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# The concept of coke based proppants for coal bed fracturing

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**Abstract.** The concept of a new type of coke-based proppant for hydraulic fracturing of coal seams for coalbed methane extraction is introduced. Our solution will facilitate gas inflow into the well due to the fact that the proppants will be resistant to embedment into the coal formation, and gas flow through porous coke grains will be possible even in the case of their partial penetration into the coal rock. Low density of the material will enable suspending the proppant particles in low viscosity frac fluids, which in turn will allow for: decreased flow resistance, minimizing water consumption and better well cleaning. Coke based proppants will allow to increase the performance of hydraulic fracturing operations in coal seams, resulting in improved efficiency of obtaining coalbed methane. The new product will be presumably suitable for stimulation treatments in other, soft rocks or even allow hydrocarbon exploitation from the formations that were previously considered as unproductive.

## 1. Introduction

The technology of fracturing the reservoirs containing hydrocarbons achieved its mature phase, nevertheless the stimulation treatments in soft rocks, especially in the Polish coal seams, encounter technical difficulties related to, among others, the phenomenon of pushing the proppant grains into the surface of fracture wall (embedment phenomenon). The proposed concept concerns the development of a new product – a coke-based proppant for hydraulic fracturing of coal seams, for producing coalbed methane. The concept is based on the assumption that new proppants will be more effective than the conventional products traditionally used to support and maintain the permeability of fractures created during hydraulic fracturing of coals or other soft rocks. The use of a new proppants will facilitate the gas inflow into the wells due to the fact, that the proppants will be resistant to embedment in the coal rocks, and gas migration through porous proppant grains will be possible even in the case, when they partially penetrate into the rock. Low density will facilitate the suspension of the proppant particles in the fracturing fluids of low viscosity, which will allow for: lowering the pumping pressure, minimizing water consumption and better well cleaning.

## 2. The purpose of the work and the scheme of their implementation

The coke material as a component of proppants has not yet been integrated with other, previously used, hydraulic fracturing proppant materials and appropriate frac fluids. Newly proposed proppant should:

- enable effective filling of the created fracture,
- ensure compatibility with coal formation and fracturing liquid,



- show an advantage over conventional proppants in terms of minimizing the embedment phenomenon and ensure adequate permeability of the generated fracture,
- have lower density and higher porosity than conventional proppants.

An adequate set of experimental works and tests has been planned, allowing to achieve the VII level of technological readiness. The implementation of this objective requires industrial research and development works leading to the prototype proppants, whose features are verified in conditions close to operational (space environment), and elaboration of technological recommendations for the use of proppants as well as indication of their suitability for specific reservoir conditions.

Main challenges for the use of proppants in hydraulic fracturing in coal seams are as follows:

- resistance to compressive stresses of 13.8 MPa, where less than 10% of grains are destroyed,
- conductivity of the proppant pack above  $130 \cdot 10^{-15} \text{ m}^2 \cdot \text{m}$  for 2% KCl,
- dimensionless conductivity of the proppant-filled fracture (proppant layer), greater than 40 [-]
- proper transport and deposition of proppant grains in the induced fracture,
- the ability to monitor the quality and extent of the proppant layer supporting the gap,
- compatibility of the proppant with the coal formation and the fracturing liquid,
- maintaining the fracture system of proper conductivity in the coal seam,
- reduction of the embedment phenomenon, consisting of:
- minimizing the depth of pushing the grains into the fracture wall (coal rock) to less than 20% of the average grain diameter, and
- maintaining the fracture wall surface with less than 35% permeability damage
- minimization the effect of fracture damage during methane extraction,
- minimization water and materials consumption.

Seven stages of work are planned for the implementation of the new proppant concept:

*Stage 1* - Density separation and grinding of coke material to obtain the product with the optimal shape and strength properties.

At this stage, it is planned to select and apply appropriate methods of coke modification in order to obtain optimal materials in terms of their strength and use as a proppant. Two groups of cokes received from coking plants will be analyzed:

- coke dust (coke breeze) with a granulation of 0.5 - 3 mm
- coke of a grain size  $> 5 \text{ mm}$ .

Due to the different grain size in both groups, the tests will be carried out using different methods of separation and grinding:

- grinding of coke that allows to obtain grains with the highest sphericity and roundness, according to PN-EN ISO 13503-2 [1], API RP 56 [2] standards.
- classification using a hydrocyclone and vibrating sieve, in order to uniform and separate several grain classes,
- enrichment using density separation methods; the purpose of enrichment is to remove grains with excessive mineral content that reduces the strength of the coke material.

In case of wet separation methods, initially it is planned to evacuate the air from the pores of the material and then, after placing it in a water slurry, modify its surface with physicochemical methods using reagents to improve the dispersion of the medium. The coke material after separation will then be dewatered.

Coke materials for hydraulic fracturing have much smaller grain size than blast-furnace coke or fuel coke, therefore when choosing the coke dust of the highest mechanical strength and resistance to abrasion, a laboratory method using the Roga drum will be used. Defining the parameters and origin of coke materials selected for further analyses, and determining the methods of modification will allow to obtain optimal materials for the new proppants.

*Stage 2* - Tests of the basic material properties to determine the suitability of coke as a proppant, and selection of coke materials or their modifications to achieve parameters consistent with the standards for proppants.

Based on PN-EN ISO 13503-2 [1] and API RP 56 [2] standards, specifying the parameters of hydraulic proppants, the physical, chemical and strength tests of coke grains will be carried out. They will identify coke samples that meet the criteria required for propping materials. The literature survey revealed that sphericity and roundness of coke grains were examined only for the production of anode electrodes [3]. The bulk density of coke is 0.7-1.1 g / cm<sup>3</sup>, and the actual density - about 1.7-2.1 g / cm<sup>3</sup> [4-9]. Compressive strength of coke was analyzed mainly to determine its behavior in a coke oven [10, 11]. It is assumed that coke is able to withstand a compressive stress of 10-20 MPa [12].

Understanding the structure and optical texture of coke grains will help to optimize the selection of material for new proppants. If none of the coke samples considered in the study will meet the requirements of the PN-EN ISO 13503-2 [1] and API RP 56 [2] standards, these tests will also help to identify the cause, and indicate how to adjust the treatment method of the coke grains. The analysis of the coke structure will mainly include the assessment of its pore space by means of gas adsorption and mercury porosimetry. The total porosity of coke reaches about 40-60%, and the specific surface area is about 1-8 m<sup>2</sup> / g [8, 9, 13-15]. Cokes of lower porosity and lower specific surface area are characterized by higher compressive strength [7, 8, 15-17].

In order to visualize the pore space and analyze the changes occurring in coke grains during the strength tests, computer microtomography (micro-CT) will be used. Studies on the morphology of coke grains will include the observation of topography of the surface and shape of grains, and the grain cracks, using a scanning electron microscope (SEM). This method allows obtaining a three-dimensional image of tested material in micro and nanoscale and is used for testing various types of coke [6, 18].

Optical texture (microtexture), i.e. the size, shape and orientation of anisotropic and isotropic areas in coke will be examined using optical microscopy. This feature is closely related to physicochemical, microstructural and mechanical parameters [8, 9, 19-21], which makes it possible to assess the suitability of coke for various technological applications. It was found, that the higher proportion of the isotropic phase in the coke, the higher is the resistance to abrasion. The presence of inert (non-carbonized) components affects the strength of coke. When they are present in large quantities and in bigger size, they promote cracks and the mechanical strength decreases [21]. On the other hand, the small organic inert particles increase the strength of coke, especially when they have a rounded shape, and they are regularly arranged [11, 21, 22].

The above mentioned tests will facilitate the selection of the best coke for proppant production or, if necessary, help to identify the reasons why coke samples do not meet the PN-EN ISO 13503-2 [1] and API RP 56 [2] standards.

*Stage 3* - Determination of the interactions between proppant material (including hybrid proppant), fracturing fluids and formation water.

Interactions with fracturing fluids, and long-term reactions with reservoir fluids trigger the degradation of proppant grains (in the case of mineral proppants this may result from dissolution and re-precipitation of secondary minerals). This may cause loss of permeability of the fractured deposit. Moreover the frac fluid absorption in the proppant and formation rock should be the subject of thoroughful tests (e.g. [23]). Simultaneously, there may occur changes in composition and properties of the fracturing fluids themselves [24], this determines the flowback composition and selection of the proper method of its treatment [25]. The main factors controlling the stability of proppants are the reaction time and composition of the brines. Previous studies have not found any direct influence of the proppant coating on its chemical stability [26].

The work of McLin et al. [27] on the modeling of water-rock-proppant interactions in geothermal reservoirs, in combination with static experiments, allowed to state that proppants based on silicates and bauxite can dissolve or serve as nucleating agents for secondary minerals.

Brinton et al. [28] presented experiments conducted with bauxite proppants and quartz sand. The results of SEM observations indicate the possibility of dissolution of quartz sand proppants in silica undersaturated formation water. It was also found that dissolution of the proppant can lead to an increase in porosity and conductivity of fractures.

Proppant tests, at conditions of different concentrations of fracturing fluids, showed a reduction in permeability under the influence of solutions with high salinity, while low salinity did not cause significant decrease in permeability. This phenomenon is explained by chemical corrosion processes. Local dissolution of the proppant particles leads to the destruction of its structure and to the zonal supersaturation of the solution, followed by precipitation of minerals and lowering the permeability in other zones [29].

Aggressiveness of reservoir waters is crucial for the stability of proppants even in conditions of low water saturation [30]. Dissolution in high salinity environments is associated with chemical corrosion, the effects of which are most intense on stress-transmitting contacts between the proppant grains. At low initial salinity of the solution, supersaturation is not possible, hence the crystallization of minerals and permeability reduction is unlikely.

The phenomenon of fracturing gel breakage, in presence of resin-coated proppants, along with the method of measurement was described by Harris [31]. Interactions between coated proppants and crosslinked fracturing gels can affect fluid rheology, and in some cases, cause fracturing to end prematurely. This may be caused by the loss of crosslinker from the liquid as a result of complexation on coating of the proppant grain [32]. A similar phenomenon can be expected, when a coke-based coated hybrid proppant will be used.

Currently, fracturing gels the structure of which can be thermally broken in a controlled way by the temperature rise, or by enzyme and oxidative breakers addition, are often used in the industry. It was found however, that at temperatures above 49 °C, when persulphate oxidants were used, breaking the gel structure was problematic [33].

The following set of works is planned in the Stage 3:

1. Autoclave experiments - to investigate reactions and structural changes in proppants under the influence of fracfluids and brines, in simulated reservoir conditions.
2. Examination of structure and composition of proppant grains after experiments, using scanning microscopy with EDS analysis and microtomography (micro CT). The aim of this work is to assess degradation of proppant grains, changes in porosity, loss of coating (in the case of coated proppants) and dissolution or precipitation of mineral phases.
3. Analysis of the chemical composition of frac fluids and reservoir water using the ICP-AES and GC-MS methods during experiments, which will allow to determine the evolution of their composition under the influence of contact with the proppant.
4. Testing the compatibility of proppants with fracturing fluids using simultaneous thermogravimetry, differential scanning calorimetry and infrared spectroscopy (TGA-DSC+FTIR). These tests will allow to determine the stages and intensity of proppant and fracturing liquid transformations in conditions of increasing temperature.
5. Assessment of changes in strength of proppants under the influence of liquid-proppant interaction.

Exploration of these interactions will allow to optimize the composition of the treatment fluid and reduce damage of the fractured formation.

*Stage 4* - Development of coke proppants and alternative, composite materials based on coke material (hybrid proppants).

For hydraulic fracturing of coals seams, fracturing fluids and proppants dedicated to conventional and unconventional deposits, are being applied. These include gelled, crosslinked, viscoelastic and VES fluids, as well as energized fluids and foams [34].

To ensure the gas flow from the deposit to the wellbore, the induced fracture is filled with proppant. For hydraulic fracturing operations in coals, large quantities of classical proppant are used, e.g. quartz sand, ceramics [35]. In order to increase the strength and conductivity of the classical

proppant, different proportions of the components are used (e.g. grains with increased compressive strength are added), or grains are chemically processed (resin coating). To determine the conductivity of the proppant layer, the API RP 61 [36] and PN-EN ISO 13503-5 [37] standards are used, covering respectively short and long conductivity tests, in which the proppant material is placed between two flat metal or rock shapes of specific dimensions [38].

It is considered that the conductivity and permeability of the proppant pack depends on the following factors: surface concentration of proppant, compressive stress and their operating time, temperature and composition of fracturing fluid and reservoir water [39].

As part of the implementation of stage 4, the following works will be carried out:

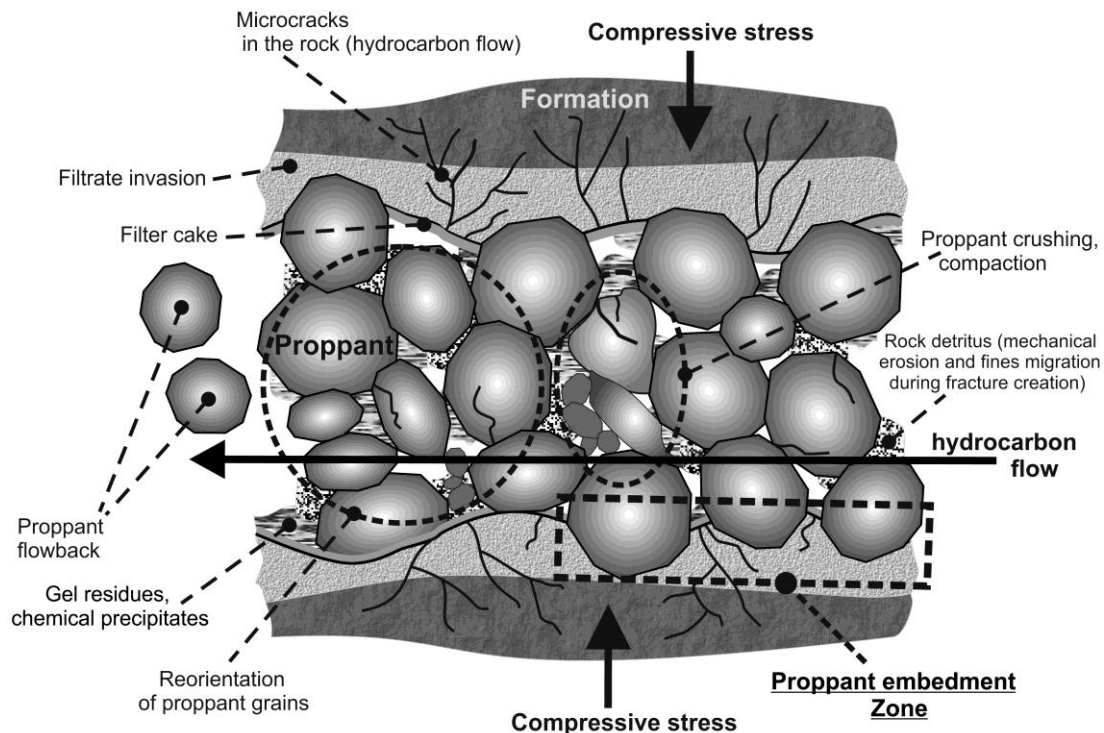
1. Strength tests of developed coke and hybrid proppants for various compressive stress values. For all proppants, crush tests will be carried out, performed according to the procedures described in the PN-EN ISO 13503-2 standard [1].
2. Proppant pack permeability and conductivity tests for coke and hybrid proppants will be performed on a test setup, consisting of a hydraulic press, an API chamber and a data recording and analysis system. They will take into account the effect of compressive stresses and temperature on the primary permeability and conductivity of the proppant pack, at a given surface proppant concentration and the duration of stress. The impact of fracturing fluids and formation water on reducing the permeability and conductivity of the developed proppant pack, under given PT conditions will be also explored.
3. Optimization of the composition and proportions of hybrid proppant components, based on the strength and conductivity for the hybrid proppant pack, in order to improve its parameters. The optimization will include mixing coke with commercial proppants, in appropriate proportions, taking into account the grain size, compressive strength and the material density.

*Stage 5* - Investigations on the embedment phenomenon of coke and hybrid proppant grains into the wall of the created fractures, taking into account the influence of fracturing fluids.

In practice, many methods of laboratory simulation of the embedment phenomenon, microscopic imaging of the fracture wall surface and interpretation of the obtained results are used [40-44]. The laboratory simulation of this phenomenon is performed, using, among others, the API chamber, for testing the conductivity of the proppant pack, and specially designed chambers or sleeves, to compress the proppant. During these tests, the proppant is placed between the rock shapes or the surfaces of the fracture formed along the cylindrical core. It is then subjected to compressive stresses and temperature in presence of frac fluids at a given time.

After the laboratory simulation of the embedment phenomenon, damage to the fracture wall surface is observed under the microscope. This phenomenon is related to the formation of dents on the surface of the wall, originating from grains of proppants or their crumbs, after hydraulic fracturing (after the fracture closure). Both the width, depth and number of dents on the tested surface of the fracture wall, affect the size of the pore space available for the flow of released hydrocarbons, as well as the width of the induced fracture.

This phenomenon affects the conductivity of the proppant pack and hydrocarbon flow through the fracture from the deposit to the wellbore. In order to minimize this negative phenomenon, proppant with lower roundness and sphericity parameters as well as fracturing with low water content liquids (energized fluids, foams) are used. This applies in particular to the hydraulic fracturing of ductile rocks or rocks prone to crumbling. Embedment is often accompanied by a decrease in the pore space of the rock within the fracture wall, and reduction of the flow of hydrocarbons from the rock to the propped fracture - figure 1.



**Figure 1.** The phenomena affecting the effective packed fracture, after the hydraulic fracturing of the reservoir formation [45].

To minimize these negative phenomena the following works have been planned:

1. Research on the embedment phenomenon of coke and hybrid proppants. Geometric parameters of the pore space damage within the fracture wall will be determined. In addition, impact of the embedment on the decrease in the original fracture aperture, which was obtained by propping it with new proppants, for given conditions, will be investigated.
2. Optimization of the composition and proportions of hybrid proppant components, in terms of minimizing the embedment phenomenon. This will allow for a more effective filling of the created fracture and, consequently, for a larger hydrocarbon flow for specific reservoir conditions. The optimization, as in the Step 4, will include mixing, in appropriate proportions, of coke propellant grains with the commercial proppants.

*Stage 6* - Development of bases for coke-based proppant production technology.

Based on the research carried out in stages 1-5, the assumptions of the technology for the production of coke-based proppant material will be developed. The current experience in the production of proppants will be taken into account [46,47].

An appropriate way to prepare proppant from the coke will be known (Stage 1). Coke considered as an optimal individual propping material or a component of hybrid proppant will have the parameters determined in the Stage 2. The effects of its interaction with fracturing fluids and formation water (Step 3) and permeability and conductivity will be recognized and accepted (Step 4). The effects of embedment will also be determined (Stage 5). Guidelines for the method of producing the optimal proppant, according to PN-EN ISO 13503-2 [1] and API RP 56 [2] standards, presenting all processing operations performed by means of the equipment in the laboratory and semi-technical scale, will be used in the creation of the technological scheme. On this basis, the technical scale equipment adapted to the assumed proppant output will be selected, and the documentation prepared. An important element in the production technology project is the development of power supply, control and monitoring methods for individual components of the installation [48].

In the case of hybrid proppants, its components will be combined in a proportion determined as part of the Stage 4. Within the framework of the production technology of hybrid proppant, there will be included a method of transportation of coke material and conventional proppant to the place of these components mixing. The assumptions will also define technical aspects of the mixing method and indicate suitable machinery for this purpose. Technical documentation of the technological line will be prepared. In order to verify its efficiency, a prototype of the installation should be designed and built, in accordance with the process requirements.

In Stage 6, the following works are planned:

1. A flowchart of the coke-based propane production steps. It will cover individual technological nodes, sampling points for control analyzes and the scope of these analyzes. It will also indicate the measures to proceed in a situation where the control tests show that the coke for proppant production or the proppant itself does not achieve the required parameters.
2. Technical documentation of machinery. The selection of machines and devices will be carried out for the expected production efficiency (output). Then, a specification of the operating conditions and installation parameters will be made.
3. A project of a prototype installation that will enable assessment, verification and optimization of the proppant production process. The project will include the power supply, control and monitoring of the plant components. A way of material transportation between particular technological nodes will be defined as well as the method of storage of raw material (coke) and the product (proppant).

*Stage 7* - Development of technological recommendations for the use of new proppants and indication of their suitability for geological conditions in specific coal deposits.

Before each hydraulic fracturing operation, or recommending new technology of frac fluids and proppant systems for specific reservoir conditions, computer simulations of fracturing process in the reservoir formation are carried out using commercial software, such as FRACPRO package [49]. They give the possibility to evaluate and determine the optimal fracture geometry, proppant conductivity and the required perforation area. This helps to assess the proppant distribution, improve fractures conductivity and dimensions [50]. It also allows to determine proppant permeability damage due to crushing, settling, stress cycle and non-Darcy flow. Based on mathematical simulations, fracturing scheme and parameters are determined, such as: fracturing pressures, fractures propagation, properties of the propped fracture depending on the distance from the well [51, 52]. The result is a numerical model describing the near-well zone along with the induced fracture.

As part of the implementation of Stage 7, the following works will be carried out:

1. Analysis of reservoir and technological conditions of hydraulic fracturing in coal formations. This is aimed at information on: formation depths, temperature and pressure, permeability, porosity, petrographic composition, saturation with hydrocarbons, reservoir fluids, mechanical properties of coals and stresses in rock massif. The technological conditions of the fracturing operation, such as borehole construction and depth, and method of the treatment, considering frac fluid and proppant parameters, will also be analyzed.
2. Selection of proppants and preparation of technical and technological recommendations for fracturing with the use of the developed proppants. To accomplish this task, numerical simulations will be performed to design and analyze fracturing treatments. This will enable modeling the fracturing process to assess and determine optimal fracture geometry and proppant permeability, the impact of proppant damage due to crushing, settling, stress and multiphase flow. The simulations will allow to evaluate possible length of induced fractures within the deposit and the volume of hydrocarbon flow from the rock to the wellbore.

### **3. The original features of coke proppants**

The proposed concept is in general described in the patent application P.418516, 2016: "Proppant for use in hydraulic fracturing of coals", filed in 2016 by the Oil and Gas Institute – National Research Institute in Cracow [53]. The research on the state of the art has shown that no inventions have been



patented for such a solution, however, worldwide, there are numerous other patents covering various types of proppants for fracturing hydrocarbon deposits as well as coal seams. For example, in patent No. US7726399 [54] an ultra-light proppant (ULW) has been described for use particularly in coal. According to the description, it comprises a base material, as peanut shells, quartz, glass, sand, silicates, partially covered with a protective or hardened coating. Other modified proppant materials are also known, such as resin-coated sands (RCP), described, among others, in patents US3962491 [55], US 4157993 [56], and sands coated with a hydrogel coating, patent WO2013033391 [57]. Another invention concerns hydraulic fracturing using a slurry of petroleum coke particles, described in US 366420 [58]. The fine particles, introduced into the end of the induced fracture, form a zone of reduced permeability, which allows the fracture to expand during the further injection of the frac fluid.

The new coke based proppants for hydraulic fracturing of coals, according to our concept are characterized by the following features that distinguish them advantageously against the background of current proppants:

- The chemical affinity of the coke based proppants composition, to the fractured coal, enables the extraction of demethanated coals as an energetic or chemical raw material, or application of underground gasification technology. The fractured coal seam is not "contaminated" with proppant like in the case of fracturing with sand or ceramics.
- High porosity (and potentially high permeability) of proppants allows for easier migration of gas. The total porosity of coke material may reach 50%, while open porosity - 15%. This feature facilitates the migration of gas through the propped fracture, and also through the coke grains, in contrast to the majority of conventional proppants. The migration of gas through the proppant grains can occur even in the case of their partial embedment into the fracture wall.
- The proppant grains porosity allows also for saturation of its grains with appropriate reagents, which while released after filling the fracture with the proppant allow enable additional control over the stimulation process – e.g. the behavior of the fracturing liquid after the stimulation.
- The structure of coke proppant reduces its embedment into the fracture walls. The development of the surface of coke material (roughness) provides support for the fracture wall in many points and reduces the effect of the embedment phenomenon compared to proppants with smoother surface grains, such as: quartz sand, ceramics and resin coated materials.
- Low density, facilitating the suspension of proppant particles in the frac fluid, and easy pumping through the fractures. Bulk density of coke material (e.g. coke breeze) may be close to  $0.57 \text{ g / cm}^3$ , which is much lower than for sand (e.g. Northern White Raw Frac sand - bulk density  $-1.49 \text{ g / cm}^3$  for 40/70 mesh) and even from ultra-light proppants (FracBlack HT -  $0.66 \text{ g / cm}^3$  for 30/80 mesh). Low bulk density and specific density of coke and hybrid proppants enables them for more effective use with low viscosity fluids - energized fluids or foams. It also allows to inject larger amounts of proppant into the formation, in order to reach more distant parts of the gas field from a certain borehole.
- The new coke-based proppant has higher electrical conductivity relative to the surrounding formation rocks. The average electrical conductivity for raw coke material is  $0.437 \text{ 1/}\Omega$ . This allows to assess the extent of propped fracture, by means of electrical resistivity method, that is not possible in the case of conventional proppants, which are characterized by a low contrast of electrical conductivity in relation to fractured formations.
- In hybrid proppants, mixtures of coke based proppant and classic proppants (e.g. quartz sand, coated proppants), the material of higher strength takes over majority of the stresses that might have closed a fracture. At the same time, porous coke proppant particles allow migration of hydrocarbons into the wellbore.

#### 4. Potential benefits of coke based proppant applications

New proppant will allow to increase the performance of hydraulic fracturing operations in coal seams and, as a consequence, improve the efficiency of obtaining coalbed methane. It is assumed that the new product will also be suitable for stimulation treatments in other, soft rocks or even allow hydrocarbon exploitation from the formations that were previously considered as unproductive. This will increase the share of natural gas on the domestic gas market, reduce imports and increase energy security.

The concept of new proppants foresees that they will simultaneously improve work safety in coal mines, and contribute to ecological effects compared to conventional fracturing methods.

Methane drainage of coal deposits prior to their exploitation, by means of hydraulic fracturing with the use of new proppants will increase the safety of future mining operations. Recently, the extraction from methane coal seams in Poland, accounts for approximately 70% of total production of hard coal. Hard coal deposits of the central and southern part of the Upper Silesian Coal Basin are classified to III and IV methane hazard category [59]. The Carboniferous deposits are covered by thick impermeable layers of Tertiary and Quaternary sediments. Under these conditions, methane gas remains in the coal seams, and poses a threat to mining operations. Through the implementation of fracturing procedures using the developed technology, the methane hazard category will be reduced from IV (methane content higher than 8 m<sup>3</sup>/Mg in pure coal substance) to II (methane content from 2.5 m<sup>3</sup>/Mg, to 4.5 m<sup>3</sup>/Mg). This result will be verifiable provided that new proppants are implemented in practice; effects will be visible after at least a few years of use of the proposed solution. The use of methane gas obtained from coal seams, with the help of the new proppants, instead of coal fuel, will contribute to the reduction of CO<sub>2</sub> and dust emissions to the atmosphere. It is estimated that using coalbed methane, CO<sub>2</sub> emissions will amount to approx. 53 kg/GJ, compared to 90 kg/GJ for hard coal fuels. The use of coke based proppants will reduce the amount of water used in hydraulic fracturing of coal seams. New proppants, due to low density, in relation to sands or most ceramic proppants, enable the use of low-water frac fluids (e.g. foams with 50% of water).

#### 5. Summary and conclusions

The concept of a new type of coke-based proppant for hydraulic fracturing of coal seams for coalbed methane extraction is introduced in the paper. Our solution will facilitate gas inflow into the well due to the fact that the proppants will be resistant to embedment into the coal formation, and gas flow through porous coke grains will be possible even in the case of their partial penetration into the coal rock. Low density of the material will enable suspending the proppant particles in low viscosity frac fluids, which, in turn will allow for: decreased flow resistance, minimizing water consumption and better well cleaning. The implementation of the concept includes the following activities:

- Tests of the basic material properties to determine the suitability of coke as a proppant, and selection of coke materials or their modifications to achieve parameters consistent with the standards for proppants.
- Development of coke proppants and alternative, composite materials based on coke material (hybrid proppants), and determination of the interactions between proppants, fracturing fluids and formation water as well as investigations on the embedment of proppant grains into the wall of the induced fractures, considering the influence of fracturing fluids,
- Development of bases for coke-based proppant production technology and technological recommendations for the use of new proppants with indications of their suitability for geological conditions in specific coal deposits.

Coke based proppants will allow to increase the performance of hydraulic fracturing operations in coal seams, resulting in improved efficiency of obtaining coalbed methane. The new product will be presumably suitable for stimulation treatments in other, soft rocks or even allow hydrocarbon exploitation from the formations that were previously considered as unproductive. The results of the planned works, due to the highly specific properties of the new proppants, will potentially boost the technological progress in the field of stimulation of methane drainage from coal seams. The

implementation of the planned results is possible within a few years horizon, however, this is related to the priorities of the energy policy of the state and economic determinants for the coalbed methane production.

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