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MICROWAVE BENEFICIATION OF BROWN COAL

1. Microwave beneficiation of brown coal

Coal is a highly hygroscopic and porous material. *In situ* normally it is saturated with water and acts like an aquifer. Water in coal influences many aspects of coal technology, like bulk flow properties, abrasiveness during grinding, spontaneous heating and combustion rates. Water in coal, however, does not only influence coal technology. Major implications that arise out of the moisture content are its diluents effect on calorific value and high shipment costs. Furthermore coal needs to be dewatered in order to avoid difficulties during the transportation, e.g. freezing, to maintain high pulverizer capacity and to improve the handling for special applications, such as coke, chemicals or briquettes. In general 5 different forms of moisture in coal are recognized, that are bulk, capillary, physical or chemical sorbed [1–4]. These are:

— interior adsorbed water in micro pores,
— surface adsorbed water in forms of layer adjacent to coal molecules,
— capillary water in small cleats,
— inter-particle water between some particles,
— adhesion water as a layer around the surface of coal agglomerates.

The first to forms of water, defined as inherent moisture, can only be removed by special techniques, normally thermal drying. Capillary water can be removed by a filter cycle depending on time and coal cleat aperture size. Contrary to the first two forms the last two forms of water, defined as surface moisture, can be technically removed with vacuum filters or centrifuges. The different forms of water associated with coal are displayed in Figure 1.

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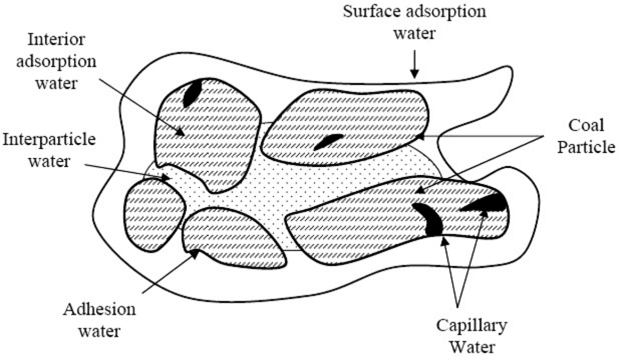

Fig. 1. Various forms of water associated with coal particles [3]

2. Microwave drying of coal

Microwave ovens have been successful established in the households since the late 1980's. Formerly microwaves were considered to be utilized in fields of coal preparation as well as in ore preparation [5]. Mainly effects of microwave radiation (mr) on coal grindability and effects on coals with low moisture content (≤ 5 wt %) have been researched. Even though tests were not focused on drying, significant reduction in moisture was documented [6].

Coal is a relatively poor absorber of mr regarding the organic compounds. Effects observed are more due to the fact, that water in the coal owns di-electric properties and is a good absorber of the energy. When water is exposed to mr, which is an alternating electric field, the molecules adjust themselves in the direction of the field with the same frequency. This fast movement generates intermolecular friction, which leads to rising temperatures. If the exposing time is sufficient the water will vaporize and expand. This process creates internal pressures in the coal particles in a first step, generating fissures, and in the second step the moisture evaporates. In principle all minerals within the coal matrix are heated up according to their ability to absorb mr as well. With exception of Pyrite, however, most of the minerals are not significantly affected by mr.

Beside the moisture reduction the grindability of coal increases as a result of the induced internal pressures. Research projects document up to 50% reduction of the relative work index for the milling process. In addition to this, the project proves that low rank coals are more sensitive to mr than high rank coals [7].

Coal is often accompanied by Sulphides. Pyrite for example causes problems in the boiler systems by generating sulphuric acid during combustion in power plants. Additionally emission control for the flue gas is asked for. Therefore low sulphur coals are mined and mixed with high sulphur coals to avoid negative effects on one hand and simultaneously been able to utilise/mine high sulphur coal deposits. Microwaves can increase the mine able reserves of high sulphur content coals, if Magnetite is added and the coal is processed with mr and magnetic separation [8].

When compared to other techniques, a general advantage of mr heating is the way energy is transferred into the coal matrix. Normally the heat energy supplied by steam or hot fumes penetrates the sample from the surface to the core known as convective drying. Contrary to that mr is able to penetrate the coal completely and transmit the energy direct to di-electric components defined as volumetric drying. Due to this effect energy can be saved, because the coal agglomerates are not heated up completely, “only” the water is heated and vaporized [9].

3. Experimental procedure

The coal (55 wt % moisture content [an], 24,3 wt % volatile matter [an], 11.900 kJ/kg gross calorific value [an]) samples were drawn at the coal stockyard Fortuna in Niederaußem. The stockyard gets varies coal qualities from the lignite mines Hambach and Garzweiler by coal trains. The coal is stacked in the Chevron mode. Taking the stacking mode, the technical equipment and the present coal mixture into account, a minimum of three different spots for sampling along the connecting conveyor to the power plant are required. The spacing between each sampling along the conveyor was determined with 20 m to guarantee that coal of different quality was selected. The samples were stored into 55 l barrels, which were then sealed to keep coal properties close to constant. At every sampling spot one barrel was filled. In order to represent the power plant input all three barrels with presumably different coal qualities were mixed before microwave treatment. This mixture was sieved and particles smaller than mesh 4 cm were set aside for separate testing. The sampling itself was geared on the DIN regulations.

The microwave oven used supports variable settings concerning conveyor belt speed, height of the reflecting mirror, length of the emitting antenna, height of the antenna, material of the antenna and power output of the magnetrons. Furthermore the thickness of the processing material can be adjusted. For the tests microwave radiation energy, exposure time (belt speed) and coal layer thickness were varied. The following During batch drying the sample box was directly placed beneath the emitting antenna. The sample was treated with mr with constant time intervals until the target moisture content was reached. During testing the drying process was controlled by reweighting and IR temperature measuring. After each microwave treatment, samples were drawn and sealed fore later laboratory analysis.

The process test were selected for moisture content according to DIN 51718, gross calorific value according DIN 51900, volatile matter according DIN 51720 and ash content according DIN 51719, since the project is intended to establish the general applicability. Due to the fact, that the volatile matter content on a dry basis in early test hardly showed any change, it was decided to refrain from further testing.

Table 1 shows the accomplished test series.

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TABLE 1

Microwave drier test series

Number	Input material	Drying mode	Energy level, kW	Exposure time interval	Remarks
1	moist	batch	5	5 min	Mesh < 4 cm, long antenna, 1 kg
2	moist	batch	10	3 min	Mesh < 4 cm, long antenna, 1 kg
3	moist	batch	10	5 min	Mesh < 4 cm, long antenna, 1 kg
4	moist	batch	10	5 min	Mesh > 4 cm, long antenna, 1 kg
5	moist	batch	5	5 min	Mesh < 4 cm, short antenna, 1 kg
6	moist	batch	10	3 min	Mesh < 4 cm, short antenna, 1 kg
7	moist	batch	5	5 min	Mesh < 4 cm, short antenna, 3 kg
8	moist	batch	10	3 min	Mesh < 4 cm, short antenna, 3 kg
9	moist	conti	10	$v =$ 0,25 m/min	Mesh < 4 cm, short antenna, 3 kg
10	dry	batch	5	1 min.	Mesh < 4 cm, short antenna, 1 kg

The following Figure 2 shows the inside of the microwave oven and the experimental setup for continuous drying. In the middle on the right side three green boxes with the coal samples can be seen. Above the boxes are the emitting antenna and the reflecting mirror.

Fig. 2. Setup for microwave radiation coal drying

4. Results

The following Figure 3 displays the results of the laboratory analysis of the treated coal. These result from three different test series. It has to be pointed out, that the temperature during all tests did not exceed 90°C.

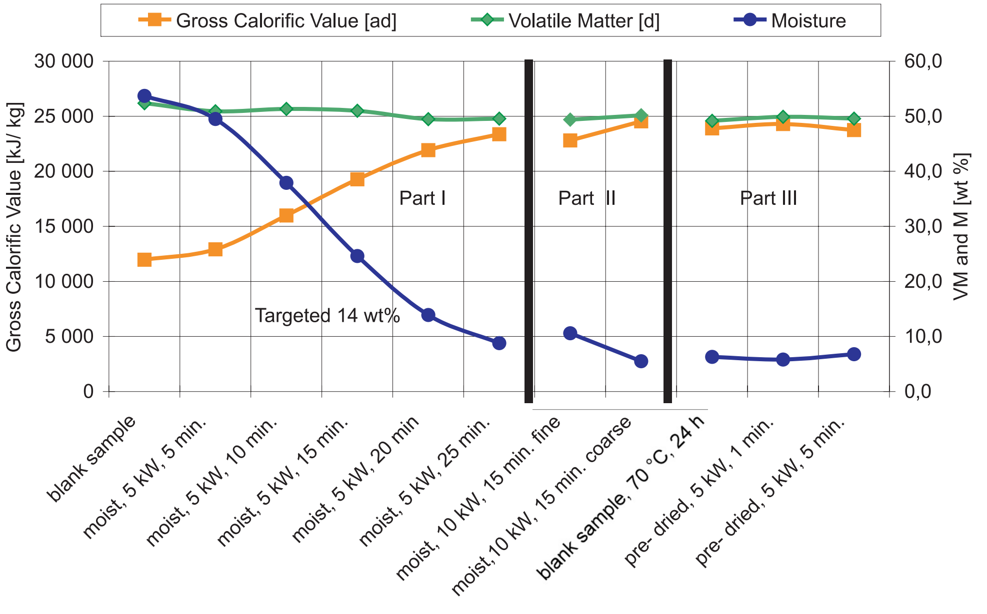

Fig. 3. Laboratory analysis results

Part I (test series 1) displays the drying curve for a moist coal treated with 5 kW in 5 minute intervals in a batch drying method, starting with the blank sample. The maximum microwave treatment time for this coal was 25 minutes. Coal with a moisture content of nearly 54 wt % was dried down to the targeted 14 wt % within 20 minutes. During the treatment the gross calorific value raises, as expected, while the volatile matter, on a dry basis, is hardly affected. Furthermore the drying with mr is able to dry the coal, in this case, to lower moisture content than targeted, even with 5 kW energy input.

Part II 2 (test series 3, 4) shows the comparison between treatment of moist fine coal (mesh < 4 cm) and moist coarse brown coal (mesh > 4 cm up to 8 cm). Both samples were treated with an energy input of 10 kW over a time period of 15 minutes. The coal for these tests was taken from the same blank sample as in test series no 1, so that to begin with coal properties are identical. After a period of 15 minutes the coarse material shows half the moisture contents of the fine material and affirms the fact, that coarse coal is more efficiently dried by mr, than fine one.

In Part III (test series 10) pre-dried samples were treated with 5 kW mr energy input for different time periods, in order to establish whether dry coal is negatively effected under continued mr. Here the moisture content, as well as the volatile matter, showed no relevant change over a time period of 5 minutes if treated and untreated pre-dried coal samples are compared.

Furthermore the test series showed that doubling the energy input from 5 kW to 10 kW halved the drying time. In addition the experimental setup gives evidence that the required mr drying time is independent from brown coal bed height on the conveyor, as long as the bed height does not exceed the wave length. The treated coal lumps show cracks and clefts. This can be taken as an indication, that internal pressures, caused by vaporizing water, crack up the coal structure and lower the work index for pulverizing the coal.

5. Conclusion

Microwave radiation is suitable for drying brown coal agglomerates. The volatile matter, on a dry basis, is hardly affected by microwave treatment at different power levels ranging up to 10 kW. The result of the microwave treatment are significantly higher gross calorific values, while moisture content drops to a suitable level for pulverized coal firing power plants. Side effects, which are stated in the literature for black coal milling, such as reduced work index, are indicated by cracks at the brown coal surface, too.

6. Acknowledgement

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