NOVEL HOT GAS CLEANING/HEAT RECOVERY SYSTEM

PROJECT SUMMARY 303

CLEANER FOSSIL FUELS PROGRAMME
– CLEANER COAL R&D PROGRAMME

OBJECTIVES

The overall aim of the project was to develop a novel integrated fuel gas cooler and sulphur and halide removal process for coal gasification plants. Specific objectives were:

- To prove the concept of using a twin-bed reactor system is suited to this application.
- To assess the performance of available sulphur sorbents in the twin-bed system.
- To assess the effect of scale up on the performance of the system and the downstream effects on filter performance, residue characteristics and gas turbine performance.

SUMMARY

This project was targeted at developing a novel integrated raw gas cooler and sulphur/halide removal process for gasification plants. This desulphurisation process is based on a twin fluidised bed system employing direct solids transfer between adjacent reactor vessels, with halide removal being achieved by means of sorbent injection.

Within this project a series of mathematical models were developed for the twin-bed desulphurisation concept. Then a 2-D cold model was designed and manufactured to demonstrate the concepts and the validity of the mathematical models produced.

Following on from this, a twin-bed unit was developed from initial design through construction to operation in the hot gas path of an air blown fluidised bed gasification pilot plant. Initially the unit was used as a 3-D 'cold model' for further testing of the twin-bed concept and producing model validation data (particle and gas transfer rates between the twin-beds).

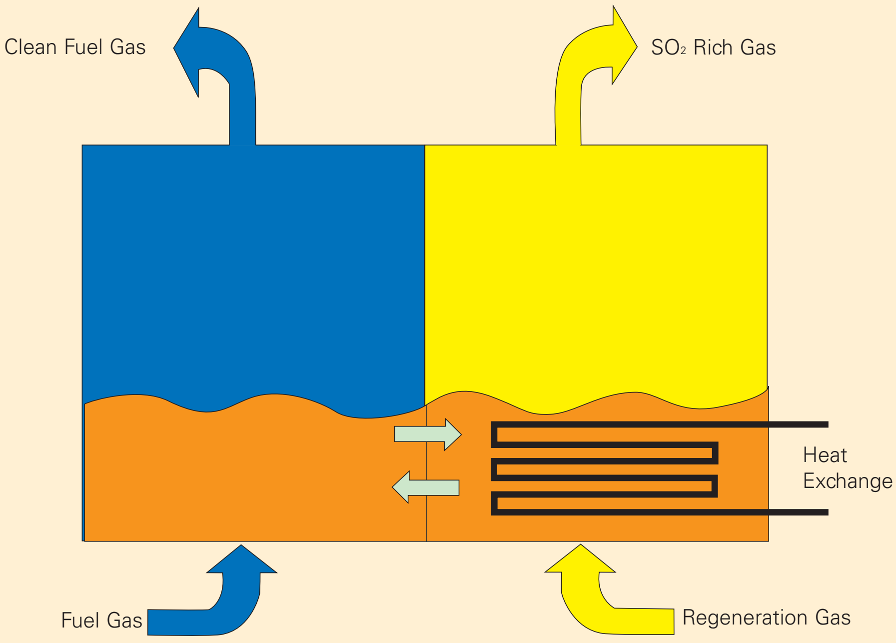

Figure 1. Twin-bed gas clean-up/heat exchanger concept

Then the twin-bed unit was linked to the gasifier and used in a series of tests to demonstrate the effect of a sulphur removal sorbent on gasifier derived fuel gases and the effect of fluidisation conditions and bed temperatures. The H_2S levels were reduced (by up to 75%) under all test conditions.

The twin-bed system is a promising technology for a heat exchanger system, due to the good communication between the two fluidised beds, and for a reduction of contaminant emissions. However further work needs to be done working with the twin-bed at higher temperature, where the sorbent performance is maximised.

Two options for the twin-bed system have been suggested as worth pursuing as viable use of this technology in gasification plant design:

- A twin-bed heat exchange system where gas from a gasifier is fed to one vessel and heat is transferred to a second by means of re-circulating solids.
- A triple-bed adsorption-regeneration-heat exchanger system, where the gas from the gasifier is fed to a vessel and the H_2S is removed. Catalyst/sorbent is transferred to a second bed for regeneration, and solids are transferred to a third vessel where heat is removed.

BACKGROUND

Nearly all types of coal gasification-based advanced power generation systems under development incorporate hot gas cleaning stages to remove particulates and gas phase contaminants prior to the fuel gases entering the gas turbine. These hot gas cleaning systems offer significant benefits over conventional wet scrubber clean-up systems. However the development of a continuous fully integrated process, in which gas cooling is combined with sulphur/halide removal, using regenerable sorbents, would give substantial benefits. Systems of this type have a number of advantages:

- The use of regenerable sorbents produces less waste and reduces the operating cost associated with disposal of classified waste products.
- The fuel gas cooler is located in a more benign environment and can therefore be used to generate superheated steam at supercritical conditions yielding a further improvement in cycle efficiency.

The removal of gas contaminants early in the hot gas path would also directly improve the environment for downstream components such as hot gas filter parts.

This benefit would apply to all types of gasifier, including conventional oxygen-blown integrated gasification combined cycles (IGCCs) where the introduction of hot gas cleaning would otherwise happen downstream of the raw gas cooler and the hot gas filter, both of which would have to operate in highly aggressive environments.

The desulphurisation process investigated in this project (Figure 1) is based on the concept of twin fluidised bed system employing direct solids transfer between adjacent vessels. Halide removal would be by means of sorbent injection upstream of the twin-bed system. Hot gas cooling/superheated steam generation would be carried out in an oxidising environment avoiding many of the problems encountered in coal based gasification systems, including the formation of aggressive deposits in sulphidising/carburising environments which can lead to rapid corrosion damage and the risk of unforseen failures. Such a system would also reduce the potential complexity of hot gas sulphur and halide removal processes whilst maintaining low emission levels of gaseous pollutants and solid waste products. In particular the need for a second hot gas filter is overcome thereby reducing capital and operating costs.

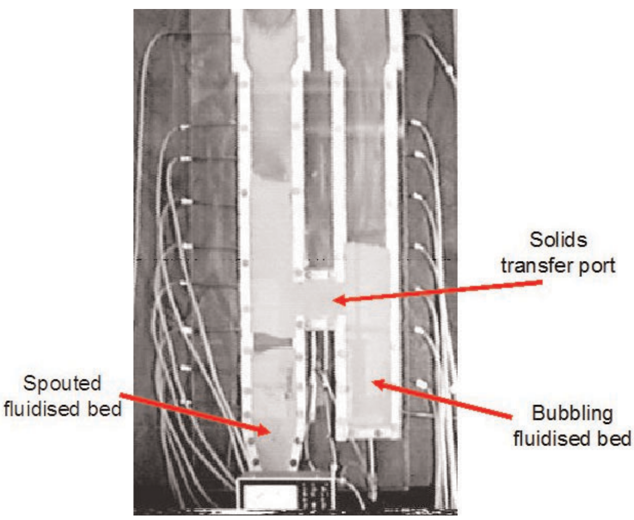

Figure 2. A 2-D cold model of the twin-bed system concept

This project was targeted at supplying the required basic scientific understanding of this integrated hot gas cleaning approach to allow the technology to move forward to subsequent industrial development and demonstration.

TWIN-BED SYSTEM REACTOR DESIGN

This activity was targeted at developing the designs of the reactors needed for the twin-bed gas cleaning/heat exchanger system. The basic concept of the twin-bed system is shown in Figure 1. Mathematical models of the twin-bed system were developed (in Pascal) to describe the function of the system in terms of the:

- Chemical reactions taking place in the adsorption and the regeneration reactor.
- Heat transfer within both reactors and between them (via the transport port).
- Flows of sorbent particles and gases with both fluidised bed reactors and through the transport port.

A flexible 2-D cold model was built to demonstrate the flows of solid particles within and between the twin fluidised beds (Figure 2). For simplicity, the beds were positioned adjacent to each other with a linking particle transfer port. The behaviour of this twin-bed system was monitored visually using a video system, as well as by using a series of pressure drop measurements. During the cold modelling process, the design of the twin bed system was progressively modified by:

- Changing the position of the particle transfer port relative to the two fluidised beds.
- Adjusting the position of the spout with the spouted fluidised bed.
- Adjusting the position of the air supply pipe(s) in the bubbling fluidised bed.

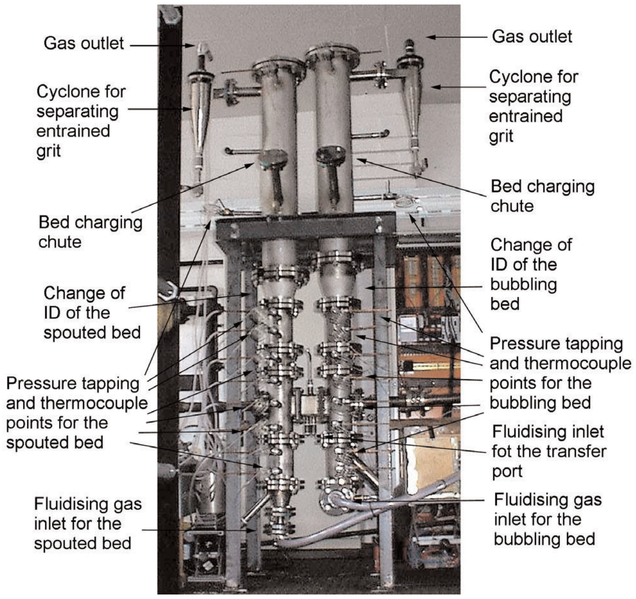

Figure 3. Twin-bed system built for use with Cranfield University's air blown gasification pilot plant

In each configuration, a series of tests were carried out to assess the effect of fluidising air flow rates in both fluidised bed reactors and the particle transfer port. These tests allowed optimum operation conditions (and associated characteristic pressure loss measurements) to be determined for this configuration of the twin-bed system.

PILOT SCALE STUDIES

Following on from the mathematical and cold modelling developments, a hot twin-bed system was designed for incorporation into the hot gas path of Cranfield University's air blown gasification pilot plant. This test rig was built, installed into the plant, commissioned and a series of tests carried out to characterise its performance.

Figure 3 is a picture of the twin-bed system that was produced (before it was lagged). This system consists of a cylindrical spouted fluidised bed (with gas supplied from the gasifier fuel gas path) linked through a rectangular section particle transfer port to a cylindrical bubbling fluidised bed (supplied with air). Both fluidised beds had cyclones at their exits to capture any entrained particles. The exit gas from the spouted bed re-joined the gasifier hot gas path enroute to the plant's flare system. In addition for halide removal studies, a particle injection system was installed in the gasifier hot gas path upstream of the spouted bed. Gas sampling points were located upstream and downstream of the fluidised bed reactors: these were used to monitor CO, CO_2, H_2, H_2S and HCl levels in the fuel gases before and after passing through the gas clean-up system.

Initially tests were carried out to determine the solid transfer and gas leakage rates between the fluidised bed reactors. Heat was used to trace the flow of particles between the reactors: it was found that the solids transfer rate between the two reactors was in the range of 5-22kg/s/m^2. Fluidising air doped with CO_2 was used to determine the leakage rates between the two reactors: this was shown to be in the range 1.1-2.6 % depending of the fluidising conditions of both reactors and the transfer port.

Finally a series of tests were carried out to investigate the performance of the twin-bed gas cleaning system when linked onto an operating gasifier. For these tests the gasifier was fired on a UK bituminous coal (Daw Mill) and a sorbent of limestone was used in the twin-bed system to demonstrate the sulphur removal performance of the system. These tests investigated the effects of different fluidising conditions and bed temperatures in both of the reactors. The results showed that the twin-bed system was effective in reducing the H_2S concentration in the fuel gas stream, with reductions of up to ~75% observed, though this value depended on all the variables investigated.

A separate sorbent feed system (using finely powdered sodium carbonate) was installed upstream of the twin bed system, and successfully used to remove HCl from the gas stream without affecting the performance of the twin-bed system.

SCALE-UP ISSUES

The mathematical models that had been developed during the design stage of this project and tested/validated (as far as possible) by the pilot plant studies, were used to investigate potential issues associated with the scale-up of the twin-bed gas cleaning/heat exchanger concept. As a result, two design concepts are suggested for further development:

- A twin-bed system for the transfer of heat from a fuel gas stream to a heat exchanger located in an oxidising gas, for the generation of superheated steam in a much more benign environment.
- A triple-bed system, in which two oxidising bubbling fluidised beds would be linked to a central spouted fuel-gas fluidised bed by particle transfer ports. Heat would be removed from a heat exchanger located in one of the bubbling fluidised beds (that consequently would operate at a much lower average temperature) and sulphur sorbents would be regenerated in the other bubbling fluidised bed (that could be operated at a higher temperature more suitable for the regeneration of these sorbents).

In addition, an assessment was carried out as to the potential impact of a twin-bed gas cleaning system on downstream components, including:

- Hot gas filter
- Ductwork/valves
- Gas turbine

All data available to the authors from the literature and other DTI funded Cleaner Coal Projects indicate that reducing the levels of sulphur containing species in the fuel gas stream will increase the lives of downstream components. In the case of the hot gas filter it may allow cheaper materials to be selected for some component parts (though materials selection for this unit is a complex issue of which high temperature sulphidation is only one part). In the case of the gas turbine, lower SO_X levels will reduce the dewpoint temperatures for vapour phase derived sulphate deposit formation: this will reduce the areas of turbine hot gas path components (especially aerofoils) that are likely to be covered by these deposits. Reduced fluxes of such deposits (as well as reduced SO_X levels in the surrounding gases) will result in reduced corrosion rates.

CONCLUSIONS

- The potential of a new type of hot gas cleaning/heat recovering system for gasification systems, based on a twin fluidised bed concept, has been investigated within this project.
- Mathematical models to describe the twin-bed gas cleaning/heat exchange process have been developed. These models have been tested/validated by subsequent testing in cold and hot models of twin-bed systems.
- A 2-D cold model of a twin-bed system was constructed and used to optimise the location of the solid transfer port, and fluidisation conditions.
- A 3-D test rig linked to an air blown gasification plant was designed, built and operated. This rig produced data on gas leakage rates and particle transfer fluxes, as well as on the performance of the twin-bed system as a desulphurisation system using gasifier derived fuel gases.
- Scale-up issues were evaluated using the mathematical models developed and tested during the course of the project. Two variations of the twin bed concept were identified for future developments.

POTENTIAL FOR FUTURE DEVELOPMENT

The twin-bed gas cleaning/heat exchanger system shows promise for use on gasification systems, as has been demonstrated by inter-bed heat flux and reduced H_2S emissions in all the experiments carried out in the pilot scale hot test rig during this project. However, further work is necessary to understand the complex nature of this process.

Modifications need to be made to the prototype twin bed system built within the current project to obtain a better control of sorbent performance and regeneration. For example, both fluidised beds in this test rig should be externally heated to achieve higher temperatures. Temperatures in the order of 600-800°C in both fluidised bed reactors would maximise the sorbent performance.

Topics for further investigation include:

- Development of sulphur sorbents specifically for use in twin-bed operating conditions.
- Development of catalysts to reduce NH_3 emissions.
- Cleaning combustion derived gases.
- Increased understanding of inter-bed hydrodynamics.
- Scale-up of twin-bed process for industrial development and demonstration.

COST

The total cost of this project is £202,430 with the Department of Trade and Industry (DTI) contributing £101,215 and Mitsui Babcock Energy Limited providing the remainder of the balance.

DURATION

36 months – May 2000 to April 2003.

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FURTHER INFORMATION

For further information about this project see contractor report Novel Hot Gas Cleaning/Heat Recovery System available from the Helpline.

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