The Use of Selected Raw Materials for Preparation Coal-Based Suspension Fuel

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Abstract

Preparation of suspensions based on coal as fuels capable to replace liquid hydrocarbons is a new, intensely developed trend in the economic and technological optimization of combustion systems. The article presents results of coal-water suspensions tests. Coal from Polish mines was used for their preparation as well as other energy-bearing components as alcohol, glycol and char from rubber pyrolysis. It was developed several recipes suspension meet previously established conditions for the calorific value, rheological parameters and stability. The selected suspension was combustion a laboratory plant equipped with a burner of similar design to those used in boilers oil. Performed tests have shown the possibility of combustion the suspension, in this type of construction.

Keywords: coal-water suspension, suspension fuel, combustion, rheology, char, coal, burner

Suspensions of coal and water have been applied in many countries all over the world, including China, Russia, Italy, France, Japan, Canada, Sweden, Ukraine and USA. In 21st century the greatest participation in the production and development of the technology of producing suspensions, as the substitute of liquid and gaseous fuels to the power plants, belongs to China, Japan and Russia [1]. The production of coal-water suspension in China is one of the directions of the development of so-called clean coal technologies [2] and the suspensions are combusted in 90 blocks of power ranging between 1.5 and 200 MWe. In 2005, in Nanhai, the block of power reaching 200 MWe [1].

The interest in the production of coal-water suspensions in the world, among others, results from the possibility to decrease the use of conventional liquid fuels, necessity to increase the range of using coal as fuel, the need of hydrotransport of coal, or the need to dose coal in the processes of combustion, gasification, etc., increase in the efficiency of combustion processes, diminishing of the emission of gaseous pollutants from coal-heated boilers. [3,4]

The advantage of the application of coal-water suspensions is, among others, lower emission of SO_2, fly ash [5], NO_x, [6] (due to lower temperature of the process), as well as high efficiency of the combustion process reaching 96–98% [7]. Stricter and stricter standards of maximum emission level (nowadays, according to the Directive of the European Parliament and the Council of Europe [8] for coal boilers with the power of 50–100 MW are for SO_2 400 mg/m^3, for NO_x 300 mg/m^3, and the maximal emission of suspended particles was defined on the level of 30 mg/m^3), encourage the development of low-emission technologies, among which coal-water suspensions.

Poland now takes second place in the world, regarding the share of the coal in electric energy production. Nowadays it exceeds 88% [9]. On one hand, during burning of 1 kg of hard coal, about 84.6–94.6 kg CO_2/GJ is emitted to the atmosphere. Other pollutants are also emitted [10]. On the other hand – the application of this fuel is desirable, because of the balance of natural energy resources of Poland. To limit the phenomenon of excessive emission and increase the efficiency of the energy production, mining sector applies deeper enrichment of coal, which results in the increase of the amount of wastes, in particular fine-grained [11]. Long time practice showed that, such side products of coal mining can be applied as the raw material to prepare coal-water suspensions [12].

Studies on the preparation of coal-water suspensions are carried out in the whole world. However, there is a lack of easily available data on the compositions of ready-to-use suspensions, often being a secret of a company. The method of obtaining coal-water suspensions, created, among others in the Institute of Inorganic Chemistry and Technology of the Cracow University of Technology [13] involved the use of various assortments of pellets (Jaret), dusts and silts. The content of coal ranged between 50 and 60%, and the content of stabilizing additions was 20%. The decrease of

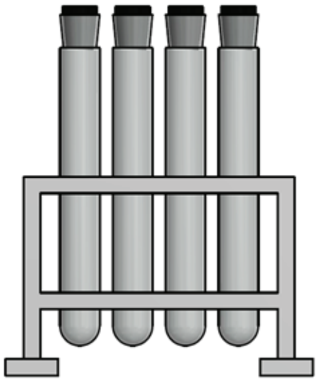

Fig. 1. Instrument for stability evaluation

Rys. 1. Stanowisko do oceny stabilności suspensji

Tab. 1. Heating value of substances used to prepare suspensions

Tab. 1. Ciepło spalania substancji użytych do przygotowania zawiesin

The name of the substance	Heat of combustion, kJ/kg
Ethylene glycol	22 059
Used oil	47 762
ethanol	29 455
Hard coal I	32 701
Hard coal II	25 076
Char	27 665

emission NO_x compared to the raw coal by 50%, and SO_2 – almost by 60%. The research carried out by Kubica and Smołka [14] showed that the efficiency of burning coal-water suspension, decreases exponentially with the increase in the viscosity of the suspension.

The promising ways of the use of coal-water suspensions include the replacement of fuels such as oils or natural gas, the use of hard coal in the cases of low quality coal, the use of small coal fractions lying on the spoil tips, or co-combustion with other fuels. Taking into account the amount of unused raw material and its price, coal-water suspension or wider: suspension fuels can make an interesting alternative in the fuel market in Poland.

Coal-water suspensions can be also attractive raw material for the gasification and combustion. Their application allows the simplification of technological facilities and increases the safety of the work of a boiler or reactor. In the process of gasification, water introduced into the suspension, later on makes the source of gasifying factor, in the form of water vapor. Dosing the coal-water suspension to the dispersion reactors allows the application of higher process pressures and influences well the composition of gas to chemical applications [15]. Moreover, there is a possibility to apply the coal-water suspension as auxiliary fuel in energy systems, or in the high furnace [16] and also as fuel to engines [2]. Suspensions have one more advantage: a low cost of production and use, also while calculating into caloricity.

The phase system coal-water, making suspension of grinded coal in water can be treated as independent mixture of fuels. However, more often, despite a popular definition, coal-water suspension or fuel, different colloid solutions can be found with or without water. Several characteristic kinds of liquid coal-based fuels can be differentiated [14,16,17]. These are:

a) coal-water fuels – typical coal-water suspension consists of coal, water and chemical additions. The impact of such variables as kind and caloricity of coal, the degree and distribution of the granulation, kind and amount of chemical additives, or the very way of producing suspension can significantly influence rheological properties of suspension.

b) coal-oil fuels– the suspension of coal in heating oil, containing up to 10% of water

c) coal-oil-water fuels are formed of the suspension of coal in oil, e.g., heating oil and water, while the mass proportion of water is above 10%

d) methanol-coal-water fuels are made of the suspension of coal in methanol and its water solution.

Tab. 2. Composition of suspensions after modification

Tab. 2. Składy badanych suspensji

Suspension 1	Suspension 2	Suspension 3
hard coal I	hard coal II	hard coal II
glikol	char	ethanol
water	ethanol	water
surfactant	water	surfactant
	surfactant	
Modifying component:		
used oil	used oil	used oil

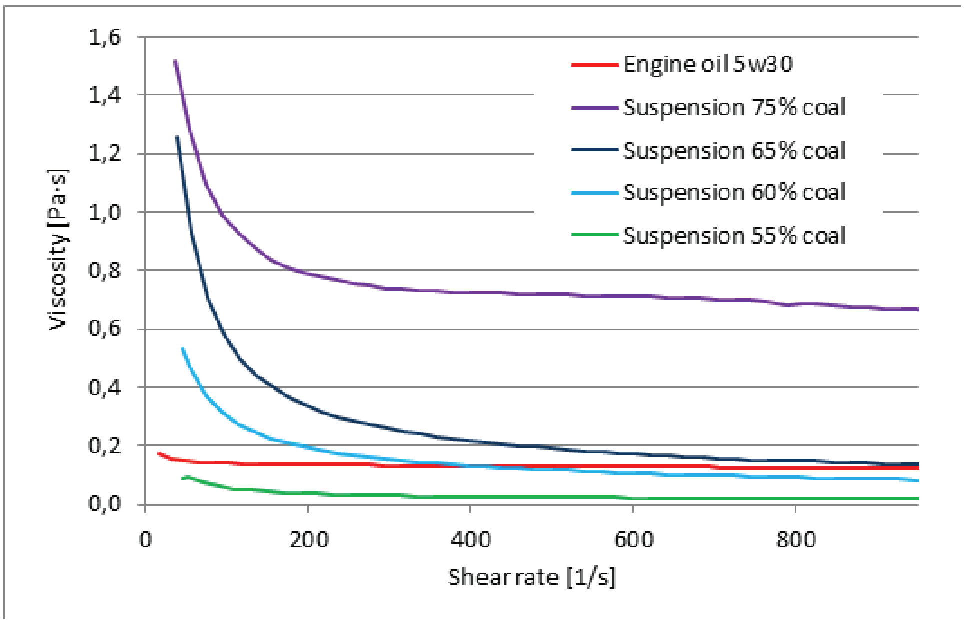

Fig. 2. Viscosity curves suspensions containing different amounts of fine coal as compared to the curve of the viscosity of the engine oil 5W30

Rys. 2. Krzywe lepkości suspensji o różnej zawartości miału węglowego w porównaniu do krzywej lepkości oleju silnikowego 5w30

Selection of components and preparation of suspension

The properties of suspension depend on the applied components and accepted recipes, but also result directly from technological solutions in fuel delivery and its combustion or gasification.

To prepare the suspension, which could substitute selected liquid fuels, it is necessary to fulfill several conditions referring to the properties, such as:

- granulation of the solid phase,
- consistency,
- caloricity,
- stability.

The first, initial criterion to define the usefulness of coal or other solid fuel for the suspensions is granulation and maximal size of the grains in particular. This criterion results both from the specifics of suspension – greater grains sediment faster (decreasing the stability of suspension in time), as well as technical requirements of the instruments, especially the burner (including the size of the intake passages) [19].

Other properties of coal, such as caloricity, promptness to sintering, and the content of ash are also important.

A subsequent criterion in the coal-water suspensions is consistency, and more precisely, the rheological properties. Depending on the kind of installation, in which they should be applied, the requirements in the area of the rheological properties can vary. A natural direction of the application of suspension is partial or complete replacement of other liquid fuels, mainly hydrocarbons (oils of

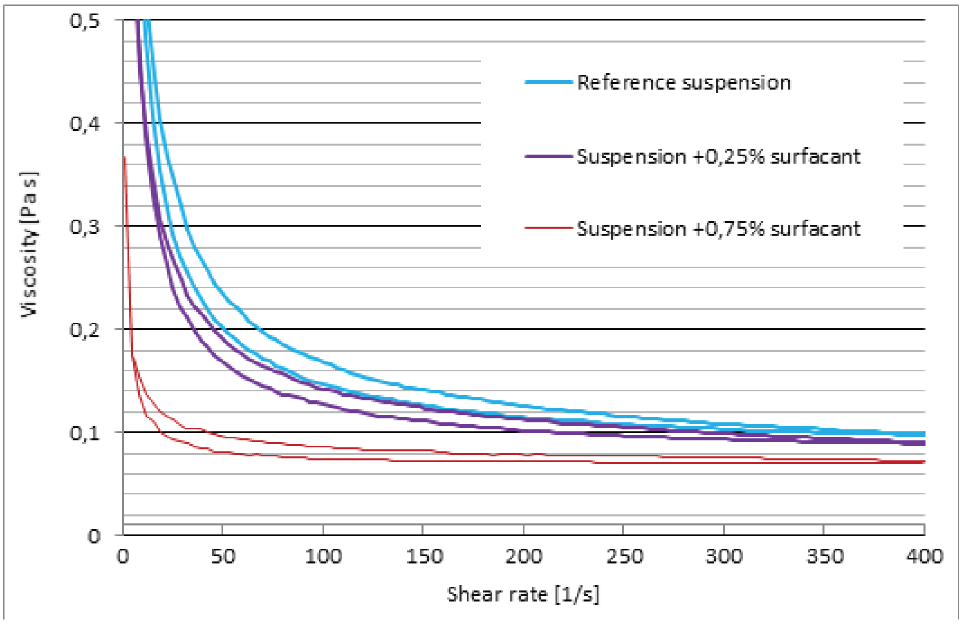

Fig. 3 Viscosity curves suspensions containing different amounts of dispersant

Rys. 3. Krzywe lepkości suspensji o różnej zawartości dyspergatora

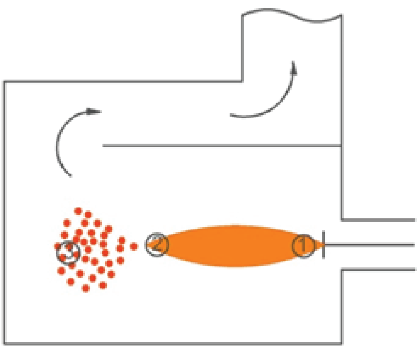

Fig. 4 The measuring of Saymon - KROLL designed to burn suspensions: (left) scheme of the combustion chamber, (right) general view , the numbers marked visors

Rys. 4. Stanowisko pomiarowe firmy SAYMON-KROLL przeznaczone do spalania zawiesin; (lewa) schemat komory spalania, (prawa) widok ogólny, cyframi oznaczono wizjery

different types). Thus similar consistency of the suspension is required, such as heating oil, or received in recycling – refined used oils. Usually it is expressed in one parameter – dynamic viscosity or, referred to density – kinematic viscosity). Due to large diversity of the applied liquid fuels, the recommended viscosity of the values of dynamic viscosity can range between 60 and 200 [mPa·s], but can also reach 700–1000 mPa·s^2). One should, however, remember that in concentrated colloid systems the phenomenon of thixotropy can be observed, i.e. the decrease of the viscosity of liquid caused by the mechanic force [20]. It is connected with other character of rheological properties. Coal-water suspensions, also these with the addition of other components, are liquids of more complex properties than water, of the majority of oils. Respectively to the description of their properties, other than Newtonian rheological models are applied, characterizing by a constant value of viscosity, regardless the value of the deformations (here: share rate) [21]. Comparison of the rheological properties of coal-water suspensions of different content of solid particles, and also engine oil of sign 5w30 is presented in fig. 1. Particularly distinct is different shape of subsequent curves of floating: in case of oil 5w30, viscosity practically does not depend on shear rate, which is here the measure of strain. This influence is visible in case of coal-water suspensions, and its meaning grows with the increase of the participation of solid parts.

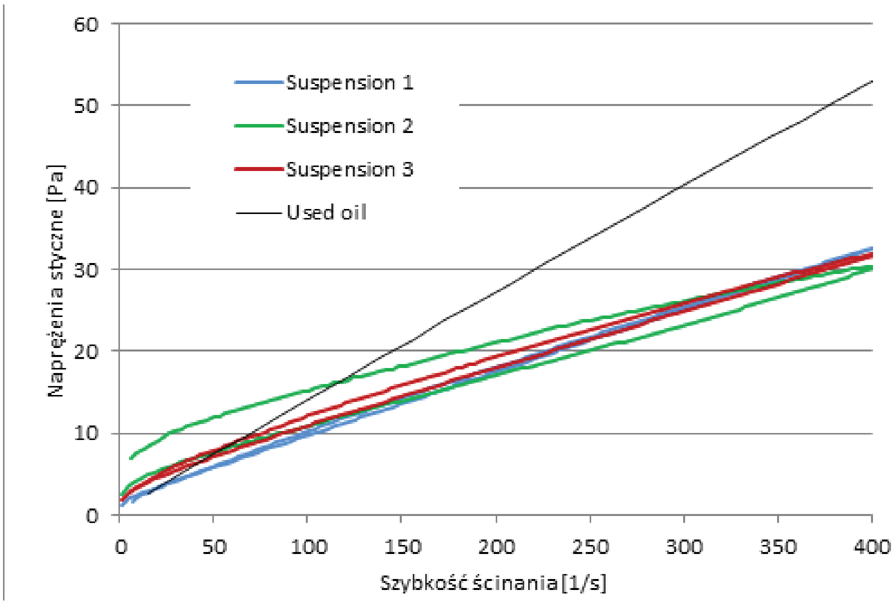

Fig. 5. The flow curves of the suspensions tested and oils used to modify their properties

Rys. 5. Krzywe płynięcia badanych zawiesin oraz oleju użytego do modyfikacji ich właściwości

The condition of acceptable viscosity is usually contradicted with subsequent significant parameter – caloricity of the suspensions. The suspensions applied for energy purposes have to be characterized by minimal values of combustion heat, usually defined on the level of 15–20 MJ/kg. This requirement is difficult to fulfill, if the only energy component is coal, and becomes impossible when it is necessary to apply poor quality coal or waste products. In such cases it is necessary to apply additional energy components.

An important factor characterizing the usefulness of coal suspensions as fuels, is their stability. Although obtaining the required rheological parameters is an important task for the combustion process itself, preserving them in the required period is necessary to preserve the continuity of this process, and also safety of preserving or transporting the suspension. Only the fuel of established and stable parameters can have real commercial significance.

The definition of particular requirements for the stability of suspension is not an easy task, due to the lack of clear requirements in this area. The most popular methods of the measurement of the stability of coal suspensions, applied both in the laboratory as in the installations [14,22]

– Organoleptic analysis – observation of the changes in sedimenting suspension. Despite the fact that it depends on human factors, and consequently, it is the least accurate method, it allows relatively easy and simple definition of the suspension stability.

– The frozen mass analysis – allows an approximate definition of the value of the changes in the suspension concentration. However, it does not allow the definition of the intensity of the sedimentation process. It does not permit on-line measurements of the changes in suspension concentration and the method is time consuming.

– The method of stability measurement by the measurement of the changes in suspension concentration taken on a certain depth. It causes disturbance in the structure of the examined suspension. This method in not very accurate, either.

– T bar method, allowing the measurement of the stability of suspensions made of the different kind of coal, also in the function of temperature. This does not allow the definition of quantitative changes in the concentration of coal suspension.

When there is the necessity of the improvement of rheological parameters and stability of coal suspension, there is also the possibility to apply various surfactants. [6,20,23] The participation of such addition is limited by the growing cost of the suspension, which can badly affect the competitiveness. Because of this, temporary recycling of the stored in the containers suspensions without additives is quite popular [1].

The obtaining of suspensions fulfilling all the requirements is not a simple task, but the studies in this direction are very advanced [24,25,26]. A significant problem is also the accessibility of devices adjusted for the combustion of this fuel in Poland, on the big market. The purpose of the carried out

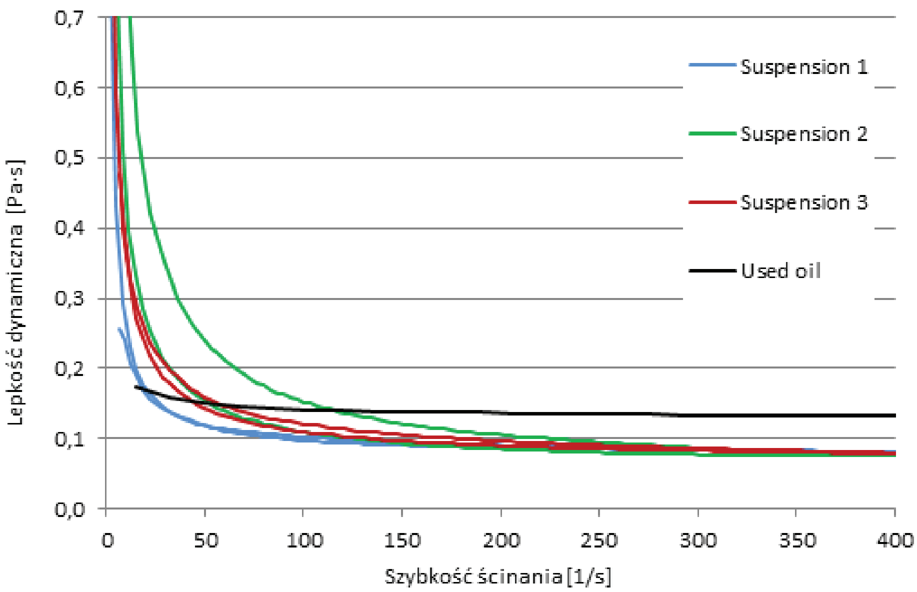

Fig. 6. The viscosity curves of the tested and suspensions of oils used to modify their properties

Rys. 6. Krzywe lepkości badanych zawiesin oraz oleju użytego do modyfikacji ich właściwości

studies was to prepare the suspension based on coal, with the highest possible application of wastes and checking the possibility of their combustion in oil burner, specially prepared for this purpose.

Subject and methods of the studies

Coal-bearing raw materials used in the preparation of the coal-water suspension were two fine-grinded kinds of coal, coming from the Polish mines, and also ethanol, glycol and – added in the last stage of experiments – used oil. Moreover, one component added, apart from coal, was coal-bearing waste, in the form of char, coming from the pyrolysis of the used tires. Such material is sometimes used as solid fuel or as black pigment in varnishing [27]. Combustion heat of individual components of suspension was put in table 1.

To prepare solid components of definite granulation, the ball mill was applied. Granular composition was defined with the use of Analysette 22 by Fritsch.

The measurement of combustion heat and the calorific value of raw materials used to prepare the suspension and the calorific value of suspension were carried out on calorimeter LECO AC-350, according to the requirements of standard PN-ISO 1928:2002.

The rheological properties of suspension were studied on rheometer RHEOTEST® RN 4.1 working in a cylindrical system. The measurement was carried out with increasing and then decreasing rotation speed. The result of such measurements are hysteresis loops.

The evaluation of the stability of the prepared suspension was conducted organoleptically. For this purpose it was necessary to design and construction of a new measuring station. For this purpose the station fo sedimentation process was used as shown in fig. 1. The tested suspensions were placed in cylinders, which are then closed with vent plugs. The measured parameters were the time of phase separation and sedimentation time of particles for each suspension. To accurately assess the process used additional light source, which was directed to the cylinders from the bottom. In addition, the cylinders were overexposed to the laser beam across the entire height.

The last stage were the trials with the combustion of suspensions carried out in the laboratory scale, in the stand equipped with the boiler for heating oil with the blow burner produced by SAYMON-KROLL. Due to the built up viewfinders, it is possible to make observations of the combustion process. The stand and scheme of the combustion chamber with the viewfinder is presented in fig. 4.

Results

Based on literature studies, parameters and requirements of the experimental installation, and also initial studies basic minimal criteria for suspensions were established in the area of:

• granulation – maximal size of grains 125 [μm],

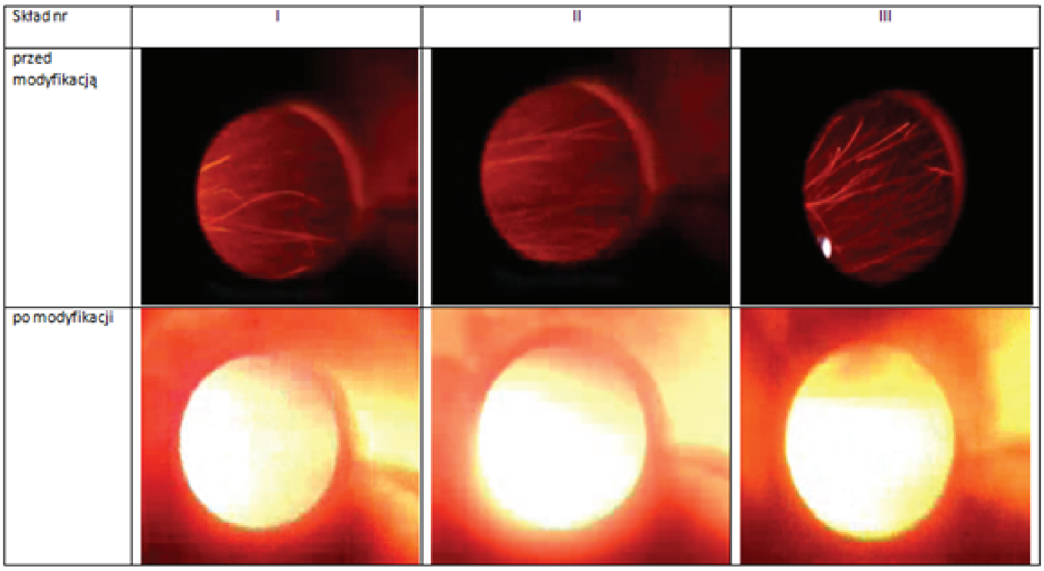

Fig. 7. Comparison of flames of burning suspensions before and after modification

Rys. 7. Porównanie płomienia spalanych suspensji przed i po modyfikacji

- dynamic viscosity – 100 [mPa·s],
- combustion heat – 19 [Mg/kg],
- stability: time of the distribution on the laboratory stand – 3 [h].

Three multi-component suspension were prepared. They varied both in the fraction of solid parts as well as the applied components (table 2.).

Granular composition or grinded and sieved coal and char fulfilled the assumed requirement, moreover 90% of coal II and char grains were smaller than 63 µm.

The rheological properties of the suspension were presented in the form of flow curves and viscosity curves in fig. 4 and 5, respectively. Despite differences in the composition, all the three suspensions were characterized with very similar course of both characteristic curves.

Based on the carried out measurements of stability of the suspension, it was defined that the time of the separation in case of the studied suspension is about 3 hours, and the suspension with the addition of stabilizing substance – 12 hours.

The most important stage of the studies were the attempts of combustion the prepared suspension in the experimental stand. To achieve this, the attempts to ignite every suspension separately were made. In case of failure, used oil was added as stabilizing substance.

Suspension 1

The purpose of suspension modification was the improvement of the flammability properties of the mixture. After adding over a dozen percent of oil, a small change (increase) in the viscosity of suspension occurred. Despite the initial ignition, jamming of the orifice of the burner with the grains of excessive size (above 100 µm) was observed.

Suspension 2

After the failure in ignition, the first modifications suspension – by adding used oil was made. After mixing, the attempt to inflame the suspension on its own was made, which did not happen. So the burner was used, where pilot fuel was used as substitute fuel. Suspension was taken for the combustion process, which was observed after the increase of the length of the flame, compared to the flame only with the application of pilot fuel. After diminishing the inflow of pilot fuel, the flame was extinguishing, which indicates the lack of spontaneous combustion of the suspension. Even after adding heating oil in the amount 50% of the volume, the fuel did not indicate the ability of spontaneous combustion. During the co-combustion the temperature of exhaust gases was about 100°C. Further addition of oil to obtain the desired properties was assessed pointless from economic point of view. Fogging of viewfinders was observed.

Suspension 3

Suspension was burning only in the presence of pilot fuel. Oil was added to the system to determine the borders, at which there would be independent combustion of the blend. For this purpose several attempts to limit the inflow of pilot fuel, however in each attempt the flame extinguished. After substantial addition of used oil, the fuel started burning spontaneously. The obtained suspension was assessed as high calorie, due to large size of the flame, reaching the viewfinder 3 – fig. 7. As a result of significant fogging the viewfinders we did not succeed in observing the path of burning grains of coal, however, judging from the temperature of exhaust gases (ca. 115ºC) and their purity, the conclusion was drawn that the fuel was completely combusted.

Conclusions

Preparing fuel based on coal in such a way that other hydrocarbons could be replaced, is a task requiring the fulfillment of many conditions. The described in the article suspensions were made based on two kinds of finely grinded coal and water. However, they also contained other energy-bearing components, such as char from pyrolysis of gum, glycol, or alcohol, and also surfactant. Due to such a composition, the fulfillment of requirements referring to the consistency, caloricity and stability is possible.

However, only combustion tests with the use of a burner reflecting the conditions of the initiation of combustion really allow the assessment of the usefulness of such fuels. Combustion tests were carried out with the application of the burner adjusted to burning heating oil, which significantly influenced the results of tests. To each prepared suspension it was necessary to add oil as pilot fuel, despite the fact that the obtained suspensions were characterized by similar rheological parameters.

The failure in the combustion of suspension 1 resulted from the presence of grains of the size above 100µm. Only the application of coal of granulation not exceeding 63µm makes it possible to limit the risk of jamming the orifices of the burner.

As failure, should also be considered the attempt to combust the suspension with the addition of char and glycol. At present the works on the optimization of the suspension composition with all these components is made.

Ending with the success attempts of the combustion was the combustion of suspension 3, containing mainly coal, water and alcohol, allowing the optimism in looking at further studies on making the recopies for the suspension possible to be applied on industrial scale in the installations so far using liquid fuels.

It is definitely necessary for this paper, to design and make proper burner combining the features of oil burners: able to burn suspension and allowing us to remove ash without problems. The works in this direction are very advanced already.

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Wykorzystanie wybranych surowców do przygotowania paliwa zawiesinowego na bazie węgla

Przygotowanie zawiesin na bazie węgla, jako paliw zdolnych zastąpić płynne węglowodory to nowy, intensywnie rozwijany trend w zakresie ekonomicznej i technologicznej optymalizacji pracy układów spalania. W artykule przedstawiono wyniki badań suspensji węglowo-wodnych. Do ich przygotowania wykorzystano węgle pochodzące z polskich kopalń oraz inne surowce energonośne, w tym karbonizat z pirolizy gumy. Przygotowano kilka receptur suspensji spełniających założone wcześniej warunki w zakresie kaloryczności, parametrów reologicznych oraz stabilności. Wytypowane zawiesiny poddano próbom spalania na stanowisku laboratoryjnym wyposażonym w palnik odpowiadający konstrukcjom stosowanym w kotłach olejowych. Przeprowadzone testy wykazały możliwość spalania suspensji, w tego typu konstrukcjach.

Słowa kluczowe: zawiesiny węglowo-wodne, paliwo zawiesinowe, spalanie, reologia, karbonizat, węgiel, palnik