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Production of Ecological Fuel from Charcoal Using High Pressure Water Jet

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1. Introduction

Different methods of coal processing into fuel [1, 5, 14] usually require its intensive comminution. Such situation needs creation of new technologies for coal micronization [3, 13, 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 [7, 9]. Such technology let to produce fuel from powdered coal in water slurry [4, 8] or in energetic fluids (methanol or low viscosity oils) [2, 10].

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 [5, 12]. It is a result of coal much higher resistance to pressing stresses than to stretching ones [6, 15, 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 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.

The aim of this work is presentation of the charcoal micronization effects using high-pressure water jet, as a potential new kind of ecological fuel. Original technological equipment and measurement instruments as well as research methodology are presented in. Charcoal micronization effects characterized by particles distribution, its quality and process energy consumption are given too. Finally a technological outline of such ecological water-fuel production is presented in the paper.

2. Research methodic

A prototype of hydrojetting grinder (Fig. 1) was used for coal disintegration which was constructed after examining of other types linear grinders [11, 17]. Such construction work is similar 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, and such apparatus was used for testing charcoal micronization.

Such machinery was used for fine charcoal comminution of granularity range 0.5–2 mm and process efficiency range 8–30 g/s. Water output was changed at the range of 0.2–0.5 dm^3/s and its pressure range of 50–300 MPa. Hydromonitor basing on HDP164 type (p_{max}=300 MPa, Q_{max}=0.5 dm^3/s) pump was used for such water output generation.

Analysette 22 Micro Tec analyzer was used for testing different particles fractions of comminuted charcoal. It enables fast results valuation of particles size range of 80 nm up to 2 mm. FEI Quanta 200 microscope equipped with chemical analyzer type EDAX Genesis XM 2i was used to observe comminuted fine charcoal 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. 1. General and detailed view of hydrojetting comminution apparatus prototype
Rys. 1. Widok ogólny i szczegółowy prototypowych urządzeń do rozdrabniania hydrostrumieniowego

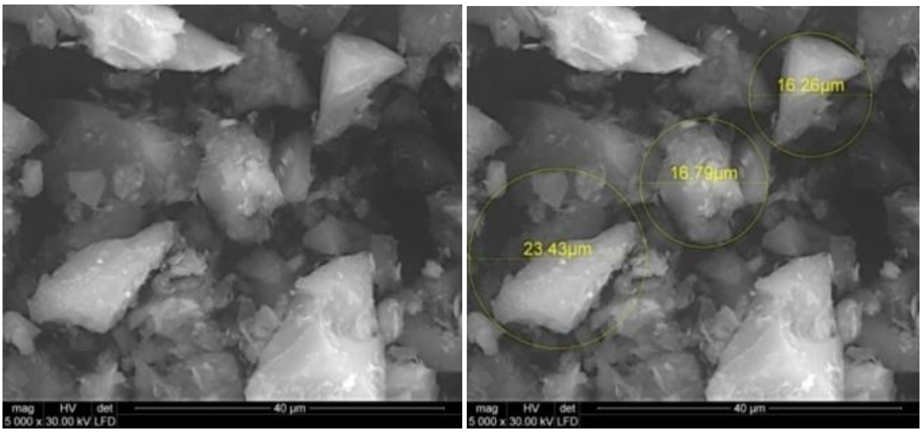

Fig. 2.SEM view of comminuted coal particles [8]
Rys. 2. Obrazy SEM cząstek rozdrobnionego węgla[8]

3. Charcoal particles distribution

Production of ecological fuel is realized during micronization of charcoal using high pressure water jet. A milled charcoal of particle size not exceeding 2 mm in diameter is used for the process (Fig. 3).

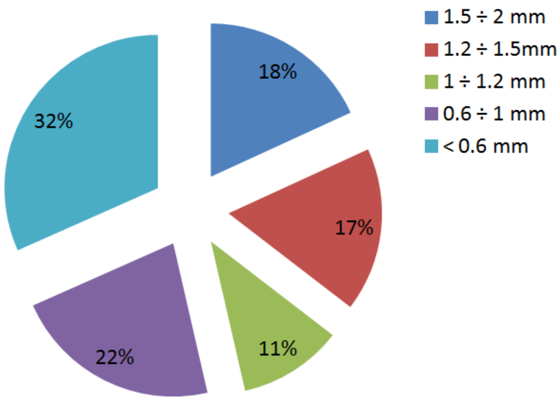

Fig. 3. Percentage composition of charcoal charge before waterjetting comminution
Rys. 3. Procentowy skład nadawy węgla drzewnego przed rozdrabnianiem hydrostrumieniowym

In order to achieve high efficiency of coal burning process one should obtain proper particles comminution with high-pressure water jet. Evidence for this can be observed in exemplary distribution of charcoal particles, which are presented for 100 MPa in Fig. 4 and for 150 MPa in the next Fig. 5.

Each of these diagrams was created as a sum of approx. 20 individual curves printed automatically by Analysette 22 Micro Tec apparatus. As it comes out from the analysis, the charcoal comminution is most often characterized by particles fractioning of the range of 10–20 μm. For the lower water pressure (100 MPa), charcoal micronization gives less repeatability (Fig. 4). Such process effects also in diversification of diagrams shapes for respective tests. In turn, increasing water pressure (Fig. 5) is favorable, ensuring charcoal comminution giving smaller particles.

All these observations can be also confirmed in the following research realized for higher water pressure: 200 MPa (Fig. 6) and 250 MPa (Fig. 7).

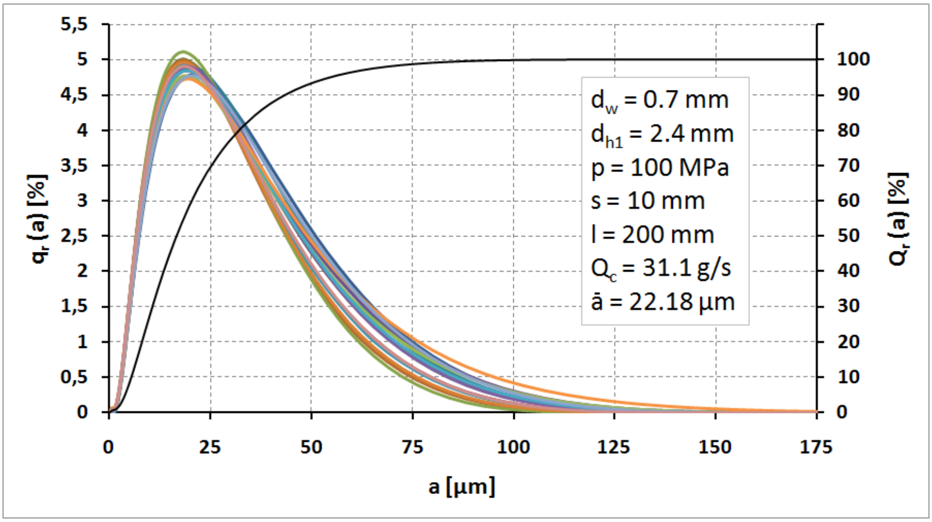

Fig. 4. Distributions of charcoal particles fractions comminuted with water pressure of 100 MPa
Rys. 4. Rozkład wielkości cząstek węgla drzewnego rozdrabnianego strugą wodną o ciśnieniu 100MPa

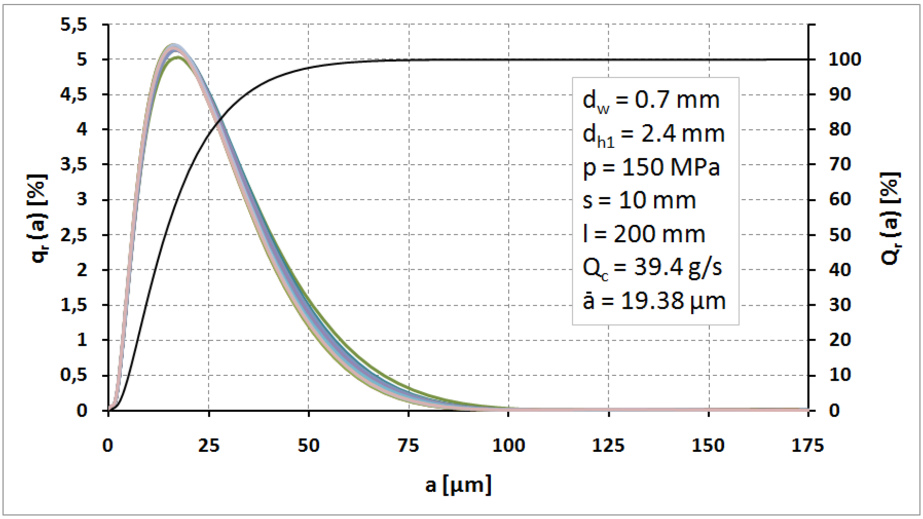

Fig. 5. Distributions of charcoal particles fractions comminuted with water pressure of 150 MPa
Rys. 5. Rozkład wielkości cząstek węgla drzewnego rozdrabnianego strugą wodną o ciśnieniu 150 MPa

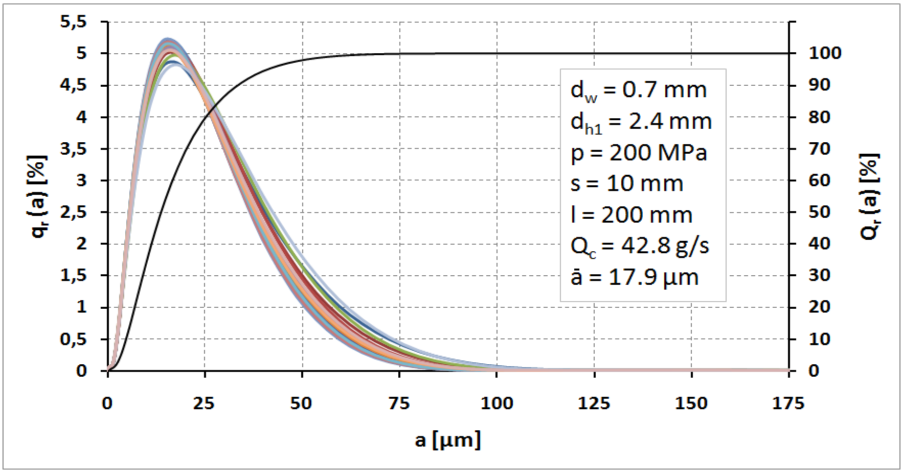

Fig. 6. Distributions of charcoal particles fractions comminuted with water pressure of 200 MPa
Rys. 6. Rozkład wielkości cząstek węgla drzewnego rozdrabnianego strugą wodną o ciśnieniu 200MPa

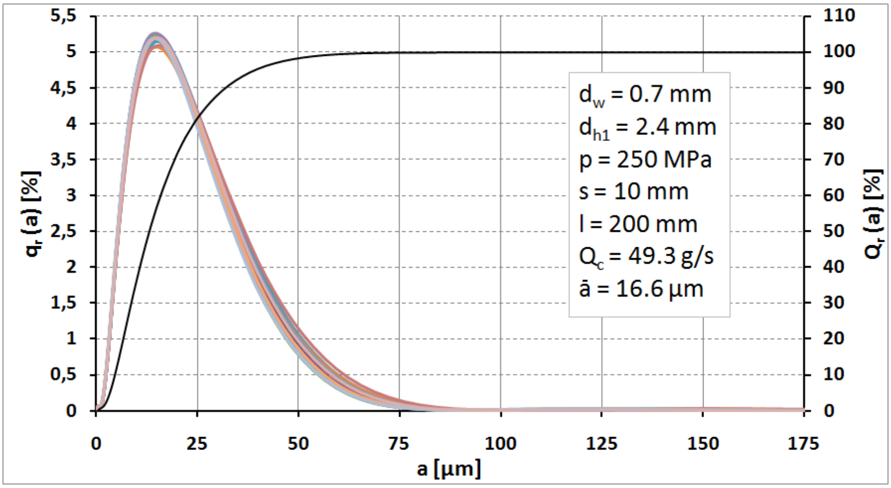

Fig. 7. Distributions of charcoal particles fractions comminuted with water jet pressure of 250 MPa
Rys. 7. Rozkład wielkości cząstek węgla drzewnego rozdrabnianego strugą wodną o ciśnieniu 250MPa

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 0–43 μm for processing water pressure of 100 MPa and respectively reaches 0–34 μm for150 MPa, and 0–33 μm for 200 MPa and the range of 0–31 μm for water pressured up to 250 MPa.One can see from above research of charcoal comminution using water jet of working pressure over 150 MPa that all that effects are similar in character and therefore material processing of such pressure is the most favourable.

4. 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 a bio-fuel. 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. 8).

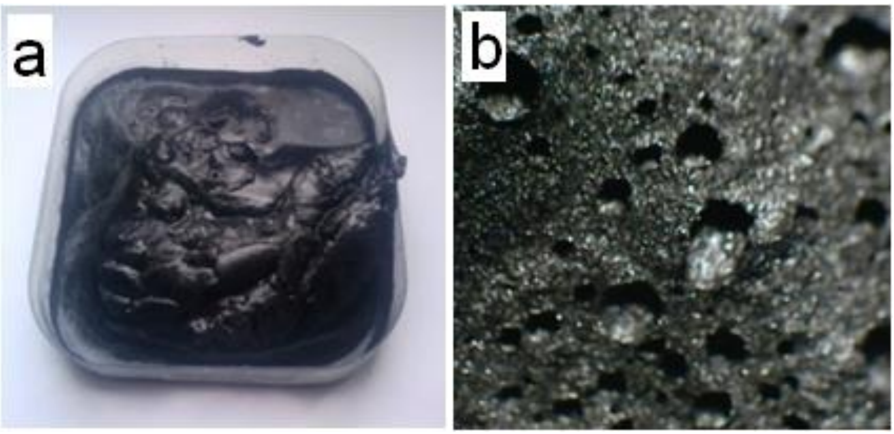

Fig. 8. Air-dried charcoal mass (a) of great porosity (b), comminuted with high-pressure water jet (p= 250 MPa) [8]
Fig. 8. Wysuszona na powietrzu masa węgla drzewnego (a) o wielkiej porowatości (b), rozdr obniona wysokociśnieniową strugą wody (p = 250 MPa)[8]

However in reality created in this 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 ecological charcoal fuel, are presented in Fig. 9.

Estimated simulation results realized for porous morphology and pyramid form of charcoal particles created during water jet comminution point out that their real surface increases even up to 660 times comparing to specific surface of usual fine charcoal. Such feature is very important taking into account efficiency of charcoal conversion into new bio-fuel.

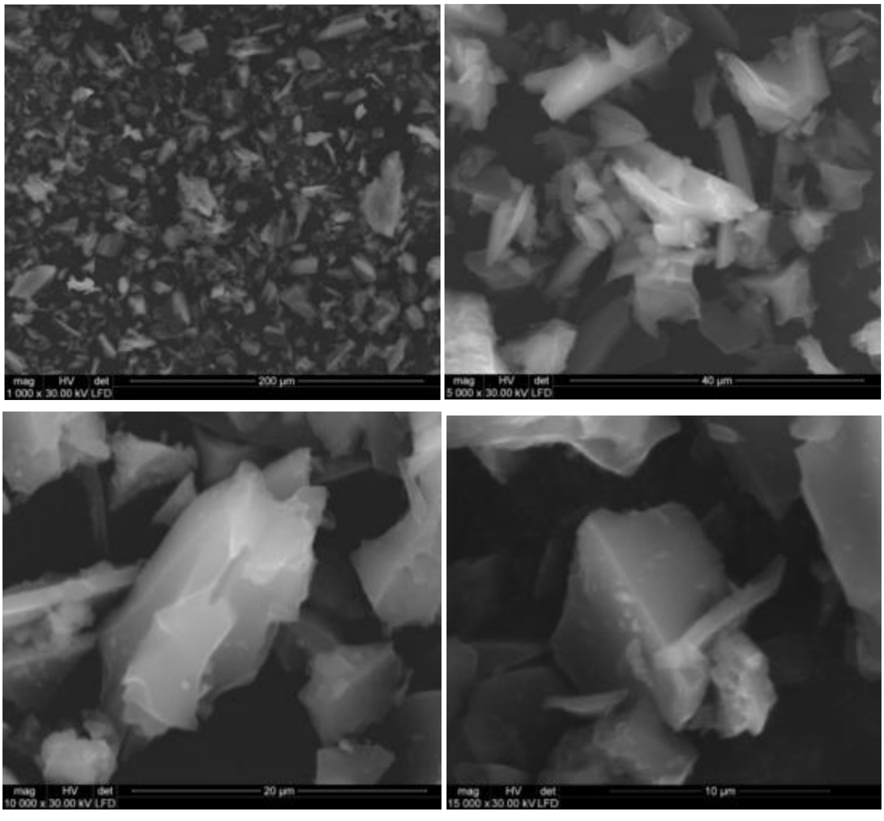

Fig. 9. SEM pictures of charcoal showing different stage of their specific surface development [8]

Fig. 9. Obrazy SEM cząstek węgla drzewnego o różnym stopniu rozwinięcia ich powierzchni właściwej [8]

5. Energy consumption on the process

Energy consumption necessary for charcoal 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 charcoal. Subtracting the value of energy lost in this way from fuel calorific value one can obtain corrected real fuel value.

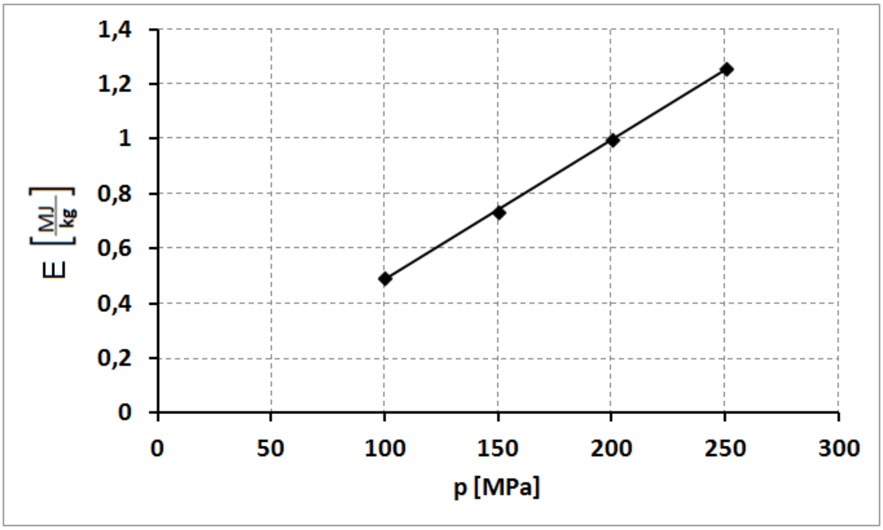

Fig. 10. Dependence of unitary energy consumption E indispensable for processing of 1 kg of charcoal vs. water jet pressure (d_w = 0.7mm; d_{h1} = 2.4mm, s = 20 mm)
Fig. 10. Jednostkowe zużycie energii E, niezbędnej do rozdrobnienia 1 kg węgla drzewnego w funkcji ciśnienia wody (d_w = 0.7 mm, d_{h1}= 2.4 mm, s = 20 mm)

The major step was the research concerning influence of fine charcoal hydrodynamic conditions. Exemplary graphs of unitary energy consumption occurring in comminution of charcoal vs. water pressure are presented in Fig. 10. It comes out that 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 water pressure for fine charcoal comminution.

6. Production of ecological charcoal-water fuel

Basing on the charcoal micronization research realized for wide parametrical range, an original method of ecological charcoal-water fuel production was developed. General view of the technology is given in Fig. 11.

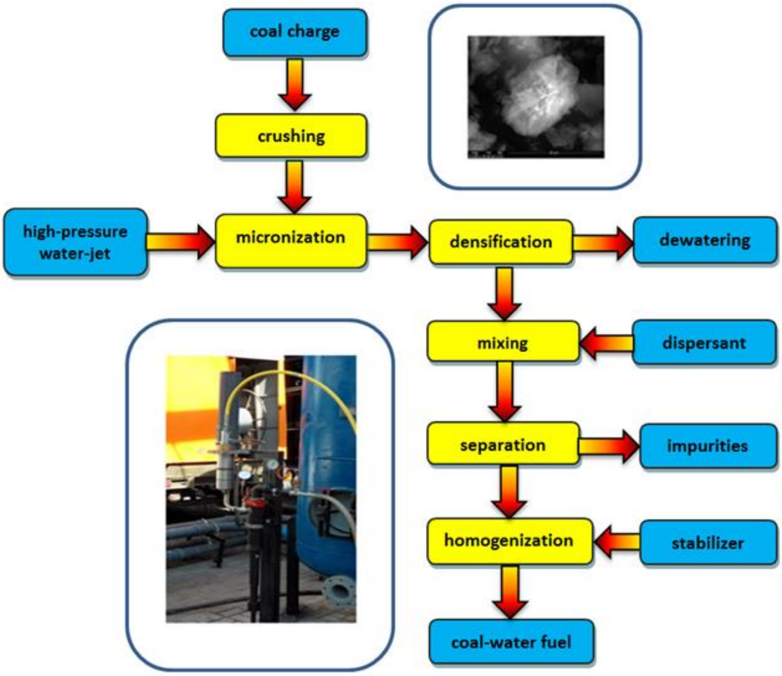

Fig. 11. Technology outline of quasi-liquid charcoal-water fuel production
Rys. 11. Zarys technologii wytwarzania quasi-płynnego paliwa z węgla drzewnego i wody

This method usage let to produce C-H_2O fuel mixture which emits several times less of harmful substances during combustion then it occurs in conventional processes. Its high practical usability is an effect of pollutions emissivity reduction, and that is crucial aspect of being environmentally friendly. Moreover combustion process of such two-phase fuel ensures improvement of physic-thermal and hydrodynamic processes comparing to combustion of traditional coal fuel.

7. Conclusions

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

- Small charcoal resistance for stretch stresses causes that water jet technique usage for comminution is very effective.
- The most often comminution fractions of charcoal are the range of 10–20 μm, and higher water pressure leads to production of more fine particles.
- Amount of approx. 90% of charcoal is comminuted after the first stage of hydrojetting comminution and such material becomes range of 0–43 μm for processing water pressure of 100 MPa while respectively reaches 0–34 μm for150 MPa. Similar comminution effectof the range of 0–33 μm can be observed for 200 MPa and the range of 0–31 μm for water pressured up to 250 MPa.
- Energy consumption necessary for charcoalcomminution 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 charcoal calorific value and unitary consumption of energy used for such micronization.
- Unitary energy consumption necessary for comminution processing of charcoal 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.
- The optimum conditions for effective charcoal comminution with high-pressure water jet can be achieved for processing water pressure of approx. 130 MPa.
- Hydrojetting charcoal micronization causes that created particles surface has often a porous morphology and pyramid form and thanks to that their real surface increases even up to 660 times comparing to specific surface of usual fine charcoal.
- 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 originalmethod as very effective technique for high-pressure water jet charcoal comminution.

8. Nomenclature

a, ā [mm] – unitary, mean size of coal particle,
d_{h1} [mm] – homogenizing nozzle diameter,
d_w [mm] – water nozzle diameter,
dQ3 [%] – frequency of unitary value occurrence of coal particle size,
E [MJ/kg] – unitary energy consumption,
l [mm] – homogenizing tubelength,
p [MPa] – water jet pressure,
Q_c [g/s] – efficiency of hydro-jetting coal comminution,
s [mm] – the length of high-pressure water jetting.

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Wytwarzanie ekologicznego paliwa z węgla drzewnego przy użyciu wysokociśnieniowej strugi wodnej

Streszczenie

W artykule przedstawiono efekty badań nad mikronizacją węgla drzewnego przy użyciu wysokociśnieniowej strugi wodnej, które są prowadzone w Instytucie Niekonwencjonalnych Technologii Hydrostrumieniowych. Zaprezentowano w nim oryginalny sprzęt technologiczny do wytwarzania nowego rodzaju paliwa ekologicznego oraz unikalną aparaturę pomiarową, a także metodykę badań. Zbudowany młyn hydrostrumieniowy, pracujący w zakresie ciśnień wody 50–300 MPa i wydatku 0,2–0,5 dm^3/s, stosuje się do rozdrobnienia węgla drzewnego o ziarnistości 0,5–2 mm z wydajnością rzędu 8–30 g/s.

Przeprowadzone badania wykazały dużą przydatność tego urządzenia do mikronizacji węgla drzewnego. Dzięki temu uzyskuje się najczęściej frakcje cząstek o wymiarach 10–20 μm, natomiast 90% zawartość wytwarzanych cząstek węgla, w zależności od ciśnienia wody, mieści się odpowiednio w przedziale wymiarowym:0–43 μm dla ciśnienia 100 MPa; 0–34 μm dla 150 MPa; 0–33 μm dla 200 MPa oraz 0–31 μm dla 250 MPa. Powierzchnia właściwa cząstek powstających podczas takiej mikronizacji węgla drzewnego wzrasta około 660 razy w porównaniu do analogicznej powierzchni użytego miału węgla drzewnego. W badaniach tych stwierdzono, że w zakresie stosowanych ciśnień, jednostkowe zużycie energii jest wprost proporcjonalne do ciśnienia wody. Zatem najbardziej korzystnych efektów można oczekiwać w zakresie najniższych ciśnień. Ostatecznie więc określono, przy uwzględnieniu wszystkich badanych tu parametrów, że optymalne warunki mikronizacji węgla drzewnego występują przy ciśnieniu strugi wodnej rzędu 130 MPa.

Podatność węgla drzewnego na intensywne rozdrabnianie pod wpływem hydrodynamicznych udarów strugi wodnej stwarza realną możliwość jego przetwarzania na nowy rodzaj quasi-płynnego biopaliwa. Na podstawie wyników badań własnych, przeprowadzonych w szerokim zakresie parametrów mikronizacji węgla drzewnego, opracowano zarys oryginalnej technologii wytwarzania nowego rodzaju paliwa ekologicznego.