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Improving efficiency of conventional and square cyclones using different configurations of the laminarizer

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ABSTRACT

In the present study, effects of different configurations of the laminarizer including inlet, vortex finder and both inlet and vortex finder on the separation efficiency, pressure drop, tangential velocity, and 50% cut size are analyzed. The computational fluid dynamics (CFD) method is applied to predict and demonstrate the flow field inside both conventional cylindrical style and square cyclones. The Reynolds stress model (RSM) is used to simulate the turbulent flow field. Particle trajectories are calculated via discrete phase model (DPM). The discrete random walk (DRW) model is used to model the turbulent dispersion of particles. The results show that installing both inlet and vortex finder laminarizers has the most effect on increasing separation efficiency compared to other configurations of the laminarizer. The cyclone with both inlet and vortex finder laminarizers has the smallest 50% cut size in both conventional and square cyclones. Installing the laminarizer caused a minor increase in the pressure drop for all cases. By installing the laminarizer at inlet and vortex finder simultaneously, a minor increase of about 4.6% and 6.4% is obtained for conventional and square cyclones at the inlet velocity of 18 m/s, respectively. Also, installing the laminarizer at both inlet section and vortex finder of conventional and square cyclones reduced the 50% cut size at inlet gas velocity of 18 m/s about 8% and 27%, respectively. This reduction proved that using the laminarizer in the square cyclone was more effective than the conventional cyclone.

1. Introduction

Cyclones are widely used for removal dust of gaseous flows in industrial processes. Cyclone dust collectors have been used in many industrial facilities to collect solid particles from gas-solid flows and reduce air pollution [1]. Cyclones are technical devices which are used for separating particles from carrier gas with the utilization of gravitational, inertial and centrifugal forces. A simple construction, possible operating reliability, low investment and operating costs and low energy consumption are the basic qualitative aspects of the cyclone [2]. The main performance characteristics of cyclone separators are collection efficiency, fractional efficiency and pressure drop. Taking into account the complex hydrodynamics of cyclones, an efficient mathematical model is required to study and predict the flow behavior and various geometrical designs of cyclones. Computational fluid dynamics has proved to be a promising tool to investigate the characteristics of cyclones [3]. Many experimental and numerical investigations have been performed on cyclone separators for determination of their characteristics [4–6]. Lee etal. [7] analyzed the effect of cylinder shape of a long-coned cyclone and showed that total pressure drop could be reduced by properly adjusting the cylinder body diameter. Chuah etal. [8] stated that the cyclone with a smaller cone diameter gives slightly higher collection efficiency and pressure drop compared to the cyclone with a bigger cone diameter. Slack etal. [9] successfully modeled a conventional high efficiency Stairmand cyclone using an unstructured mesh with both the Reynolds stress model and the large eddy simulation (LES) turbulence model. However, these studies were limited to room temperature. Recently, Shin etal. [5] investigated the physical mechanism of dust collection in a cyclone at high temperature and pressure conditions using a 2D axisymmetric geometry and the k-ε turbulence model. Gimbun etal. [10] studied the effects of temperature and inlet velocity on the pressure drop of gas cyclones using a 3D geometry and the RSM turbulence model. However, neither study presented the velocity profiles at different temperatures and pressures. The experimental data on the velocity distributions under these extreme conditions are very limited [11]. Zhao etal. [12] compared the performance of two types of cyclones with the conventional single inlet and spiral double inlets. Their numerical results show that, the new type cyclone separator using the adding spiral double inlet can improve the symmetry of gas flow pattern and enhance the particle separation efficiency. The effects of cone dimension on the cyclone performance were also

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investigated in the literature [13, 14]. Karagoz etal. [15] presented a new design cyclone separator. The design of their cyclone was based on the idea of improving cyclone efficiency by increasing the vortex length. Their cyclone was different from the conventional cyclones with the separation space. In fact, instead of conical part, the separation space of that cyclone consists of an outer cylinder and a vortex limiter. They experimentally investigated the effects of the vortex limiter position on the cyclone performance. In the study of Wakizono etal. [16], the effect on particle collection efficiency of a ring attached to the upper part of the outlet pipe of a gas cyclone was examined by experiment and CFD simulation. Their results indicated that the 50% cut size for the type Dc ring showed the minimum value and experimental partial separation efficiency qualitatively agreed with the simulation results. Winfield etal. [17] used a CFD simulation to assess the impact on cyclone performance using a triple inlet over a conventional single inlet design. The fluid flow profile and particle separation efficiency performance subjected to a specific flue dust distribution was analyzed. Their results showed that the triple inlet cyclone configuration is the better solution due to lower pressure drop, near identical efficiency performance to the single inlet configuration, and the potential for reduced wear rates as a result of lower inlet and rotational flow velocities in the cyclone body, whilst still maintaining a stable vortex air core. Balestrin etal. [18] investigated the effects of a reduction in the cross section of the vortex finder outlet duct together with a stretched cylindrical body on the flow pattern and performance of a conventional cyclone. CFD modeling and experimental studies on gas-solid flow in cyclones were performed to validate the model through a comparison between the experimental data and numerical results. Their results showed that the collection efficiency increases with a secondary swirling flow promoted by a reduction in the cross section of the vortex finder. Thus, their design represented a promising alternative for new cyclone applications. Safikhani etal. [19] presented a numerical study of the fluid flow and particle dynamics to characterize the performance of new cyclone separators. The design of cyclone is based on the idea of improving cyclone performance by increasing the vortex length. Their results showed that for all new cyclones the low pressure zone is seen in the center of the cyclones. Also, the turbulent kinetic energy has high values at the entrance of vortex finder, entrance of cylinder and top of the vortex limiter surface. In the study of Surjosatyo etal. [20], experimental study aimed to find out vortex finder dimension effects on collection efficiency trend, while CFD simulation goal was to determine the velocity profile of air inside cyclone separator. They found that increasing vortex finder length and decreasing vortex finder diameter can increase the collection efficiency. The arrangement and structure of the cyclone have influence on the overall arrangement of a boiler. Conventional cyclone which has circular cross section was the commonly used cyclone for the circulating fluidized bed (CFB) boiler. With the development of large CFB boilers, the huge body of the conventional cyclone became a major shortcoming because of the thick refractory wall that needs a long period to start the boiler. An alternative way to overcome these problems is the use of square cyclone [21]. Asquare cyclone has more advantages over the conventional cyclone including convenient construction, easier membrane wall arrangement, shorter start-stop time and at the same time easy integration with the boiler [22]. Yue etal. [23] designed a square cyclone separator with a curved inlet and applied it to CFB boiler design successfully in China [24–26]. Lu etal. [26] reported the performance of a CFB boiler with a square cyclone and demonstrated that the pressure drop of the boiler with a square cyclone was less than 800 Pa, which was very close to that of the boiler with a circular cyclone of similar capacities. Different methods were investigated to improve the separation efficiency of cyclones such as different vortex finder configurations, different conical section designs and using vortex limiter. Recently, Huang etal. [27] improved the separation efficiency of the conventional cyclone using the laminarizer at the inlet section of the cyclone and a better cyclone 50% cut size performance was achieved with the laminarizer. In the present study, the effect of installing the laminarizer on the performance of the conventional and the square cyclones were investigated. Three different configurations of the laminarizer in different sections of the cyclones including inlet, vortex finder and both inlet and vortex finder were used to analyze the performance of the cyclones. Although the use of square cyclone instead of the conventional cyclone is an alternative way to overcome the problems of using the conventional cyclone in CFB boilers but the square cyclone has less efficiency than the conventional cyclone. So in the present study, it was found that using the laminarizer can improve significantly the separation efficiency of the square cyclone. Furthermore, using the laminarizer in the square cyclone was more effective than the conventional cyclone.

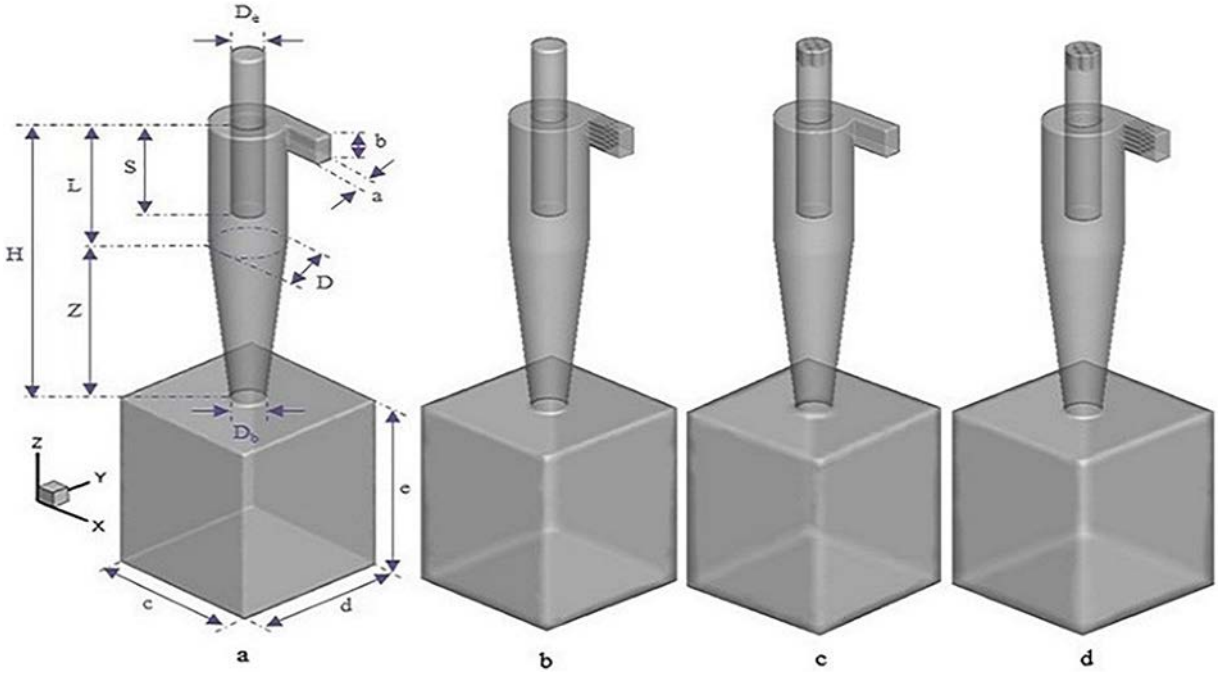

Fig.1. The geometry of conventional cyclone a)without laminarizer b)inlet laminarizer c)vortex finder laminarizer d)inlet and vortex finder laminarizer.