Journal of Machine Engineering, Vol. 12, No. 2, 2012

*high-pressure water jet,
coal, disintegration,*

Przemyslaw BORKOWSKI[1]
Jozef BORKOWSKI[1]
Michal BIELECKI[1]

TECHNICAL ASPECTS OF COAL DISINTEGRATION USING HIGH PRESSURE WATER JET

The high-pressure water jet comminution of coal is presents in the paper. For such procedure a special prototype of hydrojetting apparatus have been developed. Three different types of coal were examined: hard-, brown-, and charcoal. Obtained results point out that high-pressure water jet usage for such a purpose is very effective. Brown coal is slightly more susceptible for this method treatment than the hard one, whereas the most intensive disintegration is characteristic for charcoal. Such micronization effect gives even over 100,000 times increase of its specific surface comparing to normal fine coal after traditional comminution. Moreover charcoal susceptibility for intensive hydro-comminution causes that one can get the most comminuted structure what is a good prognosis for its modification into bio-fuels.

1. INTRODUCTION

There are different methods of coal processing into fuel [1],[7],[13] and usually they require intensive comminution of the coal. Such situation needs creation of new technologies for coal micronization [5],[12],[18] that enlarge specific surface of coal micro particles what finally intensifies burning process of such coal dust. Some interesting effects of water-coal mixture ensures waterjetting technology implementation [3],[6],[20]. Such technology let to produce fuel from powdered coal in water slurry [2-6] or in energetic fluids (methanol or low viscosity oils) [6],[15].

Traditional mechanical grinders are used for coal grid comminution by means of coal particles crushing and grinding. However such grinders' usage for coal micronization is economically unprofitable because of their low efficiency [7],[9],[11]. It is a result of coal much higher resistance to pressing stresses than to stretching ones [8],[14],[16].

Taking above into consideration an alternative technology involving high-pressure water jet can be implemented. Such a jet striking coal surface penetrates inside causing stretching stresses and such a water wedge effect leads to easy disintegration of such coal particle. It should be admitted here that hard coal structure is characterized by many cracks [17],[19] and that is the reason why such material is especially susceptible to disintegration during hydrojetting grinding.

[1] Institute of Unconventional HydroJetting Technologies, Koszalin University of Technology, Poland

2. THE RESEARCH

Special construction of prototype of hydrojetting grinder (Fig. 1) was used for coal disintegration which was constructed after examining of other types linear grinders [10],[15], [17]. Such construction work is close to injector head work that is popularly used for creation of high-pressure abrasive-water jet. However in this particular case, fine coal is processed instead of abrasive material and it is accelerated and initially comminuted inside homogenized nozzle, which is made of sintered carbide. Created this way water-coal jet is directed on a target made of sintered carbide, where final comminution process is taking place. Three different types of coal were examined: hard-, brown-, and charcoal.

Above mentioned device was used for fine coal comminution of granularity range 1÷10mm and process efficiency range 8÷30g/s. Water output was changed at the range of 0.2÷0.5dm^3/s and its pressure range of 50÷300MPa. Hydromonitor basing on HDP164 type (p_{max}=300MPa, Q_{max}=0.5dm^3/s) pump was used for such water output generation.

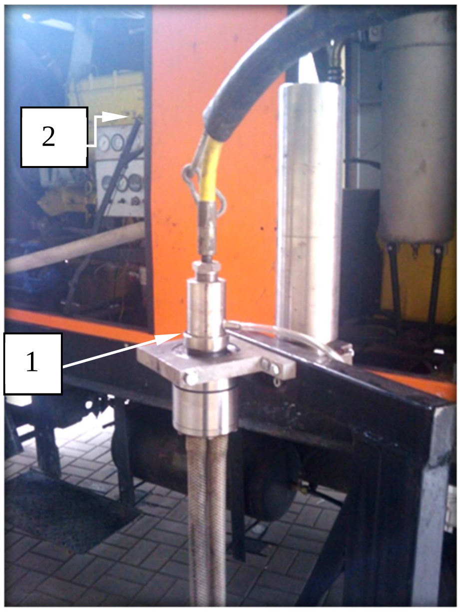

Fig. 1. General view of hydrojetting comminution apparatus prototype
(1 - hydrojetting grinder, 2 – HDP 164 type hydro-monitor)

Special fraction analyzer Analysette 22 Micro Tec was used for testing different particles of comminuted coal. It enables fast results valuation of particles size range of 80nm do 2mm. FEI Quanta 200 microscope equipped with chemical analyzer type EDAX Genesis XM 2i was used to observe comminuted fine coal surface. Additional software was used for particles shape analysis (Fig. 2). In turn, topography of cut surface and its geometry was measured with spatial surface analyzer type Talysurf CLI 2000 using laser gage as well as confocal gauge working with polarized light.

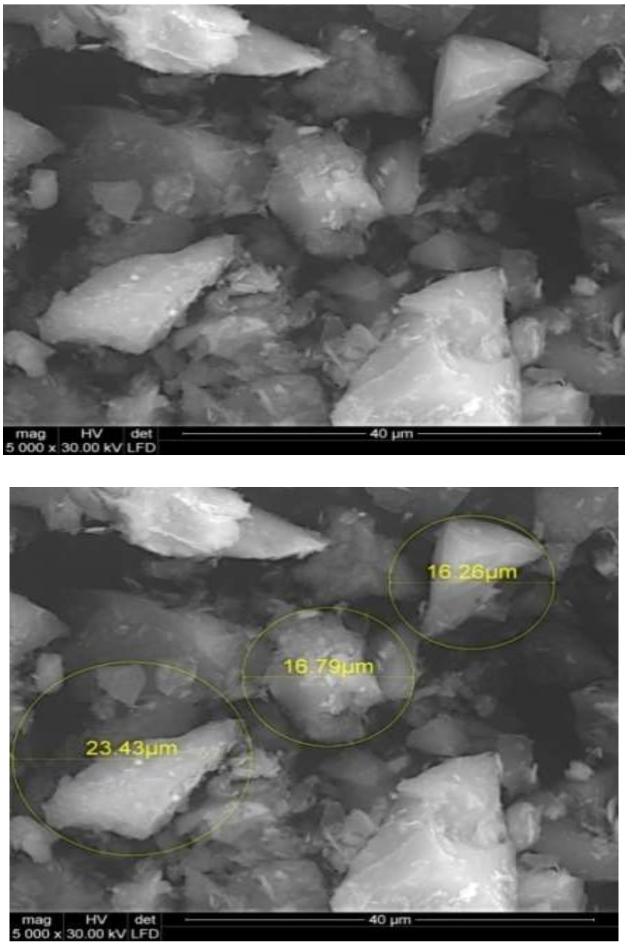

Fig. 2. General view of comminuted coal particles

3. COMMINUTION OF HARD COAL

3.1. HARD COAL PARTICLES DISTRIBUTION

In order to achieve high efficiency of coal burning process one should obtain proper particles comminution. Exemplary distributions of hard coal particles are presented in Fig. 3.

However as it occurs the water pressure increase leads to difference in comminution. Examples that illustrates such tendencies are analogical distribution plots obtained for jet pressure of 250MPa (Fig. 4). Such almost 2 times higher water jet pressure increase leads to distinct comminution of hard coal.

Analysis of fine coal particles distribution diagrams shows that single stage hydrojetting comminution let to evaluate micronization degree. For example, for water pressure of 150MPa even 90% of particles reaches dimensions range 0÷123µm. In turn, higher water pressure of 250MPa causes that 90% of particles gives dimension range 0÷71µm respectively.

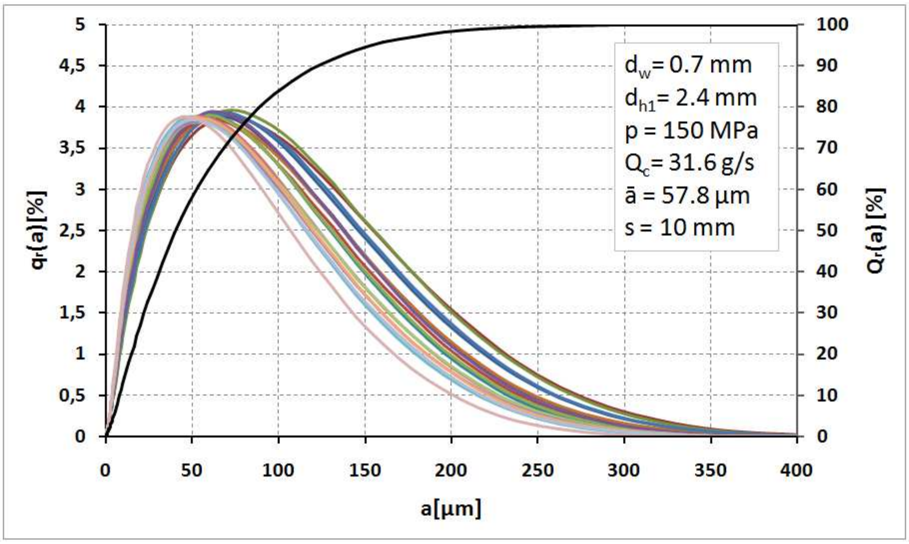

Fig. 3. Distributions of hard coal particles fraction comminuted with water pressure of 150MPa

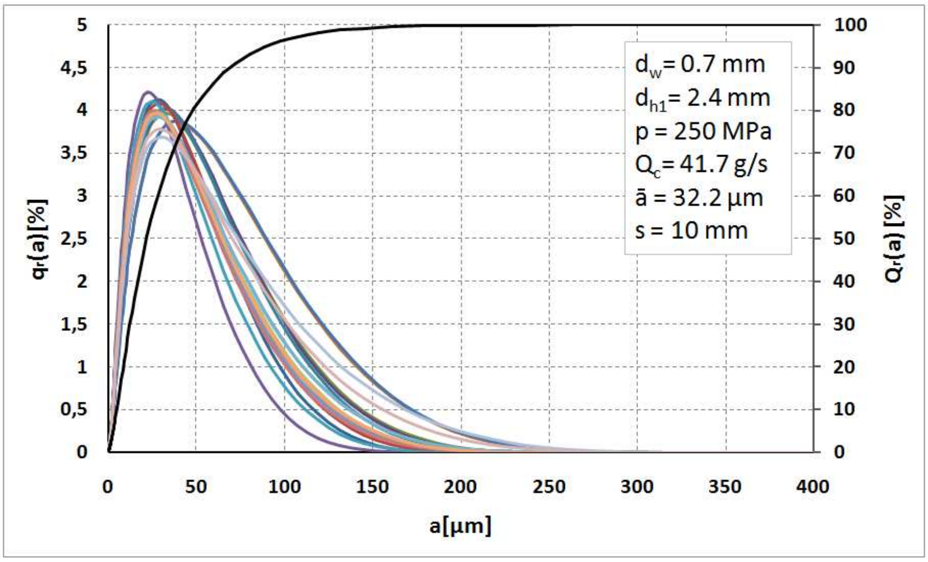

Fig. 4. Distributions of hard coal particles fraction comminuted with water pressure of 250MPa

3.2. HARD COAL PARTICLES SURFACE

Fine granularity of coal particles is limited by their specific surface increase what intensifies burning process. However, as it comes out from microscopic analysis hydrojetting micronization of coal causes specific development of created particles. Such a surface looks like shredded lamella additionally enlarging total work surface of these particles. Morphology examples of such particles being a part of new fuel type made of hard coal are presented in Fig. 5.

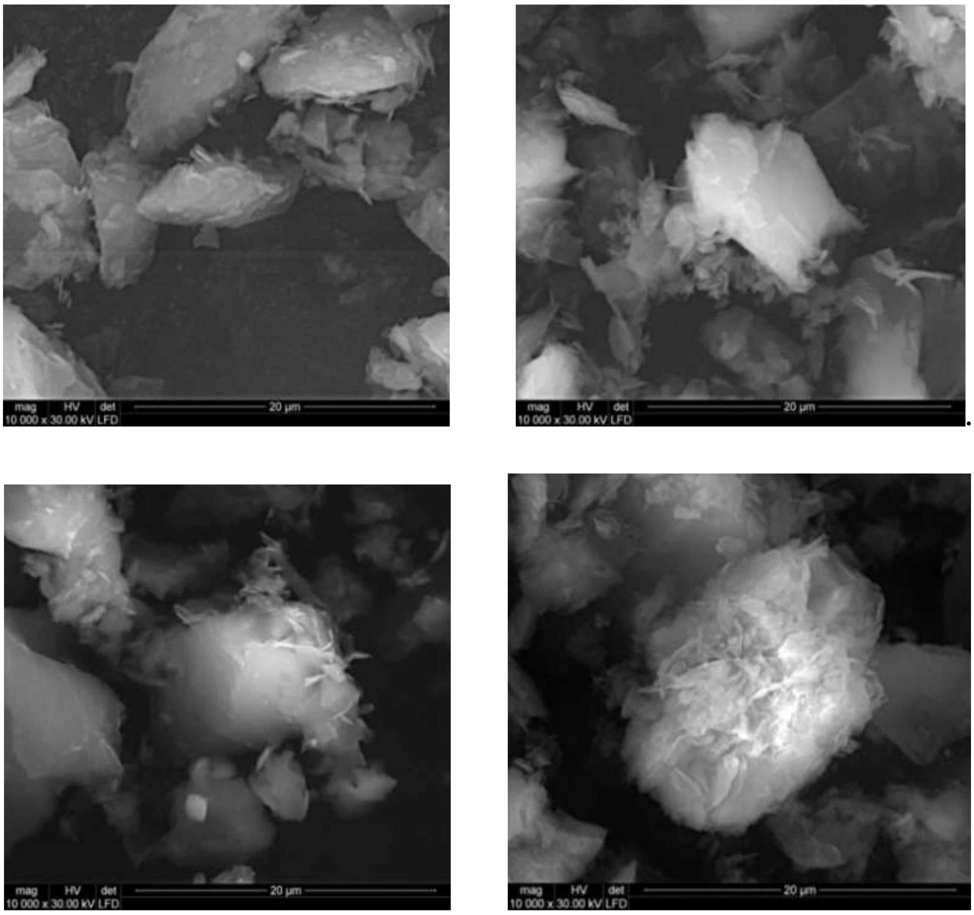

Fig. 5. SEM pictures of hard coal showing different stage of their specific surface development

Estimated simulation results realized for lamellar morphology of coal particles created during water jet comminution point out that their real surface increases even up to 100,000 times comparing to specific surface of usual fine coal. Such feature is very important taking into account efficiency of bio-chemical coal conversion into new generation fuel [7].

4. BROWN COAL COMMINUTION

4.1. BROWN COAL PARTICLES DISTRIBUTION

As it comes out from experiments, comminution of the brown coal during high-pressure water jet grinding is similar comparing to the hard one. The reason for that is huge ductility of examined brown coal material. Evidence for that can be exemplary distributions of brown coal particles which are presented in Fig. 6 and Fig. 7.

Presented research prove that during hydrojetting comminution a few millimetre particles of fine brown coal becomes efficiently micronized. Amount of approx. 90% of brown coal is comminuted after first stage and such material becomes range of 0÷176μm for processing water pressure of 150MPa and respectively reaches the range of 0÷65μm for water pressured up to 250MPa.

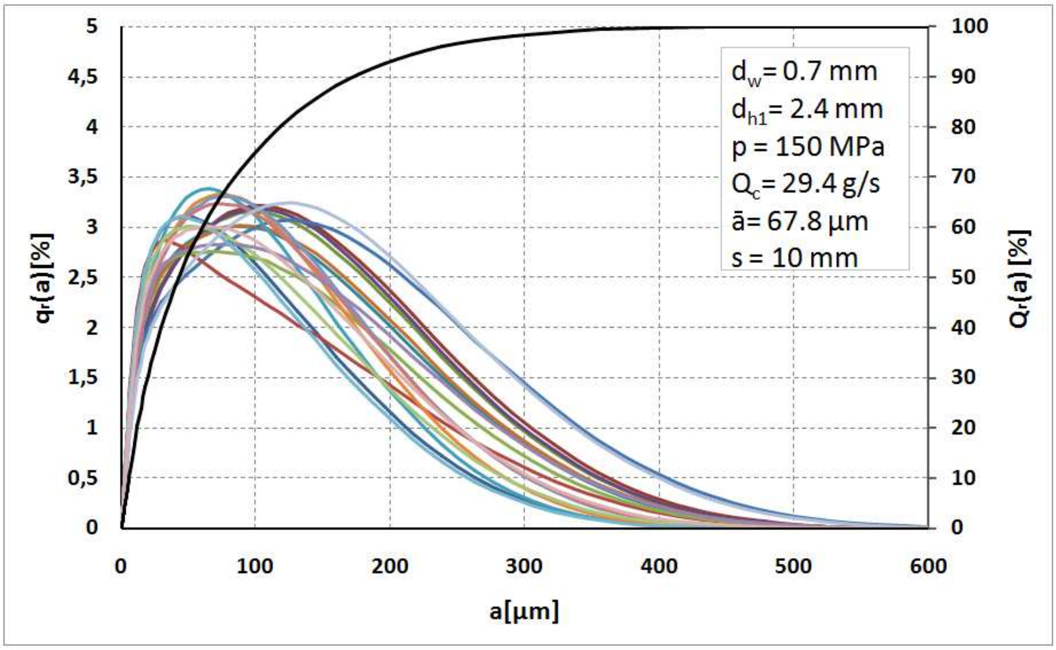

Fig. 6. Distributions of brown coal particles fraction comminuted with water pressure of 150MPa

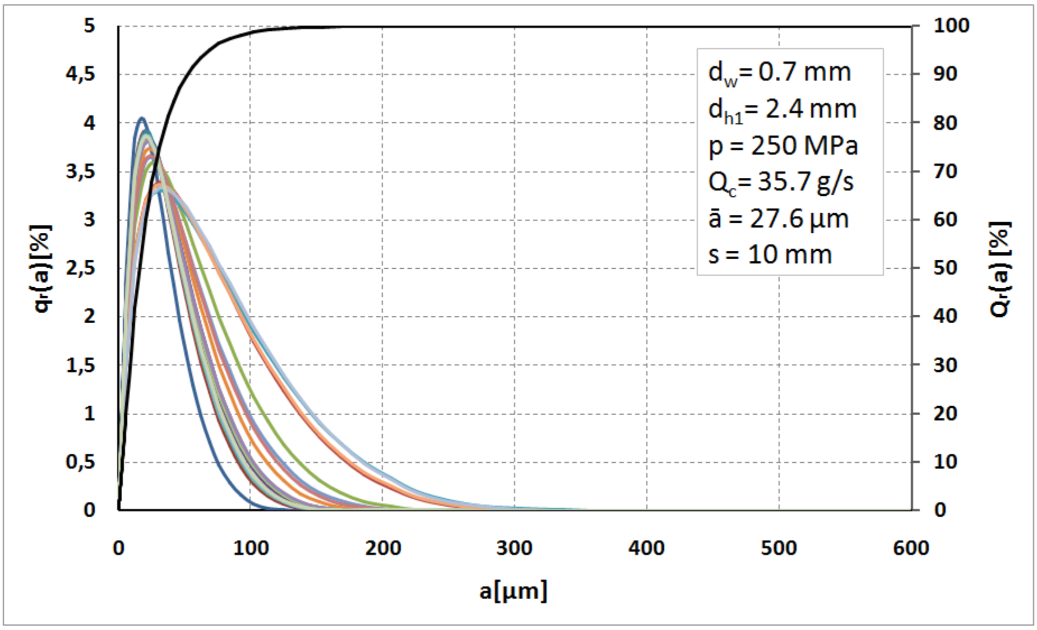

Fig. 7. Distributions of brown coal particles fraction comminuted with water pressure of 250MPa

4.2. BROWN COAL PARTICLES SURFACE

Brown coal micronization during high-pressure water jet process causes intensive comminution as well as considerable growth of created particles surface. Diversification of its size and shape are illustrated in SEM images (Fig. 8).

Shredded form of comminuted particles of brown coal greatly multiplies their total surface. It is very profitable for efficiency of their burning process. Some exemplary morphologies of such particles are illustrated in SEM images presented in Fig. 9.

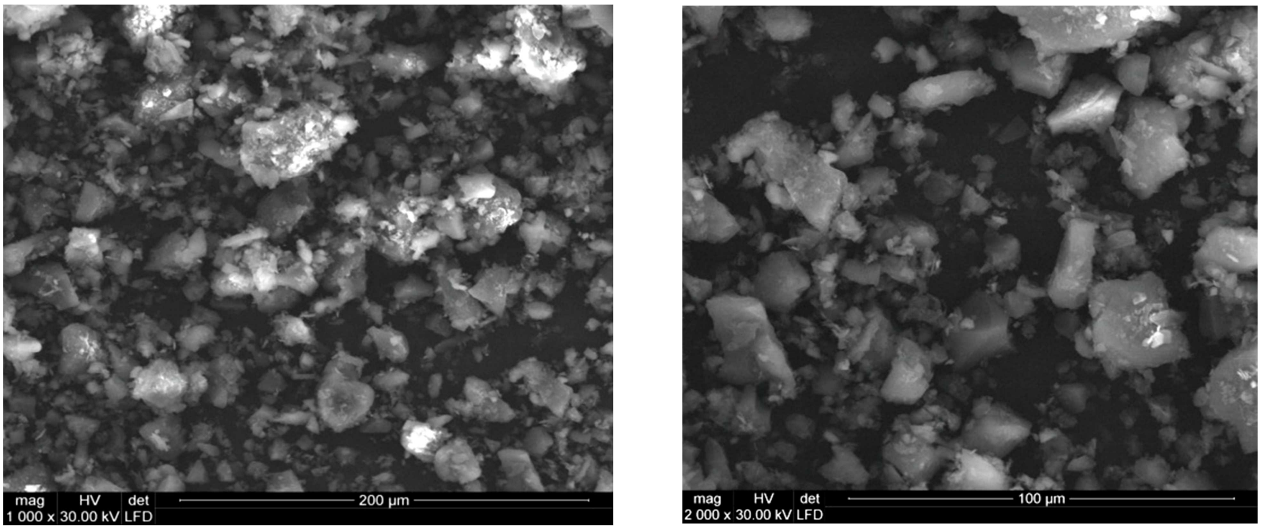

Fig. 8. SEM images illustrating diversification of brown coal size and shape after high-pressure water jet comminution (p= 250MPa)

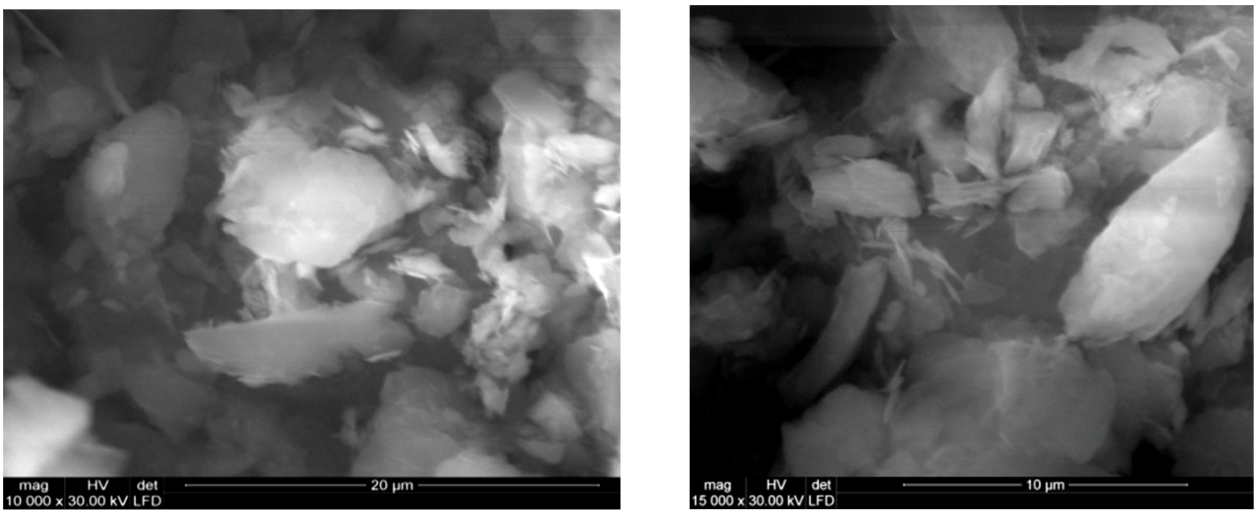

Fig. 9. SEM pictures of brown coal comminuted with high-pressure water jet of 250MPa showing different stage of their specific surface development

5. CHARCOAL COMMINUTION

5.1. CHARCOAL PARTICLES DISTRIBUTION

Much intensive comminution is characteristic for charcoal grinded with high-pressure water jet. Evidence for this can be observed in exemplary distribution of charcoal particles, which are presented for 150MPa in Fig. 10 and for 250MPa in the next Fig. 11.

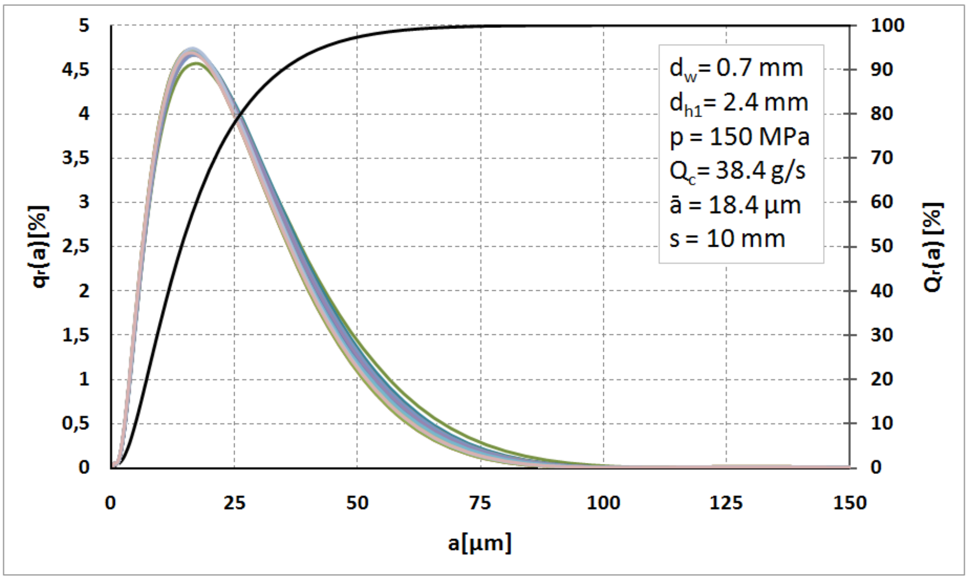

Fig. 10. Distributions of charcoal grains fractions comminuted with water pressure of 150MPa

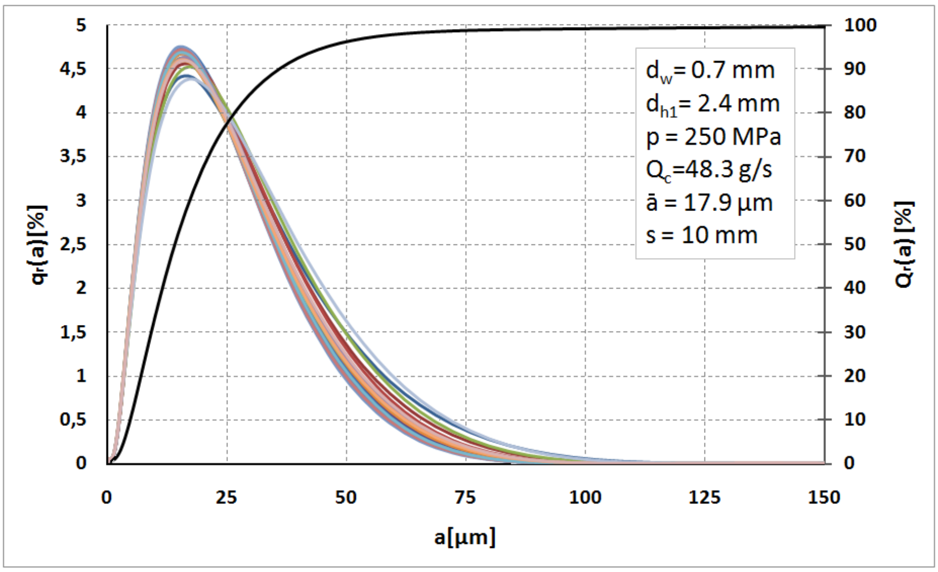

Fig. 11. Distributions of charcoal grains fractions comminuted with water pressure of 250MPa

Hydrojetting comminution of fine size charcoal definitely gives the highest micronization. Amount of approx. 90% of charcoal is comminuted after the first stage and such material becomes range of 0÷37μm for processing water pressure of 150MPa and respectively reaches the range of 0÷34μm for water pressured up to 250MPa.

5.2. CHARCOAL PARTICLES SURFACE

Charcoal susceptibility for intensive hydro-jetting comminution causes that one can process particles of the most fine granularity structure what makes good prognosis for such coal usage as bio-fuels. Thanks to hydro-jetting micronization method of charcoal one can observe that the most dominant part of after-processing material usually accumulates on the water surface in the form of foam. After drying such coal foam consistency is very porous (Fig. 12).

Fig. 12. Air-dried charcoal mass: a) of great porosity, b) comminuted with high-pressure water jet (p= 250MPa)

However in reality created such way charcoal particles are grainy in structure and characterized with regular edges and surface. Typical examples of their shape and morphology, being a part of new generation charcoal fuel, are presented in Fig. 13.

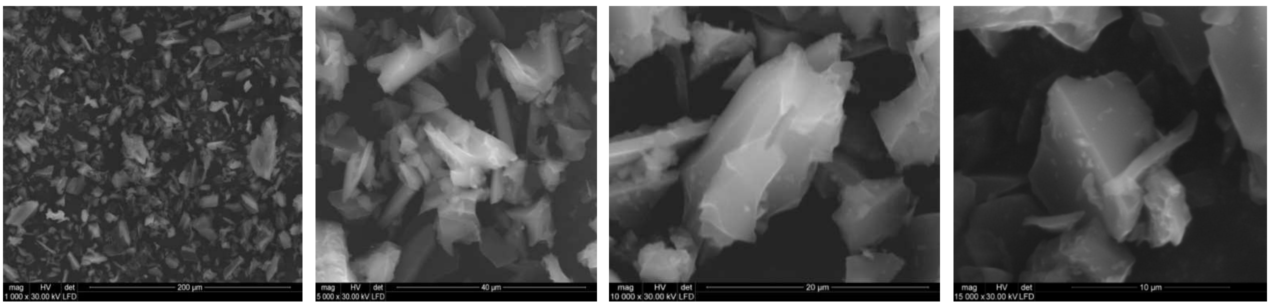

Fig. 13. SEM pictures of charcoal showing different stage of their specific surface development

6. ENERGY CONSUMPTION ON THE PROCESS

Energy consumption necessary for coal comminution is an important indicator that characterizes efficiency of such process. In some sense such consumption decides of calorific value of such quasi-liquid fuel generated from micronized coal. Subtracting the value of energy lost in this way from fuel calorific value one can obtain corrected real fuel value.

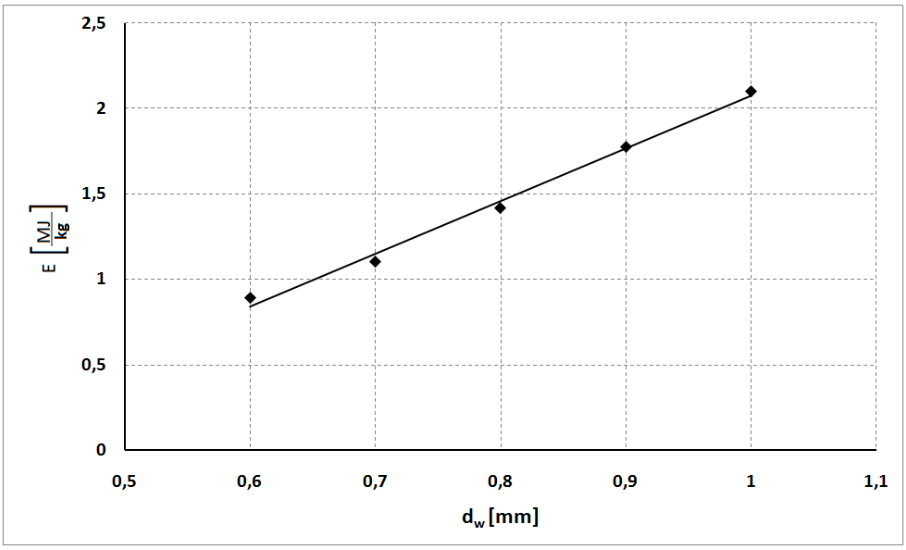

Fig. 14. Dependence of unitary energy consumption E indispensable for processing of 1 kg of hard coal vs. water nozzle diameter d_w (p = 200MPa, d_h=2,4mm)

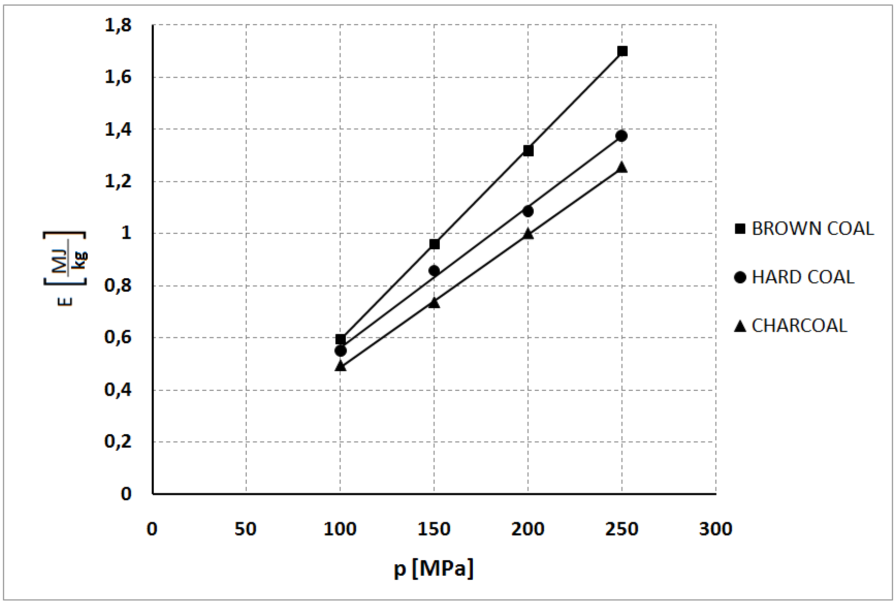

Fig. 15. Dependence of unitary energy consumption E indispensable for processing of 1 kg of different coal types vs. nominal water jet pressure (d_w=0,7mm; d_h = 2,4mm)

The first step was the research concerning influence of fine coal hydrodynamic conditions. Example of that can be influence of mill's water nozzle diameter presented in Fig. 14. It comes out practically linear increase of unitary energy consumption of fine hard coal comminution vs. water nozzle diameter.

Application of hydrojetting mill characterized with adequate nozzle choice let to comminute different types of fine coals in an efficient way. Exemplary graphs of unitary energy consumption occurring in comminution of different coals' types vs. water pressure is presented in Fig. 15. It comes out that for all types of coal one can obtain each time dependences directly proportional to water pressure. Therefore having in mind realized experiments, the most favorable is to use the lowest used pressure for fine coal comminution.

7. CONCLUSIONS

Presented results of fine coal comminution with high-pressure water jet technique let to formulate the following important conclusions of general character:

- Small coal resistance for stretch stresses causes that water jet technique usage for comminution is very effective.
- Processing of hard coal with water pressure of 150MPa causes that even 90% of particles reaches dimensions range 0÷123µm. In turn, higher water pressure of 250MPa causes that 90% of particles gives dimension range 0÷71µm respectively.
- On the other hand, hydrojetting comminution of fine size brown coal becomes efficiently micronized. Amount of approx. 90% of brown coal is disintegrated after first stage and such material becomes range of 0÷176µm for processing water pressure of 150MPa and respectively reaches the range of 0÷65µm for water pressured up to 250MPa.
- Hydrojetting comminution of fine size charcoal definitely gives the highest micronization effects. Amount of approx. 90% of charcoal is comminuted after first stage and such material becomes range of 0÷37µm for processing water pressure of 150MPa and respectively reaches the range of 0÷34µm for water pressured up to 250MPa.
- Energy consumption necessary for coal comminution is an important indicator that characterizes efficiency of such milling process.
- Such energy consumption decides of calorific value of such quasi-liquid fuel, and it may be defined as a difference of coal calorific value and unitary consumption of energy used for such micronization.
- Unitary energy consumption necessary for coal comminution processing depends in a linear way on water nozzle diameter of the hydrojetting mill.
- Unitary energy consumption necessary for comminution processing of different coals' types is directly proportional to water pressure, therefore the most favourable is to use the lowest pressure for fine coal comminution having in mind pressure range realized in this experiment.
- Hydrojetting coal micronization causes that created particles surface has very often a shredded lamellar form and thanks to that their real surface increases even up to 100,000 times comparing to specific surface of usual fine coal.

- Charcoal susceptibility for intensive hydro-jetting comminution causes that one can get particles of the most fine-grained structure giving the same good prognosis for its processing into bio-fuel.

Taking into account above results one should evaluate developed apparatus and method as very effective technique for high-pressure water jet coal comminution.

NOMENCLATURE

a, ā [mm] – unitary, mean size of coal particle,
d_h [mm] – homogenizing nozzle diameter,
dQ3 [%] – frequency of unitary value occurrence of coal particle size,
d_w [mm] – water nozzle diameter,
p [MPa] – water jet pressure,
Q_c [g/s] – efficiency of hydro-jetting coal comminution.

REFERENCES

[1] AMICK P., LYNCH G.E., NELKIN G.A., STULTZ J., ZEH C.M., 1996, *The Clean Coal Technology Program. The Wabish River Coal Gasification Repowering Project*. Topical Report, 7, 1-22.

[2] BIELECKI M., 2011, *Examining of geometrical and hydraulic parameters influence of high-pressure hydro-jetting mill on different materials comminution* (in Polish). Science Seminar of UHJT Institute. Koszalin University of Technology.

[3] BORKOWSKI P., BORKOWSKI J., BIELECKI M., 2011, *Coal disintegration using high pressure water jet*. International Conference Water Jet 2011: Research, Development, Applications. Ostrava, 73-84.

[4] BORKOWSKI J., BORKOWSKI P. 2010. *Innovative applications of hydro-jetting technologies* (in Polish). Conference of Polish Academy of Science. Kołobrzeg.

[5] BORKOWSKI P., 2010, *Basis of high-pressure hydro-jetting technologies* (in Polish). Monograph of UHJT Institute (ISSN 0239-7129, ISBN 978-83-7365-207-1), Koszalin.

[6] BORKOWSKI P., BORKOWSKI J., 2010, *Coal comminution with high pressure water jet*. 20th International Conference on Water Jetting. BHR Group (ISBN: 978 1 85598). Graz, Austria, 141-146.

[7] BORKOWSKI P., BORKOWSKI J., 2009, *High-pressure water jet application for coal conversion into new generation fuel*. Unconventional and HydroJetting Technologies. Monograph of UHJT Institute (ISSN 0239-7129), Koszalin, 43-54.

[8] BORKOWSKI P., BORKOWSKI J., 2009, *Comminution of different materials with high-pressure water jet*. Unconventional and HydroJetting Technologies. Monograph of UHJT Institute (ISSN 0239-7129), Koszalin, 493-500.

[9] BORKOWSKI P., BORKOWSKI J., MAZURKIEWICZ M., LASKO S., 2009, *Coal micronization utilizing with high-pressure water jet*. Unconventional and HydroJetting Technologies. Monograph of UHJT Istitute (ISSN 0239-7129), Koszalin, 511-518.

[10] CUI L., AN L., GONG W., 2006, *Optimizing process parameters of high pressure water jet mill*. The 8th Pacific Rim International Conference on Water Jet Technology. Qingdao, China, 15, 138-145.

[11] CUI L., AN L., GONG W., HUANG B., 2006, *Present state and perspectives of water jet comminution technique*. The 8th Pacific Rim International Conference on Water Jet Technology. Qingdao, China, 39, 361-369.

[12] GONG W., AN L., CUI L., LIU Y., XIE G., 2005, *Desulfurization of coal based on high pressure water jet comminution*. 2005 WJTA American Waterjet Conference. Houston, Texas, Paper 3B-2.

[13] KLANK M., 2007, *Perspectives of coal usage in Poland in the aspekt of clean coal Technologies* (in Polish). Gospodarka Surowcami Mineralnymi. 23/2, 27-33.

[14] MAZURKIEWICZ M., 2001, *Method of creating ultra-fine particles of materials using high-pressure mill*. US Patent No. 638649.

[15] MAZURKIEWICZ M., 2002, *Apparatus for comminution of solid materials using a processor-controlled fluid jet*. US Patent No. 6435435.

[16] MAZURKIEWICZ M., 2004, *Method of creating ultra-fine particles of materials using a high-pressure mill*. US Patent No. 6824086.
[17] MEI F., WEILI G., YUFAN C., 1999, *A new type of high pressure water jet mill*. 10th American Waterjet Conference. Houston, Texas. Paper 31.
[18] *Micronized coal-water fuel slurry for reciprocating combustion engines*. US Patent No. 4335684.
[19] SHENG F., HONG L., XIONG D., 2007, *Research on ultrafine comminution of minerals by thermally assisted high pressure water jet*. 2007 American WJTA Conference and Expo. Houston, Texas, Paper 5-C.
[20] SZADA-BORZYSZKOWSKI W., 2011, *Hard coal as a raw material for new generation liquid fuel production* (in Polish). Science Seminar of UHJT Institute. Koszalin University of Technology.