ENVIRONMENTALLY FRIENDLY PRODUCTION OF SMOKELESS FUEL FROM BRAZILIAN GONDWANA COAL

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ABSTRACT

This paper presents the results of research on the production of smokeless fuel from Riograndense Gondwana Coal. Laboratory scale investigations of coal samples from the underground coal mine Leão I of the Companhia Riograndense de Mineração have been carried out at the Aachen University of Technology, Germany. The main findings of the laboratory scale research are outlined and the plant technology and test results obtained are described. In addition, the results of current research to optimize the technology are presented. The overriding aim of this research is to design an environmentally friendly and commercially viable technology to produce smokeless fuel as substitute for firewood and raw coal, which are currently used for heating and cooking with considerable ecologically harmful effects.

INTRODUCTION

High-volatility coal (lignite to sub-bituminous coal) is available in many countries worldwide. These types of coal are efficiently used in power stations for generating electricity. However, their use in households and small-scale industries for heating is problematic for a number of reasons. Complete combustion of the large amount of volatiles requires a rather sophisticated stove design, which is expensive and usually not affordable in many regions. In the available simple stoves, only some of the volatiles are burned; the remaining ones are released into the atmosphere as bad smelling smoke causing considerable environmental pollution and adversely affecting health, particularly in densely populated areas. Consequently, wood is still the priority energy source and thus, firewood supply is dwindling resulting in the ongoing destruction of the native forests. A substitute for firewood is only accepted when showing similar burning properties. The reduction of the volatile content of coal prior to burning, i.e. the production of a smokeless fuel presents a real alternative.

For several years the Federal Institute for Geosciences and Natural Resources has been investigating jointly with German universities and industry the development of an environmentally friendly and cost efficient technology to reduce the volatile content of high-volatility coal. As a result of this research, a demonstration plant was constructed in Malaysia and has been operated by the Aachen University of Technology and the Mineral Geosciences Department Malaysia (MGDMS), Sarawak, since August 1998 within the scope of a German Technical Cooperation project. In this plant, high-volatility coal is continuously degasified in a vertical tube reaction chamber and the volatile content reduced from 30 % to as little as 2 % . The energy required for the pyrolysis is obtained from the combustion of the volatiles. The process is thermally autarkic, and produces a smokeless and odourless fuel that can even be used in an open fireplace.

Based on these results laboratory trials with Riograndense Gondwana Coal have been carried out and are culminating in promising results. Further tests, especially on possible processing and improving the energy content of the carbonizate, are currently being conducted at the Aachen University of Technology.

Basic Principles of Pyrolysis

The term "carbonization" means to convert to carbon, which in this process is achieved by pyrolysis (from Greek pyr = fire, heat and lýein = loosening), in which a thermal depolymerization (cracking) of macromolecules, like cellulose, semicellulose and lignin, occurs in the absence of oxygen. A solid, black residue (carbonizate), noncondensable gases and a liquid/oily phase are produced. The weight of the solid phase is reduced during the process. The mode and extent of depolymerization depend on the type of coal, the temperature and the duration of thermal treatment. Volatile compounds, such as CO_2, CO, CH_4, H_2, C_nH_m (tar), H_2O, H_2S, NH_3, are released. The carbonizate contains more carbon and minerals than the original material, but less volatile matter and moisture. The calorific value of the carbonizate is increased by the removal of low-energy components.

Pyrolysis Systems

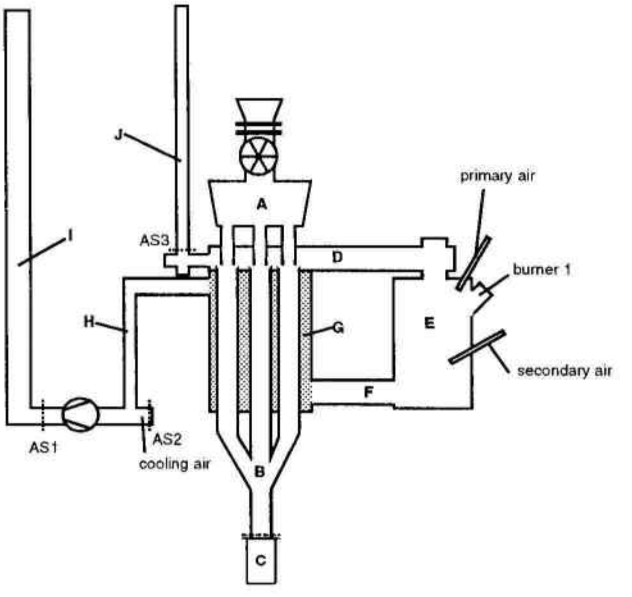
Tube Reactor (Demonstration Plant)

The demonstration plant consists of a carbonization reactor containing three vertical tubes and a separate combustion chamber. The reactor tubes are kept airtight by a special charging and discharging system. The reactor and the combustion chamber are connected by two pipes, the upper one for the pyrolysis gas and the lower one for the flue gas. The flue gas is led through the reactor between the vertical tubes and the outer wall of the reactor and heats the vertical tubes containing the coal charge. The system is shown schematically in Figure 1.

The tube reactor system is limited to a capacity of 1000 kg/h input because of the long residence time. It is ideal for regions with a poor infrastructure. This technology is being further developed jointly by BGR and the University of Aachen to increase the capacity to 5000 kg/h input.

Rotary.Kiln Reactor (Laboratory Reactor)

The rotary kiln laboratory reactor consists of one horizontal rotating kiln heated electrically to a specific temperature. The residence time of the material is determined by the rotation rate and inclination of the kiln. The carbonizate is collected in a drum at the end of the kiln. The pyrolysis gas is condensed. The pressure of the pyrolysis gas is removed by lowering the pressure at the outlet end of the system with a membrane pump. The noncondensable gases are burned. A diagram of the rotary kiln reactor and gas removal system is shown in Figure 2.



A: feed system
B: discharge system (screw conveyors)
C: collecting drum
D: pyrolysis gas
E: combustion chamber
F: flue gas
G: reactor
H: exhaust gas
I: chimney
J: emergency chimney

Figure 1: Schematic construction of the tube reactor system (Demonstration Plant)

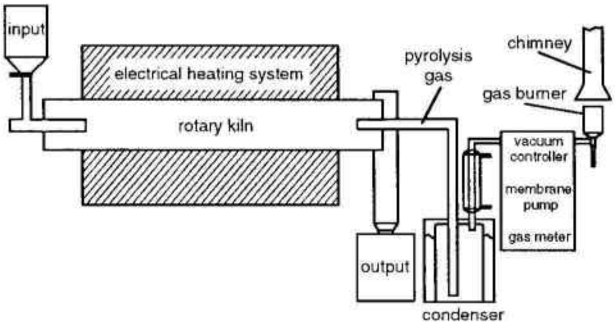


Figure 2: Schematic construction of the rotary kiln system (Laboratory Reactor)

RESULTS OF CARBONIZATION

Laboratory investigations have been carried out on coal samples from the underground coal mine Leão I of the Companhia Riograndense de Mineração. The coal has been processed at the mine. The mechanical process consists of a crushing and screening unit, jigging, washing and dewatering. The basic characteristics of the available sample are presented in table I.

Table I: Characteristics of sample *CE 5900*

Sample	H_2O (aa)*1 [%]	Ash (dry) [%]	VM (daf)*2 [%]	C (daf)*2 [%]	H (daf)*2 [%]	N (daf)*2 [%]	S (dry) [%]	GCV (daf)*2 [J/g]
CE 5900	14.13	20.42	41.68	79.09	7.71	1.43	0.64	31758

*1 as analysed
*2 dry and ash free

Pyrolysis tests in a laboratory scale rotary kiln reactor were conducted at different temperatures at the Aachen University of Technology. The products carbonizate and gas were analysed for each test run. The rotary kiln reactor was chosen since earlier test trials had shown that the mixing of the coal by rotation and the excellent heat transfer allowed several valuable qualities to be utilized. The residence time in the reactor needs to produce a carbonizate with the necessary characteristics could be reduced to 30-45 minutes, compared to the longer residence time of 12 hours or more in the tube reactor. This illustrates the increased efficiency of this technology, which is still easy to handle.

Earlier examinations on different coal qualities from various regions of the world confirmed that the process is thermally self-sufficient. These coals, however, had lower ash contents, which is favorable for the pyrolytic process for a number of reasons. The ash content of the coal, as its carbon content, increases in the carbonizate with increasing temperature. The increase in ash content lowers the calorific value of the carbonizate and thus its value as a fuel. Moreover, a higher ash content of the coal means a lower volatile matter content resulting in less available energy in the gas for combustion. Thus, the first objective of the investigation was to determine the suitability of this coal for pyrolysis technology.

Figure 3 illustrates the degasification of the coal and the increase of the ash content at rising temperatures. The degasification behaviour as a function of temperature is of particular interest. It determines the optimum residence time and process temperature required to produce a smokeless fuel with a volatile content just below the permissible limit. A carbonizate with a volatile content below 12 % burns smokelessly, which is achieved at a temperature of 600°C. At a temperature of 750°C the volatile content is as low as 1.5 %.

Due to the relatively high ash content in the starting material the ash content rises to a total of 35 % in the carbonizate at a temperature of 750°C. Developing procedures to remove the ash by a simple technology, such as magnetic separation, for example, are currently key goals of research investigations being conducted at the Aachen University of Technology.

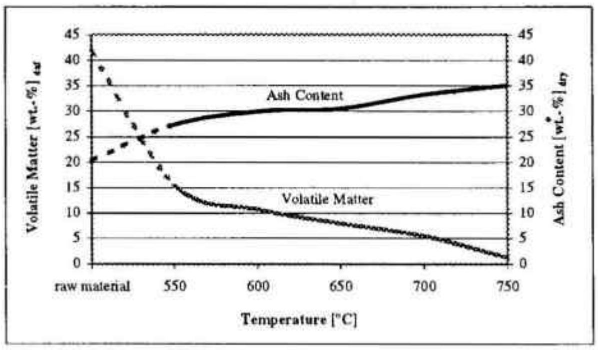


Figure 3: Volatile Matter and Ash Content of raw material and carbonizate

By relinquishing low-energy components during the degasification process, the calorific value of the carbonizate rises with increasing temperatures up to 34500 J/g at a temperature of 750°C. The rise in the calorific value is comparatively low, since the already processed starting material shows relatively good values. Tests with Run Of Mine Coal are still waiting to be done. In accordance with the decrease of the volatile content, the amount of carbonizate produced also decreases with rising temperatures, as illustrated in figure 4. For a better comparison, the figures of the raw material are included in the diagram.

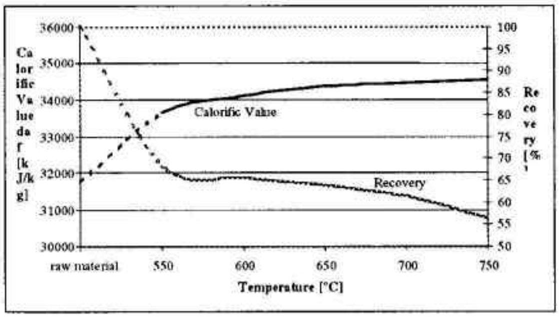


Figure 4: Calorific Value of carbonizate (daf) and amount of carbonizate product

Corresponding with the increase of the carbon content of the carbonizate; the energy content within the pyrolysis gas per kg of input material increases, too. These characteristics are presented in figure 5 and figure 6. Figure 7 illustrates the record of the composition of the permanent (non-condensable) gases during the trials. Only the main components are shown. As temperature rises, more high energy components are released, enlarging the energy content of the gas. This indicates that even coal qualities with a relatively high ash content can be pyrolysised thermally self-sufficient. Even an energy surplus, which could be used for generating electricity, can be expected.

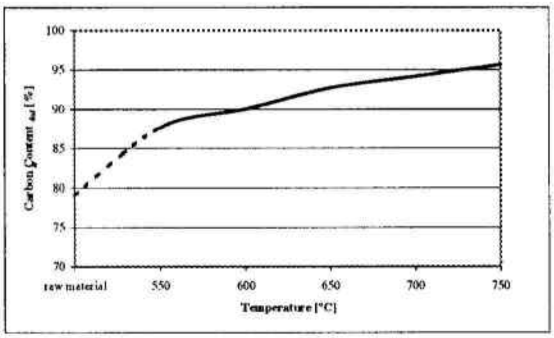


Figure 5: Calorific value of pyrolysis gas per kg coal input

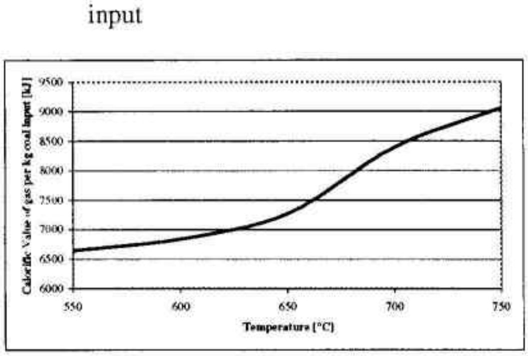


Figure 6: Carbon content of carbonizate

Throughout all test trials, the sulphur content in the product stayed below 0.5 $\%_{(d)}$ and was even reduced compared to the starting material. This may indicate that most of the sulphur is of organic nature. More detailed examinations are currently being conducted.

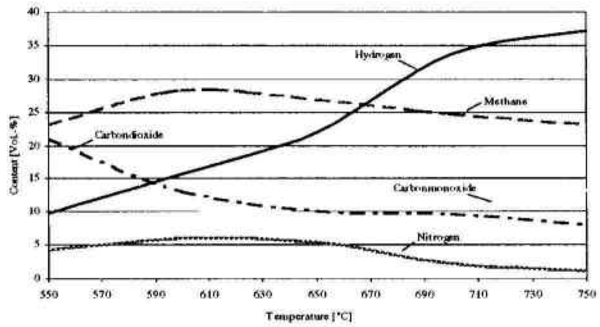


Figure 7: Composition of permanent gas during trial phase (main components)

The ash compounds of the carbonizate show no specific difference in comparison to the ash composition of the raw material. No significant pollutants could be determined. Thus, the ash can be disposed without special treatment.

Table II summarizes some of the characteristics of the carbonizates. For comparison reason, the figures from table I are added.

Table II: Characteristics of the carbonizates

Sample	CE5900	C550	C600	C650	C700	C750
Recovery [%]	100	64.8	65.5	63.7	61.3	56.3
Ash(dry) [%]	20.42	27.34	29.89	30.47	33.25	34.85
VM(daf) [%]	41.68	15.44	10.78	7.92	5.45	1.33
C(daf) [%]	79.09	87.61	89.43	92.69	94.16	97.79
H(daf) [%]	7.71	3.56	2.97	2.55	2.01	1.57
N(daf) [%]	1.43	1.09	1.84	1.78	1.63	1.61
S(dry) [%]	0.64	0.48	0.53	0.45	0.46	0.41
Gas Energy Content [J/g coal]		6638	6836	7272	8393	9054
GCV(daf) [J/g]	31758	33643	34111	34369	34457	35333

BRIQUETTING

The grain size of the raw coal is considerably reduced during carbonization. The extent to which it is reduced depends on the coal and the process temperature. For easy handling by the consumer the fine fraction can be be briquetted. Thus, the fines are crushed to below 2 mm and briquetted with polyvinyl alcohol as binder in a press using a pressure of 500 bar. The cylindrical briquettes are 3.5 cm in diameter and 2.5 cm high. Proper mixing of binder and carbonizate is imperative for high quality briquettes. If the blend is not optimal, small fractures may occur. The quality of the briquettes with regard to their behaviour during transportation, loading and burning is tested using the drop test, tumbler test and compressive strength test. Those tests are currently being performed.

COMBUSTION TESTS

The burning characteristics of carbonizate produced at different temperatures were investigated with respect to the following parameters: odour, calorific value, duration of combustion, ignition temperature among others. The carbonizates produced at temperatures higher than 600°C were registered as burning smokeless, odourless and flameless. The carbonizates are easy to ignite, the burnout is complete and lasts for about two hours after ignition; the briquettes remain intact throughout the entire process. These results correlate perfectly with investigations of various carbonizates produced from different coals worldwide.

Application

The carbonizate and the carbonizate briquettes can be used for household cooking, and household and industrial heating. In some cases it may be necessary to slightly modify the combustion chamber, e.g. to install a fan for sufficient air (oxygen) supply. Moreover, depending on special characteristics, the carbonizate can be employed as active carbon for waste water purification, gas cleaning and as a reducing agent in metallurgical processes.

FURTHER TEST WORKS

Key goal of current and future investigations is the development of a simple and easy to handle technology to reduce the mineral content either prior to or after the pyrolysis process. The aim is to enhance the calorific value of the produced carbonizate. Since a successful mechanical upgrading of the material is likely to demand a rather small grain size, the material will have to be briquetted. If upgraded before the pyrolysis, the thermal treatment will produce a formed coke; if processing is more efficient after the pyrolysis the carbonizate will be crushed and after the mechanical process briquetted as final product.

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