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Clean coal technology: Gasification of South African coals

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Abstract—Electricity demand in South Africa is increasing at a rate of 1000 MW per year. Whilst there is increasing pressure to adopt non-fossil fuel electricity generating technologies, the abundant reserves and low cost of coal makes it the preferred energy source to meet increasing electricity demand for the foreseeable future. The challenge in the future is to enhance both the efficiency and environmental acceptability of coal use by adopting clean coal technologies (CCTs).

Integrated gasification combined cycle (IGCC) is a potential CCT that could be applied in South Africa to increase efficiency and reduce carbon dioxide emissions. IGCC also holds the advantage of reduced water consumption and the potential for co-production of liquid and gaseous fuels and chemicals. Fine coal gasification is a key enabling technology for the implementation of IGCC plants. Fluidized bed gasification is being evaluated by the CSIR as a potential fine coal gasification process for incorporation into future IGCC plants.

A suite of four South African coals has been identified as being possible fuels for power stations which would operate for three or four decades, towards the middle of this century. This paper presents the results of coal characterisation, thermogravimetric analysis (TGA) and pilot plant gasification tests to ascertain the performance of the selected coals under fluidized bed gasification conditions.

INTRODUCTION

South Africa's primary energy supply is made up of the following components: coal 74.1%, oil 12%, renewable energy (hydro, biomass, solar and wind) 7.4%, nuclear 4.2% and gas 2.3%. Due to the high cost and decreasing reserves of oil and gas, its contribution to the energy mix is expected to decrease. Since South Africa is a water scarce country the contribution of renewable energy such as hydro and biomass is not expected to increase significantly. The use of solar and wind power is also currently limited by its high cost. Safety and cost are issues that inhibit the increased use of nuclear energy. Abundant and cheap coal reserves will therefore almost certainly remain our most important energy resource for the foreseeable future.

Based on scientific analysis it is generally accepted that a link exists between climate change and the use of fossil fuels such as coal. The development of CCTs has therefore received increased attention worldwide. CCTs are defined as "Technologies designed to enhance both the efficiency and the environmental acceptability of coal extraction, preparation and use".

CCTs that are being developed for power generation include [1]:

- Integrated gasification combined cycle technology (IGCC)
- Ultra supercritical pulverised coal combustion (SCPCC)
- Oxy-coal combustion
- Circulating fluidized bed combustion (CFBC)
- Post combustion capture

The CSIR has identified IGCC as a potential CCT that could be applied in South Africa to achieve near zero emissions of greenhouse gases which is likely to be a requirement for electricity producers towards the middle of the 21st century.

Integrated Gasification Combined Cycle Technology

The flowsheets for conventional and IGCC power generation cycles are given in Figure 1. In a conventional cycle all the energy in the coal is used to generate steam which is then exhausted through a steam turbine to generate electricity. The exhaust steam has to be recondensed and recycled to the boiler. Due to large energy losses during condensation the overall efficiency (coal to electrical power) of a conventional power station is between 33% and 38%. This can be raised to 45% - 47% by increasing the temperature and pressure of the steam (SCPCC). New high strength materials are being developed to achieve this target.

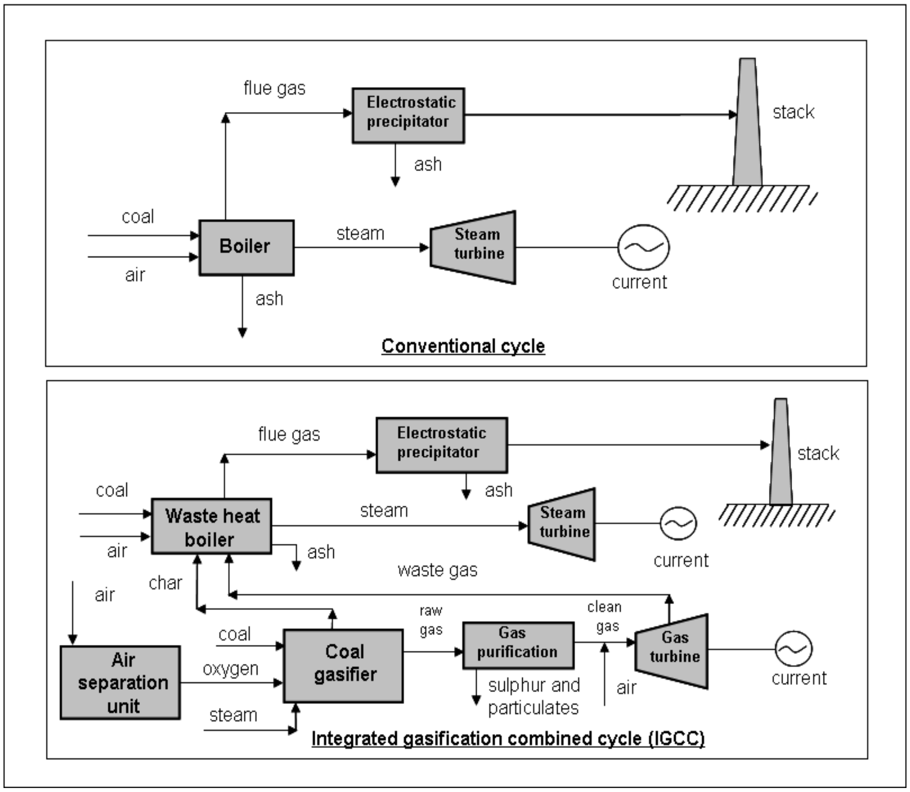


Figure 1. Conventional and IGCC power generation cycles.

In an IGCC power station a coal gasifier is incorporated into the flowsheet. During gasification coal is reacted with oxygen/air and steam to produce a combustible gas (syngas). This gas stream has a low volume compared to flue gas resulting from conventional coal combustion, and therefore gas clean-up systems can be reduced in size. The cleaned gas is combusted in a gas turbine that produces electrical power while heat is recovered from the turbine exhaust gas by means of a conventional steam cycle. This configuration (IGCC) produces higher efficiencies (45% - 55%) and lower emissions than conventional power stations.

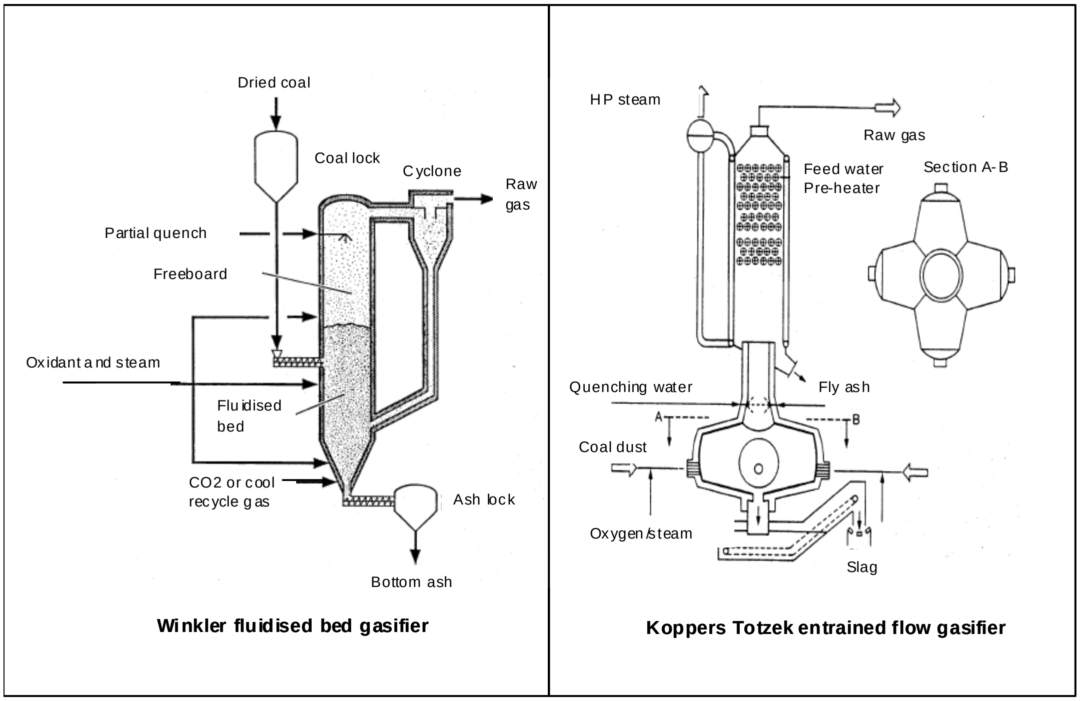
Coal Gasification

Fine coal gasification is a key enabling technology for IGCC systems [2]. Fluidized bed and entrained flow gasifiers are examples of fine coal gasifiers that have been used commercially. These gasifiers are compared in Table 1 and Figure 2.

Table 1. Comparison of fluidized bed and entrained flow fine coal gasifiers.

	Fluidized bed	Entrained flow
Coal particle size	0.5 mm - 5 mm	< 0.5 mm
Coal moisture	Dry	Dry/slurry
Coal type	Non-caking coals	Low-ash coals
Ash in coal	< 60 %	< 30 %
Gasification agents	Air, oxygen and steam	Oxygen and steam
Temperature	850 °C - 950 °C	1 300 °C - 1 450 °C
Pressure	< 25 bar	< 30 bar
Residence time	0.5 h - 1.5 h	< 10 s
Carbon efficiency	65 % - 85 %	75 % - 90 %
Gasification efficiency	55 % - 75 %	55 % - 70 %
Commercial examples	Winkler	Texaco, Prenflo, Shell and Koppers-Totzek

The only commercial example of fine coal gasification in South Africa is the 6 entrained flow Koppers Totzek gasifiers which were operated by African Explosives and Chemical Industries (AECI) in Modderfontein for ammonia production. Gas production was ± 100000 Nm^3/h containing 60% CO. The fixed carbon conversion was between 70% and 80% and the gasification efficiency was between 60% and 70%. These gasifiers were operated from 1975 to 1999.



Winkler fluidised bed gasifier

Koppers Totzek entrained flow gasifier

Figure 2. Fluidized bed and entrained flow gasifiers.

The advantages of fluidized bed gasification for the gasification of South African coal include [3]:

- Coals that are high in ash and low in grade can be gasified
- Fine coal (< 5 mm) can be utilised
- The heat and mass transfer rates are high
- Good temperature control can be achieved
- Lower temperature operation increases refractory life
- Limestone can be added for in bed capture of hydrogen sulphide
- As there are no moving parts in the furnace, the maintenance costs are low
- No tar and oil by-products are produced.

A potential disadvantage of fluidized bed gasification, however, is that due to the lower temperature in the gasifier, the carbon conversion is lower than entrained flow gasifiers which operate at a higher temperature. The low carbon conversion decreases the efficiency of an IGCC power station.

The objective of the investigation is to explore the relationship between the coal characterisation parameters, TGA results and performance of typical South African coals in a pilot-scale fluidized bed gasifier.

COAL SELECTION AND CHARACTERISATION

A suite of four South African coals has been identified as being possible fuels for power stations which would operate for three or four decades, towards the middle of this century. The selected coals are currently used as fuel for the Lethabo (New Vaal coal), Matla, Matimba (Grootegeluk coal) and Duvha power stations and are typical of South African power station feed coal.

The coal characterisation tests done on the four selected coals are:

- Proximate analysis	(Advanced coal technologies)
- Ultimate analysis	(Advanced coal technologies)
- Petrographic analysis	(SA Petrographics)
- BET surface area by N_2 adsorption	(Protechnik laboratories)
- FSI and Roga index	(Advanced coal technologies)

The laboratories that carried out the analysis are given in brackets. A summary of the analyses is given in Table 2.

Table 2. Coal characterisation parameters.

	New Vaal	Matla	Grootegeluk	Duvha
Calorific value (MJ/kg)	15.1	18.6	19.8	21.06
Ash content (%)	40.4	33.4	34.9	32.5
Carbon (%) (maf)*	79.10	80.2	81.8	89.3
Vitrinite reflectance (%)	0.53	0.64	0.68	0.75
BET surface Area (m^2/g)$^+$	7.01	2.08	<1	< 1
Porosity (%)	3.2	1.3	1.5	1.1
Reactivity index (hr^{-1})	8.92	1.56	0.75	0.52
Free swelling index (FSI)	0	0	1	0
Roga index (RI)	0	0	10	0

* Moisture and ash free

$^+$ Particle size 1 mm

Due to the high ash content and low calorific value of the selected coals they are classified as low grade (C&D). The moisture and ash free (maf) carbon content and the vitrinite random reflectance (R_r) are good indicators of coal rank. Table 2 shows that the selected coals are bituminous in rank since the carbon contents (maf) are between 75% and 85% and the vitrinite reflectance values are between 0.45 and 1.25. New Vaal coal has the lowest rank parameter being closer to the sub-bituminous coals and Duvha has the highest rank parameter being closer to the semi-anthracite coals. Approximately ninety percent of South African coals fall within the rank parameters given above.

The BET analysis measures the surface area and porosity of the coal by means of nitrogen adsorption. Due to more extensive coalification the older higher rank parameter coals have lower surface areas and porosities as reflected in Table 2.

Thermogravimetric analysis (TGA) is used to measure the reactivity index of coal. Carbon dioxide (CO_2) is reacted with a coal sample at 950 °C and the weight loss is measured as a function of time. The reactivity index (R_s) is given by $R_s = 0.5/t_{0.5}$ with $t_{0.5}$ being the time required for 50% conversion of the fixed carbon. Table 2 shows that the reactivity index increases with increasing surface area and porosity. During the above reactivity test, CO_2 diffuses into the coal, adsorbs on the active sites within the coal and reacts by means of a surface reaction. The rate of the CO_2 gasification reaction would therefore be promoted by higher coal porosity and surface area resulting in a higher reactivity index. The reactivity index is also dependant on the surface chemistry and the catalytic effect of ash in the coal.

The Free Swelling Index (FSI) and Roga Index (RI) analyses are used to measure the caking and agglomerating nature (tendency to deform and stick together) of coal. The FSI is measured on a scale of 0 to 9 with 0 being the least swelling in nature and the RI is measured on a scale of 0 to 90 with 0 being the least sticky in nature. If the coals have caking and agglomerating properties this could potentially be problematic for fluidized bed operation since the coal particles will stick together, de-fluidize and clinkers will be formed in the bed possibly causing defluidisation. Of the selected coals only the Grootegeluk coal is expected to be weakly caking or agglomerating in nature as shown in Table 2.

EXPERIMENTAL SETUP

Pilot Plant Flow Diagram and Gasifier Specifications

A flow diagram of the pilot scale fluidized bed gasifier (FBG) is given in Figure 3 and specifications of the FBG pilot plant are given in Table 3. The pilot plant, previously used for fluidized bed combustion (FBC) trials, was retrofitted in order to carry out the test programme on the four selected coals.

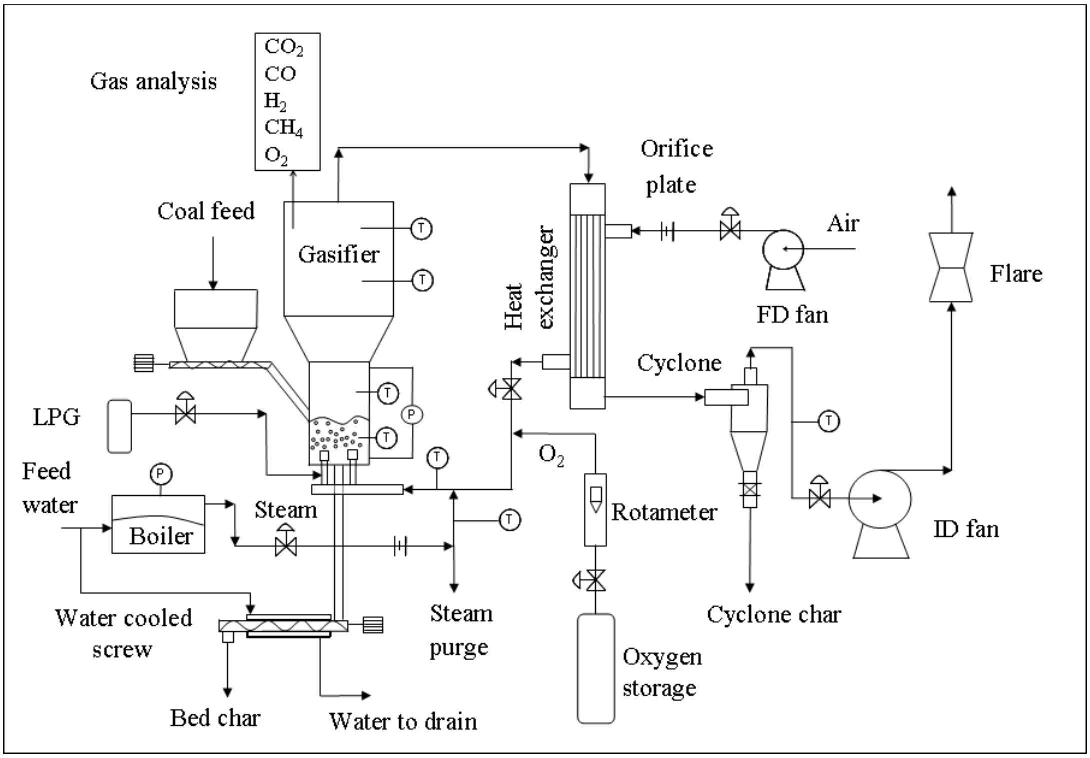


Figure 3. Flow diagram of the FBG pilot plant

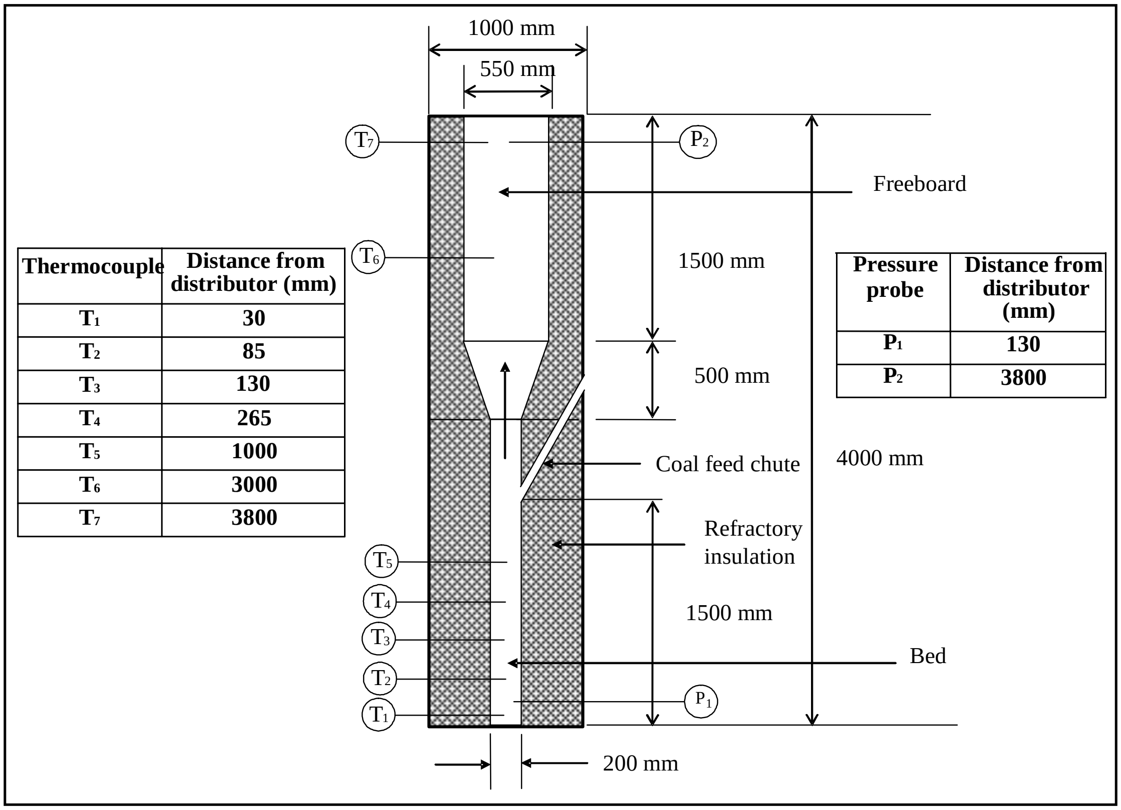
Coal, air, oxygen and steam are the input streams to the process which produce the output streams of gas and char (ash). Coal is fed to the gasifier by means of a screw conveyor at a height of 1.5 m above the distributor. Steam is generated in an electrode boiler and is mixed with preheated air before introduction into the gasifier via the distributor. The gas produced during the gasification process is used to preheat the air, using a shell-and-tube heat exchanger. Char is removed from the bed (bed char) by means of a water-cooled screw conveyor and from the gas (cyclone char) by means of a cyclone which is placed after the gas cooler. The de-dusted gas is combusted (flared) before it is vented to atmosphere.

Table 3. Specifications of the FBG pilot plant.

Operating pressure	Atmospheric
Bed dimensions (m)	0.2 × 0.2 (square)
Freeboard dimensions (m)	0.55 × 0.55 (square)
Furnace height (m)	4 (2 m bed & 2 m freeboard)
Fluidized bed height (m)	< 0.6
Coal feedrate (kg/h)	18 - 30
Coal particle size (mm) (d_{50})	1 - 2.5
Coal CV (MJ/kg)	> 10
Air flowrate (Nm^3/h)	40 - 60
Steam flowrate (kg/h)	5 - 12
Bed temperature (°C)	850 - 950
Air temperature (°C)	155 - 210
Fluidizing velocity (m/s)	1.5 - 2.5

Furnace Details

The internal dimensions of the FBG and the location of the thermocouples and pressure probes are given in Figure 4. Figure 4 shows that the FBG has a 0.2 m x 0.2 m bed section, which expands to a 0.55 m x 0.55 m freeboard section.



Thermocouple	Distance from distributor (mm)
T_1	30
T_2	85
T_3	130
T_4	265
T_5	1000
T_6	3000
T_7	3800

Pressure probe	Distance from distributor (mm)
P_1	130
P_2	3800

Figure 4. Dimensions of the FBG furnace.

Coal particles that enter the furnace via the coal feed chute drop into the fluidized bed section and start conversion to gas and char. The char particles move rapidly up and down between the gasification and combustion zones in the bed. The combustion zone is limited to the lower 10 - 15% of the bed above the air and steam distributor and is rich in oxygen.

Due to the fluidizing action of the bed, the char particles experience attrition and break down into smaller particles. When the particles are small enough, they are entrained into the freeboard section (upper part) of the furnace. Due to the expanded nature of the freeboard, the gas velocity decreases and the particles fall back to the bed, resulting in internal circulation of particles between the bed and the freeboard. Further breakdown of the char particles results in their terminal falling velocity (U_t) being lower than the freeboard velocity and they are elutriated from the furnace. A significant proportion of the char particles (40 - 60%) are not elutriated from the furnace and these are drained from the bottom of the bed in order to maintain a constant fluidized bed height.

FBG Start-Up and Control

The FBG is started up by adding 15 kg of silica sand (0.4 - 0.85 mm) to the furnace. The silica sand is fluidized by starting the forced-draught (FD) and induced-draught (ID) fans. LPG is injected into the fluidized silica sand bed via the nozzles shown in Figure 4. The LPG is ignited by means of a pilot flame which is inserted through the furnace door and directed down towards the bed. When the bed temperature reaches 650 °C, coal addition to the furnace is started. When the temperature reaches 850°C, LPG injection is stopped, the pilot flame (lance) is removed and the furnace door is closed. The temperature is further increased by coal addition and the furnace is operated in combustion mode (excess air) at 925°C for 6 h. Operation in combustion mode is required for thermal soaking of the refractories and heating of the freeboard. After 6 h, the coal flowrate is increased ± fourfold and steam is added to produce reducing conditions (oxygen deficient) in the furnace. The furnace is operated for a further 6 h to allow the bed carbon content and freeboard temperature to stabilise.

During heat-up and the test period, the airflow is set at a fixed value which is high enough to maintain good fluidisation and low enough to minimise elutriation of fine char from the furnace ($3xU_{mf} < U < 10xU_{mf}$). The bed temperature is controlled by increasing or decreasing the steam flow. If the steam flow drops below a minimum value (determined by the air/steam ratio), the air/coal ratio is adjusted. A minimum steam flow is required in order to prevent hot spots in the bed. The bed height is controlled by removing char from the bed via the bed extraction screw. The gauge pressure in the furnace is controlled at - 20 mmH_2O (- 200 Pa) by adjusting the valve before the ID fan. Once stable conditions have been achieved, operating data are recorded and samples are collected for a period of 3 to 4 h.

RESULTS AND DISCUSSION

For each coal test were done at 925°C and 950°C. The results of the eight fluidized bed gasification tests using air and steam are given in Table 4.

Table 4. Summary of fluidized bed gasification tests at 90 kPa absolute pressure.

	New Vaal		Matla		Grootegeluk		Duvha	
Test number	1	2	3	4	5	6	7	8
Coal feedrate (kg/h)	28.7	23.9	27.0	24.3	23.0	23.0	26.4	26.4
Airflow (Nm^3/h)	52.2	47.0	50.6	50.9	48.5	47.8	47.5	47.8
Steam flow (kg/h)	9.1	5.8	8.5	8.5	10.2	10.0	10.9	9.0
Air and steam temp. (°C)	202	159	190	185	173	178	176	186
Oxygen: carbon molar ratio	0.48	0.52	0.42	0.47	0.46	0.45	0.34	0.35
Steam: carbon molar ratio	0.50	0.38	0.41	0.46	0.57	0.56	0.47	0.39
Coal particle size – d$_{50}$ (mm)[1]	2.4	1.2	1.6	1.6	1.9	1.9	1.6	1.6
Fluidizing velocity (m/s)	2.2	1.9	2.1	2.2	2.1	2.1	2.1	2.1
Mid-bed temperature (°C) T$_3$	922	947	925	949	927	953	927	949
Lower bed temperature (°C) T$_1$	967	948	995	972	948	978	921	954
FBG exit temperature (°C) T$_7$	750	720	752	756	742	764	761	773
Dry gas composition								
CO (%)	NR[2]	11.1	10.8	11.6	8.7	10.2	8.8	9.9
H$_2$ (%)	NR	8.6	10.0	9.6	9.4	9.5	8.5	9.3
CH$_4$ (%)	NR	0.7	0.8	0.7	1.1	1.1	0.8	0.7
CO$_2$ (%)	NR	15.8	14.8	14.6	15.0	14.9	15.3	15.0
N$_2$ + others[3] (%)[4]	NR	63.7	63.5	63.4	65.7	64.2	66.5	65
O$_2$ (%)	NR	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Gas calorific value (MJ/Nm^3)	-	2.8	3.0	3.0	2.7	2.9	2.5	2.7
Bed pressure drop (Pa) (P$_1$-P$_2$)	2664	2115	2553	2259	2553	2553	2455	2456
Char residence time (min)	36.7	36.6	37.4	37.6	45.1	45.1	35.7	35.7
Carbon in bed char (%)	2.8	1.4	24.3	20.8	26.8	26.4	38.6	33.9
Bed char particle size (mm)	1.1	0.6	1.2	1.0	0.8	1.0	0.9	1.2
Carbon in cyclone char (%)	19.5	15.5	32.3	27.8	31.0	27.0	41.6	43.2
Cycl. char particle size (mm)	0.07	0.08	0.05	0.07	0.07	0.07	0.06	0.08
Char elutriated to cyclone (%)	60.6	66.6	53.8	55.6	51.1	51.6	58.3	59.9
Fixed carbon conversion (%)	82.7	85.9	68.2	74.0	63.2	67.0	52.0	53.7

[1] d$_{50}$ – 50 % of the coal mass is less than the d$_{50}$ size

[2] NR - no reading

[3] Others are < 0.6 % and include H$_2$S, NH$_3$, HCN and C$_2^+$

[4] (N$_2$ + others) by difference

Tests on two of the selected coal using oxygen and steam are given in Table 5.

Table 5. Summary of fluidized bed gasification tests with oxygen and steam.

Coal tested	Matla	Duvha
Coal feedrate (kg/h)	25.5	24.5
Oxygen flow (kg/h)	14.0	15.5
Steam flow (kg/h)	34.0	31.0
Oxygen and steam temp. (°C)	237	180
Oxygen: carbon molar ratio	0.5	0.4
Steam: carbon molar ratio	2.16	1.51
Coal particle size – d_{50} (mm)[1]	1.3	1.4
Fluidizing velocity (m/s)	1.8	1.7
Mid-bed temperature (°C) T_3	935	921
Lower bed temperature (°C) T_1	927	908
FBG exit temperature (°C) T_7	802	735
Dry gas composition		
CO (%)	19.0	22.1
H_2 (%)	27.6	28.4
CH_4 (%)	2.0	2.2
CO_2 (%)	46.1	36.6
O_2 (%)	0.1	0.1
N_2 + others[2] (%)[3]	5.2	10.6
Gas calorific value (MJ/Nm^3)	6.86	7.40
Bed pressure drop (Pa) (P_1-P_2)	2434	2330
Char residence time (min)	37.7	36.6
Carbon in bed char (%)	2.0	12.0
Bed char particle size (mm)	0.4	0.6
Carbon in cyclone char (%)	12.0	38.9
Cycl. char particle size (mm)	0.07	0.05
Char elutriated to cyclone (%)	52.80	67.26
Fixed carbon conversion (%)	89.4	69.8

[1] d_{50} – 50 % of the coal mass is less than the d_{50} size

[2] Others are < 0.6 % and include H_2S, NH_3, HCN and C_2^+

[3] (N_2 + others) by difference

Fixed Carbon Conversion

The data in Table 4 and 5 was used to obtain Figure 5 which shows the fixed carbon conversion achieved in the FBG plotted as a function of the rank parameter (R_r). Figure 5 shows that the fixed carbon conversion of the lower-rank coals is higher than for the higher-rank coals. A similar result was obtained by Jing *et al.* [4] who gasified three Chinese bituminous coals of differing rank in a fluidized bed gasifier.

It can also be seen from Figure 5 that the fixed carbon conversion using oxygen and steam as the gasification agents is significantly higher than when using air and steam. This could be as a result of the higher steam concentration in the gasifier and activation of the coal by steam. The results of Ye *et al.* and Zhang *et al* [5, 6] show that the gasification rate of char with steam is higher than the reaction rate of char with CO_2 and that the gasification rate is proportional to steam concentration up to 1 bar steam pressure.

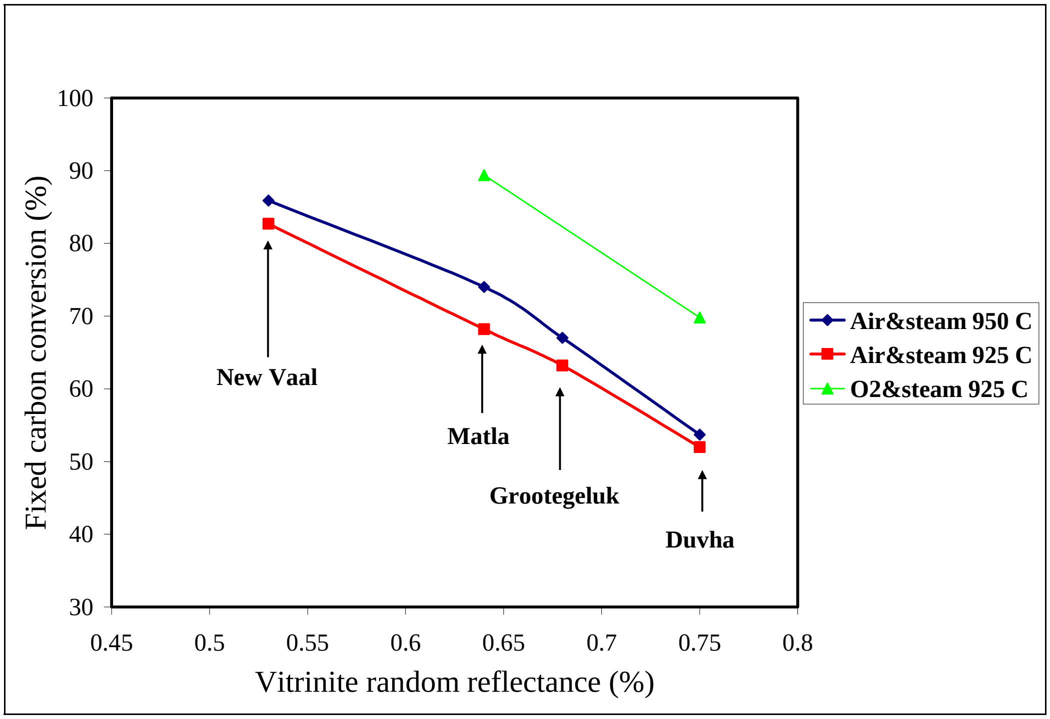


Figure 5. Fluidized bed gasifier fixed carbon conversion.

Calorific Value

Figure 6 shows that the rank parameter of the coal does not have a significant effect on the calorific value of the gas. This trend was also observed by Gururanjan and Argarval [7] who concluded that the volatile matter content of the coal has a greater effect on the calorific value of the gas than the char reactivity.

Figure 6 also shows that gasification with oxygen and steam produces a higher gas calorific value than gasification with air and steam. This is due to the absence of nitrogen and the increased rate of the steam-char gasification reaction.

$$C + H_2O \rightarrow CO + H_2 \tag{1}$$

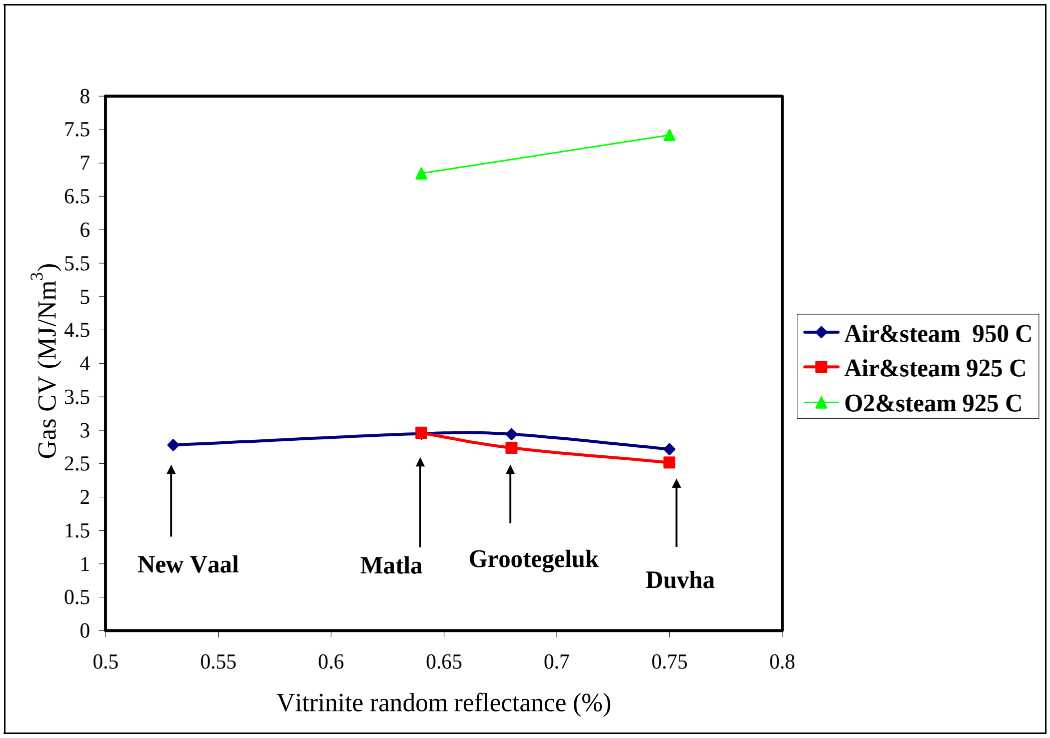


Figure 6. Gas calorific value as a function of vitrinite random reflectance (R_r).

Fines Generation and Elutriation

Tables 4 and 5 show that the particle size of the bed char is lower than that of the feed coal. This is a result of thermal shattering and attrition of the coal in the bed which results in the generation of fines that are eventually elutriated from the gasifier. The relationship between the percentage cyclone char and the Hardgrove Grindability Index (HGI) is given in Figure 7 for each coal and temperature.

Figure 7 shows that the char fines generated and elutriated increase with the grindability of the coal and with the temperature. The generation of fines in the gasifier due to attrition of char particles has a negative effect on the fixed carbon conversion. The fines generated are entrained to the freeboard of the FBG where they are exposed the freeboard gas which produces a low conversion rate of char particles due to the absence of oxygen and the inhibiting effect of CO and H_2 on the conversion rate [8, 7].

Using the experimental data and least squares regression, a correlation was developed to predict the amount of cyclone char (elutriated char) that would be produced by the gasifier. This is given by equation (2) for values of U from 1.9 m/s to 2.2 m/s and values of d_p from 1.2 mm to 2.4 mm.

$$\text{Elutriated char (\%)} = A_E = 3.13(HGI)^{0.69}(U)^{0.33}(d_p)^{-0.19} \qquad (2)$$

In equation (2), d_p is the mean particle size (d_{50}) of the feed coal.

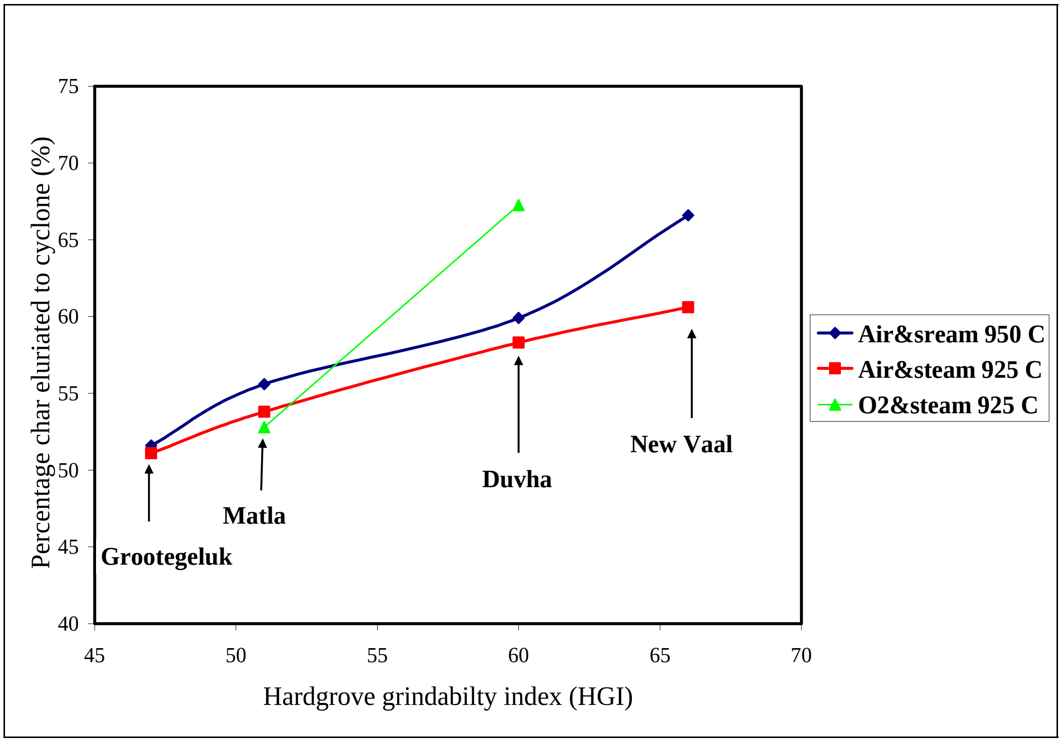


Figure 7. Char fines generated as a function of HGI.

Due to the non-caking nature of the coals tested, bed agglomeration and defluidisation of the bed did not occur during any of the tests. The same result was achieved by Gutierez and Watkinson [9] who gasified non-caking Canadian coal in an air-blown fluidized bed gasifier.

Effect of Gasifier Pressure

Since the FBG is not a pressurized gasifier, tests at higher operating pressures could not be carried out. Other investigators [10] have found that the effect of pressure on the gasification rate can be described by equation (3)

$$\frac{dX}{dt} = kF(X)P^{\alpha} \tag{3}$$

For reacting gas pressures (P) of 0 to 1 bar, the reaction order (α) is close to unity. For higher pressures, the reaction order decreases and reaches a value of 0 at pressures of 12 - 18 bar. Since the coal residence time decreases linearly with an increase in pressure, the fixed carbon conversion is likely to decrease with an increase in gasifier pressure.

CONCLUSIONS AND RECOMMENDATIONS

1. The fixed carbon conversion and gas calorific value achieved in the pilot-scale fluidized bed gasifier can be improved by:
    a. Increasing the height of the fluidized bed
    b. Increasing the temperature and height of the freeboard
    c. Recycling cyclone char to the bed
    d. Increasing the air, oxygen and steam pre-heat temperatures
    e. Reducing heat losses.

2. Fluidized bed gasifiers can utilise high ash South African coals and therefore are a potential candidate technology for IGCC power stations.
3. The vitrinite random reflectance of bituminous coal is a good indicator of the carbon conversion that can be achieved in a fluidized bed gasifier.
4. Due to the relatively low reactivity of South African bituminous coals and generation of fines (< 100 µm) in the gasifier, a secondary combustion stage may be required after the fluidized bed gasifier in order to achieve overall carbon conversions in excess of 95 %.

NOTATION

A_E	char elutriated to cyclone, %
d_{50}	mean particle diameter, mm
d_p	particle size, mm
k	reaction rate constant, min^{-1}
P	gas pressure, Pa
R_r	vitrinite random reflectance, %
R_s	reactivity index of coal, h^{-1}
U	superficial gas velocity in the bed, ms^{-1}
U_{mf}	minimum fluidizing velocity, $m.s^{-1}$
U_t	terminal falling velocity, $m.s^{-1}$
X	fractional conversion of fixed carbon in coal, -

Acronyms/Abbreviations

AECI	African Explosives and Chemical Industries
BET	Brunauer, Emmett and Teller
C_2^+	Ethane and higher hydrocarbons
CCT	Clean coal technologies
FBG	Fluidized bed gasifier
FSI	Free Swelling Index
FD	Forced draught
HGI	Hardgrove Grindability Index
ID	Induced draught
IGCC	Integrated Gasification Combined Cycle
LPG	Liquefied Petroleum Gas
RI	Roga Index
TGA	Thermogravimetric analyser/analysis

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