audit run) (mg/l)	Water (audit run) (mg/l)	Nitric Acid[1] (mg/l)	MEP[2] (1st extract) (mg/l)	MEP[2] (2nd extract) (mg/l)
Arsenic	14	<1-6	nm	nm	5.0	0.015	0.011	<0.1	0.89	0.09
Barium	490	nm	nm	nm	100	0.21	0.02	nm	<0.5	<0.5
Cadmium	<1	<0.5-2.5	<0.9	<1.4	1.0	<0.01	<0.01	<0.003-0.01	<0.001	<0.001
Chromium	340	28-200	144	180	5.0	<0.01	<0.01	0.03-0.22	0.03	0.02
Copper	2020	nm	nm	nm	none	1.29	<0.01	0.83-5.4	nm	nm
Lead	940	12-210	223	460	5.0	<0.01	<0.01	<0.01-0.23	0.32	0.16
Mercury	0.25	0.006-0.24	<0.01	<0.01	0.2	<0.001	<0.001	<0.0002	<0.0005	<0.0005
Nickel	130	nm	nm	nm	---	---	---	---	---	---
Selenium	4	<1	nm	nm	1.0	<0.05	<0.05	nm	<0.05	<0.05
Silver	9	0.9-34	nm	nm	5.0	0.015	<0.1	nm	<0.02	<0.02
Zinc	3590	nm	nm	nm	none	0.32	0.03	0.39-0.58	nm	nm

nm = not measured
* = Range of results obtained from 17 samples, various laboratories
1 = Range of results obtained from 2 runs, uncrushed aggregate extracted for 1 hour
2 = Results from single run
Krol et al., 1991

approximately 120% more cadmium than in the MSW, 45% more chromium, 10% more mercury and 300% more lead. The results indicated that there are significant variations in concentrations of less volatile metals in the aggregate, which is, at least in part, a reflection of the variation in metal content of the MSW feed. The aggregate concentrations of Cd and Hg did not show a wide variation because these metals were almost totally volatilised to the kiln off gasses during processing. However, there were no mass balances reported.

Several leaching procedures were carried out on Neutralysis lightweight aggregate:

1. Toxicity characteristic leaching procedure (TCLP)
2. A distilled water extraction test (ASTM D3987)
3. A 10% (v/v) nitric acid extract at 20:1 liquid:solid ratio
4. The US EPA Multiple Extraction Procedure (MEP, EPA Method 1320). This test involves initial use of the US EPA Extraction Procedure (EP, EPA Method 1310) followed by 9 subsequent extractions of the same solid using synthetic acid rain

The data presented (Table 19.18) indicate that in all cases the TCLP extracts were substantially below the U.S. EPA criteria. This also was the case when water, nitric acid and the EPA leaching media were used. Subsequent extractions in the MEP procedure continued to demonstrate a decline in leachate concentrations to below analytical detection limits. The aggregate produced during the trace metal spiking run also produced leachate concentrations of Cd, Cr, Pb and Hg which were below detection limits.

Aggregate produced in the trial run was also subjected to organic analysis. The concentrations of indicator polynuclear aromatic hydrocarbons (PAHs) were all below the analytical detection limit (<0.01 ng/g), as were those of chlorinated benzenes (<0.1 ng/g), chlorinated phenols (<0.06 ng/g), polychlorinated biphenyls (PCBs) (<0.01 ng/g), 2,3,7,8 tetrachloro dibenzo-p-dioxins (<0.06 ng/g) and 2,3,7,8 tetrachloro dibenzofurans (<0.06 ng/g).

The aggregate produced was reported to be less dense than conventional aggregate. Physical properties of a Portland cement concrete made from Neutralysis aggregate included compressive strengths up to 53 MPa at 28 days and cured concrete densities between 1,800-2,080 kg/m^3 (Krol et al, 1991).

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