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Study of thermal-flow processes in ash cooler cooperating with CFB boiler☆

Paweł Regucki*, Artur Andruszkiewicz, Wiesław Wędrychowicz, Barbara Engler

Faculty of Mechanical and Power Engineering, Wrocław University of Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

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Summary The article presents an example of thermal-flow analysis of the bottom ash cooler cooperating with the circulating fluidized bed boiler. There is presented a mathematical model of series-parallel hydraulic system supplying the ash cooler in cooling water. The numerical calculations indicate an influence of changes of the pipeline geometrical parameters on the cooling water flow rate in the system. Paper discusses the methodology of the studies and presents examples of the results of thermal balance calculations based on the results of measurements. The numerical results of the thermal-flow analysis in comparison with the measurements on the object indicate that the presented approach could be used as a diagnostic tool investigating the technical state of the bottom ash cooler.

Introduction

>The basic element of a conventional power plant is a boiler where chemical energy of fossil fuels (hard coal, lignite) is converted into a heat. As a result of combustion processes occurring in the boiler, a slag is produced. Later on, it must be removed from the combustion chamber and pre-cooled before its final storage. The mass flow rate of the discharged slag can vary from a few to several kg/s depending on the type of boiler and its actual thermal output as well as the mass flow rate and technical analysis of the fuel. For technical reasons, the transported from the combustion chamber slag requires pre-cooling to a temperature of about 100—120 °C. It is done in an ash cooler. The construction, number and location of ash coolers is closely related to the type of combustion chamber and is an important element of the power boiler (Kruczek, 2001).

In order to remove the heat from slag, ash coolers are supplied with cooling water circulated usually in a

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* Corresponding author.
E-mail addresses: pawel.regucki@pwr.edu.pl (P. Regucki), artur.andruszkiewicz@pwr.edu.pl (A. Andruszkiewicz), wieslaw.wedrychowicz@pwr.edu.pl (W. Wędrychowicz), barbara.engler@pwr.edu.pl (B. Engler).

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serial-parallel hydraulic system. A volumetric flow rate of cooling water has a decisive influence on the final temperature of transported slag. In most solutions, water is circulating in a closed system cooperating with cooling towers and its temperature is determined by the atmospheric conditions and the actual operating parameters of cooling tower. Moreover, hydraulic systems of cooling water are designed according to the optimization criteria in order to achieve maximum efficiency for nominal thermal output of the boiler if it operates under standard thermodynamic parameters for design fuel composition. Often, however, this approach ignores the fact that during operation the installation is subject to the processes leading to the deterioration of its nominal working conditions. An example might be to change the water mass flow rate to ash coolers resulting from the reconstruction of the hydraulic system, deterioration of circulating pump characteristics or build up of mineral deposits in pipelines of installation. In addition, temporary deterioration of the quality of fuel could cause the increase of its mineral content. It may result an increase in the mass flow rate of slag discharged from the boiler, and thus increasing demand for cooling water flow rate. All these factors affect in a significant way to the deterioration of the operating parameters of ash coolers and final temperature of transported slag (Nowak, 2003).

The article presents an example of thermal-flow analysis of the bottom ash cooler cooperating with the circulating fluidized bed boiler. It discusses the methodology of the studies and presents examples of the results of thermal balance calculations based on the results of measurements (Andruszkiewicz et al., 2014a,b).

Construction of ash cooler

In the paper there is discussed an ash cooling system of a circulating fluidized bed (CFB) boiler which consist of two bottom ash coolers denoted by SAC-L and SAC-R (respectively left and right bottom ash cooler). Fig. 1 shows schematically the most important elements of the SAC-R ash cooler — two screw coolers (designated by the acronym SC-L and SC-R on the left diagram in Fig. 1). The right diagram of Fig. 1 shows a schematic side view of the bottom ash cooler with an indication of: feeding hot ash (1), and discharging the pre-cooled ash (6), inlet and outlet of cooling water supplying SC-L ((2) and (3) respectively), inlet and outlet of the cooling water flowing through the outer walls of the cooler. The ash is delivered directly from the combustion chamber (1) and split onto two screw coolers (SC-L and SC-R) and then transported to the point (6). During its motion along the screw, ash is gradually cooled in blades, shaft pipe and outer walls.

Operational conditions of fluidized bed boiler are connected with the constant mass of the inert material circulating in the combustion chamber. This mass has a critical influence on pressure drop and temperature profile along the height of the boiler. Maintaining a proper weight of circulating bed leads to the state of fast fluidization, which guarantees the maintenance of a uniform temperature distribution along the height of combustion chamber.

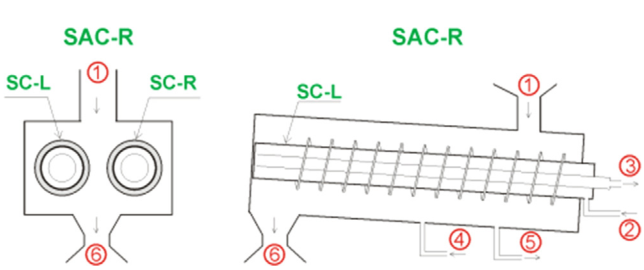

Figure 1 The main elements of the construction of the bottom ash cooler (SAC-R): two screw coolers (SC-L and SC-R), inlet and outlet of ash ((1) and (6) respectively), and inlet and outlet of cooling water cooling ((2, 4) and (3, 5) respectively).

Cooling water installation

An example of a series-parallel system of the cooling water propagation to two bottom ash coolers of a fluidized bed boiler is shown in Fig. 2.

Each of the bottom ash coolers (SAC-L and SAC-R) consists of two screw coolers (SC-L and SC-R) supplied by cooling water volumetric flow rates respectively: q_{v21}, q_{v22} and q_{v41}, q_{v42}. The flow rates which cool down the outer walls of coolers are denoted by q_{v23} and q_{v43} respectively. Cooling water is taken from the common collector and pumped into the system through a pump which gives at the inlet to the system static pressure p_1. The pump discharge is calculated based on the pressure difference $\Delta p_p = (p_1 - p_0)$. At the exit from the system static pressure is p_2. The pressure difference $\Delta p = (p_1 - p_2)$ forces to circulate the cooling water in various branches of the system. Cooling water is supplied to (and removed from) each branch by pipe having a diameter of $\phi160$ (parts R_{01}, R_{03}, R_{09}, R_{10}), and next by pipe $\phi120$ (parts R_{02}, R_{04}–R_{08}). The pipe which delivers cooling water directly to the ash coolers and its outer walls has a diameter of $\phi60$ (parts R_{21}–R_{23} and R_{41}–R_{43}).

In order to formulate a mathematical model of series-parallel network the flow resistances R_i have to be assigned to each branches of the system. The resultant resistances on the following sections of the installation are the sum of local friction and minor losses at these sections. The coefficients

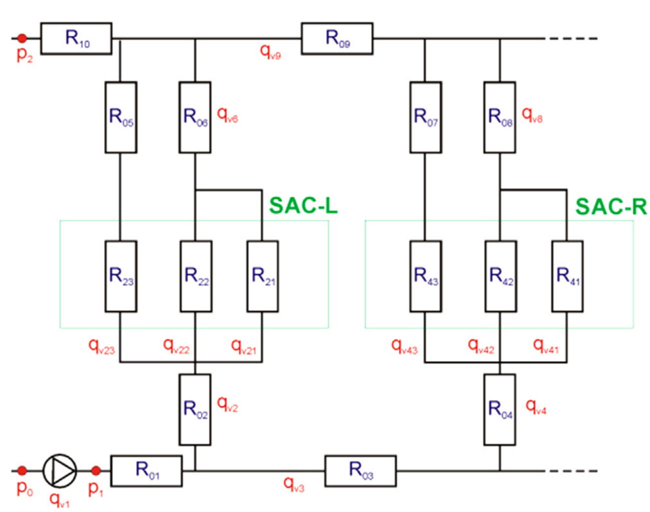

Figure 2 An example of a series-parallel system of the cooling water propagation to two bottom ash coolers of a CFB boiler.