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ABSTRACT

In the paper a novel construction of a low-pressure drop air-nozzle has been presented. It was designed in order to substitute the arrowhead nozzle working until now with a 535MW_e CFB boiler. In comparison to the arrowhead nozzle the new construction has a lower pressure-drop and geometry, which is an effective barrier for backflow of a solid. In the paper numerical simulations as well as experimental studies of a new air nozzle have been presented. Laboratory tests have been conducted on a 3D test-stand equipped with six full scale air nozzles.

INTRODUCTION

In CFB boilers, the air grid is not an isolated element, but it is part of a complex system of devices operating together, whose purpose is to uniformly distribute the primary air on the cross-section of the combustion chamber. The basic requirements and functions of a gas distributor in a fluidized bed reactor are: to support the bed of solids particles, to induce uniform and stable fluidization across the entire cross-section, to prevent nonfluidized regions on the grid, to maintain the total pressure drop (i.e. sum of the pressure drops across the distributor and the bed) constant and without appreciable change with time, (it is of special importance in multistage operations), to operate for a long periods (years) without plugging or breaking, to minimize attrition damage to bed particles and erosion of the container and immersed surface walls, Wen-Ching Yang (1), Doraiswamy *et al* (2). It is additionally proposed that the air grid be designed in a manner that will enable operation at a low possible pressure drop. This is linked with the need for the reduction of the power consumption by the fan, and thereby the reduction of the power plant's own demands.

As has been rightly remarked, in the past the design of the air distributor has had more an art than a science, Wen-Ching Yang (1). Currently, a properly designed grid must meet several criteria, the most important of which are:

- **jet penetration**, which helps in: determining how far to keep the bed internals away from the grid to minimize erosion of internals, deciding on grid design parameters such as hole size and the gas jet velocity, minimizing or maximizing particle attrition at grids,
- **grid pressure drop**, for achieving equal distribution of gas flow through many parallel paths.

Moreover, based on the design equations, pressure drop across the grid, the gas velocity through the grid hole, volumetric flow rate of gas, as well as the hole size and the hole layout, can be determined, Wen-Ching Yang (1), Doraiswamy et al (2), Kuni et al (3). These equations are only useful in the case, where the nozzle geometry is known. Unfortunately, none of the known mathematical relationships can be used to construct it. Its construction is the result of a combination of engineering intuition with the knowledge of fluid mechanics principles, with particular consideration being given to the tools of numerical fluid mechanics Mirek *et al* (4, 5, 6). For this reason, the first step in the design of a CFB boiler's air distributor is searching for the optimal construction of the air nozzle, which should follow the following steps:

- determine the preliminary design criteria resulting from the boiler construction,
- develop the nozzle geometry,
- perform the numerical studies of the nozzle geometry,
- make the 1:1 scale prototype of the nozzle, e.g. by the DDM (Fused Deposition Modelling) method,
- carry out experimental tests on a 3D stand (including tests of the air nozzles' system),
- select the material of which to construct the nozzle (based on mechanical and abrasion resistance tests).

After developing the nozzle geometry, it is be possible to proceed with the design of the air distributor using the known relationships.

AIR NOZZLES USED IN POLISH CFB BOILERS

In Polish CFB boilers, primary air is supplied to the combustion chamber most often using bubble caps or air nozzles (laterally directed flow) (Fig. 1).

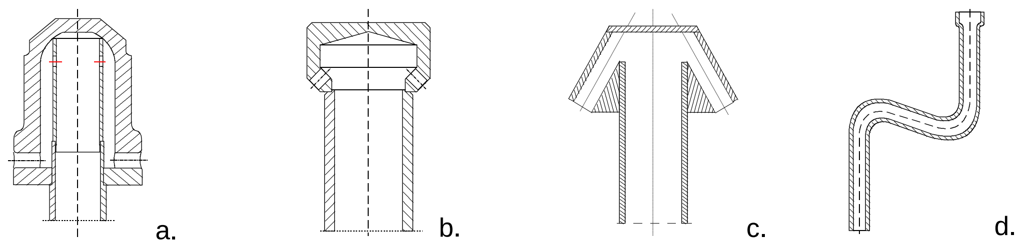


Fig. 1 Weirless nozzles used in Polish CFB boilers: a), b) bubble-cap, c) arrowhead nozzle, d) „pigtail"-type nozzle

As has been shown by industrial tests, there is no universal air distributor, and so there is no universal nozzle construction. A construction which fulfils its purpose in the case of a particular type of boiler, can turn out to be completely useless in another boiler type. An example can be the experience in the operation of the arrowhead air nozzle on Units A (conventional CFB design - Foster Wheeler, 235 MWe, 185.3 kg/s), B, C and D (Compact design - Foster Wheeler, 261MWe, 195.5 kg/s) in PGE Elektrownia Turów, Mirek *et al* (4). For Units B, C and D, no major operational problems with the air distributor have been noted. In the case of Unit A, the arrowhead nozzle does not provide an effective barrier to the backflow of the bed material. This is due to the geometry of the nozzle itself, Mirek *et al* (5), and the asymmetrical boiler construction (one external cyclone) causing one-sided loading of the air distributor with material returning from the recycle system, as well as the geometry of the windboxes, Mirek *et al* (7). The issue of selection of the proper nozzle geometry is thus a problem of a high level of complexity, which must be solved with consideration being given to the geometry of the boiler and the whole primary air supply system.

A NOVEL AIR NOZZLE CONSTRUCTION

The operation of the arrowhead nozzle has shown that the geometry of this nozzle exhibits high resistance to the erosive action of inert material. This nozzle is characterized, however, by a low resistance, and in the periods of a change in boiler load it does not provide an effective barrier to the backflow of the gas–solid particle mixture. The problem is connected with a configuration of the nozzle outlet arms, which are too short to equalize the transverse velocity profile and cannot provide an effective barrier to the stream of particles, that attempt with the air to penetrate into the nozzle inner space in the conditions of inverted pressure gradient, Mirek *et al* (5). The requirements imposed on the new nozzle construction resulted from the operation of the nozzle with Boiler A in PGE Elektrownia Turów. Therefore, several preliminary criteria were defined when designing the new geometry:

- the air nozzle should have a pressure drop less than or equal to that of the arrowhead nozzle,
- the nozzle should provide a much greater barrier to bed material backflow,
- the nozzle should be installed in the locations of the present arrowhead nozzles. Therefore, the spacing of nozzle arms should not be greater than that of the arrowhead nozzle arms,
- the weight of the new nozzle construction should not be significantly greater than that of the arrowhead nozzle.

Upon the analysis of several nozzle constructions, one nozzle has been selected, which meets the criteria defined above. Figure 2 shows the cross-section of the arrowhead nozzle and the prototype air nozzle.

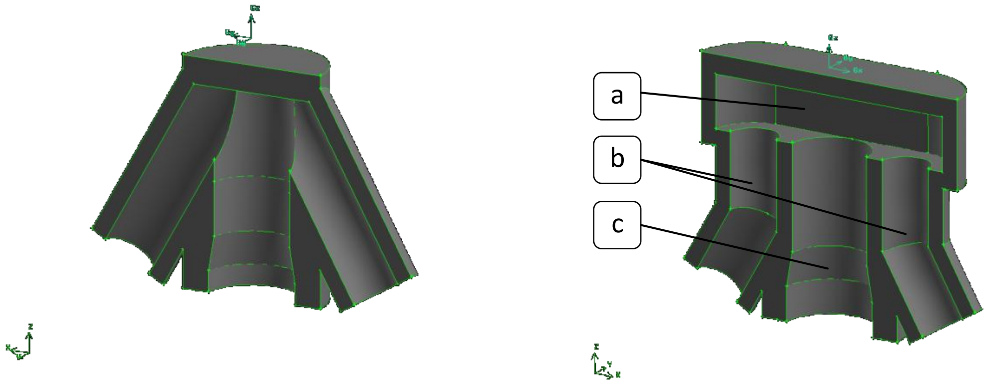


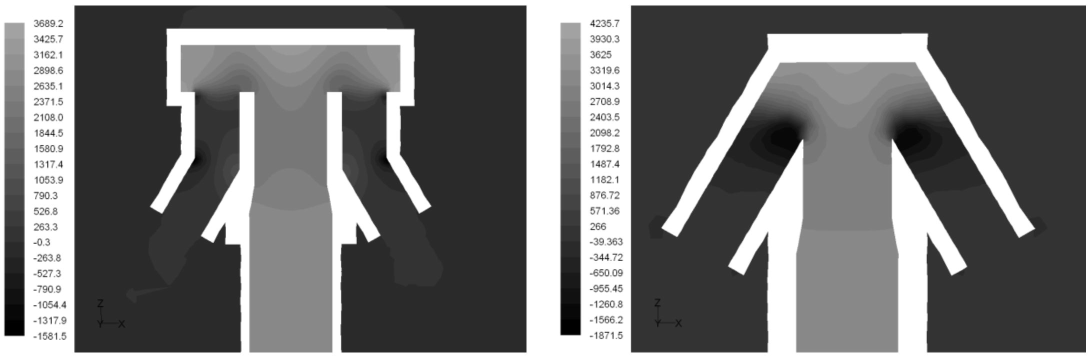
Fig. 2 Geometry of the arrowhead and prototype air nozzles: a–gas collector, b-outlet arms, c-inlet

As indicated by Figure 2, the basic differences compared to the arrowhead air nozzle are:

- the collector (Fig. 2a) connecting the nozzle inlet channel (Fig. 2c) with the outlet arms (Fig. 2b),
- change in the inclination angle of the outlet arms relative to the nozzle inlet channel axis from 150° to 180°.

Numerical examination of the new nozzle construction

The purpose of the numerical flow examination of the nozzle construction was to preliminarily determine the pressure drop across the nozzle under maximum boiler loading conditions and to determine the velocity field and the static pressure distribution in the internal nozzle region. Figure 3 shows the distribution of static pressure in the plane of symmetry of the modified nozzle (Fig. 3a) and the arrowhead nozzle (Fig. 3b).



a. b.

Fig. 3 Contours of static pressure distribution in the plane section of: a-modified nozzle, b-arrowhead nozzle

A few very important conclusions can be drawn from Figure 3:

- the pressure drop across the modified nozzle is smaller by 545Pa compared to the pressure drop on the arrowhead nozzle,

- the distribution of static pressure within the outlet arms of the modified nozzle is more uniform than the distribution within the arrowhead nozzle arms,
- the strong negative pressure zone visible in the arrowhead nozzle arms has been eliminated in the outlet arms of the modified nozzle. This zone promotes the inert material being sucked into the inner space of the arrowhead nozzle under variable boiler loading conditions.

Figure 4 shows a contour-line velocity field within the inner space of the modified nozzle (Fig. 4a) and of the arrowhead nozzle (Fig. 4b).

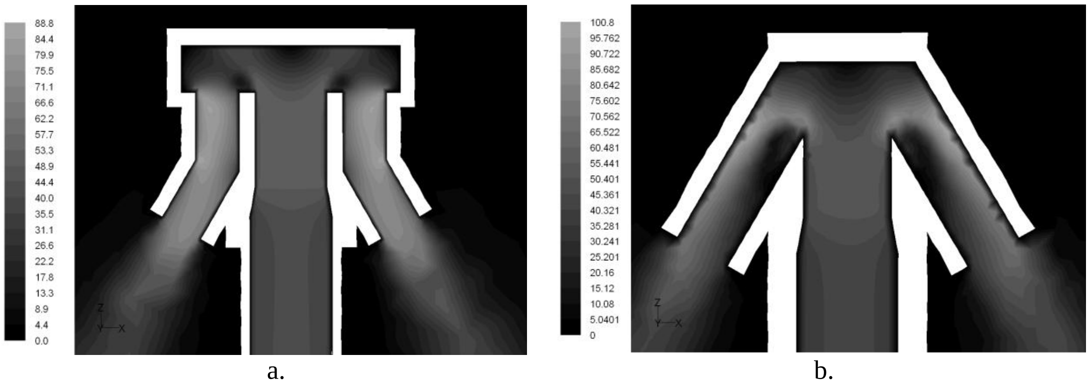


Fig. 4 Contours of velocity magnitude in the plane section of:
a-modified nozzle, b-arrowhead nozzle

Figure 4 indicates clearly that the velocity profile in the modified nozzle outlet arms is characterized by greater uniformity compared to the velocity profile in the arrowhead nozzle arms. Both profiles are illustrated in Figure 5.

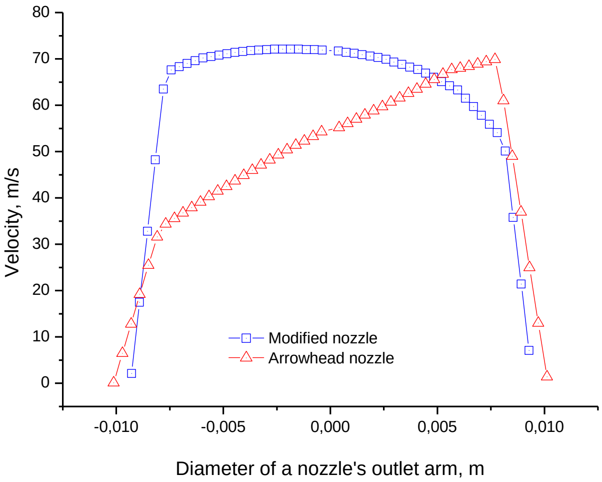


Fig. 5 Profiles of velocity magnitude at the end of the outlet arms for modified and arrowhead nozzles

As the numerical flow examination has shown, the new nozzle construction should provide a more effective barrier to the backflow of the bed material. The enhancement of the uniformity of the velocity and static pressure fields within the internal nozzle space has been achieved by designing a gas collector separating the inlet channel from the outlet arms.

Experimental tests

Experimental tests of the new nozzle construction were carried out using prototype geometries made by the Fused Deposition Modelling method on a scale of 1:1. A schematic diagram of the testing stand is shown in Figure 6. The main part of the testing stand is a transparent volume 1, within which 6 nozzles are installed. The testing stand is connected with an air fan via a confusor. The air fan has the following parameters: Q_{max}=5500m^3/h, Δp_{max}=$20kPa$. The amount of air supplied to each of the nozzles can be regulated by valves 7 and measured by rotameters 6. The installation of these valves enables the observation of nozzle operation under non-uniform velocity field conditions.

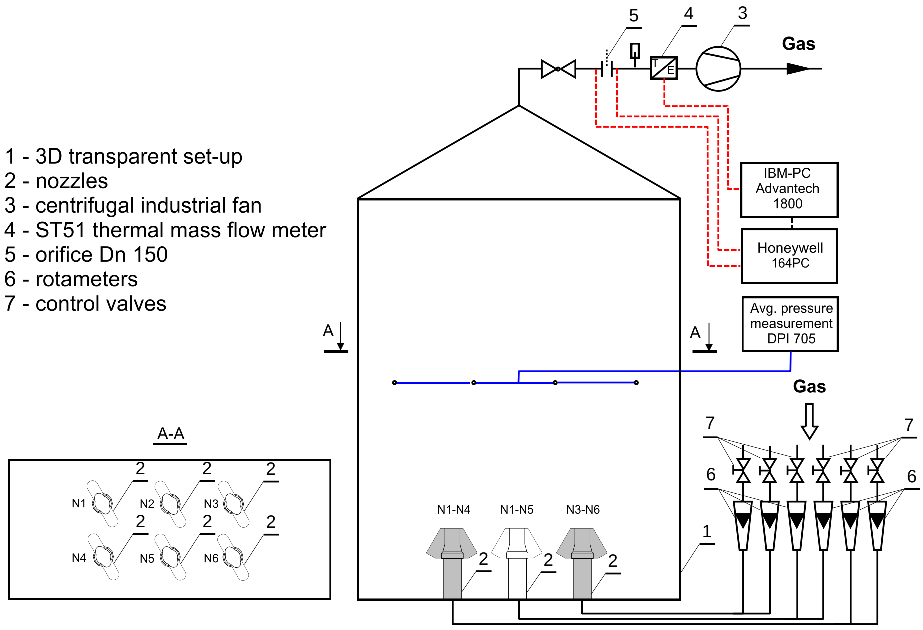


Fig. 6 Cold model test-stand for testing air nozzles

The loose material used in the tests is bottom ash from a 235 MW_e A-CFB boiler (d_{32}=118μm). During the tests, static pressure measurements were taken using a DPI705 meter. The measurement of the fan delivery was made using a ST51 thermal flow meter. The pressure sensors were coupled with a PC using an ADVANTECH PCL 1800 measuring card with a maximum sampling frequency of 330 kHz. Figure 7 shows variation in the pressure drop as a function of mass flow rate for the modified nozzle and the arrowhead nozzle, respectively.

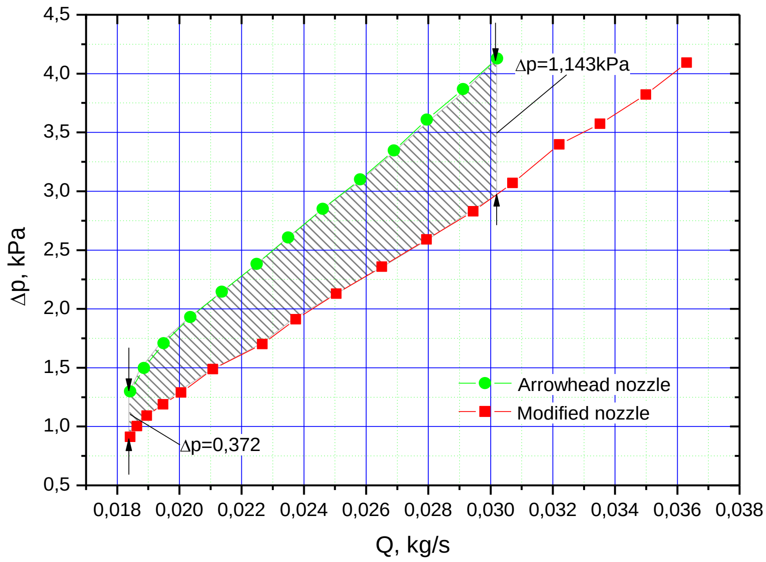


Fig. 7 Comparison of the pressure drop across the arrowhead nozzle and the prototype nozzle

The experimental test results confirm the results of numerical simulations, which showed a smaller pressure drop across the modified nozzle compared to the arrowhead nozzle. As indicated by Figure 7, the obtained differences are the larger, the greater is the mass rate of flow of the nozzle. During the experimental tests, the conditions of nozzle operation within the 6-nozzle assembly in uniform and non-uniform velocity field states were also simulated. As a result, the new nozzle construction was not found to show any susceptibility to bed material backflow under either uniform or non-uniform velocity field conditions. The new nozzle construction should also exhibit increased resistance to the material returning from the recycle system. In this regard, only numerical simulations were performed, and the final verification will take place after grid modernization.

Modernization of the air distributor

The new air nozzle construction was used for retrofitting the air distributor in 235MWe CFB boiler operated in the PGE Elektrownia Turów S.A. The air nozzles were installed in the locations of the former arrowhead nozzles; however, due to a lower pressure drop, it was necessary to install orifices at the inlet of the nozzle inlet channels. Because the boiler has been commissioned at the time of writing the present paper, the results of operational tests of the new nozzle construction will be presented in a separate publication.

Concluding remarks

The first step in the design of the air distributor of a CFB boiler is to develop an optimal air nozzle geometry which, on the one hand, will ensure the required pressure drop across the grid, and, on the other hand, will enable a uniform gas flow distribution on the cross-section of the combustion chamber. The air nozzle design should be developed for a specific boiler type. Although a number of guidelines for the requirements to be met by air distributors can be found in relevant literature, no correlations have been developed so far with regard to the geometry of the nozzle itself. In this situation, the design of air nozzles is a task of a high level of complexity, which requires a good knowledge of fluid mechanics laws and the skilful use of numerical flow tools.

On the basis of the investigation carried out, a novel nozzle construction has been developed, whose geometry eliminates the majority of drawbacks typical of arrowhead nozzles. The new nozzle construction has:

- achieved a uniform velocity profile in the outlet arms owing to a designed gas collector that separates the inlet channel from the outlet arms;
- eliminated the strong negative pressure zones in the nozzle outlet arms, resulting from the too rapid change in the direction of gas flow within the inner space of the arrowhead nozzle.

Thanks to retaining dimensions typical of the arrowhead nozzle, the new nozzle construction can be installed in the locations of the former nozzles. Thus, it is possible to perform simple and quick retrofit of the air distributors operated with using arrowhead nozzles.

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