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A numerical and experimental study on a high efficiency cyclone dust separator for high temperature and pressurized environments

Mi-Soo Shin [a], Hey-Suk Kim [a], Dong-Soon Jang [a,*], Jin-Do Chung [b], Matthias Bohnet [c]

[a] *Chungnam National University, 220 Gung-dong, Taejon 305-764, Republic of Korea*
[b] *Hoseo University, Baebang-Myun, Asan city Chung-Nam 336-795, Republic of Korea*
[c] *Institute of Chemical Engineering Technical university of Braunschweig, Langer Kamp 7, 38106 Braunschweig, Germany*

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Abstract

A numerical and experimental study has been made for the development of high efficiency cyclone dust separator applicable to the extreme environments of high pressure of 6 bar and temperature up to 400 °C. The main objective of this study is to develop a handy and reliable computer program and thereby to figure out the physical mechanism of dust collection for high temperature and pressure condition.

The program is developed using Patankar's SIMPLE method for the application of 2-D axi-symmetric flow field. The two-equation turbulence *k–ε* model is employed for the resolution of Reynolds stresses. Further the particle trajectory calculation is made by the incorporation of drag, centrifugal and coriolis force in a Lagrangian frame.

The calculated results predict well the general trend and its magnitude of the experimentally measured pressure drop with the condition of increased pressure and temperature as a function of flow rate. Further, experiment shows that the increase of pressure and temperature generally affect significantly the collection efficiency of fine particle less than 10 μm but the effect of pressure and temperature appears contrary each other. That is, the increase of pressure increases the collection efficiency, while the increase of the temperature results in the decrease of the efficiency over a certain range of flow rate. This is explained well by the

* Corresponding author. Tel.: +82 42 821 6677; fax : +82 42 823 8362.
E-mail address: p_dsjang@cnu.ac.kr (D.-S. Jang).

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variation of the gaseous density and viscosity effect on the drag force and also confirmed successfully by the result of numerical calculation. Therefore the decrease of fractional collection efficiency caused by the high operating temperature can be remedied by the increase of operating pressure.

In order to investigate in more detail the effect of extreme condition on the physics of collection efficiency, a series of parametric numerical investigations are performed in terms of major cyclone design or operational parameters such as tangential velocity and vortex finder length, etc. As expected, tangential velocity plays the most important effect on the particle collection even for the elevated temperature and pressure condition. But there is no remarkable difference noted between reference and extreme condition. And the length of vortex finder has relatively insignificant effect on collection characteristics but the diameter of vortex finder plays an important role for the enhancement of collection efficiency.

The incorporation of a proper turbulence model of the nonlinear term appeared by relative velocity between gas and particle phase for drag calculation of particle trajectory is considered as one of the important tasks for the more accurate resolution of physical feature for elevated temperature and pressure condition in near future.

Keywords: Cyclone separator; Pressure drop; Collection efficiency; High temperature and pressure

1. Introduction

The development of new energy saving technologies in power generation causes a strong impetus to develop new devices for hot flue gas cleaning at pressurized condition. A cyclone is considered as one of advantageous tools for high temperature gas cleaning due to their simplicity and low maintenance requirements. By using suitable materials and methods of construction cyclones may be adapted for use in extreme operating conditions such as high temperature, high pressure, and further corrosive gases environments. Therefore, the objective of this study is to investigate the behavior of dust particle at an elevated temperature and pressure condition.

The schematic diagram of cyclone is shown as in Fig. 1. The dirty gas enters the cyclone tangentially, describes a descending outer vortex, inverts the direction of motion due to the action of increase of static pressure and ascends by an inner vortex exiting at the cyclone top through the vortex finder.

The larger particles are swept into the cyclone wall by a centrifugal force, which is locally opposed by aerodynamic drag of radial direction, and are carried towards the bottom of the cyclone by the descending outer vortex. The finer particles exit at the top with the carrier gas, together with coarser particles that may have been re-entrained and swept by the ascending inner vortex.

Since cyclones have been used extensively in various industries, a considerable number of experimental and theoretical investigations have been performed on cyclone separators to the present. Among these, Stairmand [1] presented one of the most popular design guides which suggested that the cylinder height and exit tube length be, respectively, 1.5 and 0.5 times of the cyclone body diameter for the design of a high efficiency cyclone. Bryant et al. [2] observed if the vortex touched the cone wall, particle re-entrainment occurred and Leith [3] and Bhatia and Cheremisinoff [4] discussed the effects of the cone opening size. Rongbiao et al. [5] were suggested that flow rate strongly influenced the efficiency and the reduction in cone size results in higher collection