



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
01.11.2017 Bulletin 2017/44

(51) Int Cl.:
C10L 5/02 (2006.01)

(21) Application number: **17460023.9**

(22) Date of filing: **19.04.2017**

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**
Designated Extension States:
BA ME
Designated Validation States:
MA MD

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(30) Priority: **20.04.2016 PL 41691116**

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(54) **A METHOD FOR INTENSIFYING THE COMBUSTION OF SOLID FUELS USING ALKYL ALCOHOL AS A COMBUSTION PROMOTER**

(57) A method for intensifying the combustion of solid fuels using alkyl alcohol as a combustion promoter is characterized in that an aqueous solution of alkyl alcohol, preferably isopropanol, in concentration of 10% to 30% is prepared in a buffer tank to be supplied to a nebulization tank provided with ultrasonic transducers and a compressed air supply system. The nebulization tank is filled in a half of its volume. The nebulization process is effected by acting on aqueous solution of alkyl alcohol additive with ultrasonic waves generated by ultrasonic transducers in power range of 10 to 120 W. The compressed air flow rate is up to 2480 l/h, and the temperature is up to 40 °C. Pressure inside the nebulization tank reaches a value higher than pressure in a primary air duct, and then dispersion of the additive is dispensed continuously into the primary air duct with pulverized coal before the burner, in a temperature of solid fuel ranging from 90 to 160 °C. In alternative embodiment of the invention aqueous suspension of Al-Ni catalyst is added to the nebulization tank containing the solution of alkyl alcohol additive, wherein said Al-Ni catalyst suspension is prepared so that the catalyst content of no less than 0.046 g per 50 ml of water is subjected for at least 30 min to homogenization process with use of ultrasonic waves of power ranging from 45 to 120 W, preferably 50 W per 50 ml of homogenized suspension, then decanted. No more than 0.85 g of Al-Ni catalyst in homogenized aqueous suspension is used for every 1 l of alkyl alcohol additive solution. In still another embodiment of invented method the water dispersion of the catalyst, together with the

prepared in second nebulization tank the aqueous dispersion of alkyl alcohol additive or alkyl alcohol with the Al-Ni catalyst suspension is dispensed into the primary air duct with pulverized coal before the boiler burner.

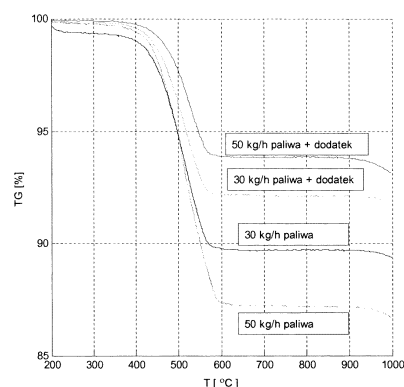


Fig. 1

paliwa = fuel
paliwa + dodatek = fuel and additive

Description

[0001] The present invention relates to a method of intensifying the combustion of solid fuels used in boilers, mainly in the heating plants and power plants.

[0002] Coal having different grain sizes and coal briquettes are the most commonly used solid fuels. The process of burning coal can be divided into two stages: separation and combustion of volatile matter, and burning of carbon residue. The length of each phase depends on the particle size, combustion conditions and coal properties, i.e. its composition and structure. Processes occurring during combustion of single particle of coal can be divided into physical and chemical ones. The most important physical processes are: water evaporation (drying), swelling (dilation) of coal particles, formation of porous structure of the char, and physical transformation of mineral substance. The most important chemical processes include: pyrolysis of coal, burning of volatiles, burning of carbon residue, and chemical transformation of mineral substances. Various types of additives that modify the processes that occur during combustion of fuels in power boilers are often used in the process of coal combustion. Especially it is desirable to prevent the build-up of soot and other deposits in boilers firing coal, lignite, coke, or culm.

[0003] Prudent use of modifiers of the combustion process can significantly contribute to the improvement of the quality parameters of exhaust emissions. Accordingly, selection of chemical composition of the fuel additive is very important, as well as the method of its administration. A number of different concepts of fuel additives have been proposed, and the most popular additives are the compounds of copper and sodium chloride. Fuel additives make it possible to reduce the burden of coal combustion thereby reducing the quantity of fuel needed for production of a unit amount of energy.

[0004] It is well known that the initial stage of combustion of solid fuel is a pyrolysis reaction and the course of the reaction is related to the presence of hydrogen stabilizing free radicals. Hydrogen may come from external sources, or internal sources of fuel. As mentioned above, efforts to improve combustion process of solid fuels and consequently improve the quality of resulting exhaust gas include usage of combustion modifiers. The best results are obtained by adding the modifier of combustion in the form of aqueous solution of alkyl alcohol, which affects dehydration process and in consequence reduction of activation temperature of dehydration reaction to conventional temperature of solid fuel feed.

[0005] In optimizing processes of combustion of solid fuels ultrasonic waves are used to reduce activation energy of dehydration reaction, thereby activating the combustion process.

[0006] From the description of Polish invention PL209480 a modifier of combustion is known, used for solid, liquid and gaseous fuels, especially wood, natural gas, coal, mazout and other hydrocarbons, and a method of modifying the fuel combustion process and the use of the fuel combustion modifier.

[0007] According to the invention mentioned above, the modifier diluted composition is dispensed into the aeration system of the combustion chamber, preferably through pumping together with air to the aeration system. The modifier of the combustion process comprises from 10% to 30% by weight of water, from 20% to 80% by weight of at least one aliphatic alcohol, from 5% to 15% by weight of carbamide or its derivatives, and from 5% to 15% by weight of morio-acetylferrocene. Addition of these compounds to primary or secondary air is conducted to reduce activation energy of the combustion process. Another aim is to intensify the entire combustion process, as well as influencing a number of different processes, however, the interactions between them are not presented. In case of aeration of the combustion chamber with cold air, the modifier is dispensed by spraying, and in case of aeration of the combustion chamber with hot air an evaporator is applied.

[0008] The invention EP0346100 discloses a method for increasing the efficiency of burning coal in a furnace by injection of an additive composition comprising organometallic ferrocene compounds or derivatives thereof, and a liquid organic carrier in which ferrocene and its derivatives are soluble.

[0009] As a ferrocene compound a compound of iron dicyclopentadienyl is used, which is selected from the group consisting of iron dicyclopentadienyl, iron di(methylcyclopentadienyl), iron di(ethylcyclopentadienyl), methylo-ferrocene, ethylo-ferrocene, n-buthyloferrocene, dihexyloferrocene, phenyloferrocene, diacetyloferrocene, dicykloheksyloferrocene and dicyclopentyloferrocene.

[0010] The solvent used is an organic carrier selected from the group consisting of high-boiling aromatic solvents, hydrocarbon solvents, and petroleum solvents. The solvent is selected from the group consisting of xylene, toluene, hexanol, octanol, kerosene, diesel oil, oil alcohols.

[0011] The description of American invention US4298450 discloses a process of coal hydroconversion, wherein the basic premise of the process is the introduction of solvent containing the appropriate alkoxide ion (the alcohol having a hydrogen atom α -H in the molecular structure) into the reaction system of carbon dissolution.

[0012] Preferred solvents are secondary alcohols, especially secondary alkyl alcohols such as isopropanol. Other suitable solvents include methanol, secondary alcohol, butyl, propanol, and the like.

[0013] It has also been found that the reaction that occurs with participation of the alcohol solvent and carbon is catalysed by the presence of a base, capable to provide a catalytically effective amount of suitable alkoxide anion, for example an alkali metal hydroxide, preferably potassium hydroxide.

[0014] A solvent used in this invention, in particular isopropyl alcohol, is advantageous by relatively low boiling point and reaction temperature, low viscosity and solubility in water. Its use reduces the temperature of the process.

[0015] Russian invention RU2007131068 discloses a method of intensifying combustion of solid fuels, by burning an air-fuel mixture in an electric field, wherein the combustion process is carried out with use of a catalyst in the combustion zone, supported on high-voltage electrode supplied with high-voltage in the range of 5-10 kV. The electrode is made of metals of variable valence or metal oxides, or other conductive material coated with a catalyst.

[0016] The process of intensification of the fuel combustion takes place by acting on the flame with strong longitudinal electric field (2 kV/cm or more) and with strong transverse electric field. The method also provides for rotation of the transverse electric field of the flame, which increases the degree of mixing and grinding of the air-fuel mixture, and further intensifies the combustion process.

[0017] Intensification of the combustion process according to the above invention is achieved by creating a plasma combustion zone which is formed between the two electrodes. The voltage on the electrodes is in the range of 5-20 kV. The invented method provides the highest degree of combustion of solid carbonaceous fuels. However, it has several disadvantages like high power consumption which reduces energy efficiency of the process, or necessity of mixing and spraying of electrostatic fuel which causes difficulties in control of combustion.

[0018] A method of intensification of combustion of solid fuels known from Russian invention RU2437028 comprises preparing a mixture of pulverized coal of low reactivity with air and nanoparticles. The mixture of pulverized coal is subject to ultrasound treatment immediately prior to being fed to the burners followed by ignition and combustion in the boiler. Astralenes i.e. multilayered fullerenes, and Taunit being a nanoparticle composed of carbon atoms (carbon nanomaterial) are used as the nanoparticles.

[0019] Nanoparticles are introduced into the mixture of pulverized coal in the form of homeopathic dosages, in the range of 0.01-0.02% based on the weight of solid fuel.

[0020] This method results in an increase of speed of ignition reaction and improvement of combustion of the fuel mixture. In addition, this method used in combustion of coal with low reactivity and fuel oil in the furnace of a steam boiler, reduces the amount of unburnt carbon, nitrogen, sulfur, and oxide emissions. This in turn contributes to reduction of corrosion of the heated surface, and improvement of the equipment reliability and durability. Besides it, increases the efficiency of combustion of a mixture of fuels of low reactivity with air, and through the use of nanoparticles an agglomeration of components is avoided.

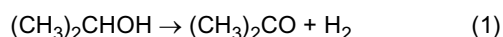
[0021] Ultrasonic treatment prevents agglomeration of the air-fuel mixture, which leads to an increase in the surface area of the reactants. This treatment contributes to the enhancement of photophysical reactions of excited molecular oxygen and the reactions of ignition and combustion of the fuel mixture. Increasing the dynamics of ignition and combustion reduces

[0022] The prior art indicates that various solutions of activation of the combustion process of solid fuels are based on fuel additives utilizing the beneficial effects of hydrogen radicals influencing the combustion process. These radicals are introduced into the combustion

[0023] It is known that the combustion process of solid fuels comprises the steps, which can be generally divided into the steps of drying, pyrolysis, separation and combustion of volatiles, combustion of solid residue, and the ash formation. Duration and spatial distribution of the first two steps is important to flame stability and is significant for the process efficiency.

[0024] The present invention relates to a method of intensification of solid fuels combustion by means of activation of alkyl alcohols as chemical additives, by the use of the additive nebulization process by sonication and with use of a chemical catalyst to intensify a dehydrogenation reaction.

[0025] Nebulization process uses a solution of an alkyl alcohol, preferably a secondary alcohol eg. isopropanol in concentration of 10% to 30% of alcohol in aqueous solution, preferably 20%. Its introduction into the fuel causes a dehydrogenation reaction, or formation of hydrogen radicals, as described by the reaction:



[0026] Use of the ultrasonic wave is a technique used for intensification of phenomena in both homogeneous and inhomogeneous materials, which is associated with an increase in the rate of heat transfer and reaction kinetics. Studies have shown that use in the method according to present invention of the ultrasonic wave in the solid fuel combustion with addition of alkyl alcohol, preferably isopropanol, reduces activation energy of reaction of dehydrogenation.

[0027] According to the invention an addition of alkyl alcohol, preferably isopropanol, is directly fed into solid fuel in the form of a suspension in air produced by the process of nebulization using an ultrasonic wave generated by ultrasonic transducer.

[0028] Nebulization process is carried out in a tank called a nebulizer, containing the liquid level sensors or float level sensors, and active and passive cooling system, and provided with ultrasonic transducers mounted on the tank float in a manner ensuring constant level of immersion in the liquid. Nebulizing tank (nebulizer) is also provided with a system

of automatic level control, emptying regulation, and compressed air supply with a regulated air flow. According to the invention air flow rate should be 2480 l/h, preferably 100-2000 l/h. Most importantly, in the top part of the nebulizer, a regulated tube called an outlet pipe is located through which the dispersion prepared in the process of nebulization is disposed.

[0029] The nebulization tank is filled with an aqueous solution of the additive prepared in the buffer reservoir in a quantity ranging from 1/3 to 1/2 of the nebulization tank volume, and subsequently the aqueous solution of the additive is treated with ultrasonic wave generated by ultrasonic transducers ranging in power from 10 to 120 W, preferably 30 to 65 W.

[0030] The nebulization process is executed at a temperature of up to 40°C until a pressure inside the nebulization tank reaches a value higher than pressure in a primary air duct. Power of ultrasonic transducers is regulated during the process of nebulization. It is noted that the volume of dispersion, i.e. a layer of dispersed solution, is linear in the specified output range.

[0031] According to the invention, ultrasonic wave energy used for preparation and activation of the additive significantly increases its dehydrogenation due to cavitation in the nebulizing process which is a rapid phase transition from liquid phase to gaseous phase induced by pressure reduction.

[0032] Yield of forming a dispersion of the additive according to the invention is up to 2400 ml/h, preferably from 50 to 1000 ml/h. A number of studies revealed that the efficiency of dispersion of the additive can be controlled not only by the air flow characteristics and power of ultrasonic transducers, but also using a possibility to change a distance of the end of the outlet pipe of a nebulizer to the liquid surface so as to increase the speed of outflow of dispersed solution droplets from the nebulizer, allowing thus correcting the negative phenomenon of coalescence of droplets of dispersed additive solution.

[0033] Analysis of the nebulization process is based on a computer simulation of the fluid dynamics (CFD simulation) and the PMB method (Population Balance Modeling), commonly used to simulate certain phenomena in the combustion processes of solid fuels. The simulation allows for an analysis of the trajectories of droplets of dispersed additive solution or dispersion of the catalyst inside the nebulizer. Simulation also informs about the number of droplets that left the nebulizer. Current analysis of results and graphical image simulation allowed for selection of geometric dimensions of the nebulizer so that yield of dispersing the solution by ultrasonic transducer is equal to the nebulizer efficiency at maximum air flow of 2480 l/h. The analysis also enabled the aforesaid adjustment of the discharge pipe end relative to the nebulizer upper cover so that at maximum air flow, reduction of volume of dissipated liquid in the subsequent quarters for at least two hours is constant within an error of no more than 2.5%.

[0034] It is noted that under the above condition, by controlling the electrical power supplied to ultrasonic transducer one can affect the population of droplets of the dispersion, as a prerequisite to control efficiency of creation of the additive dispersion. The population of dispersion droplets for given power is constant, meaning that the number of droplets formed equals to the number of droplets returning to a liquid. Modeling studies confirmed that at constant air flow rate through the nebulizer, aerodynamics within the nebulizer can be determined by adjusting the position of the discharge pipe such that the size of dispersion droplets entrained outwards is stable and proportional to the efficiency of dissipation process. Fulfillment of this condition allows to achieve performance proportional to supplied electrical power, enabling capacity control of the dosing process.

[0035] The produced dispersion of the additive is introduced from the nebulization tank to the primary air duct with pulverized coal just before the burner of the combustion boiler by means of a discharge pipe of a steady decline directed to the nebulizer to counteract a possibility of the pipe section entirely filled with liquid whereby droplets, that appear on the walls of the outlet pipe may flow down. Then the additive activation temperature is the same as the temperature of the incoming fuel, and the moment of the additive activation (dehydrogenation), is coherent with the starting time of the pyrolysis step. This method of the additive administration allows to limit the impact of an addition to the flame area, where the pyrolysis reaction takes place.

[0036] The nebulization process is thus continued the pressure within the nebulizer tank reaches a value higher than pressure in the primary air duct and then the dispersion of the additive is dispensed continuously into the primary air duct with pulverized coal. To make proper interaction of the additive possible during the volatilization phase, the dispersion of the additive is dispensed just in front of the burner in the solid fuel temperature range of 90 to 160°C, which results in a proportional reduction of the non-combustible area, thus significantly shortening the pyrolysis stage and lowering the starting temperature of this reaction.

[0037] It should be mentioned, that during the pyrolysis stage heated and dried fuel particles emit volatiles and this phase lasts until ignition of volatiles. The method proposed in present invention is focused at this stage, that is when the fuel volatile particles have not yet been ignited. On the basis of a series of measurements and simulations and taking into account overpressure in the fuel conduit (pulverized coal duct), while inside the boiler there is lower pressure, a place advantageous to provide the additive and catalyst dispersion has been determined, which is the place just before the inlet of the fuel conduit to the burner of the boiler, where static pressure inside the pulverized coal duct is close to atmospheric pressure.

[0038] One can use two nebulizers for one burner that can work in parallel or series. Each of the nebulizers has an independent regulation system of air flow.

[0039] Studies have shown that very high local temperature associated with coalescence and collapse of cavitation bubbles promotes dehydrogenation, while additional reaction consisting of use of the catalyst to the dehydrogenation process is applied to enhance the effect of thermal decomposition of alcohol by reducing the temperature of the pyrolysis reaction.

[0040] In the method according to the invention an active nickel-aluminum catalyst in aqueous suspension is also used, previously homogenized with use of energy of ultrasonic waves.

[0041] Due to the pyrophoricity of nickel-aluminum catalyst, in the process according to the invention its commercial form of aqueous solution is used, which is a subject of the process of homogenization (so-called sonication) with use of commonly available ultrasonic homogenizers (so-called sonicators) The homogenization process results in aluminum oxides deposition on the surface of catalyst particles. Action of ultrasonic wave on the catalyst solution thus causes formation of oxides restricting the phenomenon of autoflammability.

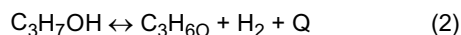
[0042] The Al-Ni catalyst homogenization process is carried out for at least 30 min with use of ultrasonic waves of power from 45 to 120 W, preferably 50 W on 50 ml of homogenized suspension. Activated homogenized aqueous suspension of Al-Ni catalyst with a catalyst content of not less than 0.046 g per 50 ml of water is added to the nebulizer tank containing a solution of the alkyl alcohol additive. No more than 0.85 g of the homogenized aqueous suspension of the Al-Ni catalyst is added to 1 l of alkyl alcohol additive in the nebulizer tank. Nebulization of alkyl alcohol additive solution along with aqueous suspension of Al-Ni catalyst is carried out in the nebulizer tank at a temperature of no more than 40°C, until pressure inside the nebulizer tank reaches a value higher than pressure in the primary air duct. Then the dispersion of the additive with the catalyst is dispensed continuously to the primary air duct with pulverized coal before the boiler burner, in the solid fuel temperature ranging from 90 to 160 °C, i.e. as in the case of dispensing the dispersion of alkyl alcohol additive without catalyst.

[0043] In a further embodiment of the method according to the invention, aqueous suspension of Al-Ni catalyst having a catalyst content of no less than 0.046 g of catalyst per 50 ml of water is dispensed into the nebulizer tank containing water in a volume of 1/3 to 1/2 of the tank volume. The suspension is homogenized for at least 30 min using ultrasonic waves of power of 45 to 120 W, preferably 50 W per 50 ml of homogenized suspension. No more than 10 g, preferably 0.6-2.5 g of the previously prepared Al-Ni catalyst suspension is added to 1 l of water contained in the nebulizer. The nebulization process is carried out continuously at a temperature of no more than 40°C, until pressure inside the nebulizer reaches a value higher than pressure in the primary air duct. Then the water dispersion with the catalyst together with the aqueous dispersion of the additive of alkyl alcohol or alkyl alcohol with Al-Ni catalyst suspension produced in the second nebulizer is dispensed into the primary air duct with pulverized coal before the boiler burner, in the solid fuel temperature range of 90 to 160°C.

[0044] The nebulization tank to which the homogenized suspension of Al-Ni catalyst is dispensed is equipped with the same tooling as the tank for nebulization of alkyl alcohol additive or Al-Ni catalyst suspension additive, the ultrasonic transducer being mounted in the tank wall, preferably the bottom wall.

[0045] As in the case of dispensing the additive of alkyl alcohol only or additive with a suspension of catalyst, the intensity of total air flow through the nebulizer is 2480 l/h, preferably 100-2000 l/h. The control system also ensures that the ratio of the air flow rate through the nebulizer containing the catalyst to the air flow rate through the nebulizer with additive of alkyl alcohol only or additive with a suspension of catalyst, amounts to 12:1.

[0046] Application of activated catalyst enhances thermal decomposition of alcohol by lowering the temperature of the pyrolysis reaction. Reaction occurring in the presence of a catalyst is as follows:



[0047] It shall be emphasized that this reaction takes place under the conditions immediately before introduction of fuel into the combustion zone at a temperature of 90-160 °C. The dispersion formed is fed to the fuel immediately upstream of the burner, as indicated above. Moreover, studies have shown that this site enables monitoring the combustion process in the pulverized coal burners with a thermal capacity of up to 0.5 MW. By changing the flow of fuel, primary and secondary air, post-combustion air, it is possible to analyze the effect of different combustion conditions on the flame stability and exhaust gas composition.

[0048] It is also to emphasize that, apart from the desired dehydrogenation reaction (which occurs according to the invention in the presence of a catalyst and at temperature of the fuel, i.e. 90-160 °C, wherein the additive is being activated in compliance with the starting time of the pyrolysis stage) other reactions also take place which are not preferred from the viewpoint of the combustion process. These include the reaction of nucleophilic addition of alcohols to the carbonyl group, the reaction of nucleophilic addition of water to the carbonyl group, and the reaction of keto-enol tautomerization. Therefore, as a result of a number of studies it was found that to proceed the dehydrogenation reaction with known speed and make it dominant it should be provided as follows:

- constant composition of the activator solution at constant temperature lower than activation temperature of the dehydrogenation reaction, and
- constant activity of the catalyst.

[0049] Constant distribution of the catalyst solution is provided by minimizing retention time in the nebulizer. This means that retention time resulting from the quotient of air volume in the nebulizer and the air flow rate through the nebulizer is slightly greater than the time required to transport the dispersed solution droplets from the nebulizer. In practice this means conducting the process with maximized air flow through the nebulizer and simultaneous restriction of the flow, so that a movement parallel to the liquid surface of up to a maximum of 2500 l/h would appear just above the liquid surface. Thus evaporation of alcohol is limited and homogeneity of the composition of the additive dispersion is maintained. At the same time vertical speed of the droplets transported out of the nebulizer is not limited.

[0050] Maintaining correct yield is achieved by adjusting power and cooling of ultrasonic transducers in the float, therefore according to the invention permissible maximum temperature of the product inside the nebulizer is up to 40°C, and maximum rate of temperature rise is up to 10°C / 15 min.

[0051] Studies have shown that the use of the method according to the invention lowers the burner power much below the technical minimum while maintaining stable operation, and reduces NO_x emissions. Properties of the ashes have also improved by reducing the carbon residue content, which results in an increase in efficiency of the combustion process. The content of reactive silica also increases, which improves the commercial characteristics of the ash resulting from combustion of solid fuel.

[0052] The process is carried out using the available and slightly adapted technical means, with devices and measurement instrumentation appropriate to the devices used in the combustion process. Nebulizers have the active and passive cooling system, the liquid level sensors, and an automatic control system controlling the level, emptying and filling from the buffer reservoir, which can cooperate with a number of tanks of nebulizers. The nebulizers also have the system of compressed air supply, preferably autonomous, with regulation of air flow wherein the air flow rate is up to 2480 l/h, preferably 100-2000 l/h. They also have a control system stabilizing the air flow to make it independent from changes in static pressure in the fuel supply line. The control system acts on variable pneumatic resistance. The air flow is generated by the system, wherein static pressure is significantly (several times) greater than static pressure in the pipeline, and the maximum air flow rate is at least five times higher than the demand of the nebulizer. This results in flat characteristic of the flow rate dependence on static pressure.

[0053] Ultrasonic transducers of the nebulizers also have controlled power, preferably from 30 W to 65 W.

[0054] Yield of production of the additive dispersion is up to 2400 ml/h, preferably from 50 to 1000 ml/h.

[0055] In the present invention, for each nebulizer a continuous measurement of all relevant parameters is carried out: air static pressure before and after the nebulizer, air flow rate before the nebulizer, the liquid level in the nebulizer, supplementary liquid flow rate, state of inlet valves, shut-off valves and air flow regulating valves, the liquid temperature inside the nebulizer, the temperature of the outer walls of the nebulizer, ambient temperature, internal temperature in the housing of the control system, voltage supplied to the control system and ultrasonic transducers, and the current drawn by the ultrasonic transducers and the cooling system.

[0056] The measurements provide inter alia observability of significant changes in the flame (its intensity and frequency) for automatic correction of metering of the activator and are performed using the measurement data coming from the flame scanner.

[0057] All measured data is stored with use of dedicated driver, which also performs control algorithm for stabilizing air flow rate, controlling power of ultrasonic transducers, operation of the cooling system and the valves allowing for automatic refilling of the tank containing the additive. All ultrasonic transducers have independent cut-off system, activated when the liquid level falls below minimum limit value.

[0058] In addition to a significant improvement in the dynamics of the combustion process, and reducing energy consumption of the process, the method according to the invention results in significant improvement in the fuel burnout degree. Therefore a content of combustible particles in fly ash is substantially reduced which is shown in the table 1.

Table 1. The content of combustible particles in fly ash:

Variant	Flammable parts [%]
Fuel 50 kg/h	12,14
Fuel 50 kg/h + additive	5,45
Fuel 30 kg/h	10,89
Fuel 30 kg/h + additive	8,53

[0059] Technical tests resulted in a series of thermo-gravimetric studies of ash, which are presented in Figure 1 in the form of graphical representation of results of the thermogravimetry (TG) analysis. During the TG study changes of weight during the heating process were recorded. Weight loss in TG study at a temperature between 500°C and 600°C proves combustion of carbon residues in the ash samples. The smaller decrease of TG, the lower content of carbon residues.

Four samples of ash were subjected to the tests: two for burner capacity 50 kg/h and two for 30 kg/h. For each capacity the fuel was supplied with enabled and disabled dosing system. It was noted that addition of an activator reduced the levels of carbon residues in ash.

[0060] The applicability tests of the invention have been conducted in the range from the rated capacity of the fuel (50 kg/h) to the extremely low fuel flow rate (less than 15 kg/h) using the activator of the combustion process in the form of air suspension introduced into fuel-air mixture contained in the pulverized coal duct with the air flow capacity of not more than 200 l/h, and the nebulizer efficiency of 150+/-2 ml/h of additive, and 23 mg/h of catalyst or 69 mg/h of catalyst. The study confirms positive effects of the present invention. Significant increase in flame stability has been recorded, enabling a significant reduction in fuel flow. Moreover, during the tests no effect of the catalyst on emissions of NO_x was observed. The test results are shown on graphs in Figure 2 and Figure 3.

[0061] In course of the study the research installation was equipped with a flame scanner D-LX 200 UA-20/MP from DURAG. Its spectral range is 190 ÷ 520 nm. The scanner provides continuous data of intensity and frequency of the flame.

[0062] Figure 2 shows in a graph the results of one hour-long experiment, which began with the fuel expense of 50 kg/h. Then the burner was supplied with fuel at decreasing capacity, down to 13 kg/h, which is shown by top line on the graph. Intensity of the flame is shown by bottom line on the graph. The figures are presented in relative units of the scanner.

[0063] Figure 3 shows for the above-described experiment the graphs of the flame intensity (bottom line on the graph) and the flame frequency (top line on the graph). Despite the reduction in fuel flow rate to a value below the technical minimum level of 30 kg/h of the applied burner, the flame frequency signal remained in a range corresponding to stable operating conditions.

[0064] The invention is further illustrated in the examples, below, describing the embodiments of the invention.

Example 1

[0065] The buffer tank was filled with 1 l of 16.6% aqueous solution of isopropanol dispensed into the nebulizer provided with the ultrasonic transducers mounted on a tank float and treated with ultrasonic wave in the power range from 40 W to 50 W. At the same time compressed air was fed to the nebulizer with a capacity of 100 l/h to 200 l/h. The additive has been immediately dispersed by energy of ultrasonic wave. The transducer power was stabilized which resulted in an increase of volume of the dispersion up to a value of 50 ml/h within an error of 2 ml/h. The process was subject to continuous monitoring and measurement after reaching a volume of dispersion ensuring dosing efficiency of at least 50 ml/h. Then opening the nebulizer valves enabled the flow of the additive dispersion to the flowing fuel, causing activation of the additive in the temperature of the pulverized coal duct and thus starting the process of dehydrogenation in the presence of the fuel particles. The dispersion of the additive was dispensed by a discharge pipe of the nebulizer, mounted at right angle to the fuel pipe just before the burner of the boiler where the static pressure inside the pipe is close to atmospheric pressure, and temperature of the fuel is in the range of 90-160 °C. Dosed amount of the dispersion was 50 ml/h +/- 2 ml/h.

[0066] The burner was running in nominal conditions, i.e. the fuel supply of 50 kg/h (power of the fuel: 345 kW), and then was switched to a value of 30 kg/h (power of the fuel: 205 kW), which was a value lower than the previously used value of the minimum load i.e. 35 kg/h.

[0067] Power of the transducers was stabilized all the time by the power supply using the PWM (pulse width modulation). The system properly responded to extreme changes of the burner power.

[0068] Power stabilization at constant cooling by air flow provided a constant temperature not exceeding 38 °C.

Example 2

[0069] The buffer tank was filled with 1.5 l of 30% aqueous solution of isopropanol dispensed into the nebulizer provided with the ultrasonic transducers mounted on a tank float and treated with ultrasonic wave in the power range from 30 W to 35 W. At the same time compressed air was fed to the nebulizer with a capacity of 100 l/h to 200 l/h. Nebulization process and measurements are the same as in Example 1.

[0070] An amount of 46 mg of a catalyst in a commercial formulation Raney®-Nickel SIGMA-ALDRICH was previously homogenized using 50 ml of water in a sonicator of power equal to 50 W. Sonication process was performed twice for periods of 30 minutes. The prepared suspension in an amount of 20 ml was added to the nebulizer containing 1 l of 16.6% aqueous solution of isopropanol.

[0071] The energy of ultrasonic wave immediately dispersed the additive. The process has been constantly monitored and measured until a volume of dispersion ensuring dosing flow of 150 ml/h has been achieved. After the desired volume

of the dispersion was achieved, the valves were opened and the dispersion begun to flow into the flowing fuel, allowing activation of the additive at the temperature of the pulverized coal duct, and thus starting the process of dehydrogenation in the presence of the fuel particles.

[0072] Transducer power was gradually reduced in proportion to the change in fuel flow rate in the range of 100% to 30%. The temperature inside the nebulizer was from 35 to 30°C.

Example 3

[0073] The buffer tank was filled with 2 l of 10% aqueous solution of isopropanol dispensed into the nebulizer provided with the ultrasonic transducers mounted on a tank float and treated with ultrasonic wave in the power range from 30 W to 35 W. At the same time compressed air was fed to the nebulizer with a capacity of 100 l/h to 800 l/h.

[0074] An amount of 46 mg of a catalyst in a commercial formulation Raney®-Nickel SIGMA-ALDRICH was previously homogenized using 50 ml of water in a sonicator of power equal to 50 W. Sonication process was performed twice for periods of 30 minutes. The prepared suspension in an amount of 20 ml was added to the nebulizer containing 100 ml of water. The nebulization process was performed in the described above nebulization tank (nebulizer) used in nebulization process of alkyl alcohol additive, wherein the ultrasonic transducer was mounted in the bottom wall of the tank.

[0075] The energy of ultrasonic wave immediately dispersed the additive. The process has been constantly monitored and measured until a volume of dispersion ensuring dosing flow with the additive of 49.4 ml/h and with the catalyst of 3.5 ml/h have been achieved.

[0076] After the desired volume of the dispersion of both nebulizers was achieved, the valves were opened and the dispersion begun to flow into the flowing fuel, allowing activation of the additive at the temperature of the pulverized coal duct, and thus starting the process of dehydrogenation in the presence of the fuel particles.

[0077] The transducer power was gradually reduced in proportion to the change in fuel flow rate in the range of 100% to 30%. The temperature inside the nebulizer was from 35 to 30°C.

Claims

1. A method for intensifying the combustion of solid fuels using alkyl alcohol and Al-Ni catalyst as a combustion promoters, **characterized in that** an aqueous solution of alkyl alcohol, preferably isopropanol, in concentration of 10% to 30% is prepared in a buffer tank, then the nebulization tank is filled in a half of its volume and the nebulization process is executed until pressure inside the nebulization tank reaches a value higher than pressure in a primary air duct, and then dispersion of the additive is dispensed continuously into the primary air duct with pulverized coal before the burner, in a temperature of solid fuel ranging from 90 to 160°C or to the nebulization tank containing the solution of alkyl alcohol additive aqueous suspension of Al-Ni catalyst is added, wherein said Al-Ni catalyst suspension is prepared so that the catalyst content is of no less than 0.046 g per 50 ml of water and **in that** no more than 0.85 g of Al-Ni catalyst in homogenized aqueous suspension is for every 1 l of alkyl alcohol additive solution and the nebulization process is executed until pressure inside the nebulization tank reaches a value higher than pressure in a primary air duct, and then dispersion of the additive is dispensed continuously into the primary air duct with pulverized coal before the burner, in a temperature of solid fuel ranging from 90 to 160°C.
2. The method according to claim 1, **characterized in that** concentration of alkyl alcohol additive in dispersed aqueous solution equals to 20%.
3. The method according to claims 1 or 2, **characterized in that** yield of creation of dispersion of the additive equals to 2400 ml/h, preferably 50 to 1000 ml/h.
4. The method according to any of claims 1 to 3, **characterized in that**, the homogenization process of suspension of Al-Ni catalyst is executed for at least 30 min to homogenization process with use of ultrasonic waves of power ranging from 45 to 120 W, preferably 50 W per 50 ml of homogenized suspension.
5. The method according to any of claims 1 to 4, **characterized in that** the ultrasonic transducers have power ranging from 30 to 65 mW.
6. The method according to any of claims 1 to 4, **characterized in that** compressed air flow rate ranges from 100 to 2000 l/h.
7. The method according to any of claims 1 to 5, **characterized in that** the nebulization process is executed at a

temperature of up to 40°C and maximum rate of temperature increase in the nebulization tank is no more than 10°C / 15 min.

- 5 8. The method according to any of claims 1 to 7, **characterized in that**, the nebulization process is carried out in nebulization tank provided with ultrasonic transducers and a compressed air supply system is effected by acting on aqueous solution of alkyl alcohol additive with ultrasonic waves generated by ultrasonic transducers in power range of 10 to 120W and at a compressed air flow rate of up to 2480 l/h.
- 10 9. The method according to any of claims 1 to 8, **characterized in that** the nebulization process of aqueous solution of alkyl alcohol or aqueous solution of alkyl alcohol and Al-Ni catalyst is carried out in the nebulization tank containing liquid level sensors and ultrasonic transducers mounted on the tank float; active and passive cooling system; automatic liquid level regulation system; drainage regulation system and compressed air supply system together with air flow regulation, as well as an adjustable discharge pipe mounted in the upper part of the tank, for dispensing dispersion produced during the nebulization process.
- 15 10. The method according to any of claims 1 to 7, **characterized in that** aqueous suspension of Al-Ni catalyst is added to the nebulization tank, but no more than 10 g. Al-Ni catalyst in homogenized aqueous suspension for every 1 l of water, while the nebulization process is conducted continuously at a temperature of up to 40 °C, until pressure inside the nebulization tank reaches a value higher than pressure in the primary air duct, then the water dispersion of the catalyst, together with the prepared in second nebulization tank the aqueous dispersion of alkyl alcohol additive or alkyl alcohol with the Al-Ni catalyst suspension is dispensed into the primary air duct with pulverized coal before the boiler burner, in the solid fuel temperature ranging from 90 to 160 °C.
- 20 11. The method according to claim 10, **characterized in that** homogenized suspension of Ni-Al catalyst is added to aqueous solution in the nebulization tank in a rate of 0.6 to 2.5 g/l.
- 25 12. The method according to claims 10 or 11, **characterized in that** the nebulization process of the aqueous solution and the catalyst suspension is carried out in the nebulization tank containing ultrasound transducers mounted on the tank wall, preferably on the bottom wall of the tank and liquid level sensors, active and passive cooling system, automatic level regulation system, discharge regulation system, and compressed air supply system along with air flow regulation and also mounted in the upper part of the tank, adjustable discharge tube for dispensing dispersion produced during the nebulization process.
- 30 13. The method according to any of claims 1 or 13, **characterized in that** the ratio of intensity of the airflow through the nebulization tank containing aqueous dispersion with the catalyst to the intensity of the airflow through the nebulization tank containing the aqueous solution of alkyl alcohol additive or the aqueous solution of alkyl alcohol additive with the suspension of the catalyst equals up to 12:1.
- 35 14. The method according to any of claims 1 to 13, **characterized in that** the nebulization process is carried out in a regime of continuous monitoring with use of the trajectory analysis and information on population of droplets leaving the nebulization tank, respectively: the droplets of dispersed aqueous solution of the additive, or aqueous solution of the additive and the catalyst suspension, or aqueous solution with the catalyst suspension, thereby allowing proper selection of the process parameters.
- 40 15. The method according to any of claims 1 to 14, **characterized in that** during the process of delivering the dispersion of aqueous solution of the additive, or aqueous solution of the additive and suspension of the catalyst, or aqueous solution with the catalyst suspension, at the maximum air flow rate, the position of the end of the drain tube of the nebulization tank relative to its upper cover is maintained so that reducing the volume of the dispersed liquid in subsequent fifteen minutes intervals is equal for at least two hours.
- 45 16. The method according to any of claims 1 to 15, **characterized in that** the automatic fluid level control system and the liquid level sensors of the nebulization tanks maintain a constant level of the non-dispersed aqueous solution of the additives.
- 50 17. The method according to any of claims 1 to 16, **characterized in that** the nebulization process is carried out in a regime of continuous monitoring with use of the trajectory analysis and information on population of droplets leaving the nebulization tank, respectively: the droplets of dispersed aqueous solution of the additive, or aqueous solution of the additive and the catalyst suspension, or aqueous solution with the catalyst suspension, thereby allowing proper selection of the process parameters.
- 55 18. The method according to any of claims 1 to 17, **characterized in that** the nebulization process is carried out in a regime of continuous monitoring with use of the trajectory analysis and information on population of droplets leaving the nebulization tank, respectively: the droplets of dispersed aqueous solution of the additive, or aqueous solution of the additive and the catalyst suspension, or aqueous solution with the catalyst suspension, thereby allowing proper selection of the process parameters.

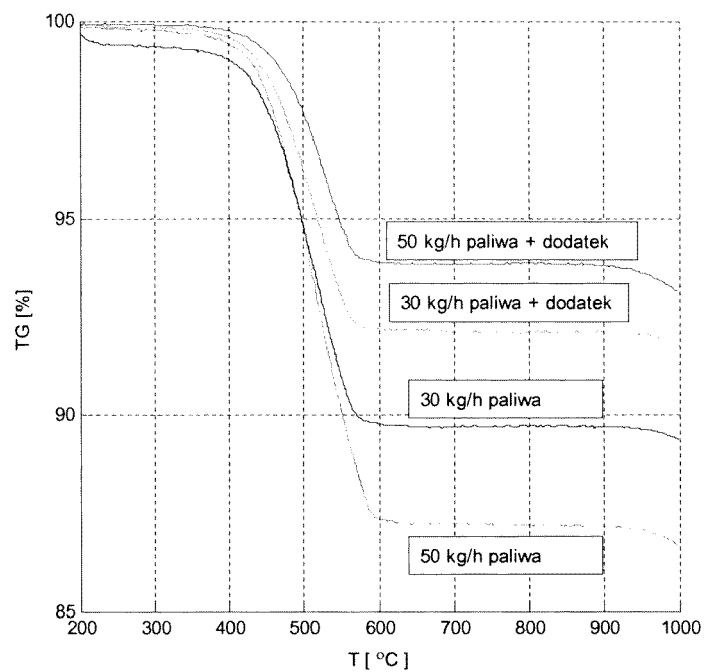


Fig.1

paliwa = fuel

paliwa + dodatek = fuel and additive

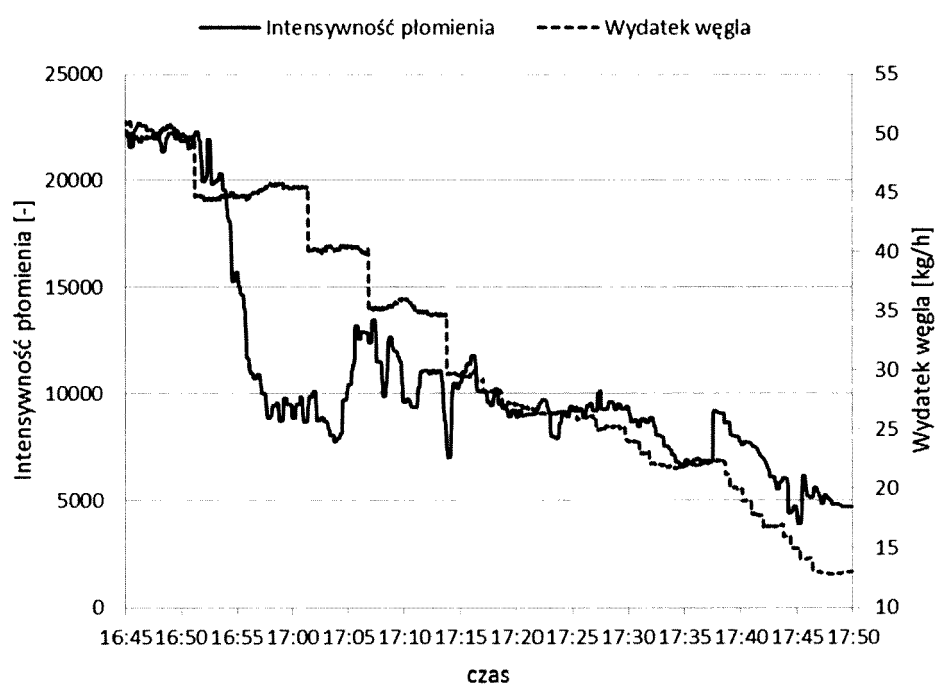


Fig.2

intensywność płomienia = flame intensity

wydatek węgla = amount of carbon

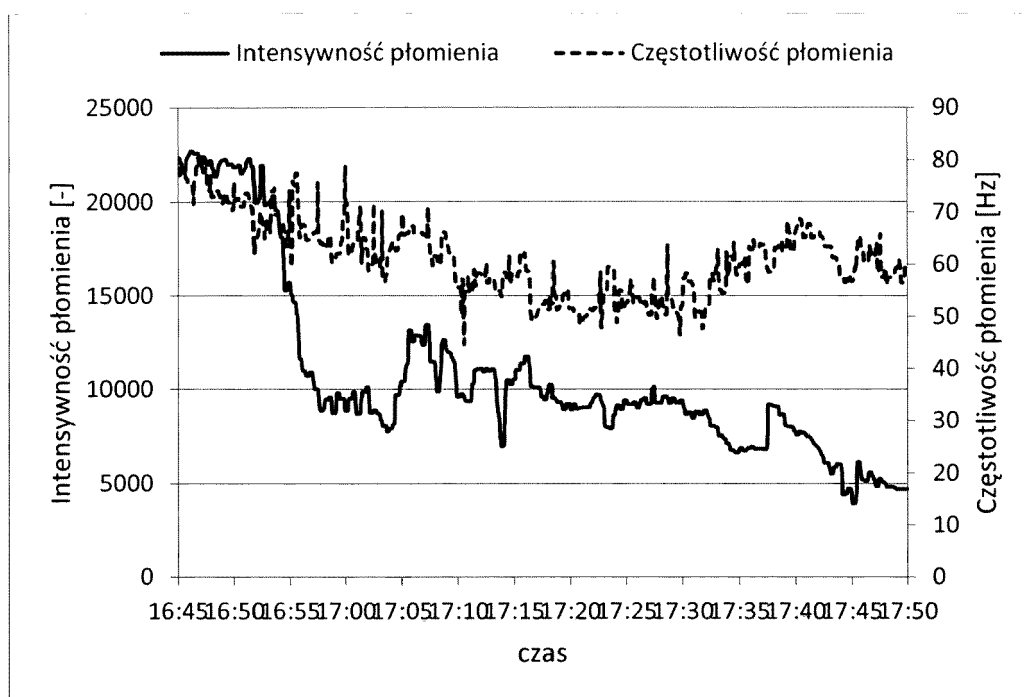


Fig.3

intensywność płomienia = flame intensity
częstotliwość płomienia = flame frequency



EUROPEAN SEARCH REPORT

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Place of search Munich		Date of completion of the search 12 September 2017	Examiner Pöllmann, Klaus
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