



EQual Pulverised fuel ash (PFA) field trial

Summary report

LIFE10 ENV/UK/176 Task 2

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EQual programme

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Introduction

The EQual LIFE+ programme aims to promote the re-use and recycling of waste materials whilst protecting human health and the environment. Deriving value from waste materials by turning them back into safe, high quality products is an essential element in the move towards a more circular economy. Offering both economic and environmental benefits if supported and regulated appropriately, waste-derived products improve business resource efficiency and competitiveness, reduce reliance on landfill, and help to conserve virgin raw materials.

The Environment Agency led the programme with six partners: Rijkswaterstaat (the Netherlands' Ministry of Infrastructure and the Environment), the Chartered Institution of Wastes Management, Organics Recycling Group, Environmental Services Association, Northern Ireland Environment Agency and Energy UK.

As part of the EQual programme, field trials were carried out for four waste derived materials to improve understanding of the behaviour of these materials in the environment. The evidence base obtained from the trials will support the appropriate use of these materials in place of non-waste materials. Two of the field trials focused on the construction industry - pulverised fuel ash (PFA) and incinerator bottom ash aggregate (IBAA), and two on agricultural use - poultry litter ash and paper sludge. This report summarises the pulverised fuel ash (PFA) field trial.

PFA field trial

Pulverised fuel ash (PFA) is widely used in construction applications. Current regulation in England is based on the outcome of a generic Quantitative Risk Assessment (QRA), carried out to evaluate the risks to human health and the water environment from the use of PFA in construction applications. The QRA was based on extensive laboratory analysis of samples from nine coal-fired power stations across the UK. However, the hydrological and geochemical conditions which occur on site cannot be replicated fully in the laboratory; leading to uncertainties with respect to how well the QRA based on laboratory results reflect the environmental risks. A PFA field trial was carried out to reduce uncertainties in the QRA by improving the understanding of water movement and leachate production and quality within unbound PFA under UK environmental conditions.

The trial was designed to address two specific hydrological and geochemical uncertainties:

- Infiltration: The relative proportions of infiltration into, basal discharge from, and runoff from a PFA embankment slope; and
- Attenuation: The extent to which different aquifer materials attenuate key substances in leachate draining from PFA.

The design and size of the trials were balanced to ensure meaningful results were obtained within the available time (15 months) and results were applicable to 'real-world' applications of the material. The trials were designed to collect data by measuring the amount and quality of water draining from eight field lysimeters.

A field lysimeter is a container filled with soil or other solid media that is exposed to field conditions for the study of one or more components of a water balance, e.g. infiltration, runoff, evapotranspiration, storage capacity and soluble substances leached and removed in drainage. A lysimeter represents a larger scale experiment than laboratory column or tank tests.

The PFA field trials were carried out by a consortium of TRL, the ACS Group of companies and the Geomechanics Research Group at the University of Southampton, with technical support provided by Bone Environmental Consultants. Construction was undertaken during July and August 2013 and monitoring commenced in September 2013. The trial was monitored until December 2014.

Trial design and construction

Design

The design of the lysimeter trial was developed by the project team in collaboration with the EQual programme, in accordance with the Specification for Highway Works, Design Manual for Roads and Bridges and other relevant standards. The trial consisted of eight lysimeters:

- Five geochemical lysimeters.
- Two control lysimeters.
- A water balance lysimeter.

Each of the five geochemical lysimeters was constructed with a 600 mm layer of different aquifer materials (chalk, limestone, basalt, siliceous sand & gravel, sandstone, flint gravel) beneath a 450 mm layer of PFA. A range of aquifer materials was used to assess whether any evidence of attenuation of key substances occurs when PFA-derived leachate percolates through a basal layer. The basal layer was specified as a starter layer conforming to Class 6D of Table 6/1 in Specification for Highway Works Series 600, Selected uniformly graded granular material – Starter layer below pulverised fuel ash. Class D has a coarse to medium sand grading.

A 100 mm cover layer of Type A flint gravel was used to prevent erosion of the PFA. The lysimeters were 1.5 m by 1.5 m in plan. A diagrammatic cross-section of a geochemical lysimeter is shown in Figure 1.

Two control lysimeters were constructed, one of uncrushed flint gravel (Lysimeter 6) and one of PFA (Lysimeter 7). Lysimeter 6 contained 600 mm of uncrushed flint gravel with no PFA or Type A material. Lysimeter 7 contained 450 mm of PFA compacted in three layers, underlain by 200 mm of uncrushed Class 6D flint gravel and overlain by 100 mm of Type A flint gravel, reflecting the materials used in the geochemical lysimeters. The control lysimeters were the same shape and size as the geochemical lysimeters.

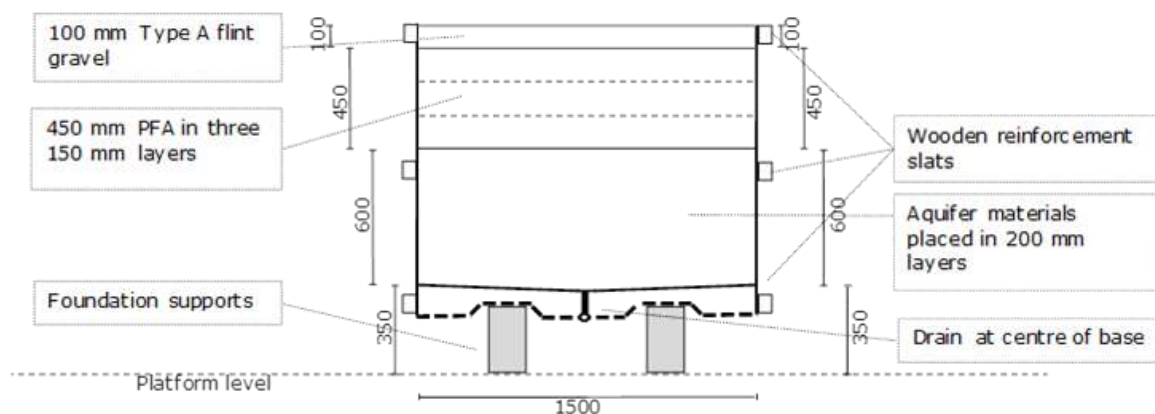


Figure 1 Cross-section of a geochemical lysimeter

The water balance lysimeter (Lysimeter 8) was constructed with a layer of PFA including a 1:3 slope at the top. The slope was underlain by a further 600 mm of PFA, compacted in 150 mm layers. The PFA was underlain by a 200 mm layer of uncrushed Class 6D flint gravel. The slope was covered with 100 mm of a locally-derived soil. This was amended with compost to improve nutrient levels to support grass growth. The soil in the water balance lysimeter was sown with a grass seed mixture.

The water balance lysimeter was 2.0m in length across the slope and 1.0m in width down the slope. It contained instrumentation to enable a water balance to be calculated. A drain was located at the toe of the slope to collect runoff, and lead it to a measurement and sampling point. Drainage from the base of the lysimeter was led to a separate measurement and sampling point.

Diagrammatic sections through the water balance lysimeter are shown on Figure 2 and Figure 3.

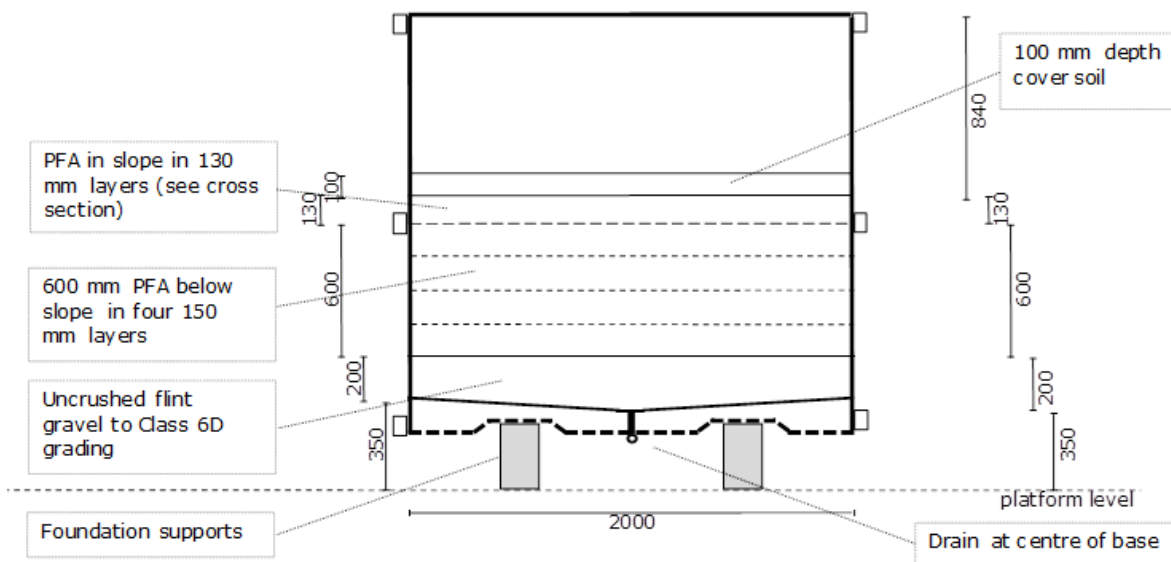


Figure 2 Longitudinal section through water balance lysimeter

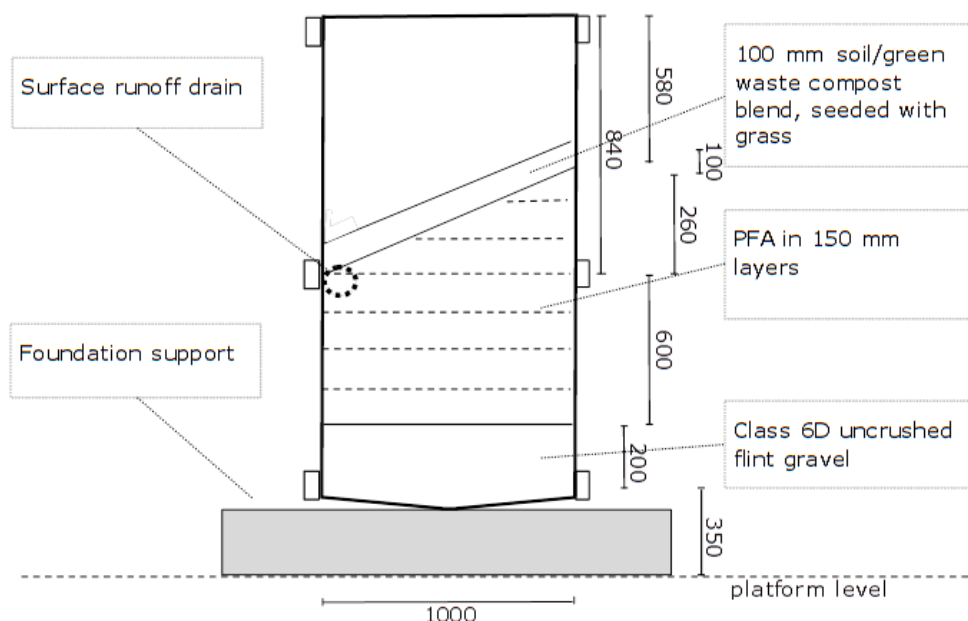


Figure 3 Cross section through water balance lysimeter

The drainage from each lysimeter was led to a measurement and sampling point. All drainage and runoff was then directed to an underground storage tank. The instrumentation cables led to an instrumentation hut in which the readout units were installed. A separate installation collected precipitation for chemical analysis.

Tipping bucket gauges were installed within the drainage collection units to measure the amount of leachate draining from the lysimeters. Pore water samplers were installed in all lysimeters, except the flint control (Lysimeter 6). Tensiometers were used to measure the pore water pressure (or suction) within the PFA, and Theta Probes were used to measure volumetric water content. A weather station was installed adjacent to the lysimeters to collect measurements of rainfall, wind speed, wind direction, temperature, relative humidity and solar radiation to determine the water balance.

The construction operations were carried out over the period July to September 2013. Figure 4 shows the lysimeters in place on the trial site.



Figure 4. Lysimeters ready for commissioning

Material characterisation

The PFA material supplied for the EQual field trial was sampled and subjected to compositional analysis and 2-stage batch leaching tests. The composition results show a relatively low level of variability for most substances. Compared to the range of samples used for the QRA, potassium and selenium content in FT PFA are at the high end of the QRA range; all other substances are low in the FT PFA compared to the QRA.

The 2-stage batch test results show relatively high amount leached for the major anions, cations and boron. The release of metals most commonly found as oxyanions, including chromium, molybdenum, selenium and vanadium, tends to be higher than the release of cationic metals. The fraction of substances leached from the field trial (FT) PFA show a high proportion of oxyanions, in particular molybdenum, and also calcium and fluoride.

The batch test results show leached masses of antimony, arsenic, boron, cadmium, magnesium, molybdenum, selenium and sulphate are relatively high in the FT PFA compared to the QRA range. Calcium and fluoride are consistent with the mid-range of the QRA data. Aluminium, barium, chromium, mercury, sodium, nickel and vanadium are relatively low compared to the QRA data.

Compositional data and results of 2-stage batch tests are also available for aggregates and cover soil used in the trials. These results show little within-material variability in pH and ORP measurements. However, the pH value ranges by over three orders of magnitude between materials, from 9.06 to 5.77. There is therefore potential for substance concentrations in FT

leachates to be influenced by pH. ORP shows significantly less variation with all materials in the range +213 to +270 mV indicating mildly reducing conditions.

Sampling

Samples of leachate draining from the lysimeters, pore water from lysimeters containing PFA, surface runoff from the water balance lysimeter and precipitation were collected for chemical analysis. There were two sampling stages, before leachate began draining from the lysimeters (Phase 1) and the remainder of the trial (Phase 2).

During Phase 1 the site was visited on a weekly basis check whether leachate had started draining from the lysimeters. Samples of runoff were collected on a weekly basis if enough water had collected to enable a sample to be taken. Pore water was sampled bi-monthly where sufficient water could be extracted. Precipitation was collected quarterly.

During Phase 2, sampling was carried out monthly, with the exception of precipitation, which was collected quarterly. Pore water was sampled quarterly, where sufficient water could be extracted.

Leachate began draining from all the geochemical and control lysimeters in late October, and the first samples were taken on 4th November, 52 days into the trial. Leachate did not begin draining from Lysimeter 8, the water balance lysimeter, until mid-February 2014, some 154 days into the trial.

Results: water balance

The water balance was calculated using the results of on-site measurements.

The field trial site experienced normal conditions followed by heavy and prolonged rainfall in October and early November 2013. It continued to be extremely wet from mid-December 2013 to the end of February 2014. This resulted in the wettest winter on record in England. A drier period followed in March, but became wet again in April and early May. June and July were hot and dry, but August was cool and very wet, followed by the driest September on record in Southern England. October and November were again wetter than the long-term average for the area. Over the period of the trial the monthly totals at the site were 130% of the Long Term Average for a nearby weather station. Values for individual months ranged from below the LTA in June and July 2013 to 232% LTA in January 2014.

The water balance for Lysimeter 8 was calculated from the start of the trial on the 12 September 2013.

For a given time period, the water balance may be defined as:

$$R - E_T + \Delta S - RO - OU \approx 0 \quad \text{Equation 1}$$

where R is rainfall, E_T is evaporation, ΔS is the change in stored water, RO is surface runoff and OU is outflow from the base of the PFA layer. The initial stored water was taken as that measured in the lysimeter on the first day of the calculation. The time step for the calculation was daily until 09 December 2014, a period of 453 days. The overall water balance for the period 12 September 2013 to 09 December 2014 was:

- Rainfall: 1457 mm;
- Change in stored water: 87 mm;
- Estimated evapotranspiration: 407 mm;
- Outflow: 121 mm;
- Surface runoff: 842 mm.

Loss of some data from failure of a datalogger meant some runoff and outflow had to be estimated. Nonetheless, it was possible to get a sensible fit between measured water content data and estimated parameters for the model.

For Lysimeter 8, little rainfall was converted to leachate from the base (around 8%). The sloping surface and relatively low permeability of the PFA was very effective at reducing the rainfall that could infiltrate into and pass through the PFA. Around 86% of the total rainfall could be attributed to runoff and evapotranspiration. The low quantities of outflow from the lysimeter mean that the L/S value is small – using the estimate of the outflow volume above gives a L/S value for 09 December 2014 of 0.14, which is well below that used in a typical leaching experiment in the laboratory, but is sufficient to reflect the first eluate from the column test (L/S = 0 - 0.1). This is important as it is the first eluate that is used to define the source term in risk assessment for most substances that exhibit declining behaviour.

Results: chemical analysis

The project collected a comprehensive set of data to improve understanding of leaching of key substances from PFA and the extent to which different aquifer materials attenuate these substances. The field trials data were analysed to assess whether laboratory data form a reasonable estimation of leachate quality produced under field exposure conditions (after infiltration through the PFA and starter layer).

The chemistry of leachate flowing from the lysimeters may be influenced by the chemistry of precipitation and the properties of each layer (chemistry and mineralogy). The results show that the greatest influences on leachate quality are the properties of PFA and associated pore water and interaction with drainage/aquifer materials.

The 2-stage batch test results for the PFA show relatively high leached mass for most major ions and boron, with boron, calcium, fluoride, molybdenum, selenium and sulphate being most available in comparison to their total concentration. In comparison to the QRA dataset, leached mass of antimony, arsenic, boron, cadmium, magnesium, molybdenum, selenium and sulphate in the FT PFA are relatively high. Aluminium, barium, mercury, sodium, nickel, vanadium and carbon and chromium are relatively low compared to the QRA data. Figure 5 and Figure 6 show examples of these comparisons, for molybdenum and chromium (total), as examples.

In general, the concentrations in FT leachate are consistent with QRA concentrations; both QRA laboratory and FT leachate concentrations tend to reflect the level of leached mass in batch tests. This is demonstrated in Figure 7 and Figure 8.

There are some notable differences in behaviour between the QRA column test data and FT leachate, however. For example, chloride does not show the declining behaviour demonstrated by the QRA column test leaching data. In FT leachate (Figure 9); chloride shows apparent constant behaviour, with low early concentrations, but higher than in the QRA data by L/S = 1.

The leaching behaviour of each substance in pore water (PW) is broadly comparable between most lysimeters. A notable exception is chromium (total and hexavalent) in Lysimeter 7 (PFA control). Both forms are non-declining in this lysimeter; showing an initial decline followed by a return to initial concentrations, compared to a continued decline in all other lysimeters.

Interaction of the PW with drainage/aquifer materials may result in release or attenuation of substances. Some substances, including calcium, magnesium, barium and sulphate, show an increase in concentration (release) from PW to leachate. However, apparent attenuation is indicated for a number of substances, mainly oxyanions such as antimony, arsenic, selenium and vanadium. Order of magnitude differences are observed for these substances between PW and leachate.

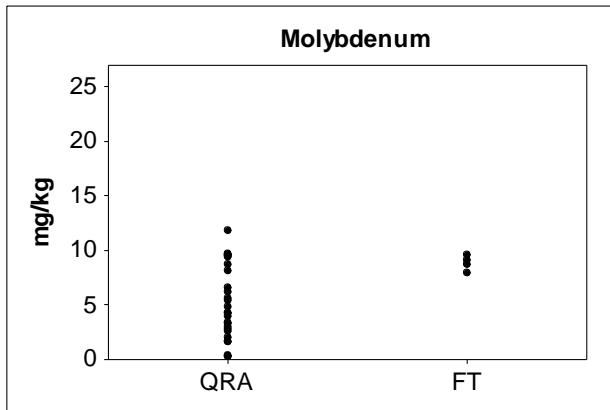


Figure 5. Leached mass: Mo

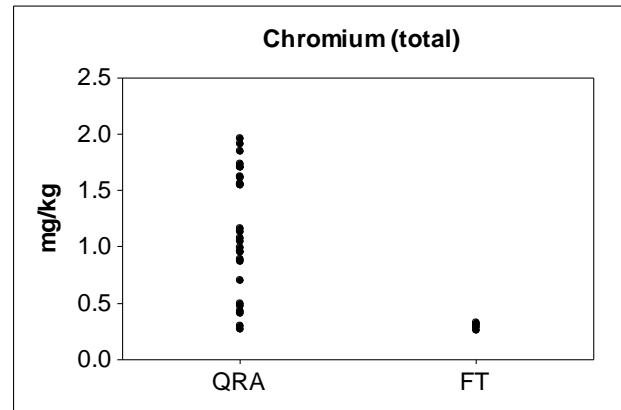


Figure 6. Leached mass: Cr total

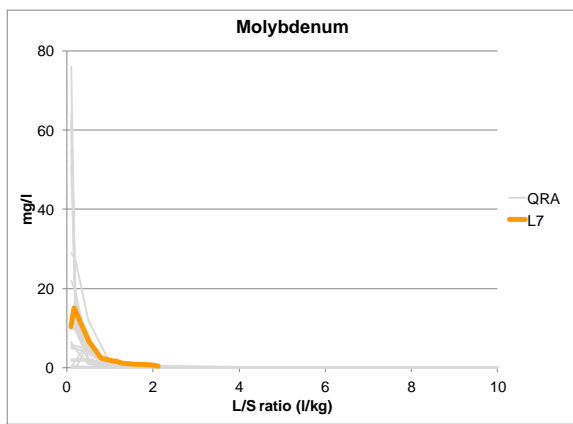


Figure 7. Leached mass: Mo

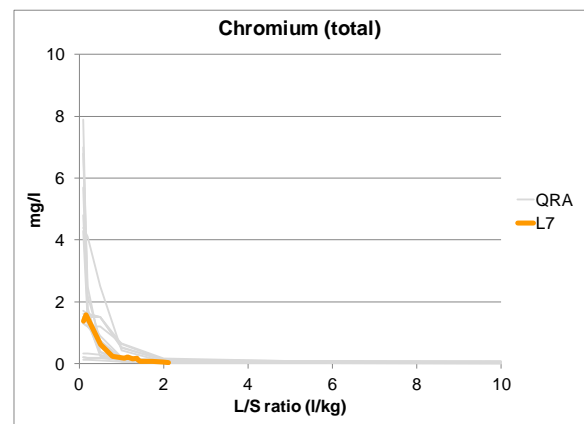


Figure 8. FT Leachate: Cr total

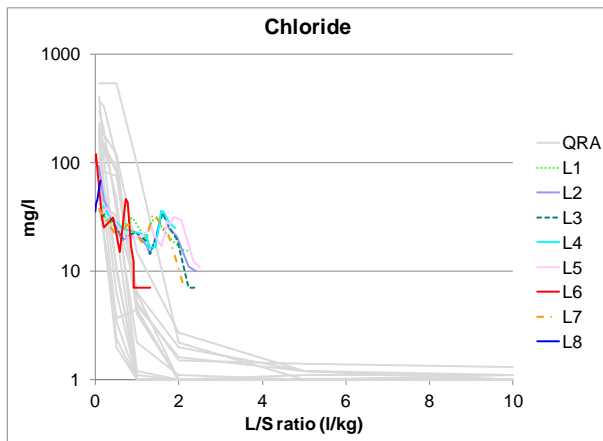


Figure 9. Leachate Cl

Conclusions

The PFA field trial developed and constructed a series of lysimeters designed to ensure meaningful results could be obtained within the available timescale and results were applicable to 'real-world' applications of the material.

During the trial, the PFA was exposed to a wide range of weather conditions. The summers of 2013 and 2014 were dominated by hot, dry weather and fairly low drainage flows. However, the flows never stopped completely during these periods and it was not necessary to irrigate the lysimeters to obtain leachate results. Winter 2013 was the wettest winter on record in England.

The instrumentation generally coped well with the extremes of the weather; although there were problems with some instrumentation within two of the lysimeters, which led to some loss of data. Resulting errors due are thought to be small, however, and do not significantly affect the overall water balance.

The trial provided a robust data set which enabled the water balance to be calculated. As a result, the field trial results have improved understanding of the infiltration and movement of water within and out of PFA.

The field trial enabled assessment of how well the laboratory results transfer to applications exposed to UK weather conditions. The trial demonstrated that the QRA laboratory tests generally represent field conditions well, and has improved understanding of the extent to which different aquifer materials attenuate key substances in leachate draining from PFA.

The field trial results will be used to review the QRA for unbound PFA, reducing uncertainties in the QRA model and giving greater confidence in the assessment of environmental risks. This will inform development of the future regulatory approach to PFA and increase confidence in the appropriate use of this material.