Modern cyclone burners for the increase of operational flexibility of pulverized-fuel boilers

Nowoczesne palniki cyklonowe dla zwiększenia elastyczności kotłów pyłowych

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In this paper, the concept, as well as a model pilot cyclone burner are presented and discussed in order to provide a solution for both combustion and gasification of solid fuels (e.g. pulverized coal). The burner design allows to operate it as a separate structure or a part of an existing pulverized-fuel boiler. In the latter case, the cyclone burner increases the flexibility and dynamics of the power generation system, as well as boiler thermal output. The burner also provides the conditions for the reduction of boiler technological minimum without the necessity to ignite boiler startup burners, and also enables the realization of treatment and processing (e.g. the vitrification) of coal combustion by-products. The proposed solution can also become an interesting technological option aimed at the retrofitting and modernization of old 200 MW PC-based power generation facilities within the Framework Program "Power 200+. Revitalization and restoration of power on the basis of 200 MW power units".

In many countries, including Poland, the basis for the generation of electricity and heat is the combustion of fossil fuels, mainly hard coal and lignite. In the combustion of these fuels, the greatest emphasis is placed on increasing the capacity of generating units, while at the same time increasing their efficiency and availability and meeting the growing environmental requirements [1, 2]. As a result, many boiler designs (grate, pulverized and fluidized) have been built over the years, most of which are the basis of the National Power System (NPS). These units act as the primary source of power, but they must have broad possibilities for load changes, resulting from the current demand of the NPS [3]. So far, the working units have a technical minimum of around 40% of nominal power and must provide the required flexibility of load changes at 4% of the nominal power change per minute.

Professional energy based on the use of fossil fuels is, however, the main emitter of pollutants and greenhouse gases into the atmosphere. Despite the implementation of many technologies that limit the negative impact of energy on the environment – i.e. dust extraction (electrostatic precipitators, bag filters, cyclones), flue gas desulphurization (wet, dry and semi-dry methods), flue gas denitrification (SNCR, SCR, primary NOx reduction methods) - many issues require further work, since, for example, we have failed to significantly reduce CO_2 emissions.

The European Union places on its countries the need to reduce CO_2 emissions and to increase the use of renewable energy in the generation of electricity and heat. In order to ensure this, in recent years, the co-combustion of biomass in power boilers was developed resulting in a series of blocks fueled only with this fuel.

The contribution of renewable energy sources to power in the NPS is undoubtedly contributing to the reduction of fossil fuel consumption and thus to the reduction of CO_2 emissions to the atmosphere. On the other hand, due to the stochastic nature of the work (supply of power) of wind-based sources and forming a significant part of the Polish energy system, the maintenance of an assumed energy mix requires coal and lignite blocks to be quickly adapted to their current needs and without delay in the case of changing atmospheric conditions affecting the wind speed. This is especially important when the demand for NPS is low (currently, it is in the order of several GW) and a significant part of the energy is generated by wind turbines. In such cases, conventional power units must, unfortunately, work with minimum power and require stabilization using flash firing gas or light fuel oil burners. In extreme cases, it may even be possible to short-term shutdown of the block, followed by its start-up using expensive fuel.

Solution to this problem, which significantly reduces the amount of start-up fuel (sustained), proposed in this paper, is the installation in the existing boiler system of a cyclone burner (or group of burners) fed with coal dust allowing the boiler to remain hot without burning gas or fuel oil. This approach will undoubtedly also improve the economics of measures aimed at modernizing existing power units with pulverized boilers, such as the 200+ program.

Idea of cyclone burner

The cyclone burner proposed by the authors is an energy device, in which a combustion or gasification process can be carried out in a strongly swirled gas stream. Cyclonic burners allow the combustion of gaseous and liquid fuels, but the highest predicted

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potential is achieved by using as a jet / dispersant reactor for solid fuel gasification. It is possible to co-incinerate / gasify low-calorific fuel and high ash content. Burners of this type are characterized by high heat load and high operating temperature, which on the one hand is advantageous, because it allows the use of low calorific fuel and the discharge of ash as a liquid slurry and, on the other hand, a drawback as high process temperatures can result in an increased NOx emissions in the waste gases. The solution to the problem of high NOx emissions can be replacement of the air (the working medium and the oxidizing medium) with a mixture of recycled oxygen-containing exhaust gas. This solution additionally fits into the widely promoted and most recently developed oxy-combustion technology.

The cyclone burner presented in this article was developed at the Department of Energy Engineering at Czestochowa University of Technology [4]. It consists of two chambers (Figure 1): upper (PC2) and lower (PC1). The PC2 chamber is shaped like a roller. At its upper end, there are tangentially built-in ducts for pneumatic delivery of particulate fuel and a plunger intended to limit the flow of fine coal dust outside the PC2 chamber. The lower chamber PC1 consists of several degrees of decreasing diameters. At each step, nozzles are placed tangentially to allow the introduction of a "propellant" gas of the assumed composition (O_2, CO_2) into the PC1 chamber. Both chambers (PC1 and PC2) are connected through a duct, in which an appropriately shaped internal plunger is installed to distribute the flue gas from PC1 to PC2 from the fuel flow (coke residue) from the PC2 chamber to the PC1 chamber (fig. 1). In the lower part of the PC1 chamber, the nozzle is arranged axially to allow the introduction of recirculated gases of the composition into the PC1 chamber.

The developed burner construction consisting of two chambers allows for:

- realization of the process of heating, drying and degassing of fuels in the PC2 chamber;
- carbonaceous gasification (CO_2 and O_2) or (CO_2 and O_2 and H_2O) to maximize the production of CO and H_2, as well as combustion of some part of the coke residue to generate the required amount of heat to maintain and control the course of endothermic reactions.

Experiments and numerical calculations have shown that the developed cyclone burner can serve as both a combustion and coal gasification gasifier. The change in the nature of the burner is due to the change in the fuel flow to the device and change in the stream and composition of the "propellant" gas (O_2, CO_2) used in the combustion/gasification process. In the process of gasification of coal dust, it is also possible to use water vapor to obtain high CO and H_2 content in the products.

According to the research at the outlet of the burner, CO concentration can be reached at 80% in the case of gasification of coal dust in O_2 and CO_2. Whereas for a mixture of O_2 and CO_2 and H_2O is applied as a gasifying agent, the gases leaving the furnace have a CO and H_2 content close to 50%. In this case, it is possible to obtain gas with a calorific value of over 11 MJ/Nm^3.

Due to the strong turbulence inside the cyclone burner, it is possible to significantly reduce the fly ash flow to the dust chamber and to minimize even incomplete burns to zero. Since the combustion and gasification process of coal dust can also be carried out at temperatures higher than the melting point of ash, it is possible to disperse mineral substances in liquid form.

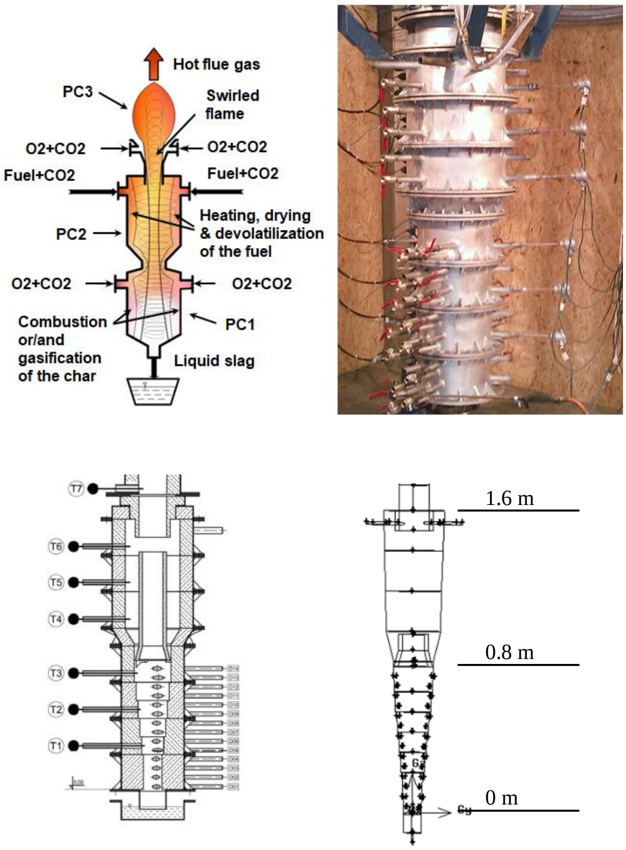

Fig. 1. Diagram and geometry of the cyclone burner

Cooperation of cyclone burner with dust boiler in variable load conditions

As mentioned at the outset, pulverized boilers constitute a significant part of the NPS's generating units. Their work depends on the current demand of the consumers for electric power, taking into account the daily and seasonal variability. These boilers must be characterized by high flexibility and low technical minimum (minimum load). At present, most furnaces are characterized by a technical minimum load of 40% MCR and load dynamics of at least 4 %/min. Current trends in the world, however, provide for a technical minimum of 15% MCR block and the ability to change the load at a speed of 10 ÷ 20 %/min.

The ability to lower the technical minimum of the boiler on one hand is related to ensuring a stable combustion process in the furnace without the use of flashlights, and on the other hand requires proper circulation of water in the boiler tube. In addition, other systems and blocks must be designed to work in such extreme conditions. Of course, it is crucial to ensure a stable combustion process. Reduction of dust boiler output is achieved by turning off the dust burners sequence and by reducing the amount of coal dust fed to the individual burners. Consequently, the average temperature in the furnace chamber is lowered and the boiler screens are radiated only locally in the vicinity of the burner. Continuing to reduce performance outside of this state can cause unstable operation of the burners and break of the flame, and consequently - "falling out" (emergency shutdown) of the block. The solution to this problem can be illustrated in fig. 2 of the group of cyclone burners working with the dust boiler and supporting its performance at low efficiency.

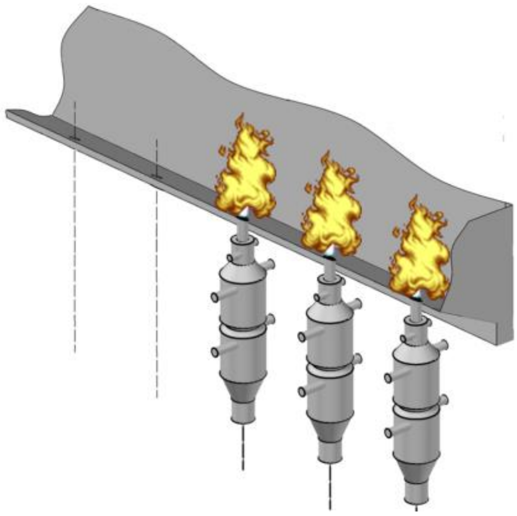

Fig. 2. Proposal for the development of a group of cyclone burners in the lower part of the dust boiler

The burner proposed in this article is very flexible. The burner (or group of burners) can work in the following four regimes:

1. A cyclone burner is fed with a fuel stream smaller than the nominal one. In the PC2 chamber, the heating, drying and degassing of the fuel and partial combustion of the volatiles take place. In the PC1 chamber, coke residue and volatile components are burned. In this case, the cyclone burner only emits the hot combustible gases without flammable gases. These fumes heat up the dust chamber but do not affect the operation of the dust burners. This variant of operation allows the cyclone burner to be kept in a hot state where it is ready for immediate load change.

2. The cyclone burner is fed with a nominal fuel flow (100% yield), which allows the aerodynamic conditions to completely burn the degassed fuel in the PC1 chamber as a coke residue. In the PC2 chamber, heating, drying and degassing of the fuel take place, and in the PC1 chamber combustion (complete and complete) of the coke residue. The cyclone burners emits in this case a mixture of flammable gases (unburned volatiles) and exhaust gases. Tail gas heats the boiler chamber where the volatile components from the burner are burned.

3. The cyclone burner is fed with a fuel stream greater than the nominal one. In the PC2 chamber, heating, drying and degassing of the fuel take place. Due to the excess of fuel in the PC1 chamber, however, it is only partially burned and the remaining amount is gasified. The cyclone burner emits gases consisting of degassing, gasification and fuel combustion products - these gases can be ignited in the dust boiler chamber. In this case (when the power requirement is below the technological minimum of the dust burners and it is necessary to turn them off), most of the heat required to maintain the required furnace temperature is provided by the cyclone burner and the boiler can be kept hot without the need for oil or gas burners.

4. The cyclone burner is supplied with a stream of fuel and fly ash (e.g. containing a lot of flammable parts). The coal dust stream is then fed to the PC2 chamber where the heating, drying and degassing processes take place, and the coke residue is burned in the PC1 chamber. In the PC1 chamber, combustion of coke residue is carried out at high temperature (over 1400 ÷ 1500 °C), and additionally pneumatically ash is introduced. As a result of the turbulence and high temperature, the ash undergoes rapid warming and melting, so that it flows down the walls of the PC1 chamber to the slag tank where it cools and solidifies. This cyclone burner mode allows flexible disposal of fly ash and their refining. In this case, the burner leaves a mixture of flammable gases (volatile components) and high-temperature flue gases. Burning of volatile parts and transfer of physical heat contained in these gases takes place in the dust boiler chamber.

Described cases of cyclone burner operation can be realized both at maximum boiler output (which causes it to increase the dynamics of the system) and to lower the technological boiler. In the latter case, depending on the power and number of cyclone burners built into the pulverized boiler system, it is possible to switch off a specified number of pulverized burners and stabilize the boiler operation by burning gas generated in cyclone burners. It is also possible to consider the complete disconnection of the dust burners and the maintenance of the boiler in a hot reserve (e.g. according to regime 4) due to the implementation of the vitrification (or post-combustion) of ash e.g. during the so-called *night valley*.

Conclusions

The solution of the cyclone burner, being a part of the pulverized boiler described in this paper, allows for:
- increasing the flexibility and dynamics of blocks with dust boilers,
- increase in thermal efficiency of boilers,
- reduction of the minimum technological operation of the dust boiler without the need to start the firing torches,
- implementation of the combustion and/or gasification process of solid fuels,
- carrying out the process of ash refining (e.g. during the so-called *night valley*).

The proposed solution constitutes an interesting technological option aimed at retrofitting and modernization of 200 MW class of dust mills within the framework of the "Energy Sector 200+ Framework Program. Revitalization and Reconstruction of Power Based on 200 MW Blocks".

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