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Original Research Paper

Study of inlet temperature effect on single and double inlets cyclone performance

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ABSTRACT

In this paper, a comprehensive study is performed in order to demonstrate the effect of the flow and particle temperature on cyclone performance. Three main characteristics of the low-mass-loading gas-solid cyclone separators, including: pressure drop, particle separation efficiency and natural vortex length are investigated. Eulerian-Lagrangian approach is employed to solve the unsteady Navier-Stokes and energy equations to model the flow of particles. Because of the strong swirling flow in cyclone, Reynolds stress transport model (RSTM) is used to calculate the Reynolds stresses. Numerical simulation is accomplished at a temperature range of 293–700 K and four inlet velocities. Also, a comparison is conducted between two Stairmand high efficiency cyclones with the same dimensions, one with single inlet and the other with double inlets to declare the effect of the second inlet on cyclone performance. The analysis of results shows that the swirling flow becomes weaker for higher temperature cases and thus, flow pressure drop and particle separation efficiency is noticeably decreased. Increasing in temperature causes decrease in natural vortex length. Also, study of natural vortex length is performed for the studied range of temperature.

1. Introduction

Cyclones are one of the most popular separators at different industries. Centrifugal force is employed to separate solid particles from a gas or bubbles from a liquid in a cyclone. Cyclones are suitable tools for removing particulates from streams, without the use of filter elements. Large cyclones are used in mills to remove dust from air; while their smaller ones are used to analysis airborne particles. Also they are widely used in the household, as the core technology in bag less types of portable vacuum cleaners and central vacuum cleaners. Cyclones are also used in industrial and professional kitchen ventilation for separating the grease from the exhaust air in extraction hoods. They are also used in oil refineries, cement industry, HVAC systems and natural gas stations as the pre separator to decrease the load of the main filters.

The study of the fluid flow and particle trajectories in cyclones receives many attentions due to its numerous applications. Zhu and lee [1] conducted a set of experiments on the particle collection efficiency and pressure drop of small cyclones operating at high flow rates. They studied seven cyclones with different dimensions at a wide range of flow rates and particle sizes. They also investigated the effects of the cylinder height and exit tube length on the particle collection efficiency. Their results shows that increase in flow rate can help to collect more small particles. Also they found that increase in cylinder height leads to increase in collection efficiency and decrease in Pressure drop. Lim et al. [2] experimentally investigated the effect of vortex finder shape and dimensions on cyclone performance. They considered four cylinder-shaped and six cone-shaped vortex finders to compare their collection efficiencies at different flow rates. Their results indicates that cyclones with conical vortex finder have higher efficiency and lower pressure drop than another type. Dirgo and Leith [2] performed an experiment study on a high efficiency Stairmand cyclone with the body diameter of 0.305 m at a flow rate of 0.139 m^3/s and compare their results with different theories. They found that none of the available theories cannot have an accurate prediction of the experimental cyclone efficiency. Although the Lapple theory underestimated efficiency, this theory contains a correction factor that can be set to produce better matching between theoretical and experimental data.

CFD techniques can fully predict the cyclone performance. Numerical prediction of the effect of cone tip diameter on the cyclone performance is performed by Gimbun et al. [3]. It was found that computational fluid dynamics can predict the collection efficiency and pressure drop of a cyclone at different cone dimen-

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Nomenclature

A	inlet area (m^2)
a	inlet height (m)
a_1, a_2, a_3	constant (–)
B_c	cone tip diameter (m)
b	inlet width (m)
C_D	drag coefficient (–)
C_p	specific heat (J/kg K)
D	cyclone diameter (m)
$D_{T,p}$	thermophoretic coefficient (N m)
D_H	hydraulic diameter of inlet channel (m)
D_x	vortex finder diameter (m)
d	diameter (m)
F_D	drag force per unit particle mass (N/kg)
g	gravity acceleration (m/s^2)
H_t	total height (m)
h	barrel height (m)
$\bar{h}$	convection coefficient (W/m^2 K)
I	turbulence intensity (–)
k	conduction coefficient (W/m K)
l	natural vortex length (m)
m	mass (kg)
$\dot{m}$	mass flow rate (kg/s)
P	inlet perimeter (m)
S	vortex finder length (m)
T	temperature (K)
Δt	time step size (s)
u, v, w	particle velocity components (m/s)
V	velocity magnitude (m/s)
x	particle trajectory (m)

Greek letters

μ	dynamic viscosity (Pa s)
ρ	density (kg/m^3)
∇	gradient operator (1/m)

Subscripts

in	inlet
p	particle
g	gas
t	tangential

sions with a deviation less than 5.5% from the experimental data. Also they showed that Reynolds stress turbulence model is an effective method for modelling the swirling flow in cyclone. The obtained results indicates that a cyclone with a bigger cone diameter has lower collection efficiency and pressure drop compared to a cyclone with a smaller cone diameter. In addition to the tangential inlet cyclones, axial cyclones are also used in many applications. At these cyclones, guide vanes are considered to swirl the fluid. Gong et al. [4] conducted a CFD study of the effect of vane angle on the flow pattern and the performance of the axial flow cyclone separator. They developed a two-stage turbulence model based on the combination of RNG κ-ε model with the Reynolds stress model to analyze the fluid flow. The results shows that the pressure and velocity fields in the axial flow cyclones had a good symmetry. For particles with diameter equal to or higher than 5 μm, the cyclone has the highest separation efficiency. While for diameter less than 1 μm, it has not a good performance. Azadi et al. [5] performed a three-dimensional simulation of the fluid flow and particle trajectories inside the cyclones with different sizes. Their results shows that the Reynolds stress transport model has a good prediction of the cut diameter with the deviations of 2.3%, 3.4%, and 3.6% of the experimental data for three different cyclones; while the RNG model has lower accuracy. Chlebnikovas and Baltrenas [6] analyzed the flow in a new type of cyclone with six channels inside its body. They showed that particles with the diameter higher than 10 μm has the highest efficiency. Funk et al. [7] investigated the effect of inlet flow velocity on cyclone performance. They showed that cyclone performance firmly dependent on its flow rate. For example, if the inlet velocity reduces by 25%, pressure drop and collection efficiency decreases by 46% and 31%. Lakhbir Singh Brar et al. [8] numerically simulated the effect of cyclone length on its performance. They showed that if the cylinder length increases up to 5.5 times of the cyclone diameter, pressure drop decreases by 34% and the collection efficiency increases by about 9.5%. Also, increasing the cone length causes to decrease in pressure loss and increase in collection efficiency. Misiulia et al. [9] used LES[1] to investigate the effects of inlet angle on the flow pattern and pressure drop in cyclones. Their results indicates that increase in inlet angle and height causes to decrease in the absolute values of the static pressure and tangential velocity at central and close to the wall regions of cyclone body. Wu et al. [10] studied the effect of exit pipe diameter and inlet dimensions on entropy generation of cyclone separators. They calculated three types of entropy generation caused by direct dissipation, turbulent dissipation and wall friction. Their results indicates that increase in inlet velocity and decrease in exit pipe diameter causes increase in the exergy loss in cyclones. Karagoz and Kaya [11] investigated the fluid flow and the heat transfer parameters in a cyclone. They showed that heat transfer from all of the cyclone walls increases with increasing in inlet velocity. They used the steady state RNG κ-ε turbulence model in their simulation. Not only this model is not appropriate for cyclonic flow, but although the flow in cyclone is substantially unsteady and steady state solutions are not reliable. In this simulation, constant temperature boundary condition is considered for walls; while this boundary condition is not realistic and wall temperature should be calculated. They found that the maximum rate of the heat transfer stands on the surface opposite to the inlet and decreases toward the dust bin.

Gimbun et al. [12] evaluated the effects of inlet temperature and velocity on the pressure drop of gas cyclones. They found that pressure drop decreases with increase in inlet temperature. Also they show that the relation of Shepherd and Lapple [13] has more accurate prediction of pressure drop at different temperatures. Recently, Song et al. [14] studied the motion of solid particles in a cyclone. Their results shows that centrifugal force has determining role on large particles trajectories. While for smaller particles, the drag force is the dominant force. Also the trajectory of small particles strongly depends on the movement of fluid.

In an overview, cyclones are classified in to three categories (1D2D, 2D2D, 1D3D) based on the ratio of the cylindrical and conical part length to cyclone diameter. Safikhani et al. [15] numerically studied the above mentioned cyclones performance at the same flow rate. Their results shows that the magnitude of axial velocity in 1D2D is less than two other cyclones. Also, the numerical analysis shows that the pressure drop, velocity field and turbulence parameters are almost independent of cyclone body diameter.

Natural vortex length is one of the important parameters in cyclone design. In fact, it is the efficient length of a cyclone. Hoffmann et al. [15] performed an experimental study on a specified

[1] Large Eddy Simulation.

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