

Numerical investigation of the effect of DBD plasma actuator on performance enhancement of an air-solid particle cyclone separator

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ABSTRACT

In this paper, the effect of secondary flow induced by the DBD plasma actuators on the flow and separation performance of solid particles in a cyclone is numerically investigated. The effect of the effective parameters such as the applied voltage of the DBD plasma actuator, the arrangement of plasma actuators, the velocity of the incoming flow of the cyclone, and the size of solid particles are evaluated. The results show that the separation performance of the cyclone in the presence of the DBD plasma actuators increases in all particles with different diameters between 1 and 2 mm, compared to the cyclone without the presence of plasma actuator, and the performance enhancement is higher in the particles with a larger diameter (2 mm). The arrangement of plasma actuators has a significant effect on the particle separation performance of the cyclone, and the uniform installation of plasma actuators in the entire height of the cylindrical part of the cyclone (type one arrangement) improves the particle separation performance compared to other arrangements. The results show that the use of the DBD plasma actuators inside the cyclone can increase the cyclone separation performance by 26.5% compared to the cyclone without the DBD plasma actuator.

KEYWORDS

Cyclone, Plasma actuator, DPM, Numerical investigation, Particle separation performance.

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Introduction

Several studies have been conducted on flow control to improve the performance of cyclones. Flow control methods are divided into active and passive categories. The most important studies conducted on passive methods to improve the performance of cyclones have focused on cyclones' geometry. In this field, studies have been carried out on the general changes in the geometry [1], the inlet section [2], and also the conical section [3]. On the other hand, the use of active methods to flow control and improve the separation performance in cyclones has attracted the attention of many researchers [4]. Among all of the active flow control devices, the DBD plasma actuator is of interest due to its advantages for flow control [5]. Hence, this article studies the impact of DBD plasma on the flow inside cyclones and improves their performance. For this purpose, the effect of the velocity of incoming flow to the cyclone, the size of the particles, the applied voltage to the plasma actuator, the number, and the arrangement of the plasma actuators on the flow field, and the performance of the cyclone were comprehensively analyzed.

Methodology

Fig. 1 represents a schematic view of the computational domain used for the present study. It should be noted that the DBD plasma location is shown by red boxes. The dimensions of the cyclone geometry are listed in Table 1.

The governing equations of the flow inside cyclone including continuity, and momentum equations are as follows [1]:

$$\frac{\partial u_i}{\partial x_i} = 0 \quad (1)$$

$$\rho \frac{\partial u_i}{\partial t} + \rho \left(u_j \frac{\partial u_i}{\partial x_j} \right) = -\frac{\partial P}{\partial x_i} + \rho g_i + \frac{\partial}{\partial x_j} \left[\mu \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) - \rho \overline{u_i' u_j'} \right] + F_{ei} \quad (2)$$

Furthermore, the Reynolds stress turbulence model is used for turbulent flow simulation. Also, F_{ei} in Eq. (2) indicates the electric body force. It is assumed to be a sinusoidal function and is defined as follows [5]:

$$F_e(x, y) = \frac{\pi^2 \text{thrust}}{4lh} \sin\left(\frac{x-x_s}{l} \pi\right) \sin\left(\frac{y-y_s}{h} \pi\right) \quad (3)$$

$$x_s \leq x \leq l+x_s$$

$$y_s \leq y \leq h+y_s$$

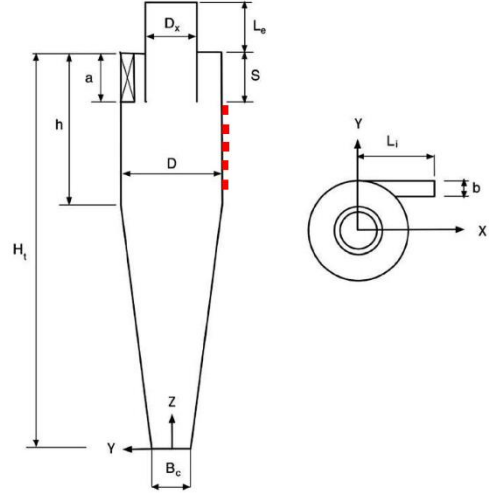


Figure 1. Schematic view of the computational domain.

Table 1. Dimensions of the cyclone geometry

Parameter	Value (mm)
D	205
a	102.5
b	41
D_x	102.5
H_t	820
h	307.5
S	102.5
B_c	73.8
L_i	205
L_e	126.69

This study employs a unique UDF code for plasma body force (from Eq. (3)) in C++ in the ANSYS Fluent software. The Navier-Stokes equations are calculated in this method using the SIMPLE-C algorithm to define the flow pressure and velocity fields.

Results and Discussion

To express the effect of the DBD plasma actuator on the flow field and separation performance of solid particles in a cyclone, cyclone separation performance in various particle diameters for different inlet velocities are shown in Fig. 2. It is clear that applying the plasma actuator has a favorable effect on the cyclone flow field and cyclone separation performance. Also, it is obvious that by increasing the velocity of incoming flow to the cyclone, the performance of applying the plasma actuator decreases.

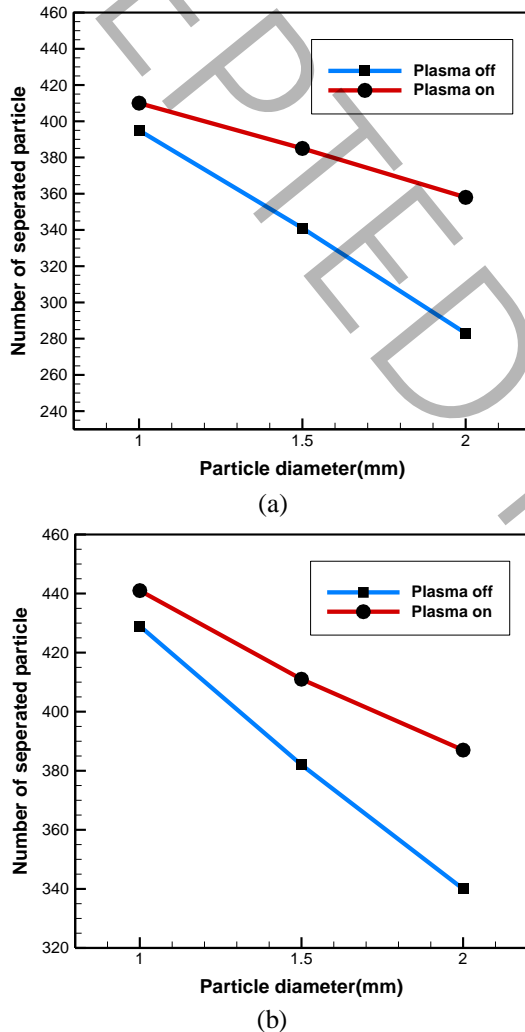


Figure 2. Cyclone separation performance in various particle diameters (a) at the inlet velocity of 7 m/s (b) at the inlet velocity of 10 m/s

According to Fig. 3, the results indicated that increasing the applied voltage enhances the cyclone separation performance. It can be seen that at $V=10$ kV, 301 particles are separated in the cyclone, and by increasing the voltage applied to the plasma actuators to 25 kV, the number of collected particles has increased significantly and the cyclone has been able to separate 358 particles.

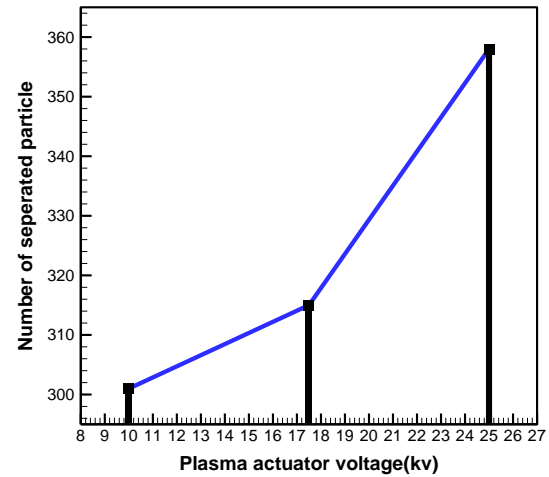


Figure 3. Cyclone separation performance for different applied voltages

Conclusions

In this study, the impact of the DBD plasma actuator on the flow field and separation performance of a cyclone was numerically investigated. The effects of effectiveness parameters as: the applied voltage of the DBD plasma actuator, the arrangement of plasma actuators, the velocity of the incoming flow of the cyclone, and the size of solid particles were studied. Results indicate that using the plasma actuator inside cyclone could improve its separation performance in different conditions.

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