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Numerical Simulation of Gas – Solid Cyclone Separators Operating at High Temperatures

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ABSTRACT: Although cyclones have simple geometries their flow is really complicated. Inlet fluid temperature is one of the factors that increases its complexity. Variation of the thermo-physical properties of the working fluid with temperature causes cyclones to have different pressure drop and particle separation efficiency. In this paper, the effect of fluid and particles temperature on two main performance parameters (pressure drop and separation efficiency) of low-mass-loading Stairmand high efficiency cyclone are numerically investigated. Eulerian-Lagrangian approach is used to model two-phase flow. Simulation is performed at a temperature range of 293-700 K and four inlet velocities. Also, the turbulent equations are solved with unsteady Reynolds stress method. Results show that increasing in dynamic viscosity due to increase in fluid temperature, causes increment in shear stress in cyclone body. Therefore, separation efficiency and pressure drop are decreased. If the inlet flow temperature increases by 100 K, pressure drop decreases between 14% and 16% at different inlet velocities. Also, separation efficiency is decreased by 4.64% between the minimum and maximum of inlet temperatures.

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1- Introduction

Cyclones are one of the most popular separators at different industries. Centrifugal force is employed to separate the particles from a gas stream. High separation efficiency, zero energy consumption and lack of rotating parts are the main advantages of cyclones. Zhu and lee [1] experimentally investigated the performance of small cyclones with conical and cylindrical vortex finders under high flow rates. Their results show that if the flow rate is doubled, the cut diameter increases by 80%. Also, conical vortex finders have lower pressure drop. Safikhani et al. [2] optimized the dimensions of a specified cyclone with genetic algorithm to minimize the pressure drop and cut diameter. Song et al. [3] numerically investigated the forces acted on particles. They showed that drag is the dominant force and the effect of other forces like pressure gradient and lift can be neglected.

In a lot of industrial units like cement industries, some processes in heat power plants and chemical production, it is necessary to separate solid particles from a high temperature gas. In this study, performance parameters of a high efficiency Stairmand cyclone including pressure drop, particle separation efficiency, velocity and temperature fields are investigated.

2- Governing Equations

2- 1- Continuous phase

Reynolds stress turbulence model is an effective method for solving the closure problem in unsteady turbulent equations of momentum, energy and continuity on a structured grid [4]. SIMPLE algorithm is chosen for pressure-velocity coupling and second order upwind scheme is applied for discretization of momentum and energy equations with Δt=0.005 s as time step size.

2- 2- Discrete phase

After the flow field equations are converged, particles are injected from the inlet surface. Due to the diameter range of injected particles, 1-7 µm, and as it was shown in previous studies [3], drag is the dominant force acted on solid particles. Also, thermophoretic force is applied to include the effect of temperature gradient on particle trajectory.

$$\frac{dx_p^i}{dt} = F_D\left(u^i - u_p^i\right) + g^i + F^i_{thermophoretic} \qquad (1)$$

3- Boundary Conditions

Velocity inlet and outflow boundary conditions are considered for the inlet and outlet boundaries [5]. No slip boundary condition is applied for all walls. Also, outer walls convective heat transfer coefficient is equal to $\bar{h}$=3 W/m^2.K and temperature of 293 K. In this study, 4200 particles are injected from the inlet surface. Particles are injected with zero velocity and the same temperature with inlet flow. All of the walls (except dust bin) are perfectly elastic. It means, once a particle touches these walls, reflects with the same impact velocity and angle (coefficient of restitution is equal to 1). But if a particle reaches dust bin, reported as ‘trapped’ [6].

4- Validation

To examine the accuracy of the numerical solution, the obtained pressure drop and particle separation efficiency at the inlet temperature of 293 K and four inlet velocities are compared with the experimental results of Zhao et al. [7].

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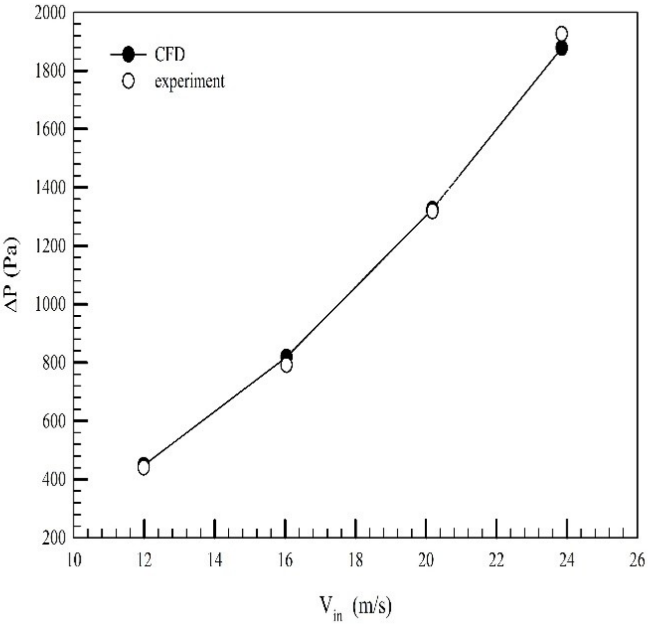
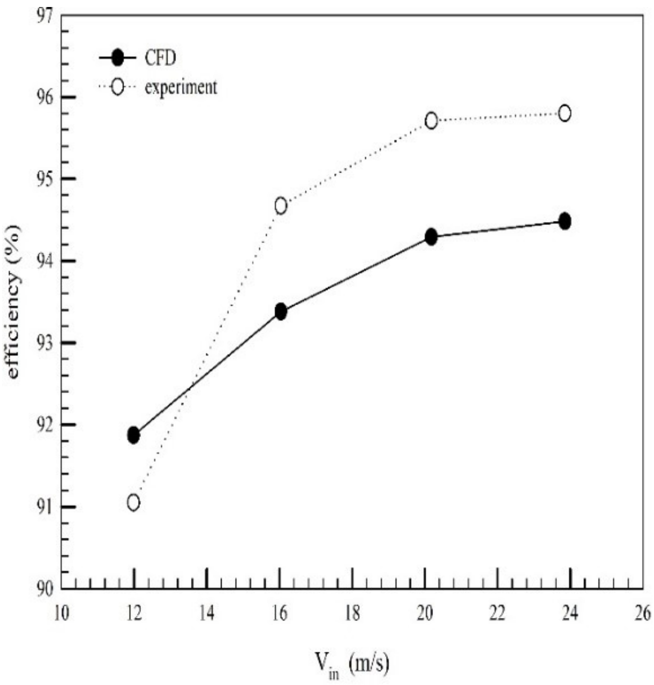
Results (at inlet velocity of 23.85 m/s) show that numerical simulation can predict the experimental trend and value with maximum deviation 3.46% and 1.2% for pressure drop and separation efficiency. In average deviation values are 2.1% and 0.8% (Fig. 1).



(a)



(b)

Figure 1. Validation of numerical results

5- Results and Discussion

Non-dimensional tangential velocity profile at is presented in Fig. 2. It is clear in that increasing in dynamic viscosity, causes increment in shear stress in cyclone body. For example, by increasing of inlet temperature from 293 to 700 K, the maximum of tangential velocity at the inlet velocity of 23.85 m/s, is significantly decreased by 9.93%.

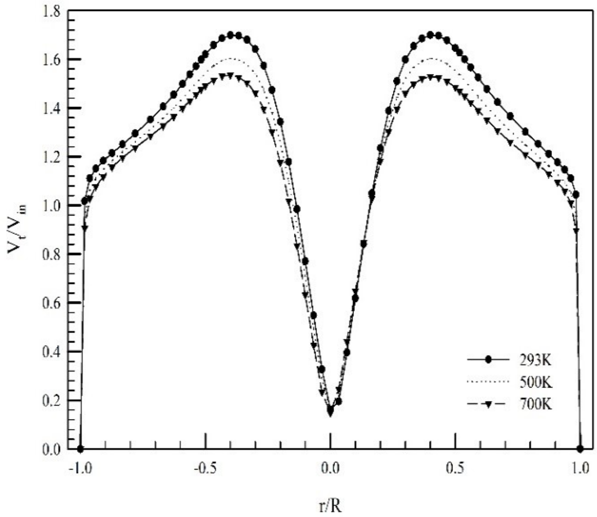


Figure 2. Tangential velocity profile

Higher tangential fluid velocity in the cyclone, means a more intense vortex causing the centrifugal force on particles rotating there to be higher, improving the separation performance and increasing the pressure drop.

6- Conclusions

The most important results are concluded as follows:

- Increase of inlet temperature causes increase in dynamic viscosity of fluid and increment of shear stress in cyclone body. Therefore, pressure drop and particle separation efficiency are noticeably decreased.
- Thermophoretic force plays a negative role on particle collection process.

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