

PFA and the environment

Introduction

Pulverised Fuel Ash (PFA) has been used for many years in concrete, fill, grouting, etc without any evidence of environmental problems. However, since the introduction of the Environmental Protection Act^a in 1990 and subsequent legislation, consideration has to be given to the effect of any material on the environment when used in construction. The following considers the various factors relating to PFA:

Chemistry of PFA

Around 60% to 90% of PFA is present as an amorphous glassy material composed of silica, alumina and iron oxides, with other metals present in smaller quantities, as shown in Table A. The constituents apart from the glass that are of most significance to the properties of PFA are the calcium oxide content (lime) and sulfate content.

If there is sufficient lime present in the PFA then it will result in hardening due to a combination of further crystal formation and reaction between the lime and the glassy material in the PFA (the pozzolanic reaction^b). In addition, the high pH is likely to reduce the availability of the trace elements.

Table A - Typical oxide analysis of PFA

Element	Typical range of values for PFA	Element	Typical range of values for PFA
Aluminium (% as Al ₂ O ₃)	20 - 40	pH ¹	9 - 12
Calcium (% as CaO)	1.8 - 10	Potassium (% as K ₂ O)	2.3 - 4.5
Chloride (% as Cl)	0.01 - 0.02*	Silicon (% as SiO ₂)	38 - 52
Free calcium oxide (%)	<0.1 - 1.0	Sodium (% as Na ₂ O)	0.8 - 1.8
Iron (% as Fe ₂ O ₃)	6 - 16	Sulfate (% as SO ₃)	0.35 - 2.5
Loss on ignition (%)	3 - 20	Titanium (% as TiO ₂)	0.9 - 1.1
Magnesium (% as MgO)	1.0 - 3.5	Water soluble sulfate (g/l as SO ₄)	1.3 - 4.0 using 2:1 water solid extract

* Chloride may be up to 0.3% for PFA conditioned with sea water

¹ The pH for lagoon ash is lower, typically about 9



Figure 1 - Restored land at Barlow Mound, Drax, North Yorkshire

^a The Environmental Protection Act 1990, ISBN 0-10-544390-5

^b See Technical Datasheet 1 for explanation of the pozzolanic reaction

The calcium content of PFA means that most of the sulfate is present as gypsum, which has a limited solubility and will come out of solution as crystals in compacted PFA. The sulfate level of lagoon PFA is usually very low because the water/solids ratio used to slurry the PFA means the majority of the sulfate is washed out. Other water-soluble materials are also removed in the process. The sulfate content of lagoon ash is typically less than 0.1 g/l.

The sulfate content of PFA means that it cannot be placed within 500mm of metallic items according to the Department of Transport Specification for Highway Works (SHW). The water-soluble alkali content of PFA is also sufficiently high to restrict the types of reinforcement that can be used in reinforced earth structures.

Trace Elements in PFA

Typical trace elemental analyses are shown in Table B, which demonstrates that these elements are present in only small quantities, less than 1% of the total. The values quoted are generally in agreement with other quoted values.

Table B - Solid phase trace element analysis - Typical ranges from UK sources of PFA

Element	Content in mg/kg	Element	Content in mg/kg
Antimony	1 to 325	Lead	<1* to 976
Arsenic	4 to 109	Manganese	103 to 1,555
Barium	0 to 36,000	Mercury	<0.01* to 0.61
Boron	5 to 310	Molybdenum	3 to 81
Cadmium	<1.0* to 4	Nickel	108 to 583
Chloride	0 to 2,990	Phosphorus	372 to 2,818
Chromium	97 to 192	Selenium	4 to 162
Cobalt	2 to 115	Tin	933 to 1,847
Copper	119 to 474	Vanadium	292 to 1,339
Fluoride	0 to 200	Zinc	148 to 918

* Indicates below the limit of detection

Leachable Elements in PFA - DIN Leaching test

As discussed above, there is only a small fraction of the constituents that are present on the surface of PFA and that are leachable in water. Typical data obtained from routine analysis are shown in Table C, the extraction in this instance is to the German standard DIN 38414-S4 (10:1 water/solids ratio).

**Table C - Leachates found using the DIN 38414-S4 and NRA leaching methods (10:1 extraction)
Typical range of leachable elements for UK PFA (mg/l except pH)**

Trace element	Leachate mg/l	Trace element	Leachate mg/l
Aluminium	<0.01* to 9.8	Manganese	<0.01*
Antimony	<0.01* to <0.2	Mercury	<0.001*
Arsenic	0.06 to 0.16	Molybdenum	0.1 to 0.88
Barium	0.2 to 0.4	Nickel	<0.01*
Boron	0.1 to 6	pH	7 to 11.7
Cadmium	<0.005*	Phosphorus	<0.1* to 0.4
Calcium	15 to 250	Potassium	5 to 29
Chloride	1.6 to 17.5	Selenium	0.04 to 0.16
Chromium	0.02 to 0.06	Silicon	0.5 to 1.5
Cobalt	<0.01*	Sodium	5 to 44
Copper	<0.01*	Sulfur	15 to 510
Fluoride	<0.1* to 2.3	Tin	<0.01*
Iron	<0.01*	Titanium	<0.01*
Lead	<0.01*	Vanadium	<0.01* to 0.55
Magnesium	<0.1 to 100	Zinc	<0.02*

Notes: The above data include a seawater-conditioned sample resulting in higher chloride values. The Boron content may also be increased.

* Indicates below the limit of detection

From the data it can be seen that the major water-soluble constituents are calcium and sulfur (usually present as sulfate). There are smaller amounts of sodium and potassium, and traces of chloride, magnesium, aluminium and silicon. If it is assumed that all the water soluble calcium, sodium and potassium is present as hydroxide (ignoring the sulfate or chloride) then the total water soluble hydroxide, based on the highest values from Table C would be 2.1% (m/m). However, calcium hydroxide would make up approximately 2.0%, the others would represent less than 0.1%. In all instances quoted the calcium is very dominant with sodium and potassium present in very small quantities in comparison.

Other materials

Polyaromatic Hydrocarbons (PAH) can arise from a wide range of combustion processes. However, the furnace temperatures in a coal-fired power station are so high that relatively low PAH levels are found. The leachate from PFA contains very small amounts of PAH's, in fact it has been shown that PFA can absorb PAH's.

Dioxins are formed when chlorine is present in furnaces. There is little chlorine in coals used in the UK and the furnace temperatures are so high that dioxins cannot form. Typically, dioxins of less than 10 ng/kg were found in the ashes when tested.

Considerations for use

In general terms PFA will not have any significant environmental impact because:

- ❖ The majority of the ash is present as an alumino-silicate glass;
- ❖ Most elements are present in very small quantities and are largely entrained in the glassy material;
- ❖ Typically less than 2% of the PFA is water-soluble; calcium and sulfate constitute the majority of the water-soluble fraction. There are smaller amounts of sodium, potassium and, in low pH leachate, magnesium;
- ❖ The pH is mainly determined by the water-soluble calcium and sulfate;

The water-soluble fraction, though small, can be sufficient to produce a pH above 11.5. However, dilution can rapidly reduce the pH. In addition, PFA when used as a fill material has a low permeability, typically 1×10^{-7} , which makes it difficult for the trace elements to be leached, e.g. a slow release, if any, over a very long period of time. Unbound PFA should never come into direct contact with drinking water, however, if one presumes a 10:1 dilution of the leachates from PFA, barring the initial flush of leachates, the trace elements would quickly reduce the values required for materials in contact with drinking water.

PFA is not normally used as a growing media, because it lacks nitrogen. However, if nutrients are added to the PFA, either artificial or natural sources, plant growth can be established. Plant species that are tolerant of boron should be chosen and the grazing of ruminants on planted areas should be monitored due to the effects of molybdenum on their copper uptake^c.



Figure 2 - Llanelli Millennium Coastal Park - restored using 500,000 tonnes of PFA

^c For full details see "Ashes to Assets?", Woolley GR, Simpson DT, Graham J, published by PowerGen UK plc, 53 New Broad Street, London, EC2M 1JJ

When PFA is used in bound applications, e.g. concrete, road sub-base construction, etc. the hydration products and resulting relatively low permeability reduces the leachates derived from the PFA to extremely low levels. As a result, the Drinking Water Inspectorate approves PFA concretes for use in contact with drinking water^d.

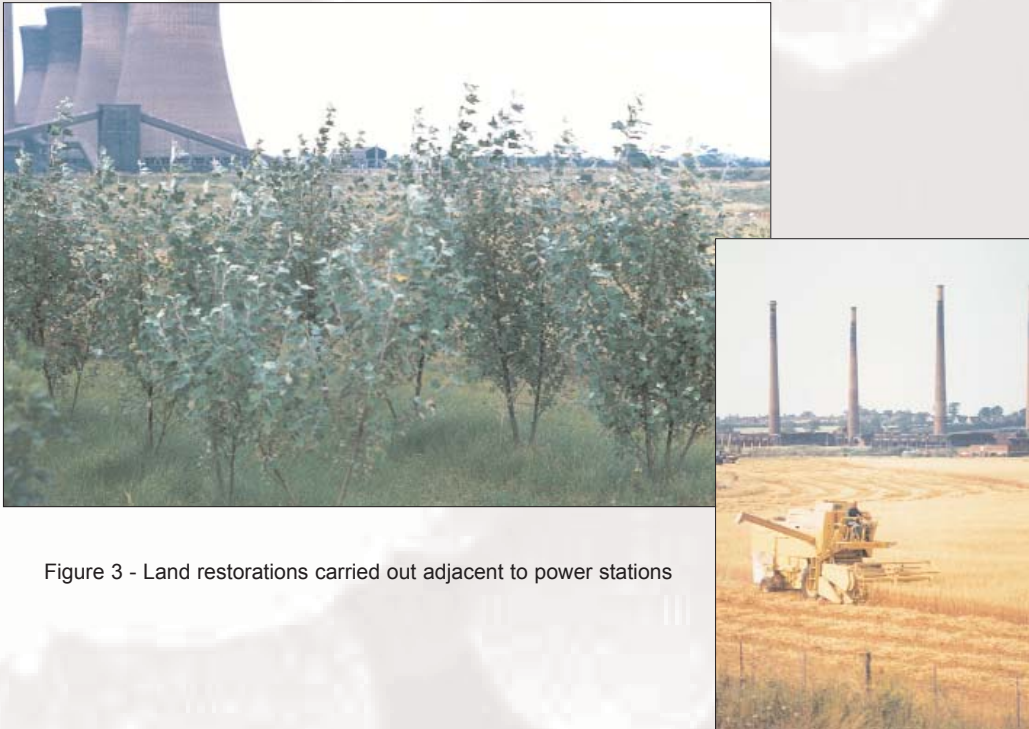


Figure 3 - Land restorations carried out adjacent to power stations

Conclusions

PFA has no significant environmental impacts when used in a sensible manner. The low permeability coupled with the majority of trace elements being held in the glassy matrix means little material can escape to cause problems. Even though PFA is relatively benign, when used for fill applications, it is important that the correct procedures are used. Further details are given in the UKQAA 'Environmental Code of Practice'^e. When used in areas close to water aquifers advice should be taken from the Environment Agency.



Figure 4 - Sheep grazing on a restored ash lagoon

^d Note: Some types of admixtures are not approved. DWI has lists of those that are not suitable

^e Environmental Code of Practice for the sale and use of Pulverised Fuel Ash (PFA), Joint submission to the Environment Agency, UKQAA January 2003 - available on our website: www.ukqaa.org.uk

In general usage the term 'fly ash' is used for pulverized coal ash but it can also cover ash from burning other materials. Such 'fly ash' may have significantly differing properties and may not offer the same advantages as ash from burning pulverized coal. UKQAA datasheets only refer to PFA / fly ash produced from the burning of coal in power stations.