Combustion Testing and Research

The Combustion Technology Centre (CTC) was established in 1985 to conduct technical investigations related to the assessment and use of thermal coals. The centre has internationally recognised expertise and facilities for evaluation of thermal coal combustion behaviour and the optimisation of coal combustion processes.

The Centre has conducted numerous pilot scale evaluations on a large number of other coals (in excess of 400) from over thirteen countries. Coal evaluations focus on optimising process efficiency and assessing the effect of coal properties on the combustion performance of coals in industrial applications, principally pulverised coal-fired power plant boilers. Testwork has been undertaken on coals supplied from borecores, current mines, coal preparation plants, superintending samples and power plant stockpiles.

Thermal Coal Evaluation Programs

For an in-depth and comprehensive understanding of a thermal/steaming coal, technical evaluation programs are formulated to address most aspects of assessing the expected utilisation performance in a pulverised coal fired utility boiler. The program includes performing a comprehensive list of laboratory analyses, handling and spontaneous combustion tests, pilot scale milling and pilot scale combustion testing. The program includes a technical evaluation report to provide an interpretation of the results by an experienced coal utilisation consultant.

The CTC has conducted numerous pilot scale evaluations on a large number of other coals. The objectives of the evaluation and report include the following:

- To characterise the coal for marketing.
- To assist with mine development decisions.
- To explore alternative beneficiation or blending options.
- To assist in the design of mine-mouth power stations.
- To investigate reported difficulties with coals in power station boilers.
- To support due diligence procedures.

A comprehensive testing program requires approximately 1,500kg of coal but programs can be designed utilising less coal samples. The centre frequently performs research programs investigating areas such as:

- Blending investigations and identifying optimal blend proportions.
- Effects of additives on performance.
- Effects of blending with biomass.
- Gaseous trace elements.
- Fine particulate measurement.

Laboratory Analysis

Laboratory analysis of a thermal coal is critical to understanding the underlying quality of the test coal. Some of the test results are required for mill configuration and configuring operational parameters for the Boiler Simulation Furnace. The laboratory test results also allow further investigation of results in the technical evaluation report and are used to compare pilot scale test results with.

Laboratory analysis of the test coal would include determination of the following analyses:

- Total Moisture
- Proximate Analysis
- Ultimate Analysis
- Calorific Value
- Hardgrove Grindability Index (HGI)
- Abrasion Index
- Forms of Sulphur
- Chlorine
- Ash Fusion Temperatures
- Ash Elemental Analysis
- Moisture Holding Capacity
- Trace Element Analysis
- Petrographic Analysis

BURNOUT EFFICIENCY

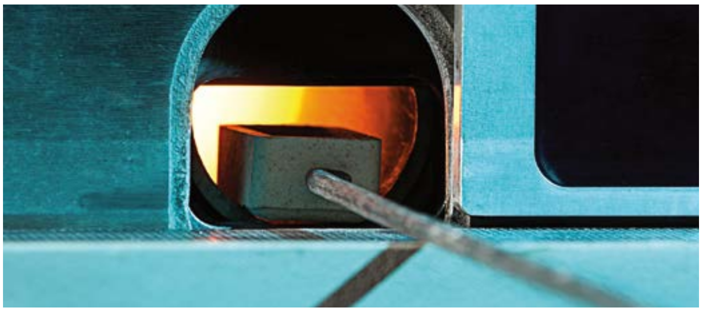
A drop tube furnace is used to measure burnout efficiency of small coal samples. The testing is done according to an inhouse procedure and is typically performed at three temperatures (1200oC, 1300oC, 1400oC) and two size distributions (+63-90µm & +125- 150µm).

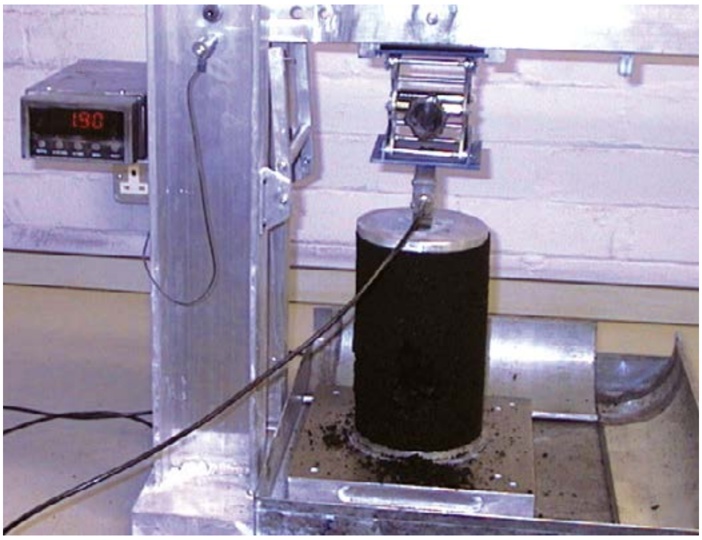
FLY ASH RESISTIVITY

The efficiency with which fly ash particles are attracted to the collecting plates of an electrostatic precipitator (ESP) is directly related to the strength of the electric field between the plates and the emitting wire, among other factors. The strength of this field is limited when the layer of fly ash adhering to the precipitator plates has a high electrical resistivity. The resistivity of the fly ash sample is measured in a synthetic flue gas environment at temperatures between 95oC and 210oC at a constant moisture ratio of 9 percent (by volume). It is preferable to use a fly ash sample from either pilot scale testing or collected from a power station but testing can be performed on a laboratory generated ash sample.

COAL PARTICLE SIZE DISTRIBUTION

A Malvern Particle Sizer is used to measure size distributions from 2µm to 500µm. The equipment is regularly used to measure the size distribution of milled product, especially to determine the percent passing 75µm. The equipment can be used to measure the particle size distribution of any particulate matter.





Storage and Handling Characteristics

Coal Storage Tests

RELATIVE IGNITION TEMPERATURE

A sample of freshly prepared coal is placed in a furnace and heated at a rate of 2oC/minute. The rise in temperature of the coal sample is monitored. The point at which the temperature of the coal “crosses” the temperature of the furnace (ie. the crossing point) is nominated as the ignition temperature. The lower the value of the ignition temperature, the higher the propensity of the coal to self-heat.

ADIABATIC SELF-HEATING

The test consists of measuring the self-heating rate of a freshly prepared sample of coal under adiabatic conditions. The average rate of self-heating between 40°C and 70°C (ie R70) is used as an indication of the propensity for self-heating to occur. The lower the value of R70, the lower the propensity of the coal to selfheat.

Coal Handling Tests

EDINBURGH COHESION TEST (ECT)

Research conducted at Edinburgh University and ALS Coal has shown that the ECT accurately measures the cohesion in a compressed coal column and that this cohesion is a good measure of the handleability characteristics of coals. The ECT test is the only handleability test conducted in Australia that measures the cohesion on a sample with the same size distribution as normally shipped products. The test includes cohesion versus moisture curve (6 moisture levels) and cohesion version consolidation load (3 loads) curve for two moistures.

DURHAM CONE

This test is a measure of possible difficulties of slow coal flow through hoppers and chutes. 12 kilograms of the test coal is placed in a conical hopper, which is vibrated. A trapdoor at the bottom is opened and measurements are made of the time taken for all of the coal to pass through. The test is performed at various moisture levels to ascertain whether a “least-favourable” moisture level exists.

Pilot Scale Mill Testwork

Coal samples are initially homogenised by passing through a rotary sample divider. The homogenised coal is crushed with a Jacques crusher to -4mm before testing and milling in the pilot scale mill.

The test mill is a Verticle Spindle Mill (Raymond Bowl type) with a 400 mm table diameter, 3 rollers and an integral double cone classifier. Crushed coal is fed from a weightbelt feeder to the mill table at a rate of between 300 and 600 kg/hr. The mill is swept by hot air, simulating power station practice, and heated using a natural gas fired air pre-heater. Raw coal falls onto a rotating table and is pulverised under three rollers under pressure. The pulverised coal is carried by hot air through a classifier. Small particles are carried to the mill outlet whereas larger particles fall onto the table with the raw coal. The mill outlet temperature is automatically controlled by regulating the natural gas air heating and thus the mill inlet temperature. The mill operates under suction and a bag filter recovers the pulverised coal carried out of the mill. Mill output and operational parameters are measured and logged by a control computer and include air flow, air temperature (inlet and outlet), grinding pressure, energy consumption, mill differential air pressure, and table bed depth. Coal feedrate and classifier angle are set on controllers attached to the mill.

The milling performance of a test coal is assessed under two sets of mill conditions:

- The mill is operated at "standard" settings with a coal feed-rate of 500 kg/hr, air flow-rate of 253 L/sec, classifier angle set to 15° and roll pressure set to a value deemed to be the optimum based on the HGI value of the test coal.
- The mill settings adjusted to give a "standard" coal fineness of 70 percent (nominal) passing 75 µm

A comparison of performance for reference coals at standard mill settings provides an indication of how the test coal can be expected to perform in cases where no special provisions are made by plant operators to adjust mill settings for each coal being fired. Alternatively, adjusting mill parameters to produce "standard" pulverised coal allows evaluation of the relative performance of coals in the case where mill operators are prepared and able to adjust the mill conditions to suit the coal.

COAL FINENESS

Mill product fineness is measured by collecting a representative sample of the milled product a Malvern 2600c droplet and particle sizer.

MILL WEAR

Mill wear is measured by calculating the difference in weight of a roller wear piece before and after a mill run. A wear rate is calculated from the difference in masses and the mill test duration.

MILL POWER CONSUMPTION

Power consumption is measured and recorded on the control system for every mill run. After a mill test, power consumption trend is extracted from the control system and manipulated with coal quality data to determine the power consumption on a coal mass basis and coal energy basis.

The Boiler Simulation Furnace (BSF) is designed to simulate the combustion and heat transfer processes which occur in utility power plant boilers. The ability of the Boiler Simulation Furnace to properly simulate the combustion processes occurring in power station boilers has been demonstrated by the results of initial calibration procedures on a number of Australian reference coals. The most important objective during these procedures was to obtain a proper simulation to match the time/temperature profile of coal particles through the Boiler Simulation Furnace, with that found in full-scale power station boilers.

The BSF consists of a feeding section, furnace region, electrostatics precipitators and auxiliary equipment. The feeding system stores the pulverised coal in a hopper with a weighbelt underneath that transports the coal to an inductor, where heated primary air carries the coal to the variable swirl burner at the top of the water cooled, refractory lined furnace. The furnace region is approximately 2.9 m high with a diameter of 0.7 m. The furnace has a normal firing rate of 150 kW, equivalent to a coal feed rate of approximately 25 kg/h depending on coal specific energy. The residence time within the furnace is approximately 3 seconds. The furnace is preheated by firing natural gas for approximately 15 to 18 hours, after which the furnace is 'hot enough' to ignite the coal feed.

The burner is an International Flame Research Foundation design. It is a conventional swirl burner, designed to give rapid ignition and a stable flame. The burner has a central gas pipe to inject natural gas for preheating the furnace. Surrounding this is the annulus for primary air/coal. Primary air is not swirled, but there is an array of studs placed in the flow path to distribute the coal stream, i.e. to prevent "roping". Surrounding the primary air annulus is the secondary air annulus. Heated secondary air enters the annulus through a moveable block swirl generator. The secondary air swirl can be adjusted by a manual lever. The air and coal enter the furnace via a conical quarl cast into the refractory lining of the furnace top. The function of the quarl is to provide a stable attachment of the flame front to the burner throat.

The furnace has three water-cooled slagging panels at positions flush with the inside refractory wall of the furnace, for simulating furnace ash deposition. The furnace has several port holes available for viewing the combustion process probing. Temperature profiles of the furnace and photographs of slagging deposits are taken through these port holes. Combustion products proceed down the furnace to the tunnel region with ash deposition occurring on the furnace walls.

The flue gas leaving the furnace (radiant) section of the BSF enters the convective section, in which the fouling behaviour of coals can be investigated. Flue gas is continuously sampled from the convective section providing on-line measurements of flue gas composition including O2, CO, SO2 and NOx. On leaving the convective section of the BSF, the flue gases are cooled before entering the electrostatic precipitator (ESP). The ESP consists of four tubular stages with interconnecting pipe work. A high tension rectifier set is provided for each of the stages and is connected to the stages by a high tension busbar. The discharge and emitting electrode system on each stage is rapped separately to dislodge collected dust, which is discharged into a removable bin located at the bottom of each stage.

All system variables are controlled/monitored by a new generation distributed input/output network, coupled to a PC with sophisticated graphics and data access software. Graphics include schematic logging of system variables with separate displays for the BSF operating variables, as well as screens for the slagging panels, fouling probes, electrostatic precipitator, and pulverising mill. Real time and historic gas analysis trend screens can be displayed, and all historic data can be readily accessed and transferred into spreadsheet or database format.A comprehensive test program includes 4 combustion tests in the BSF consisting of:

- 150kW Standard Test - includes ash deposition, burnout efficiency, ESP testing, and gaseous emission levels (NOx and SO2)
- 150kW Ignition/Flame Stability/Turndown - A separate 150kW test is required primarily because this testing would significantly affect ash deposition results if performed at the same time.
- 170kW Ash deposition - high temperatures in this test can indicate varying ash deposition behaviour
- 200kW Ash deposition - high temperatures in this test can indicate varying ash deposition behaviour

ASH DEPOSITION

The tendency of a coal to cause ash deposition in the radiant (slagging) and convective sections (fouling) of a boiler is affected by the quantity and nature of the mineralogy in the coal, the geometry of the boiler and the operating conditions used to burn the coal. The ash deposition behaviour of a test coal is assessed by monitoring the nature of ash deposits formed on the slagging panels and the fouling probes, as well as the heat flux, in the Boiler Simulation Furnace during combustion tests conducted at firing rates of 150, 170 and 200 kW.

BURNOUT EFFICIENCY

Burnout efficiency is an important component of boiler efficiency, and has a direct effect on the relative cost of power generation. Char samples are collected isokinetically at the "Tunnel", where the burnout is considered to represent the final burnout in a boiler. Burnout efficiency is calculated from measurements of the level of unburnt combustible solids in the collected char.

DISPOSAL/UTILISATION OF FLY ASH

Fly ash collected by the electrostatic precipitator is analysed and tested for the levels of trace elements in the fly ash and leachate from a leaching test to assess the release of trace elements into groundwater and surface water. A Pozzolanic Activity Index test on the fly ash determines the suitability of the fly ash for use as a component of concrete.

ELECTROSTATIC PRECIPITATOR (ESP) PERFORMANCE

ESPs are widely used to remove particulate matter (or fly ash) from the flue gas before emitting to the atmosphere. The collection efficiency of ESPs is dependent on coal quality. The collection efficiency of the fly ash would be measured in the electrostatic precipitator (ESP) fitted to the Boiler Simulation Furnace. This would enable stack emissions to be estimated for various sizes of ESP. Collection efficiency is determined from measurements of inlet and outlet dust burdens using isokinetic sampling probes. Calculations are performed on the measurements to determine the ESP collection efficiency, migration velocity and estimated dust emissions.

FLAME IGNITION

The ignition behaviour of pulverised coal at pilot-scale is best assessed by measuring the flame liftoff distance at zero swirl for varying primary air-to-fuel ratios. Under these conditions the flame is not attached to the burner, that is the flame front or ignition point is observed to be separated by some distance (the lift-off distance) from the burner.

GAS POLLUTANTS (NOX AND SO2)

Emissions of NOx and SO_2 from power generating plant contribute to production of environmental problems such as photochemical smog and acid rain. Therefore in most countries, particularly heavily industrialised countries, stringent statutory regulations limit the level of NOx and SO2 emissions from power generating plants. These pollutants are measured continuously by a Servomex gas analyser calibrated with reference gases for every combustion test. Results from the 150kW standard test are recorded for assessment.

FLAME STABILITY

The stability of a pulverised coal flame in a swirl burner involves the interaction of burner and furnace geometry with the combustion properties of the coal to achieve a fully attached and stable flame with minimum pulsation. The pilot-scale test procedure used to evaluate relative flame stability are aimed at isolating the impact of coal properties on flame stability, by determining the extent to which increased swirl was required to maintain stability with increasing primary air/fuel stoichiometric ratio. During the test procedure, the secondary air swirl was increased from a low value, at a particular primary air stoichiometric ratio, until the flame became established within the burner quarl. This is known as 'critical swirl', i.e., the minimum swirl required to achieve a stable flame.

TURNDOWN CAPABILITY

The turn-down test procedures are designed to predict the behaviour of a coal in power station boilers as the load is reduced, with mills remaining in service. Normal practice in full-scale power boilers is to maintain the primary air flow through the mills at the full load level to prevent mill blockages, thus maintaining a constant quantity of primary air. This is simulated in the pilot-scale procedures where the load is reduced by reducing the coal flow while maintaining the primary air flow rate constant at the level which gave a stoichiometric ratio of 0.2 at 150 kW. The overall stoichiometry in the furnace at the reduced loads was maintained at 1.2 by reducing the secondary air flow as required.

Report

The Combustion Technology Centre currently offers only one type of report for documenting test results, a Technical Evaluation Report. The primary reason for this is because the test results are given meaning by comparison with reference coals which is only included with a Technical Evaluation Report. Technical evaluation reports are an interpretative, comprehensive assessment of the expected performance of a thermal coal in a power station boiler by an experienced coal utilisation consultant. The reports can either focus on a set of results for one or more coals or focus on an interpretive analysis of a research program.

The objectives of a Technical Evaluation Report are to:

- Examine the utilisation behaviour of the test coal in a power station.
- Benchmark the performance of the coal against that of a wide range of reference coals previously tested by the Combustion Technology Centre.
- Highlight positive and negative aspects of the coal's behaviour.
- Assess where the coal fits into the market
- Explore potential blending partners (optional)
- Provide recommendations for future testing requirements.

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