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METALLIC FILTERS FOR HOT GAS CLEANING

PROJECT SUMMARY 305

CLEANER FOSSIL FUELS PROGRAMME
– CLEANER COAL R&D PROGRAMME

OBJECTIVES

- To improve metallic filter media for high temperature applications in aggressive environments.
- To design a prototype element for Integrated Gasification Combined Cycle (IGCC) and Air Blown Gasification Cycle (ABGC) applications.
- To produce a filter element life prediction model for gasification environments.

SUMMARY

Advanced power generation systems, based on gasification, are being developed. Hot gas cleaning technologies for gasification systems offer the potential of a lower cost approach to pollutant control and gas turbine protection, leading to simpler cycle configurations with associated efficiency advantages. The unreliability of the ceramic filter elements used in demonstration trials and the high capital cost of these systems have hindered their application and are factors restricting the uptake of gasification power plants in general. The successful development of a durable metallic filter system for the ABGC would be a major step towards its implementation.

Metallic filter media provide a number of significant advantages over ceramics. In order to realise fully the cost and environmental advantages, it is essential that the systems provide not only efficient contaminant removal but also have the reliability and availability required of the overall system. It is now apparent that reliable, lower cost filter systems can be operated using metallic filter media, provided improved materials selection and advanced fabrication methods are developed.

This project investigated the performance of candidate materials for the construction of metallic filter media.

Figure 1. Metallic filter elements

Testing involved a range of furnace exposures in simulated gasification environments, to first screen materials and then to provide data relating to filter element construction and the prediction of their service lives. Life predication was based on an existing framework corrosion model at Cranfield University, developed for other gasification system components. The project also investigated design requirements for different types of metallic filters and identified the critical design parameters.

BACKGROUND

Around the world a diverse range of advanced power generation systems are being developed that are based on the gasification of coal and associated fuels. IGCC systems have reached the demonstration stage in Europe, with plants in Holland and Spain both based on oxygen blown entrained flow gasification processes. In the UK, the ABGC system continues to be investigated although an ABGC system demonstration plant has yet to be built. Elsewhere, the USA has an extensive programme for the demonstration of gasification technologies.

The development and introduction of hot gas cleaning technologies offer the potential of a lower cost approach to pollutant control, leading to simpler cycle configurations with associated efficiency advantages. Hot gas filtration has not only been adopted as an essential system component in hybrid technologies like the ABGC, but is also being used to remove particulates prior to water scrubbing of fuel gases in first generation IGCC plants.

The filters currently employed are based on the designs developed for pressurised fluidised bed combustion applications in the 1980s using ceramic filter elements. The unreliability of the ceramic filter elements in demonstration trials and the high capital cost of these systems have hindered their application and are factors restricting the uptake of gasification power plants in general.

The hot gas filtration systems need to operate in aggressive gasification environments at 250-700°C and at pressures of 10-25 barg, depending on the particular gasification system. In order to realise fully the cost and environmental advantages, it is essential that the systems provide not only efficient contaminant removal but also have the reliability and availability required of the overall system. Over the years, adaptations to system configurations and more realistic expectations of filter performance have led to the original choice of ceramics for the filter medium being questioned. It is now apparent that reliable, lower cost filter systems can be operated using metallic filter media, provided improved materials selection and advanced fabrication methods are developed.

Metallic filter media provide a number of significant advantages over ceramics including lower pressure drop – leading to a reduced filtration area and hence reduced capital costs, more predictable durability and reliability and simpler installation and handling requirements.

The potential for fuel gases to cause sulphidation, erosion and fouling raises concerns over the selection of materials and the lifetimes of filter components, similar to those for the heat exchanger which is used to cool the fuel gas before the hot gas cleaning stages. Also down-time corrosion, resulting from deposits of particles and condensates which develop during operation, may lead to severe pitting damage and stress corrosion cracking.

Microfiltrex (a Division of Porvair Filtration Group Limited) is a world class manufacturer of metallic filter media for a wide range of applications. In recent years, trials have been carried in conjunction with a major US IGCC demonstration project to evaluate the potential of metallic filter elements in these systems. These trials have confirmed the benefits indicated above. However, they have also highlighted the problems of using metallic media in such aggressive environments due to the highly corrosive nature of the fuel gas and the deposition of condensates within the filter element's structure. As the success of metallic filter media is dependent on achieving an economic life while ensuring adequate filtration performance and reliability, optimisation of materials selection and fabrication methods for IGCC/ABGC applications is required.

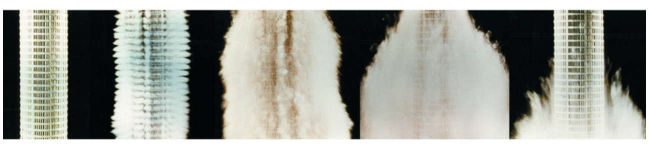

Figure 2. High speed photography showing the action of pulsed jet cleaning

(Moving across the photograph from left to right: the metal fibre element loaded with dust; the dust is removed from the surface by the pulsed jet action; the dust is carried away; the dust begins to settle; and quickly falls to the bottom of the vessel leaving a clean element. Sequence time – half a second.)

MATERIAL SCREENING

The range of fibrous and wire materials currently used in filter applications were reviewed and the best candidates selected for a corrosion screening test in a typical IGCC high sulphur coal fuel gas environment at 450°C for 1000 hours. These materials covered Iron, Nickel and Cobalt based alloys and included a number of welded specimens. Baseline alloys were also included to provide an indication of the relative corrosive nature of the environment.

MATERIAL PERFORMANCE ASSESSMENT

The best performing materials from the screening test together with a number of 'new' materials under development were used for the materials performance assessment. The materials were Haynes D205 EN2691, Fecralloy, Iron aluminide, HR160, IN690, HA188, INC276, Hastelloy X, AISI316L, IN800HT and AISI310 reference materials.

For this part of the project, attention was paid to testing the materials in the correct product forms, with treatments used in element manufacture as these may promote a different balance of damage mechanisms that could initiate premature failure. Fabricated parts were also included in this task so that the effects of the methods used to manufacture elements could be assessed.

Two environments, simulating high sulphur content IGCC fuel gases (generated from high sulphur coals and petroleum coke) and low sulphur content fuel gases (such as cleaned coal-derived fuel gas, ABGC fuel gas, biomass or co-fired coal and biomass fuel gases), were used in this part of the test programme. The materials were evaluated at temperatures of 450, 500 and 550ºC for the high sulphur gas and at 550ºC for the low sulphur gas, for periods up to 3000 hours. Simulated deposits were added with a re-coat interval of 1000 hours to simulate the effects of the deposits that are known to occur in such filter systems.

Typical and observed maximum oxide thicknesses were measured from cross-sections. Measurements were made on both the areas exposed to the gases through the applied deposits and also areas that were not deposit coated. Damage was greatest on the deposit coated specimens. The damage to alloys exposed in the low H_2S (ABGC) gas test was significantly lower than in the equivalent high H_2S (IGCC) gas test.

MODELLING AND DETERMINATION OF OPERATING CONSTRAINTS

The development of models to allow prediction of materials performance in gasification systems, for many of the complex synergistic modes, is limited by the data available. However, for isothermal corrosion in gaseous gasification conditions, a large amount of materials performance data has now been generated from a number of laboratories and this is enough to model the performance of at least some materials in such conditions.

A framework isothermal corrosion model for gasifier hot gas path conditions was developed previously by British Coal for an EU JOULE programme and applied to Alloy 800H and AISI 310. The models were based on materials performance data available during the programme and published literature data. These models were further extended during the COST501 Round III programme by British Coal, JRC Petten, KEMA and ENEL to cover the temperature ranges 500-900°C (though at some temperatures only single data points were available). This project has provided data needed to greatly extend the range of conditions and materials for which these models can be used.

FILTER ELEMENT DESIGN

By far the most common barrier filtration configuration used in hot gas cleaning for power generation is the filter candle, where dirty gas flows from the outside to the inside of the candle wall, and contaminant which accumulates on the surface is regularly removed by pulsed-jet cleaning. Such filter systems are widely viewed as the best prospects for hot-gas cleaning in clean-coal power plants, from both a technical and economic view, and Microfiltrex have based their development work around improving the performance of such filter candles.

A test programme was conducted utilising a cold flow test rig to evaluate the performance of metal fibre elements for hot gas applications. Sintered metal powder (SMP) and sintered metal fibre (SMF) elements were manufactured from AISI 316L stainless steel (suitable for cold flow atmospheric air testing). The fibre and pore structures were designed to provide equivalent performance to that utilised for high temperature service. Four filter elements were installed and initially the flow pressure loss characteristics of four different metal fibre media were determined and compared with commonly used ceramic and sintered metal powder filters providing similar filtration efficiency.

The tests were conducted at ambient conditions with media superficial face velocities in the range 0.01 – 0.06 m/s, which is typical for this type of application.The results showed that the metal fibre media filters had high permeability and low pressure loss characteristics compared to ceramic and sintered metal powder materials.

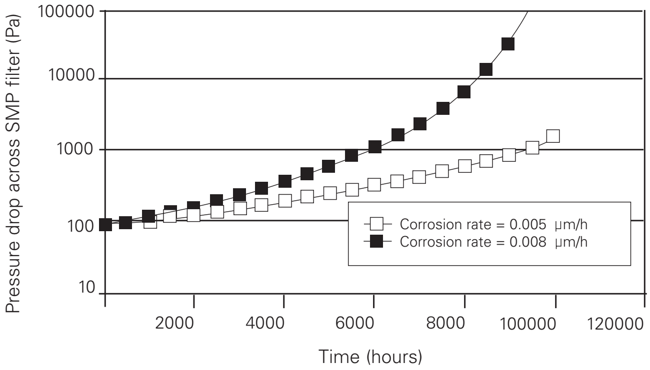

Figure 3. Example of life plot for sintered metal powder filter for two corrosion Rates

Thus the metal fibre filters would give substantial improvements in performance in terms of clean flow pressure loss and the generation of a stable baseline pressure loss when compared to ceramic and SMP materials. While the architecture of the filter element and structure of the filter media are critical to the on-line performance of the filter element, the metallurgy of the filter media is equally as important in defining on line performance. The structural integrity of the filter media to maintain efficiency is clearly a must. However the build up of corrosion products, oxide scale and spalling will considerably increase the residual pressure loss of the filter and may ultimately blind the filter element completely.

Experience has shown that the life assessment of SMP and SMF filter media will be based on different methodology. SMP filter media with its relatively closed pore structure, typically 30-50%, will be life limited by oxide scale growth, corrosion spalling and blinding of the pores resulting in a reduction in the porosity of the filter medium.

SMF media has a very open pore structure (70-85%), giving high porosity, and so is arguably more tolerant of corrosion product and oxide growth in terms of its filtration and regeneration characteristics than SMP media. The small fibre diameters used for SMF media are more susceptible to structural failure and total consumption than its larger powder counterpart. SMF media will be life limited by structural failure of the fibres or a steady rise in the differential pressure loss of the filter under operating conditions to an unacceptable level for plant operation.

The latest filter element designs incorporate several different metallic parts each with different requirements in terms of strength and corrosion resistance resulting in each part having a different failure criterion. For example, the diameter of fibres in a SMF filter are typically 1.5-40 μm and could have a failure criteria of 50% loss, whereas the support structure can be several millimetres thick and a failure criteria of 1mm. Using this corrosion allowance failure criteria and an operational life of one year (8760 hours) the upper corrosion rate limit would be of 2.23×10^{-3} μm/hour for a 40 μm diameter fibre and 0.114 μm/hour for a support structure. The calculated corrosion rate limits together with the measured corrosion damage for deposit coated specimens allow the upper working temperatures to be identified. For example, the above analysis yields Fecralloy, Haynes 160 and Haynes D205 as the only candidate materials for fibre media under IGCC conditions at 450ºC.

Corrosion rate data can also be used to estimate life of the filter where the life is limited by a reduction in the porosity of the filter media by oxide scale growth. This life criterion is more applicable to filters manufactured from SMP than fibres.
An example plot for SMP media showing the effect of two corrosion rates on the pressure drop across the filter with time is shown in Figure 3.

CONCLUSIONS

- This project has successfully investigated the performance of a range of candidate materials for the manufacture of filters for use in gasifier (IGCC and ABGC) hot gas paths.

- Damage was greatest on the deposit coated specimens.
- The damage to alloys exposed in the low H_2S (ABGC) gas test was significantly lower than in the equivalent high H_2S (IGCC) gas test.
- Existing corrosion life prediction models developed at Cranfield University have been modified and extended. It has been demonstrated how to predict the expected service lives and upper temperature limits of filter media under operational IGCC filter conditions.
- The design requirements for a prototype element for IGCC/ABGC applications have been identified and related to the data produced in this project. Life prediction models have been illustrated for sintered metal fibre and sintered metal powder filter media.

POTENTIAL FOR FUTURE DEVELOPMENT

Metallic filter elements continue to demonstrate excellent results in numerous coal gasification demonstration and development facilities; however, on stream life remains a barrier to the economic exploitation of this technology. Further development of suitable materials remains high on the priority list. The project has provided the basis for new opportunities for the development of metallic filter media in gasification environments. To confirm this potential the manufacture of full sized elements is required together with their demonstration in pilot scale trials and in commercial installations.

In addition to coal, biomass gasification can benefit from the improved reliability and filtration performance offered by metallic filters and it is recommended that further work is undertaken to evaluate materials suitable for operating in such environments.

COST

The total cost of this project is £58,000 with the Department of Trade and Industry (DTI) contributing £29,000 and Microfiltrex (a Division of Porvair Filtration Group Limited) providing the remainder of the balance.

DURATION

24 months – February 2001 to January 2003.

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FURTHER INFORMATION

For further information about this project see contractor report Metallic Filters for Hot Gas Cleaning available from the Helpline.

Further information on the Cleaner Fossil Fuels Programme, and copies of publications, can be obtained from:
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