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PROBLEMS OF WATER CONTENT IN LIGNITES — METHODS OF ITS REDUCTION

1. Role of coal in the world

Coal is the most important global source of energy and the fuel in about 40% of power plants around the world. The modern world has huge energy needs. Electricity demand is growing and is expected that by mid-century will more than double. This clearly shows the increasing role of the indigenous, cheap and abundant energy resources. Lignite and hard coal are the raw material complies with interest criteria: the amount of resources, their availability and quality of raw [1, 2].

In determining the source of coverage of Polish energy needs, the overriding criteria should be the economic criteria related to the maximum use of its own sources of raw materials. Considering the criteria of economic competitiveness should be noted that lignite is today a leader in this category, because the costs of producing electricity from brow coal are about 20% lower than the same costs for coal, so the energy produced from this fuel is the cheapest.

Lignite plays a positive role in the Polish economy, constructive strength of the Polish electric power engineering regardless of the prevailing system of social, political or economic. This demonstrates clearly the objective superiority of brown coal over other fuels.

Prognostic lignite resources as of 31.12.2009 amounts to 27 540.71 million tonnes. This figure is more than 40% higher than anticipated economic resources calculated as of 31.12.2010. Prognostic resources occur in 90 prognostic deposits or prognostic areas near documented deposits within 7 coal-bearing regions: Bełchatów, Konin, Legnica, Łódź, north-western, Wielkopolska and western. At the end of 2010 Poland's anticipated geological resources of brown coals amounted to 19 819 million tonnes [3].

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These resources ensure Polish energy independence, and thus the energy safety and independence from foreign sources.

From existing brown coal resource base is used about 2.5 billion tons in three mining basins and these resources are sufficient for the first half of the twenty-first century. They are a source of fuel for 30% of the installed capacity of Polish power plants producing the cheapest electricity.

Lignite respecting the conditions of the country's energy security, high profitability of the cheapest electricity production, fulfilling all the requirements of environmental protection should be fuel of the future for Polish power [4].

2. Water in lignite

The big disadvantage of lignite is high moisture content, which varies from 30% to as high as 70%. The literature contains various terms that have been applied by different investigators to the classification of moisture in coal. According to [5] there are three types of moisture in the coal:

- external moisture (W_{ex}) — moisture, which can deprive of the coal drying in air at ambient temperature (approximately 298 K). It depends on water conditions in deposit, or on the way of dewatering or enrichment;
- hygroscopic moisture — moisture in the air-dry state. It is chemically bound water, so called constitutional and intermolecular water. With the increase of coal rank decreases the hygroscopic water content;
- decomposition moisture — this is the water formed during thermal decomposition of coal.

In practice, precise fuel bring to the air-dry state is possible only in case of black coals and anthracites, which are characterized by minimal variations in moisture content in the range of the most common relative humidity of the atmosphere in Poland: φ = 60–70%.

Excavated lignite contains of moisture on levels ranging from 25% up to 70%. Moisture in coal causes many difficulties during processing, storage, transport and combustion. The high moisture content significantly reduces the calorific value and combustion efficiency of raw material. In conventional combustion methods — in boilers — about 20–25% of produced heat is lost due to removal of moisture. Moreover, the amount of CO_2 produced per 1 MWh of energy from brown coal is also higher. It is important now to possibly increase the efficiency of energy production, for example by pre-drying of lignite implementation [6].

Reducing the water content in the coal reduces energy consumption by the mills, lowers heat loss with flue gases, reduces transportation costs while increases combustion efficiency, safety, and reduces the amount of exhaust gas.

According to the analysis of RWE Power AG combustion of pre-dried lignite may improve the efficiency of energy blocks (power) by 4–6%.

Moisture levels to be achieved during the drying brown coal depends on the end use of coal. It varies from oscillating around 0% for the hydrogenation process to about 15% for briquetting and gasification processes.

3. Methods of coal drying

Drying or dewatering of coal should be the first and essential step in most processes and technologies using brown coal. Unfortunately there is no one universal method of drying brown coal. Over the last 30 years, the U.S. Patent Office has notified more than 300 patents for, more or less, the issues of coal dryers and drying. Of course, only a few of these patented technologies are truly viable. Many of the ideas suggested are not practical, e.g. use of acoustic radiation, ultrasonics [7]. There is a need for methods that the drying process by heating the material, make use of heat (vapor) resulting from this process.

3.1. Fleissner process

This is a very old process for drying low-rank coals, first developed in Austria by Prof. Hans Fleissner'a in 1927. He believed that uneven shrinking of the coal and consequent desintegration could be prevented by controlled removal of the water. The saturated steam atmosphere would prevent evaporation until the lump was heated, and then loss of water could be controlled by gradual reduction of the steam pressure.

It's a thermal drying process, in which the action of high-pressure steam on a lump of lignite produces the some effects. As the temperature rises and the pressure increases part of the colloidal water is expelled from the lump as a liquid. The lump shrinks as water leaves and the cells collapse, and when the pressure is lowered, more water leaves by evaporation caused by the sensible heat stored in the lump. When the pressure is lowered further by vacuum, additional moisture is evaporated, which cools the lump [8]. Many methods of drying are based on Fleissner process.

3.2. Coldry process

Coldry technology was worked out in Australia in the early 1980's as a result of investigations begun in the Department of Organic Chemistry, University of Melbourne, in collaboration with CRA Advanced Technical Development, and patented by Environmental Clean Technologies Limited. It's a coal upgrading technology to specifically beneficiate low-rank brown coal (lignite) and sub-bituminous coal by removing natural high moisture content and certain pollutants [9].

The method is based on the release of moisture in the coal, by initiating an exothermic reaction, due to abrasion of the carbon particles together. The result is a concentrated product in the form of densified pellets, which are durable, easy to store and transport, and are of similar energy value to many black coals, whilst significantly reducing CO_2 emissions compared to its original brown coal form.

The feed of lignite is crushed and sieved to < 8 mm diameter. Then the carbon grains and water mixture is fed into an "Attritioner" that rubs the coalfaces together. This initiates an exothermic chemical reaction that triggers a natural process for expelling water from the coal. The reaction accelerates when the now plasticized mixture is extruded under low pressure and sent to the conditioning unit. Here is heated for about an hour at a temperature just 40°C. The hardened and dry product is separated in the form of pellets and directed into the dryer. The final moisture content ranges between 10 and 14% depending on the as-mined moisture, the characteristics of the feedstock and parameters of the process, especially the temperature provided by the heat exchange unit and the drying time allowed. The product can be used in most existing brown coal boilers.

The dry Coldry pellets, produced from Latrobe Valley Lignite are typically 16 mm in diameter and 45 mm in length, have a bulk density of approximately 700–750 kg/m^3, a moisture content of around 12%, and energy content of 5521 kcal/kg.

Table 1 summarizes the results of conducted tests on different lignites: Victorian Medium Ash, Polish and Greek, before and after the Coldry process.

TABLE 1

Comparison of lignites parameters before and after the drying process by Coldry

Region	**Australian Lignite**		**Polish Lignite**		**Greek Lignite**	
	Before Coldry	**After Coldry**	**Before Coldry**	**After Coldry**	**Before Coldry**	**After Coldry**
Moisture, [%]	60,5	12,1	55	11,9	50	14
Gross wet calorific value, [kcal/kg]	2460	5400	2370	4610	2960	4130
Net wet calorific value, [kcal/kg]	2030	5140	1940	4350	2060	3900

The main benefits of this method:

- increase up to 200–250% in calorific value of lignite;
- liberating large volumes of water; water recovered from the coal is ready for immediate industrial use without expensive treatment; can be fed to the power stations' cooling circuits;
- decrease in ash content;
- reduction of CO_2 emissions;
- reduction of ash accumulation;
- low temperature process — it requires waste heat of around 40°C; this low heat is sourced via heat exchange from a co-located power station;
- low pressure process — Low pressure requires less energy;
- possibility of using the existing power boilers.

3.3. Mechanical Thermal Expression (MTE)

Mechanical Thermal Expression is the combination of mechanical expression and thermal dewatering process. It is a method that uses mild heat and mechanical wring. To obtain substantial benefit from MTE, it is necessary to heat the lignite above the normal boiling point of water [10]. However, the processing temperature is low enough to prevent significant release of organics into the product water. During the compression stage between 10 and 60% of the initial water is removed. The compressive pressure is the major factor influencing the quantity of water removed.

Mechanical dewatering process is held in back-pressure to prevent evaporation, ensuring that the water is removed only by mechanical forces. Further moisture reduction is achieved by flash evaporation in the processed lignite by exposing it to atmospheric conditions.

The MTE affects the removal of water within about 75%. The MTE method creates new problems such as: the need for prior grinding of coal, the need for clean water produced, time-consuming, high investment and operating costs.

3.4. Electromagnetic mill

Lignite drying in the electromagnetic mill can be divided into the thermal-mechanical methods. In this method, coal is heated by steam at elevated temperature 150–200°C and 5–16 bar pressure, then is compressed in a hydraulic chamber to “squeeze” the water. The electromagnetic mill uses ferromagnetic grinding mediums with a very low weight. Wherefore the power consumption is very low. The grinding mediums follow changes of the magnetic field reaching high kinetic energy. To increase the productivity of the mill, or get a finer grain size of the product, the multi-section structure (parallel or serial) can be introduced.

Advantages of this method include: a short drying time, which is about 30 seconds, low energy consumption, and water removal of about 75% [11].

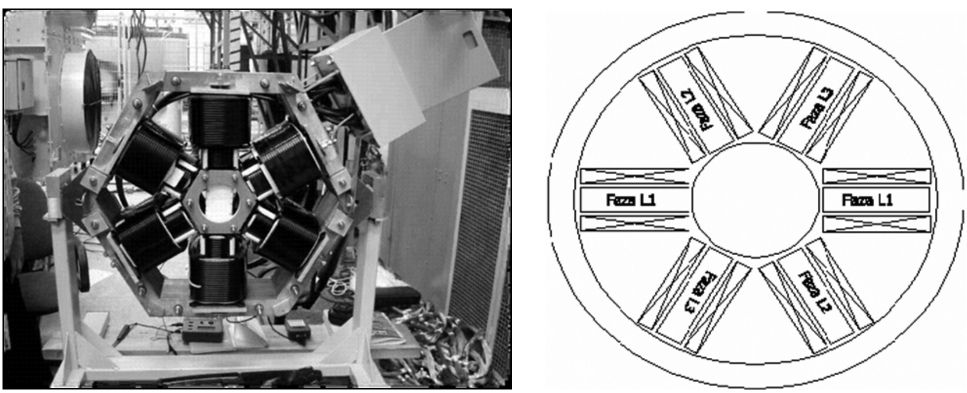

Fig. 1. Physical model of inductor (a);
Three-phase of inductor winding to produce a transverse rotating field (b)

3.5. The WTA Technology (Wirbelschicht Trocknung Anlage)

WTA technology was developed by German company RWE Power AG. It is a technology of drying in a fluidized bed with internal waste heat utilization. Figure 2 shows a schematic overview of the process.

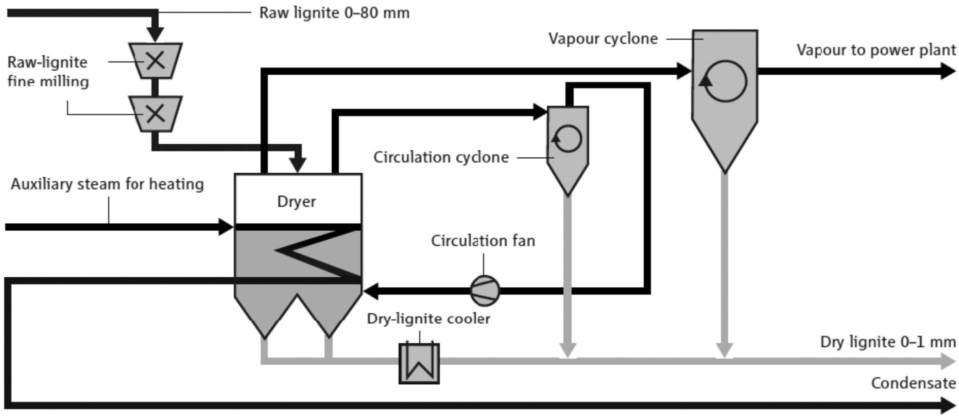

Fig. 2. Schematic of the WTA fine grain drying process [13]

The raw coal is ground from 0 to 80 mm down to 0 to 2 mm in two hammer mills directly connected in series. After the milling stage, the fuel is fed into the fluidized bed, in which the fluidizing medium is the vapour arising from the drying process.

Evaporation of water occurs at 110°C under slight over-pressure by heat exchangers integrated into the fluidized-bed dryer and heated with steam. The residence time of lignite in the drying chamber is about 60–90 minutes.

The dried fuel exiting the stationary bed is separated from the accompanying vapour first in a cyclone and then in an electrostatic precipitator. The vapour at the outlet of the cyclone is the vapour used for fluidization of the bed and the vapour at the outlet of the electrostatic precipitator is exhausted into the atmosphere. In addition, there is a coarse extraction for the fuel at the bottom of the bed, which is mixed with the fuel separated at the cyclone and the electrostatic precipitator after having passed an intermediate cooler.

The heat needed for the drying of the fuel is supplied by external steam, which is normally taken from the turbine with the heat transfer taking place in tube bundles located inside the bed.

The drying in the fluidized bed further reduces the grain size, so that the dry coal leaving the drier, with a moisture content of 12%, typically has a grain size of less than 1 mm, with about 9% greater than 1 mm.

Currently the large WTA prototype plant works at the Niederaussem power station. This 1000 MW plant is currently the most powerful, modern, efficient and environmentally friendly lignite-based unit worldwide. The system, which can process 210 tons of raw coal an hour, has an evaporation capacity of 100 tons of water per hour and is the biggest lignite drying plant in the world. It can generate 110 tons of dry lignite an hour — that's up to 30% of the overall coal requirements of the BoA unit at Niederaussem.

RWE AG is planning to introduce the industrial production of these installations after 2014. WTA technology is an important element to reduce CO_2 emissions in lignite-based electricity generation — higher efficiency means more climate protection [12]. The WTA process enables much better energetic use to be made of coal and lead to a further rise in efficiency of some four percentage points to as much as 48% then.

By controlling the fluidized-bed temperature, the moisture content can be adjusted and kept constant at the desired value. For example, with a system pressure of approximately 1.1 bar and a fluidized-bed temperature of 110°C, a residual-moisture content of some 12% emerges.

The major advantages of the WTA technology can be summarized as follows:

— High energy efficiency thanks to drying at low temperature, and energetic use of the evaporated coal water (through vapour condensation or mechanical vapour compression).
— Very safe in both normal operations and in powering up/down thanks to drying in an inert atmosphere. This avoids explosive coal dust-air mixtures from the outset.
— Compact design due to integrated raw-lignite fine-milling system and — where required — secondary dried lignite milling as well.
— Utilizing the energetic vapour avoids significant steam and dust emissions. The vapour condensate is a water source that can be used by industry.

3.6. Combined grinding and drying

Lignite is often ground prior to utilization. The heat produced during grinding can reduced the moisture content significantly while reducing the particle. One of the commercial devices combining these two functions in the application for coal drying is the KDS Micronex (*Kinetic Desintegration System*) grinder/dryer (Fig. 3). The device is a high volume grinder, which grinds and dries materials in a single-step process, without needing any heat input. The mechanism of drying is partly thermal and partly mechanical dewatering. KDS technology uses significantly less total energy (70%) than conventional drying and grinding combined.

4. Lignite drying in Poland

Lignite drying process has become very important from the standpoint of improving the efficiency of combustion process. Numerous studies looking for optimal solutions on an industrial scale are conducted. One of the biggest projects related to this problem is: "Pre-drying of brown coal for energy purposes", implemented under the Operational Programme Innovative Economy.

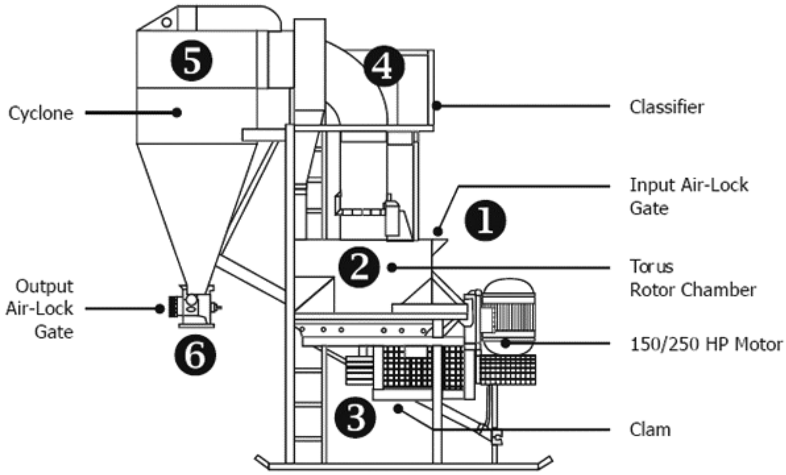

Fig. 3. An Overview of the KDS Micronex™ Grinder-Dryer [14]

The research team, chaired by Wrocław University of Technology also includes: Opole University of Technology, Institute of Opencast Mining POLTEGOR — Institute, PGE Turów Power Plant. The main aim is primarily to increase the power innovation in energy production from brown coal.

Among many research tasks should be mentioned e.g.: development of different concepts of drying coal, modification and construction of laboratory drying installation, selection of coal for drying and it's physico-chemical characteristics, development and implementation of modified construction of laboratory models, developing and implementation an initial feasibility assessment of a pilot plant based on the guidelines to the developed methods, executive project of modifying, building and mechanical structures.

The project is co-financed by the European Regional Development Fund under the Innovative Economy Operational Programme and the state budget (15%) [15].

Preliminary market analysis showed that the cost per unit of heat obtained from coal is now seven times lower in comparison with the fuel gas and fuel oil. For this reason, in addition to the large interest in this subject of both a lignite mine and power plant, the strong demand of individual customers is also observed. The estimated demand for dried coal is around 1 million tonnes per year.

5. Conclusions

The share of lignite as a carrier of primary energy in Poland is very significant. Because of the high water content in raw coal and its negative impact on the efficiency of the combustion process, it is important to use pre-drying of coal before use. Choosing of coal drying technology is dependent primarily on the further use of raw material and the expected productivity of the method.

Innovative coal drying technology will allow to improve the production of electricity and the production of high-quality fuel with high market potential, which will significantly reduce the cost of energy production from low-rank fuels. This implies a fossil fuel savings of 3–4% annually, while reducing exhaust and CO_2 emissions.

REFERENCES

[1] *Jangam S.V., Karthikeyan M., Mujumdar A.S.*: A critical assessment of industrial coal drying Technologies: role of energy, emissions, risk and sustainability. Drying Technology, 29: 395–407, 2011.

[2] *Kasztelewicz Z., Sikora M.*: Węgiel brunatny na świecie i w Polsce Węgiel Brunatny — Kwartalny Biuletyn informacyjny. 2012 nr 1/78 Numer specjalny.

[3] http://surowce-mineralne.pgi.gov.pl.

[4] *Żuk S.*: Przyszłość należy do węgla brunatnego. Węgiel Brunatmy — Kwartalny Biuletyn informacyjny. 2012 nr 1/78 Numer specjalny.

[5] *Blaschke W.*: Przeróbka węgla kamiennego — wzbogacanie grawitacyjne. Wydawnictwo Instytutu Gospodarki Surowcami Mineralnymi i Energią PAN. Kraków 2009.

[6] *Pakowski Z., Adamski R., Kokocińska M., Kwapisz S.*: Generalized desorption equilibrium equation of lignite in a wide temperature and moisture content range. Fuel, 90: pp. 3330–3335, 2011.

[7] *Mujumdar A.S. i in.*: Handbook of Industrial Drying, 3rd Ed; CRC Press Taylor & Francis Group, Boca Raton, FL, 2006.

[8] *Harrington L.C., Parry V.F. and Koth A.*: Technical and economic study of drying lignite and subbituminous coal by the Fleissner process. Washington, D.C.: U.S. Govt. Print. Off., Bureau of Mines, 1942.

[9] http://www.ectltd.com.au/coldry/coldry-overview/.

[10] *Clayton S.A., Scholes O.N., Hoadley A.F.A., Wheeler R.A., McIntosh M.J., Huynh D.Q.*: Dewatering of Biomaterials by MechanicalThermal Expression. Drying Technology, 24: pp. 819–834, 2006.

[11] *Michalski M., Ostrycharczyk M.*: Metody suszenia węgla brunatnego. Górnictwo Odkrywkowe. R. 52, nr 1–2, s. 127–131, Wrocław 2011.

[12] Halawa. T.: Postęp w budowie bloków energetycznych dużej mocy opalanych węglem brunatnym. „Energetyka" — grudzień 2007.

[13] http://www.rwe.com.

[14] http://www.fasc.net/fasc-brochure.php.

[15] http://www.swb.pwr.wroc.pl/informacje.html.