Draft APC Residue Case Study
Carried out by ESA for Minimisation and Arisings Group
Hazardous Waste Forum

1. DIRECTIVES AND OTHER REGULATORY EFFECTS

Legislation and regulation is an important driver for the development of the waste management system in general, and this includes the treatment and safe disposal of air pollution control (APC) residues. Modern incinerators minimise the release of pollutants to the atmosphere by careful design to limit their formation and by the use of sophisticated air pollution abatement equipment to remove the pollutants from the flue gases. Consequently, these pollutants are captured in the APC residues, which are finely divided strongly alkaline materials containing high concentrations of lime and other calcium compounds and soluble metal chlorides. They are regulated by the Environment Agency under the Environmental Protection Act as hazardous waste because of their high alkalinity (pH 12 and above) due to the high levels of lime they contain.

The following legislation governs the management of APC residues in the UK.

- Waste Incineration Directive (2000/76/EC)

The Waste Incineration Directive (WID) applies to the incineration and co-incineration of waste as defined in the Waste Framework Directive (75/442/EEC) and includes municipal waste, clinical waste, hazardous waste and waste derived fuels. WID incorporates and extends the requirements of the 1989 Municipal Waste Incineration Directives (89/429/EC and 89/369/EEC) and the Hazardous Waste Incineration Directive (94/67/EC), forming a single Directive on waste incineration. The Waste Incineration Regulations came into force on 28 December 2002, however existing plants only need comply by 28 December 2005. WID specifies air emission limit values for incineration and co-incineration and outlines how the resulting residues should be managed.

- IPPC Directive (96/61/EEC) and PPC regulations

The Integrated Pollution and Control (IPPC) Directive aims to minimise pollution from various point sources throughout the EU and sets out common rules on permitting for industrial installations. PPC regulations implement the Directive. Incineration plants are classified as Part A(1) installations under the PPC regulations and require an authorisation permit to operate, based on the concept of Best Available Techniques (BAT). The permit takes into account the whole environmental performance of the plant, i.e. emissions to air, water and land, generation of waste, use of raw materials, energy efficiency, noise, prevention of accidents, risk management, etc. The APC abatement system of an incinerator captures pollutants before they are emitted to air and the process results in the generation of APC residues.

- Waste Incineration BREF

PPC permits are based on BAT and for each of 30 sectors, BAT Reference (BREF) documents are being produced and are due to be completed by the end of 2005. The BREF document for waste incineration sets out the best available techniques for all aspects of the process, including air pollution abatement equipment and treatment of the APC residues which arise.

- EA Guidance on classification of hazardous wastes

The European Waste Catalogue (EWC) 2002 is a comprehensive list of all wastes, grouped according to generic industry, process or waste type, and is subject to periodic review. APC residues are included under EWC 19 01: Wastes from incineration or pyrolysis of waste. Hazardous waste entries are marked with an asterisk and are set out separately in the Hazardous Waste List. Publishing of a new revised Hazardous Waste List is imminent. The Environment Agency's 'Technical Guidance WM2 Hazardous Waste: Interpretation of the definition and classification of hazardous waste' serves as a reference document for use by the waste industry, producers and regulators of hazardous waste.

- Landfill Directive (99/31/EC) and Waste Acceptance Criteria

The main aim of the Landfill Directive is to prevent or reduce as far as possible the negative effects of landfilling waste on the environmental and human health, ensuring strict regulatory controls on their operation, environmental monitoring and long-term care after closure. One of the requirements of the Directive is that all waste, including APC residues, will have to meet Waste Acceptance Criteria (WAC). WAC requires that waste must meet specific leaching limit values prior to landfilling, failure of which would necessitate pre-treatment of that waste. Such pre-treatment cannot include the dilution of material, for example with sand or sawdust. DEFRA has recently published its consultation on the implementation of the Landfill Directive's detailed WAC in England and Wales, but has made no firm proposal on whether WAC should be introduced in July 2004 to coincide with the ban on co-disposal or in July 2005.

- Water Framework Directive and associated legislation

The Water Framework Directive (2000/60/EC) establishes a strategic framework for managing the water environment, setting environmental objectives for all groundwaters and surface waters within the Community.

A new daughter Groundwater Directive has been proposed by the EU Commission to replace the existing Directive (80/68/EEC). This will implement specific measures set out in the Water Framework Directive to prevent and control groundwater pollution and establish a requirement to prevent or limit indirect discharges of pollutants into groundwater.

The Groundwater Regulations(1998) were implemented as an environmental protection measure to groundwater, to complete transposition of Directive 80/68/EEC. The Regulations place a duty on the Environment Agency to protect groundwater by prohibiting both direct and indirect discharges of List I substances to groundwater, and preventing pollution of groundwater by List II substances. APC residues contain substances in both Lists I and II.

2. CURRENT SITUATION AND LIKELY FUTURE ARISINGS OF APC RESIDUES

Over the past three decades, MSW incineration technology has developed significantly and increasingly more stringent air emission standards have led to continuous improvements in air pollution control abatement systems. This has, however, led to an increase in both the volume and pollution potential of APC residues.

APC residues result from the flue gas cleaning process in the air pollution abatement equipment of an incinerator and are only regarded as hazardous primarily due to their unreacted lime content. The 15 existing moving grate MSW incinerators currently operating in the UK generate approximately 100,000 tonnes per annum of APC residues, while clinical waste incinerators generate in the region of 8,000 tonnes per annum. It is estimated that 10-20,000 tonnes per annum APC residues are generated by other industrial waste treatment processes such as straw burning and glass reprocessing facilities.

The potential increase in the generation of APC residues depends on long-term waste disposal plans and how quickly new incinerators are commissioned. In the next five years, generation should increase by approximately 40,000 tonnes per annum with the commissioning of Portsmouth, Marchwood, Lakeside, Allington and Isle of Man.

Although there is no regulatory driver in place requiring the pre-treatment of APC residues, the alkalinity, dryness and very small particle size and therefore large surface area render APC residues useful reagents for treating a range of industrial wastes. The wastes are adsorbed onto or absorbed by the powders, making them capable of conventional solid waste handling techniques. Between 1996 and 2000, 12% of APC residues from MSW incinerators went to waste treatment plants where they were used for mixing with non-volatile organic liquids or sludges prior to landfilling. However, in the same period the large majority, 88%, were landfilled directly as special waste either in a dry bagged form or by exploitation of the pozzolanic properties of the material through the addition of water to solidify the material into a monolithic waste. It is unlikely that this process will continue since it is doubtful that APC residues will, without pre-treatment, meet the WAC for granular wastes when they are introduced in July 2004/2005.

The leaching limit values imposed by WAC are problematic for APC residues due to the presence of a high number of mobile chlorides and sulphates in the material. It is highly unlikely that APC residues would be able to attain a single set of leaching limits, since this material is currently being landfilled at six times the chloride limit value. It is, however, likely that a derogation will be granted for certain elements, including chlorides, sulphates and Total Dissolved Solids (TDS), to three times the limit value until July 2007. It is predicted that in order to landfill APC residues beyond the derogation deadline, significant investment in pre-treatment technology would be required by the waste industry immediately.

Stabilisation or solidification using cement would be a potential pre-treatment process for APC residues. This would require the installation of a washing plant, a liquid waste treatment plant and a cement solidification plant. Currently, no such facilities exist in the UK, therefore new infrastructure would be required but long time delays for planning permission and construction would be incurred. This pre-treatment option is considered further under section 4.

3. POSSIBILITIES FOR MINIMISATION AND REDUCTION OF APC RESIDUES

In assessing the potential for minimisation and reduction of APC residues, it is necessary to consider how the quality of the residues might be affected by the composition of the waste input and how operating conditions might act as important controlling factors.

Currently all existing MSW incinerators in the UK are operating to full capacity. The dynamics of UK waste management and the requirements to meet the landfill diversion targets set out in the Landfill Directive are such that even if significant waste minimisation was achieved, substantial volumes of post-recycling residual waste would still require another form of treatment, necessitating the construction of further MSW incinerators. Hence, the volumes of APC residues, as explained in section 2, would be likely to increase in the future.

Separation and segregation of certain categories of waste from the waste stream may, however, impact on the future nature and volume of APC residues. For example, separation of PVC from the waste stream could minimise the generation of APC residues through reduced chloride formation, consequently reducing the number of mobile chlorides present in the APC residues and the overall requirement for lime. However, separation of other recyclable materials rather than plastics would change the ratios and have the reverse effect.

Different thermal technologies produce different volumes of APC residues. For example, APC residue generation from moving grate technology is in the region of 3-5% by weight of waste input, compared with around 2% for fluidised bed technology where a pre-filter has been incorporated as part of the process.

The potential for re-using APC residues is determined by the content of organic compounds and the leachability of metals and salts. Many efforts have been made to improve the environmental quality of residues from waste incineration and to recycle or utilise at least part of specific residue flows. Both in-process and post-treatment techniques can be applied. In-process measures aim to change the parameters of the incinerator operating conditions in order to improve burn-out or shift the metal distribution over the various residues. Post-treatment techniques include ageing, mechanical treatment, washing, thermal treatment and stabilisation and are covered in section 4 below.

Installation of an Ecotube system is a good example of an in-process technique:

The Ecotube system was installed in both boilers of the Halmstad incinerator in Sweden in 1998 to reduce the plant's NOx emissions. Ecotubes are retractable lances that penetrate the boiler furnace wall and are equipped with injection nozzles. A small proportion of the combustion air is supplied under high pressure through the high velocity nozzles, which radically improves mixing of the partially burned combustion products, optimising the combustion process and significantly reducing emissions of pollutants such as NOx and unburned components of carbon monoxide, volatile organic compounds, particles etc. Improved mixing also enables the boiler to run at a lower air/fuel ratio, resulting in a higher thermal efficiency and thermal output. In addition to these benefits, the operator also reported reduced generation, by up to 27%, of APC residues.

In the UK, Coventry and Solihull Waste Disposal Company (CSWDC) has installed the Ecotube system in one of its three boilers, primarily to reduce the rate of corrosion of the boiler tubes and to improve combustion, and will be installing Ecotubes in the other two boilers in the summer of 2004. Once all three boilers have been installed with Ecotubes, CSWDC will be in a position to report whether it is able to achieve the same level of APC residue reduction.

4. ASSESSMENT OF THE FUTURE TREATMENT AND DISPOSAL CAPACITY FOR APC RESIDUES

As discussed in section 2 above, direct landfill of APC residues is likely to continue for a few years under derogation, allowing the opportunity for the development of alternative treatment options in the UK. A number of options are being investigated for both the re-use and pre-treatment of APC residues, some of which are described below.

Solidification and stabilisation of APC residues

Solidification generally implies the physical encapsulation of APC residues with cement or pozzolanic (cement-like) materials to reduce the leaching of constituents, and is widely used in Europe and Japan. The main purpose of this technique is the production of a material with physical and mechanical properties that reduce the hydraulic conductivity and porosity of the residue, thereby promoting a reduction in contaminant release from the residue matrix, while increasing its durability, strength and volume. The hazardous components of APC residues are trapped within the crystalline structure of the cement polymer by chemical fixation and there is also mechanical entrapment in the crystalline structure. However, the pH and alkaline capacity of the mixture is raised, which increases the leaching behaviour of metals and chlorides from the residues.

Solidification is typically performed at dedicated plants located near the end-destination of the material, negating the need for individual incinerators to install solidification equipment. Silos are required for the mixing of residues with organic pozzolanic binder reagents such as cement or lime (cement stabilisation is the most prevalent stabilisation technique). Approximately 1/3 to 1/2 tonne cement is required per tonne APC residue. Additives and sufficient water are also incorporated to ensure binding, resulting in the incorporation of residues into the cement/lime matrix. Metal hydroxides or carbonates are formed which are usually less soluble than the original metal compounds in the residue matrix. A monolithic waste is created, which can either be cast into blocks or landfilled directly.

Stabilisation is generally defined as the addition of reagents to chemically transform soluble contaminants into a less soluble form, making use of both the precipitation of metals in new minerals as well as the binding of metals to minerals by sorption. Several stabilisation methods incorporate an initial washing step where a major part of soluble salts and to some extent metals are extracted before chemical binding of the remaining metals. The process is completed by de-watering the stabilised material, which can then be landfilled.

Solidification may result in altering the chemical nature of the residues by providing a highly buffered solid matrix which further limits the solubility of many trace metals, a process which is also referred to as solidification/stabilisation (S/S). Most S/S processes are based on treatment with binders, normally using cement. The advantages of using cement are that the price is reasonable, the equipment is commercially available, the technique is relatively tolerant of waste variability and the resulting strength and permeability can be modified based on cement content. Selection of the proper type of cement is of great importance when developing solidification formulations. For example, sulphate resistant cements are generally recommended to prevent sulphate attack on the pozzolanic bonds. A significant proportion of APC residues consist of chloride salts, therefore potential diffusion of salts out of the solidified APC residues may be problematic. This may in turn result in the loss of both physical strength and durability of the solidified matrix, as well as the rapid release of metals if the PH of the leaching environment is very alkaline. The solidified material should therefore be evaluated for long term durability and potential leachability to ensure that the physical retention mechanisms of the process remain intact over a long period of time. Removal of soluble salts from APC residues by washing may be necessary prior to S/S treatment.

Reservations:

- WAC for monolithic wastes are still being developed, so there is uncertainty regarding the requirements;
- Swiss studies report that the leaching behaviour of a landfilled material is only influenced over the first few years of storage;
- It is uncertain whether the process will prevent the leaching of soluble salts, eventually leading to the physical disintegration of the solidified matrix, allowing further leaching. Compliance is especially difficult to prove, especially when tests require grinding of the material which destroys the crystalline structure;
- The addition of cement, additives and water typically doubles the tonnage of original residue output and may also increase the volume; and
- There may still be an unacceptable liquid effluent.

Thermal Treatment of APC residues

The thermal treatment of APC residues takes place extensively in a few countries, such as Japan where there are more than 30 plants in operation. The main reasons for implementing this technology are to reduce the volume of the residues and to improve their leaching properties. The most common thermal treatment techniques are vitrification and melting, both resulting in a more homogenous, denser product with improved leaching properties. Vitrification and melting are similar in many respects, the main difference being the addition of glass-forming additives in the former. Both processes result in the destruction of dioxins.

Vitrification involves the mixing of residues with glass precursor materials such as silica at high temperatures (1,300-1,500^{o}C) to form a single-phase amorphous glassy material. This results in chemical bonding of inorganic species in the residues with glass-forming materials and encapsulation of residue constituents in a layer of glassy material. A study conducted by Sheffield University found that the process achieves dioxin reduction and stabilisation of metals, however chlorides can still be problematic.

Melting is similar to vitrification but does not include the addition of glass precursors. It results in a multiple-phase material, usually with the production of several molten metal phases. It is possible to separate specific metal phases from the melted product and recycle these metals after refinement. Temperatures are similar to those used in vitrification.

Usually the residue input must comply with certain quality requirements. The residue volume is typically reduced to 30-50% of the input volume. Vitrification and melting result in the mobilisation of some metals such as lead, mercury and zinc, which in some processes may be recovered as recyclable products.

Reservations:

- The release of vaporised heavy metals from the process necessitates an additional flue-gas treatment system, which in turn creates a new solid residue that requires treatment;
- The high salt concentrations in APC residues can cause corrosion problems in the flue gas treatment system;
- Plants tend to be small scale – 100kg per hour;
- Thermal treatment processes use substantial amounts of energy to reach and maintain the elevated temperatures required; and
- This technique is expensive compared to other treatment options.

Acid Extraction from APC residues

Use of the alkaline content of APC residues to neutralise waste acids has been researched, however this is not considered a feasible option as the content of mobile chlorides remains high.

Acid extraction from APC residues can be incorporated into incinerators with a wet APC abatement system, combining an acid extraction of soluble heavy metals and salts by using the acidic scrubber blow down. Techniques using extraction and separation can in principle cover all types of processes extracting specific components from the residues.

Several techniques have been proposed both in Europe and Japan. The most common technique is the FLUWA-process, which makes use of the acidic solution from the first scrubber in wet APC systems, with discharge of the treated wastewater. Five plants in Switzerland and one in the Czech Republic utilise this technology.

The 3R-process is similar to the FLUWA-process and involves a return of the treated residues to the combustion chamber for sintering with bottom ash. This process uses acid scrubber solution to extract heavy metals followed by a de-watering step.

The MR process combines acid extraction with thermal treatment. The APC residues are washed with the first stage wet scrubber solution and dewatered. The residues are then treated in a rotary kiln for one hour at 600^{o}C, which destroys dioxins and volatilises mercury. The emissions are treated in an activated coal filter and wastewater is treated to remove heavy metals. The scrubber solution from the second scrubber is used to wash incinerator bottom ash and neutralise acidic effluent streams.

Carbonation

Carbonation involves the addition of lime to APC residues and the subsequent exposure of the material to carbon dioxide to form carbonates. This mimics and accelerates a process that occurs naturally over a long period of time in incinerator residues and can lead to reduced leachability of heavy metals.

The Lulea University of Technology in Sweden has conducted research on the use of carbonation to stabilise metals in APC residues. Carbonation was tested at bench scale and was successful in significantly reducing the mobility of lead and zinc. Chromium was demobilised with the addition of water, but remobilised again over time. The mobility of cadmium was increased, necessitating further research on the effect of silicate formation in halting this process. The effect of carbonation on the mobility of chlorides was not reported.

There is scope for the use of carbonation at full scale as a future pre-treatment option for APC residues, provided that a reasonable and practical source of CO_2 is available. Carbonation is being developed commercially, especially for use with contaminated soils, and specific treatment processes are being developed for APC residues. This involves washing the material and reaction with iron or phosphorous compounds to reduce heavy metal leachability. Approximately 3-5 m^3 waste brine is generated per tonne of APC residue, discharge of which could be problematic at some locations.

In the UK, Knox Associates has undertaken work on the Environment Agency's Leachate Source Term Project, which examined the effect of acid neutralisation and carbonation on various WAC parameters. Whilst the research is ongoing, early results have shown that both methods could reduce the total dissolved solids levels of APC residues to within the WAC.

Long-term storage

Long-term storage of hazardous waste in salt mines requires substantial investment but has proved to be a viable option for the management of APC residues in other European countries, notably Germany and France.

In the UK, Minosus Limited is in the process of developing a 170 metre deep salt mine in Cheshire into a long-term storage underground hazardous waste landfill. This would provide the opportunity to deposit APC residues in dry bagged form into the salt mine without the requirement for pre-treatment as the naturally controlled atmosphere in salt mines eliminates any leachate problems. A public enquiry resulted in the granting of planning permission in July 2002, however this was challenged and planning permission was revoked by the High Court in January 2003. A decision from the Office of the Deputy Prime Minister for the re-issue of planning permission is currently being awaited.

Case studies on re-use opportunities for APC residues

Cement solidification in Germany

Several salt mining companies in Germany accept APC residues and perform cement solidification on these. The solidified residues are mainly utilised as backfilling material or for reinforcement. For some of the mines, cement solidification is performed at a central plant using varying recipes according to the final destination and specific requests.

Cement solidification in Switzerland

A variation of cement solidification is used in Switzerland, where APC residues are washed with water then dewatered prior to mixing with cement. This has the benefit of removing most of the soluble salts from the residues, thus improving the longevity of the solidified product. After solidification, the residues are deposited in surface level landfills before hardening. In some plants, the mixture is cast into moulds to produce blocks that are transported to surface landfills.

5. KEY ACTIONS AND REQUIREMENTS

The key issue for the Government with regard to the future management of APC residues is the provision of regulatory certainty. There is ongoing lack of clarity on what standards will apply, when such standards will apply, what components are likely to be derogated and for how long. There has been an unhelpful delay in the production of the necessary guidance. There is an urgent need for the development of facilities in the UK to treat APC residues, however the time constraints are such that it is doubtful whether the necessary planning permission will have been acquired and construction and commissioning have taken place by July 2004/July 2005/expiry of the proposed derogations. What is certain is that in the current climate of uncertainty, this situation will not improve. It is therefore essential that DEFRA:

- Finalises the WAC for hazardous wastes and provides clarification on derogations to three times the leaching limit values so that operators are able to assess what pre-treatment requirements would be necessary for the management of APC residues;
- Finalises the stability criteria for WAC for monoliths, so that operators are able to assess solidification and stabilisation techniques for the pre-treatment of APC residues; and
- Provides this clarity as soon as possible in order to provide the regulatory certainty that is essential for the encouragement of significant investment by the waste management industry in pre-treatment technology for APC residues.

The key issue for Local Authorities is the rapid granting of planning permission for the development of pre-treatment infrastructure. Currently the planning process acts more as a barrier to than a facilitator of sustainable waste management. Decisions are often subject to delay and the process remains unpredictable.