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# The influence of swirl burner structure on the gas/particle flow characteristics

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## ABSTRACT

Improvements were made to a low-$NO_x$ axial swirl burner (LNASB), aimed at mitigating slagging in a 600-MWe boiler burning bituminous coal. The new design is referred to as improved low-$NO_x$ axial swirl burner (ILNASB). This paper describes investigations of the influence of swirl burner structure on the gas/particle flow characteristics using a three-dimensional particle-dynamics anemometer. In comparing results from both ILNASB and LNASB, a central recirculation zone is seen to form in the region $x/d = 0.1–0.3$ within the ILNASB. This zone had shifted from the region between primary and secondary air in LNASB to a region between inner and outer secondary air. In the vicinity of the burner outlet, particle volume flux is reduced significantly in the central recirculation zone. In contrast, this flux is high near the central axis in ILNASB, thus concentrating a great fraction of pulverized coal near the central axis. Form the study, the gas/particle flow characteristics of the ILNASB show that the improved burner has the ability to ease slagging and reduce $NO_x$ emissions.

## 1. Introduction

The power industry requires coal combustion techniques that exhibit flame stability, zero slagging propensity and high combustion efficiency, and also meet pollution control standards. Slagging results in many operating problems and higher running costs. Devir et al. [1] state that “slagging costs the global utility industry several billion dollars annually in reduced power generation and equipment maintenance”. Slagging in the burner vent area can partially plug and even cause deformation of the burner throat, influencing normal flame shape. In China, LNASBs are used in many power plants, although during actual operations these typically exhibit serious slagging problems at the burner nozzle, as well as high $NO_x$ emissions [2]. Interestingly, slagging has been reported [3] to be less in burners with higher ratios of coal mass flux along the centerline axis. This finding was taken into consideration during the redesign of the LNASB which lead to the ILNASB.

The flow field downstream from the swirl burner nozzle is complicated by the turbulence flow. Moreover, the gas/particle flow characteristics have significant impact on ignition and burnout of pulverized coal and the flame stability. At the same time, to verify the accuracy of the numerical results, more detailed export parameters are also required so that the measurements of the flow field after the swirl burner nozzle can be meaningful. In a two-phase flow system, optical techniques can yield simultaneous measurements of particle sizes and velocities that can then be analyzed using Particle-Dynamics Analysis (also known as Phase Doppler Anemometry or PDA) [4–10]. Jing et al. [11,12] investigated gas/particle flow characteristics for centrally fuel-rich swirl coal combustion burner with the use of a three-component particle-dynamics anemometer. Jing et al. [13] also investigated gas/particle flows for a double swirl flow burner using a three-dimensional PDA. Zhou et al. [14] investigated the performance of a collision-block-type fuel-rich/lean burner, using a fiber-optic measurement system in a two-phase flow test facility. Fan et al. [15] measured particle interactions in the turbulent boundary layer for cross flow over a tube. Lin et al. [16] investigated the flow field in a tangential-fired furnace using a PDA. Chen et al. [17–19] studied the influence of different structure on gas/particle flow characteristics of a centrally fuel-rich swirl coal combustion burner.

In the present work, a three-dimensional PDA was used to study an ILNASB on a gas/solid two-phase test bench. Mean axial, radial, and tangential velocities, the root mean square (RMS) fluctuation velocities, and the particle volume flow in different exit sections of the burner were measured. To assess the practicality of the new design, the velocity and particle concentration fields were measured at different exit planes perpendicular to the centerline axes of the burners, both LNASB and ILNASB, for comparison. The study of the particle-gas dynamics of these types of burners aids in designing new more efficient burners.

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## 2. Experimental setup

### 2.1. PDA setup and methods

A three-dimensional PDA made by Dantec was used in this study. The instrument (see Fig. 1) included an argon ion laser, a transmitter, fiber optics, receiver optics, signal processors, a traversing system, a computer system, and a three-dimensional auto-coordinated rack. The PDA uses the proven phase Doppler principle for simultaneous non-intrusive and real-time measurements of the three velocity components and turbulence characteristics, and makes use of new methods to exploit phase differences between Doppler signals received by three detectors located at different positions. The particle size and concentration are measured based on the phase difference arising from Mie scattering and the number of particles passing the measuring volume during a certain time interval. The parameters of the optical system are shown in Table 1. 60 × fiber flow optics and 57 × 10 PDA receiving optics are used. The distance from the measurement volume to the receiving optics is 500 mm. Several optical configurations from 0 to 500 mm are readily available. All instrument settings, such as bandwidth and high voltage, are computer controlled. An analog-digital converter allows computer recording of the anode current from the photomultipliers. The combination of photomultiplier and particle velocity correlation bias can contribute to uncertainty, but the error is likely to be small.

Concentration measurements in a phase Doppler system are complicated by the fact that large particles scatter more light than small ones. Consequently, the larger the particle is, the larger the effective measurement volume. To deal with this, the particles are classed according to size, so that each class can be analyzed separately. The total number density (number of particles per unit measurement volume) is then obtained. Many factors, such as detector sensitivity, optical focus on the measurement volume, detection limit, optical set-up, main flow direction, turbulence and particle size, affect measurement results to some degree. For instance, weak signals from very small particles can be overlooked. For a poorly-tuned PDA system, this can be a problem because the detectable diameter threshold is high. For a finely-tuned PDA, the threshold is lowered significantly that missed small particles do not affect the analysis. The accuracy of the concentration measurements clearly relies heavily on the accuracy with which the volume can be estimated. To get the best well-defined volume, there is a spatial filter in the form of a narrow slit in the receiving optics, in front of the optical fiber. In the Fiber PDA, however, one slit is located in front of the three optical fibers of the probe. The slits are oriented along the same axis at right angles to segments of

**Table 1**
PDA optical parameters.

| Transmitting optics | $U_x$ | $U_y$ | $U_z$ |
|---|---|---|---|
| Laser wave length (nm) | 514.5 | 488 | 476.5 |
| Diameter of Gaussian laser beam (mm) | 1.35 | 1.35 | 1.35 |
| Expander ratio | 1 | 1 | 1 |
| Beam spacing (mm) | 38 | 38 | 38 |
| Focal length (mm) | 500 | 500 | 500 |
| Fringe spacing (μm) | 6.7746 | 6.4256 | 6.2742 |
| Fringe number | 36 | 36 | 36 |

| Receiving optics | Parameter |
|---|---|
| Effective scattering angle | 159° |
| Focal length | 500 mm |
| Receiving polarization | 90° |
| Direction of fringe movement | Positive |
| Particle/medium refractive indexes | 1.51/1 |
| Particle density | 2500 kg/$m^3$ |
| Transmitting polarization | Vertical (90°) |
| Max. particle diameter | 418.94 μm |
| Max. Concentration | $6 \times 10^{10}$ particles/$m^3$ |
| Phase factor: between detector U1 and/U2 | −1.241°/μm |
| Phase factor: between detector U1 and/U3 | −0.620°/μm |
| Scattering mode | Reflection |

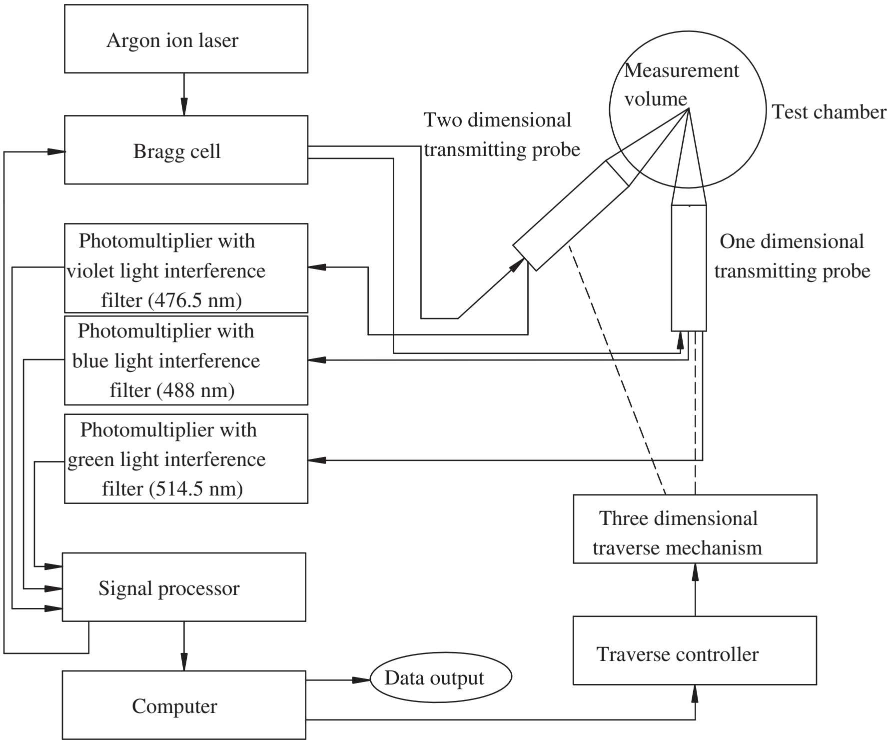

**Fig. 1.** Schematic 3D-PDA system.