Carbon Dust Filtration in Three Different Nuclear Process Environments:

A comparison the challenges Carbon Dust Filtration Presents Under Different Process Conditions

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Abstract

In its thirty five years of activity as an engineering company in nuclear filtration sector, the Porvair Filtration Group has experienced several demands to remove of Carbon/graphite dust from several nuclear gas streams.

Of particular interest among those applications are, and those to be reported upon in this paper, are;

- High temperature, high pressure, high DP resistant (high strength) filters operating in the CO2 environment of the UK fleet of AGR (Advanced Gas-Cooled Reactors)
- Removing gross quantities of Carbon dust from the exhaust stream of a radioactive, nuclear organics decomposition, waste process
- High pressure Helium filtration to remove Carbon dust for a gas flow associated with the Fuel Handling System in the High Temperature Reactor programme

Each process is different from the other and presents its own unique problems.

The paper will present to this conference the very different properties Carbon dust appears to exhibit in each of these very different applications, and to discuss the effects those significant differences had/have on Porvair’s responses to each application.

An interesting comparison will be made of the substantial difference between the performance of the UK AGR filters and those used in the US for the removal of decomposed organics, and the significantly different properties the Carbon appears to exhibit in each unique set of conditions

Two UK AGR stations which are described are taken out of service when their bypass blowdown filters reach an operating DP of about 700mB DP (starting at a clean DP of around 100mB) to enable their replacement. The used filter assemblies are lifted from their housings and placed in an active storage area. Analysis of the used filter assemblies has shown that, where they are observable, they appear to be pristine with no apparent surface discolouration. It is only when examined under magnification that it becomes obvious that the filter medium, under the outer layer of fibres, is coated in what seems to be almost a ‘plating’ of something. EDACs examination of the medium shows strong Iron, Nickel, Chrome and Carbon peaks, so it is assumed that the collected contaminant is Carbon in some form.

Conversely, when the US organics destruction filters were being inactively commissioned, a fault condition led to the very large filter vessels (each containing a number of approximately 500 dia tubesheets in a single main tubesheet). When lifted out of the vessel, the smaller tubesheet assemblies came out as complete Carbon dust cores, leaving behind equivalent holes in the dust filled vessel below.
These Carbon ‘plugs’ were then carried by fork lift truck across the site (in the Idaho desert, so the ride was not smooth) to a specially constructed shelter where the assemblies were stood to be reviewed.

Eventually they were manually brushed clean with some difficulty, but, interestingly, when a sample of the dust was sent to Porvair in the UK, it pulsed clean from our test filter systems very easily.

These observations and more detailed examination of the performance and effects of these experiences will be reviewed, together with test data and fault resolution data to provide an overall picture of the various characteristics Carbon dust can present when trying to remove it from various systems.

Introduction

In several areas of Nuclear activities, the removal of Carbon dust contamination presents challenges to the filtration industry, most particularly in the variety of behaviour the solid material exhibits in capture. The paper discusses three separate duties where the same elemental dust exhibited three very different behaviours. These various behaviours also appear to be process chemistry and physics dependent, as there appears to be a change in the nature of the material and its characteristics when taken out of service and exposed to a natural atmosphere. This range of behaviours makes it difficult for the filtration engineer to predict the performance of the filter before and after service. Therefore a repertoire of empirical knowledge and experience is relied upon in order to attempt to design the filter system properly at the inception of the project, rather than try to correct afterwards. The paper will review some of that Porvair Filtration Group knowledge base in order to perhaps assist other engineers in avoiding pitfalls and wrong assumptions when dealing with materials of this nature. The UK fleet of AGR reactors exhibit and interesting and unexpected behaviour as far as particular Porvair filters in those systems are concerned, which is described in more detail below, together with a non-active commissioning incident in the US and the early indications of performance of filters associated with the fuel handling systems on HTGR plant in China.

Advanced Gas Cooled Reactor Graphite (Carbon) Dust

As the AGR reactor fleet ages, one consequence is an increase dust burden being recirculated around the system, a burden which is captured at various points, requiring expensive and large filters, operating at high temperatures and pressures, to be changed at regular intervals, at considerable cost in terms of both in money and man hours/plant downtime, as well as carrying the additional risk of increased worker dose. The Bypass Blowdown filter system, originally designed by another company as a ‘life-of-plant’ item was redesigned in the late eighties by the then Microfiltrex (now part of the Porvair Filtration Group) to provide a more cost effective and long lasting filter assembly.

Fig 1 shows a comparison of filter life between original sintered metal powder equipment and the Porvair Sintered metal fibre, pleated equipment, illustrating why the then UK Central Electricity Generating Board (CEGB) changed its filter systems from Sintered Powder tubes to pleated Sintered
Fibre filter elements. The blue line is the performance of Sintered Powder filters and the green line Sintered Fibre. The filter elements were both cleaned in-situ by a back flushing system. The sintered fibre filters went on to last 13 years before being changed (as they had become sufficiently active to create a handling problem – not because they were blocked).

![Graph](image)

Fig. 1

**HINKLEY ‘B’ SDC/BLOWDOWN FILTER**

![Micrographs](image)

Fig. 2 Micrographic images of the blowdown filters showing the character of the carbon deposits on them.

When removed from service, the Bypass Blowdown filter tubesheet looks pristine, and only after micrographic examination (Fig. 2) can the captured solids be observed. The actual nature of the
solids is unclear, as the micrographs show what appears to be a landscape of homogenous ‘plating’ under the outmost layer of sintered fibres rather than a collection or cake of discreet particles.

To try and better understand the issues with this filter assembly the plant operators commissioned a UK university to conduct some research and test work into the premature blinding of the filters (by characterising the solids captured and trying to establish the mechanisms behind the appearance of the captured solids). As part of their research the university, used a very wide range of Carbon based simulants in a range of sizes, to try and replicate the appearance, behaviour and pressure loss characteristics routinely seen in service, however they failed to replicate any of these properties in their test program.

There is some conjecture that the Carbon deposited on the filter is not the result of a purely mechanical range of Interception/Impaction/Diffusion mechanisms, but maybe also be the result of subtle chemistry, in as much as, when in service, one set of conditions exists for the material capture on the filters (for instance that precipitation or nucleation of transphase materials is encouraged by the very high reactive area per superficial media area due to the very fine fibres in the makeup of the filter medium) which, when removed from the high temperature, high pressure, CO2 environment in the reactor circuit to the ambient oxidising atmosphere of the out-of-reactor environment, there is a chemical change in the captured solids. It has been reported elsewhere that deposits of a ‘black, oil-like substance’ had been observed in reactor circuits, although its precise definition remains unclear.

In order to extend the life of these expensive items of equipment, the plant operators have undertaken to install effective cleaning systems and, indeed, a parallel self-cleaning filter in one line, as it is thought that the majority of the ‘dust’ which leads to the blinding of the filters is deposited immediately after filter replacement on startup of the heat exchange gas circulation, so that the filters begin their operational campaigns already burdened with dust. Future work with these self-cleaning and parallel duty/standby filter experiments will further inform the examination of the problem. It is also planned to build and install a special filter tubesheet with a number of removable test pieces which would enable easier, in-depth examination of the actual nature of the solids and mechanisms blinding the filters. That work will be reported upon in due course.

The Consequences of an Upset Condition During Non-Active Commissioning of a US Waste Conditioning Facility

During the inactive commissioning of an organics thermal destruction facility in the USA the incorrect choice of a test simulant followed by an attempt to correct the resultant problem with a process change resulted in the production of a large amount of carbon dust which was subsequently deposited on the surface of the filters.

In brief, the process uses a very high temperature heat source to decompose organic materials to gases. In commissioning, the operators chose woodchip as an organic simulant to prove the process.

In the process there are four filtration stages, all mounted in large vessels. Each vessel comprises a number of ‘mini’ tubesheets, mounted on openings in a single large tubesheet, each of the smaller
tubesheets being held in place and compressing its gasket seal by weights, sized to resist the maximum design pressure differential whilst still compressing the gasket seals.

The woodchip, rather than decompose to gases, instead reduced to charcoal briquettes. The operators then increased oxygen flow to create CO2, but instead fluidised the charcoal bed, producing sufficient carbon dust that it filled the first filtration vessel to such an extent that the weights holding down the tubesheets lifted and allowed large amounts of the carbon dust to pass to the clean side of the vessel and out of the housing to the next stage of the filtration system, where the same thing happened, and this process continued until all the filter vessels were filled and the final glassfibre HEPA filters were burst by excessive pressure differential due to the overload of carbon allowing the inactive carbonaceous material to flow out of the process exhaust stack.

When the recovery process was initiated, the vessels were opened and tubesheets removed. The filter vessels were filled to such a capacity that, when the filter assemblies were removed they came out as complete ‘plugs’ of carbon which, even when drive by a forklift truck across the site to a specially built, covered cleaning area, the ‘plug’ of Carbon remained intact.

The filter tubesheet assemblies were mechanically cleaned by brushing with stiff brushes and, as the filters were of the pulsed jet, self-cleaning type, the internal fuses had to be removed as blinded because the pulsed jet cleaning system was, of course, driving the Carbon dust which had bypassed the filters into the centres of the individual elements, blinding the fuses.

The operators were puzzled by the behaviour of the Carbon. When touched with finger or brush it was both soft and friable, but stood as a coherent whole when attached to the framework of the filter assembly. They theorised that possibly electrostatic charge or weak chemical or physical bonds were holding the material together. A large sample of the very fine dust was sent to Porvair’s Segensworth facility for examination and testing on its pulsed jet test rig to see if it was a failure of the Porvair designed pulsed jet system installed in the main vessels.

The dust was subjected to a microscopic examination and a size range around 2 to 5 microns for the particles was established, and when fed into the company’s pulsed jet test rig showed a capacity to pulse clean from the elements very successfully, although this was only performed at ambient temperature, whilst the main filters operated at process temperatures. The operators further wondered if the issue was in fact that the Carbon changed character at temperature. Porvair are not equipped to run its pulsed jet test rig at 500 celsius so, instead, suggested that we try a qualitative comparison of the Carbon dust by taking a small ladle of the material at ambient temperature and simply turning it over to allow the powder to fall to the ground to examine whether or not there was any sort of binding or agglomeration of the material.

A similar ladle full of the material was then heated to 500 celcius and the same qualitative test was carried out. Interestingly, when heated and emptied from the ladle, the heated dust did not even fall to the ground, but instead, on a clear, dry, still day, floated upwards into the atmosphere, completely dispersing.

Later discussion of the incident concluded that the most likely mechanism for the coherence of the Carbon on the filter tubesheets was compression as a consequence of the high differential pressure. A similar characteristic can be seen in in the preparation of sintered materials, before being entered
into the sintering oven, by which the powders are compressed into a fragile but coherent ‘green state enabling their shape to be maintained in the sintering furnace.

**Pulsed Jet, Self-Cleaning Filters in Carbon and Other Dust Applications**

The Porvair Filtration Company has been supplying metal filter systems to the nuclear industries (in the power generation, fuel production, waste treatment and storage, and decommissioning fields) in many parts of the world for more than thirty years, and so has a great deal of experience in the removal of solids from both liquid and gaseous streams. It is with that experience in view that we write this paper in order to illustrate just how varied the behaviour of (supposedly) individual solids types can be, and how little can be taken for granted when trying to mitigate for their presence in process streams.

The company has provided pulsed jet systems used in the fuel handling systems to support the HTGR programme in China.

The dust should be both dry and its characteristics reasonably predictable as (apart from a significant pressure in service), the duty is neither chemically or, in terms of temperature, challenging.

Some years ago the Company supplied a pulsed jet system (Fig. 3) to the Belgian MOX fuel manufacturer ‘BelgoNucleaire’ which was the subject of an extensive test programme.

![Fig. 3](image)

That filter was fitted into the company’s pulsed jet test rig and examined at length.
Fig. 4 (below) shows raw data during its stable operating regime, the lowest line is the reservoir pressure (the dips being the pulsed jet cycle operations), the middle line the flow and the upper line the pressure loss (the spikes of which are clearly related to the spikes in the reservoir pressure), which shows the over-pressure consequence due to the additional mass of gas introduced during the pulsed jet cleaning operation. The top curve also illustrates that, even with a very fine solids burden, filters may be cleaned on line and a stable regime established without having to take the filter off-line.

The BelgoNucleaire pulsed jet unit was tested using an Iron oxide simulant dust, with a 90% by mass content smaller than 1 micron. In its clean condition the clean pressure loss was a stable 9 mB, the unit stabilised its operating pressure loss was 13 mB.

However (see Fig. 5), when the cleaning pulses were stopped, whilst maintaining dust loading, the DP rose to a new level (and would have continued to rise). The resumption of the cleaning pulse brought the DP down again and it was trending towards an asymptote of the operating DP (around 13 mB). The dust loading was then stopped whilst continuing to pulse and the DP began trending towards a second asymptote of the clean DP of around 9 mB.
Fig. 4a, evolution of the stable operating regime.

Fig. 5 Raw data showing the recovery of the filter system from normal operating condition, through blinding to recovery.
Fig.5a Synthesis of the raw data describing pulsed jet filter recovery

It will be interesting to see, when the fuel handling system filter is operated with the Carbon dust from the HTGR whether or not that dust behaves in any way similar to the other Carbons have behaved.

Conclusions

This paper is written as an illustration of various behaviours of Carbon dusts we have experienced in various applications, and aims to support and assistance to the HTGR programme the project encounter similar anomalous behaviour exhibited by Carbon dust on the filters or anywhere else in the system.

The HTGR offers only high pressure as a challenging parameter, and Porvair are entirely confident that the Porvair pulsed Jet self-cleaning filter system will work equally as well in the HTGR programme as the PJ system did for the BelgoNucleaire plant (where it operated continuously for eight years until the plant closed without any spares replacement).

It will, however, be very interesting to see exactly how well the equipment performs under actual process conditions. Porvair remain committed to the HTGR programme and stand ready to provide any assistance necessary to overcome any problems that might arise.