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Impact of waste soot on properties of coal-water suspensions

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ABSTRACT

The study was conducted in order to implement the principles of Clean Production (CP) in the production of coal-water fuel. Promoting environmentally friendly technologies impact on the reduction of systemic waste, emissions and inputs, which in turn is beneficial to the environment, health and social security. Coal-water suspensions can be a substitute for fuel oil, which from an ecological point of view, is very advantageous with respect to reduced emissions of CO_2, SO_2 and NOx during the combustion of fuel. To improve the rheological properties of coal-water suspensions, various kinds of additives are used. Coal materials that belong to different assortments: jaret and fine coal and waste soot were used to prepare stable coal-water suspensions. The tests were performed on a laboratory scale in a disc mill. On the basis of the results, the most favourable parameters of process have been chosen (type of raw material and additive content and grinding time). The resulting suspensions are characterised by low viscosity and density, small equivalent diameters and high stability. Gas analysis of burning process of coal-water suspensions with (and without) soot (determination of O_2, CO, NO, NO_2, SO_2, H_2S, H_2, CH_4 and CO_2) were conducted and compared.

1. Introduction

Coal-water suspensions (name convertible: coal-water liquids – CWL) are a mixture of finely ground coal and water. They can be a substitute for fuel oil, which from an ecological point of view, is very advantageous with respect to reduced emissions of CO_2, SO_2 and NOx during the combustion of fuel. In addition, combustion efficiency is almost 99%. As a raw material, for the preparation of this type of dispersions, coal waste, fine coal and coal sludge can be used (Glushkov et al., 2015). The solids content of a typical CWL fuel is 65–75% (Boylu et al., 2004). It should be characterised by good stability and low viscosity, which allows the slurry to pass into the combustion chamber. In order to improve the rheological properties of coal-water suspensions, various kinds of additives are used. In the literature, the effect of synthetic surfactants and electrolytes (e.g. sulphonic acids, lignosulphonates etc.) on the properties of the coal-water slurries is broadly described (Lee et al., 2007; Aktas and Woodburn, 2000; Gopan and Axelbaum, 2014; Seshadri et al., 2008; Panda, 2014; Naik et al., 2009; Mosa et al., 2008; Mukherjee et al., 2015a, 2015b; Shin and Shen, 2006). The literature also apply additives of natural origin (e.g. the resin) to change the physicochemical properties of water-coal suspensions; however, these additives are used to a lesser extent, and the research is still being conducted (Atesok et al., 2005; Das et al., 2013; Li et al., 2012). Some of the additives have a double function, and in addition to the dispersion of slurry, are also used during the grinding of coal in order to facilitate this process by reducing the viscosity of the slurry in the mill (low molecular weight polyelectrolytes, or mixtures of suitable glycols). The results confirmed that the rheological properties and stability of suspensions depends on the surface charge of the carbon particles and the type of additive used can be selected to modify the rheological properties of CWL (Mosa et al., 2008; Sarti et al., 1992). To apply additives on a large scale, it should be characterised not only by efficiency but also by the low price and easy availability. Following these assumptions, there were attempts to use waste soot in order to stabilise water-coal suspensions. The use of waste contributes to the reduction of its overdue amounts which is the first step to improve the economy of waste management that can bring rapid and beneficial results (Peteka et al., 2016).

Soot particles are created in the process of incomplete combustion of fossil fuels and biomass. Its major constituent is carbon in the amorphous form. Soot is a serious problem in heating, because it mounts in the chimney portion, causing a fire hazard and inhibiting the flow of the exhaust gases and it pollutes the air and surfaces onto which falls (Taghavifar et al., 2016). Observations by

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scanning electron microscopy carried out by Griffin and Goldberg showed that the soot particles have a size less than 1 μm (Griffin and Goldberg, 1979, 1981). Thanks to its size, fine particles of soot should fit into the spaces between the coal particles and hydrophobic properties of soot (Shrestha et al., 2010; Singha et al., 2015) will result in the stabilisation of water-coal slurry. The use of soot as an additive for coal-water slurry will solve the problem of stored soot and at the same time modify the properties of these suspensions.

Conducted research implies the use of waste soot in addition to coal-water slurry which can be a substitute for conventional fuels. This type of operation involving the use of waste in the production process is in accordance with the clean practices. Properly implemented CP leads to the more efficient use of energy and raw materials, lowers production costs, increases product yield and profitability of the process (Vieira and Amaral, 2016; Bai et al., 2015; Yonga et al., 2016).

Reducing emissions of sulphur dioxide and nitrogen oxides during combustion of CWL - which is the main advantage of this fuel, will significantly reduce the negative impact of the use of conventional fuels on the environment. The aim of this study was to develop a process for the preparation of water-coal slurries, allowing for the management of waste soot.

2. Materials and methodology

Coal materials which were used to prepare a suspension were: fine, flaming coal with low content of ash (called: jaret) and fine coal. The study also used the soot created in the process of incomplete combustion of methane (natural gas) to acetylene and gas. Soot was stored.

The process of preparing CWL was carried out on a laboratory scale in the mill disc. The installation consists of a reservoir with a volume of 100 dm^3 and pump capacity of 30 dm^3/h and a disc mill with a disc diameter of 150 mm. Coal and water were administered to the mill. For the preparation of ternary suspensions coal material and water were administered with soot in an amount of 2.5, 5.0, 7.5 or 10% mass. The water content was constant at 50%. Coal material was replaced with soot to make the 50% solids content. Time of milling was equal 6, 12 or 18 h.

The last stage of the study was burning CWL and measurement of gas emissions during this process. Dosage of CWL to the combustion chamber was achieved by spray nozzle of the burner disposed at the bottom of the gas damming shield. The spray nozzle was made specifically for research. It had a join for hydro-carbon fuel and a join for atomising air. Thanks to that it gave out the slurry to the furnace chamber. Positions of the two joins were parallel to each other. In the final section of the nozzle, the CWL join was directed towards the nozzle outlet so that the CWL was mixed with compressed air and its atomization occurred. The burner contained a throttle that regulated the amount of gas added to the burner. It also contained a throttle for air using in gas combustion. Combustion of obtained suspensions was carried out in a rotary kiln, heated to 800 °C. Under such conditions, measurement of emission during the process was performed.

3. Research methods

Chemical composition of raw materials was determined by XRF method. There was used compact X-ray spectrometer PW4025/00 PW4025/00 MiniPal of PANalytical B.V. company with built-in rhodium lamp (for this reason, on each spectrum is visible peak derived from rhodium). Microscopic observations are made of materials with a scanning electron microscope Hitachi TM-3000 equipped with an X-ray micro analyser EDS. Thermal analysis of materials was performed using the apparatus SDT 2960 Simultaneous DTA-DTG of TA Instruments Company. Analysis was carried out in a porcelain crucible in air at a temperature range 20–1000 °C and the increase in temperature of 20 °C/min. For determination of the chemical composition, the absorption spectra were measured in the basic the infrared (4000–400 cm^{-1}) with a spectral resolution of 4 cm^{-1} using a spectrophotometer Scimitar Series FTS 2000 from Digilab. Test samples were prepared by pelleting with KBr. The heat of combustion of jaret, fine coal and soot was determined by calorimeter KL-12Mn from Precyzja-Bit. The analysis of the C, H, and N was performed with the use of the CHN analyser from Perkin Elmer (Type 2400). Determination of the coefficient of reflectivity of the materials were made using an AxioImager 2 m polarising microscope from ZEISS with an extra table electro-mechanical (scanning) and the MCW-2 ECO control panel.

The resulting suspension was subjected to analyses that enabled the determination of usable properties. Equivalent diameter was determined by a direct method as a result of observation of the particles under a Hitachi model TM3000 scanning electron microscope at 1500-fold magnification. The images were obtained in digital form in order to size the particles and were analysed using the software NIS-Elements. Density of suspensions was determined by pycnometry method. Viscosity coefficient was determined for a shear rate of 100/min and 200/min using a rheometer Rheotest Medingen GmbH, Rheotest RN 3.1 at 25 °C. The stability of the mixtures was defined as the difference in height [mm] between the surfaces of the mixture after being prepared, with a phase boundary formed by sedimenting the coal particles 24 h after homogenisation. With the increase in height difference (H), the stability decreased. Analysis of exhaust gas in combustion processes of natural gas, coal, coal-water suspension and coal-water suspension with the addition of soot was performed. The amount of burnt coal corresponded to the average amount of coal burned in coal-water slurry. Gas analysis was performed using a Madur portable gas analyser, model GA-40T Plus, with embedded electrochemical sensors (determination of O_2, CO, NO, NO_2, SO_2, H_2S, H_2) and based on infrared absorption (determination of CH_4 and CO_2). The statistical analysis of results was carried out in version 10 of STATISTICA from Statsoft®. Using the agglomeration method obtained by coal-water, slurries were grouped in terms of their physical properties in clusters, in which the objects characterised most similar to each other and at the same time showed the least similarity to other objects in clusters. The effects of grouping are presented in the form of dendrograms, and Ward's method was used to connect clusters, which aims to minimise the sum of squared deviations within the cluster. In order to confirm the accuracy of clustering by Ward (hierarchical), the grouping by k-means method (non-hierarchical) was performed, in which the objects were transferred to different clusters, in such a way that the variability within the clusters was as small as possible, as opposed to variability outside the clusters. The effect of clustering by K-means method is a plot of the average values of objects, where none of the clusters is an undercluster of another cluster (Hill and Lewicki, 2007). As a result, objects in individual clusters have similar properties. On the basis of analysis of variance, Pareto charts were established, graphically showing the impact of independent variables on the dependent variables (standardised effects). A vertical line on the graph corresponds to the adopted level of significance ($\alpha = 0.05$) and separates statistically significant effects from negligible ones. Profile approximation was determined in order to determine the value of independent parameters which allow obtaining most desirable, estimated value of the output factor. The approximated values output quantity for each combination of input values have been converted to a desirability scale. The relative desirability of different values determines the output volume of the desirability