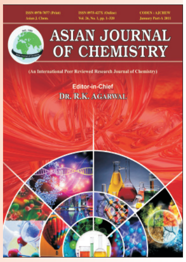
Asian Journal of Chemistry; Vol. 26, No. 13 (2014), 4073-4076

ASIAN JOURNAL OF CHEMISTRY

http://dx.doi.org/10.14233/ajchem.2014.17716



An Experimental and Numerical Study on the Chemical Particle Fractional Collection Efficiency in Cyclone†

JIN DO CHUNG[1,*] and SANG-GWAN LEE[2]

[1]Department of Environmental Engineering, Hoseo University, 79 BaeBang, Asan City, ChungNam, Republic of Korea
[2]Graduate School, Department of Environmental Engineering, Hoseo University, 79 BaeBang, Asan City, ChungNam, Republic of Korea

*Corresponding author: E-mail: jdchung@hoseo.edu

AJC-15412

Cyclone separators are still one of the most widely used of all industrial dusts from air or process gases, also provide simple to construct and is very low in first costs compared with other types of dust collecting equipments. In this study, a highly effective cyclone system was produced that could operate under operational condition of high temperature and high pressure in order to exclusively apply cyclone to collecting dust of integrated coal gasification cycle and pressurized fluidized bed combustion combined cycle and an experiment to measure the dust-collection efficiency of cyclone system and its pressure drop was executed. In addition, this study reviewed the possibility of optimized design of a high-temperature and high-pressure cyclone system through comparing the result of the experiment and the result of numerical analysis of 3-D flow analysis, dust-collection efficiency and prediction on the behaviour of dust particles.

Keywords: Cyclone, Pressure drop, Collection efficiency, Numerical study, Experiment.

INTRODUCTION

Dust collection in the existing thermal power generation has been used for complying to the regulation of air pollution control. However, the dust collection for IGCC (integrated coal gasification cycle) and PFBC-CC (pressurized fluidized bed combustion combined cycle) is more strictly required to protect gas turbine from wear and tear by dust particles[1,2]. To prevent damage on gas turbine, dust-collection process in high temperature and high pressure is essential. Currently available dust-collection systems with high temperature and high pressure are cyclone, electrostatic precipitator, granular bed filter and ceramic candle filter. Among them, cyclone has a simple structure and can operate in high temperature and high pressure with less energy consumption and low cost for production and maintenance[3,4]. Its size is also small enough to commercialize. Cyclone is known as the only dust collector[5,6] that can operate in high temperature close to 1000 ºC.

In this study, a highly effective cyclone system was produced that could operate under operational condition of high temperature and high pressure in order to exclusively apply cyclone to collecting dust of IGCC and PFBC-CC and an experiment to measure the dust-collection efficiency of cyclone system and its pressure drop was executed[7]. In addition, this study reviewed the possibility of optimized design of a high-temperature and high-pressure cyclone system through comparing the result of the experiment and the result of numerical analysis of 3-dimensional flow analysis, dust-collection efficiency and prediction on the behaviour of dust particles.

EXPERIMENTAL

Experimental set-up: To receive reliable data for extreme operating conditions, the set-up shown Fig. 1 has been installed. It allowed measurements of pressure drop and grade efficient in a temperature range 15-600 ºC at a maximum pressure of 6 bar. A three stage compressor delivers the flow rate, which is adjusted by two control valves in the bypass. The pressure is adjusted by one control valve at the end of the set-up. The air is heated electrically with two heaters[8,9]. A rotating brush dosing device installed within a pressure vessel is used to feed solids continuously to the gas. A valve in the main stream controls the flow rate through the dosing devices. The collection efficiency curve is determined by measuring the particle size distribution and the particle concentration within the inlet and outlet gas stream of the cyclone[10]. These data are measured with two light scattering aerosol counters in-line and simultaneously. The cyclones are fixed in a pressure vessel. This simplifies the variation of the cyclone geometry, because the cyclone itself has to be designed temperature resistant only[11].

---

†Presented at 5th International Symposium on Application of Chemical and Analytical Technologies in Nuclear Industries (Nu-ACT 2013), Daejeon, Korea

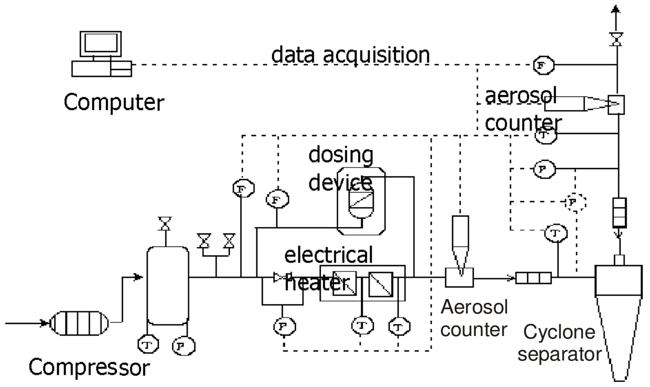


Fig. 1. Experimental Set-up

Numerical modeling: For the numerical study, a general thermo-fluidic analysis code, FLUENT V. 6.0 was used.

The basic gas-phase conservation equations for mass, momentum, energy, turbulence quantities and species concentration can be expressed, in Eulerian cylindrical framework, as:

$$\frac{\partial(\rho\phi)}{\partial t} + \nabla\cdot(\rho\vec{u}\phi) = \nabla\cdot(\Gamma\nabla\phi) + S_\phi \quad (1)$$

where, denotes general dependent variables expressed as a physical quantity per unit mass. Further, u, ρ, Γ, S, and standard for, ∇, tangential velocity components, density, temperature, diffusion coefficient and source term corresponding to, respectively. Turbulence is modeled using the Reynolds stress model (RSM). The Eulerian gas phase equations were solved by a control volume based finite difference procedure. Upwind scheme for the convection term appeared in the governing eqn. 1 and SIMPLE (Semi-Implicit Method for Pressure Linked Equations) algorithm for the resolution of pressure-velocity coupling were both employed.

Schematic diagram (Fig. 2) and specification cyclone geometry and operating conditions used in this study is given in Table-1.

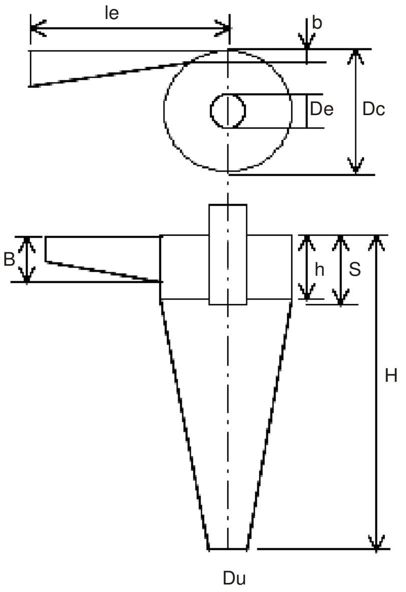


Fig. 2. Schematic diagram of cyclone

TABLE-1
SPECIFICATION OF CYCLONE GEOMETRY AND OPERATING CONDITION USED IN THIS STUDY

Geometry		Type I
Length of inlet	le [mm]	245
Cyclone body diameter	Dc [mm]	150
Exit diameter	De [mm]	50
Dust outlet diameter	Du [mm]	50
Cyclone body height	H [mm]	387
Height of inlet	h [mm]	104
Vortex finder length	S [mm]	110
Width of inlet	a [mm]	80
	b [mm]	20

The equation for particle motion can be expressed as

$$m_p \frac{d\vec{u}_p}{dt} = \vec{F}_{dr} + \vec{F}_p + \vec{F}_{am} + \vec{F}_b \quad (2)$$

$$\vec{F}_{dr} = \frac{1}{2} C_{d\rho} A_p \,|\vec{u} - \vec{u}_p|\,(\vec{u} - \vec{u}_p)$$

$\vec{F}_{dr}$: drag force, C_d: drag coefficient number, A_P: particle cross-sectional area.

$$\vec{F}_p = -V_p \nabla P$$

$\vec{F}_p$: pressure force, V_P: particle volume, ∇P : pressure gradient.

$$\vec{F}_{am} = -V_p F_{am} = -C_{am\rho} V_p \frac{du_p}{d_t}$$

$\vec{F}_{am}$: virtual force, C_{am}: vitual mass coefficient (generally 0.5).

$$\vec{F}_b = m_p[\vec{g} + \vec{w} + (\vec{w}\times\vec{r}) + 2(\vec{w}\times\vec{u}_p)]$$

$\vec{F}_{am}$: body force, $\vec{g}$: gravitational acceleration vector, $\vec{w}$: coordinate angular velocity vector, $\vec{r}$: distance vector to the axis of rotation.

RESULTS AND DISCUSSION

Figs. 3 and 4 shows the measured pressure drop curves as function of flow rate for various temperature and pressure conditions of temperature up to 400 ºC and pressure up to 2 bar. As might be expected, for a given volumetric flow rate, the pressure drop generally increases with the increase of gaseous density, *i.e.*, high pressure and low temperature condition. This is attributed to the effect of increased dynamic pressure and thereby large pressure drop by the increase of density for the same flow rate.

Fig. 5 is comparison result of the effect of increased temperature on the measured fractional collection efficiency for the case of 80 m^3/h with 1.2 bar. Fig. 6 is comparison result of the effect of increased pressure and flow rate on the measured fractional collection efficiency for the case of 500 ºC. As shown in the figure, the collection efficiency generally increases with the increase of pressure and decrease of temperature. Based on the results, it is clear that the decrease of collection efficiency by the increase of temperature can be alleviated by the proper increase of operating pressure of cyclone.

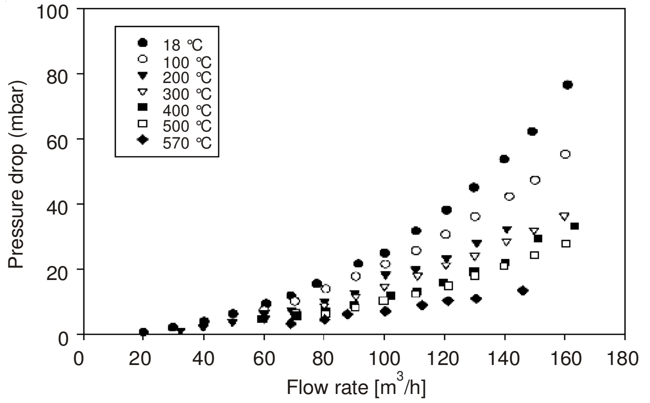


Fig. 3. Pressure drop as a variation of temperature in cyclone under ambient pressure

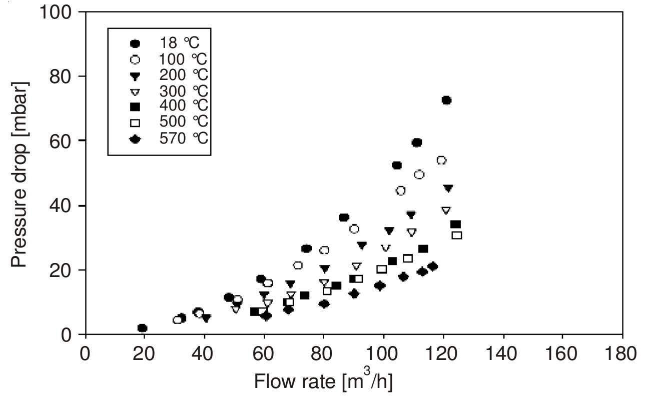


Fig. 4. Pressure drop as a variation of temperature in cyclone under 2 bar

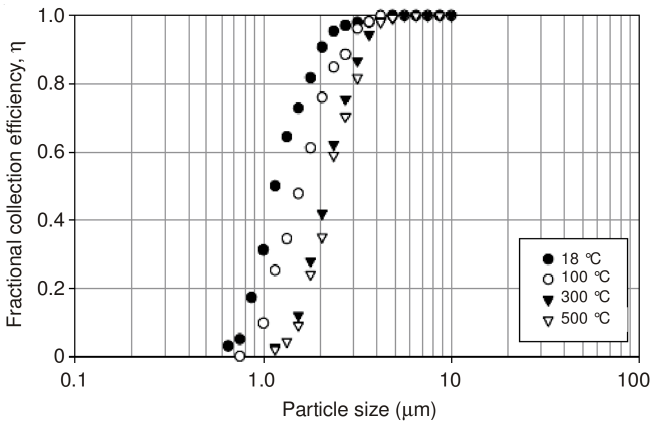


Fig. 5 Comparison of fractional collection efficiency as a variation of temperature in cyclone. [1.2 bar, 80 m^3/h]

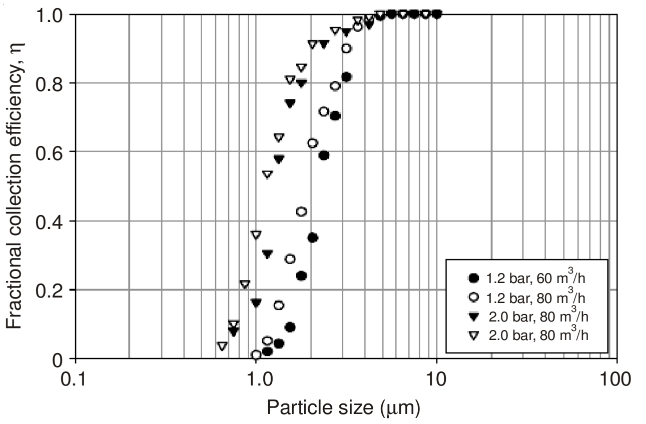


Fig. 6. Comparison of fractional collection efficiency as a variation of flow rate and pressure in cyclone, [500 °C]

Figs. 7 and 8 represent the velocity vectors of numerical results. Fig. 9, to observe the effects on cyclone separation characteristics more clearly, shows the spiral flow of pathlines. This figure is represented that the flow pattern has cycloid motion near the wall when the collection efficiency is high.

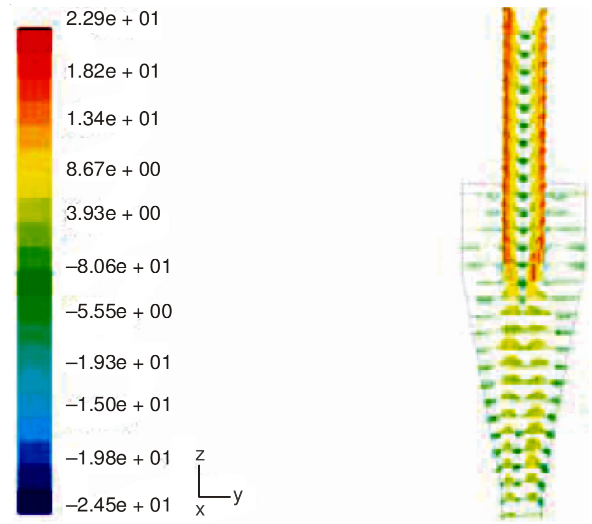


Fig. 7. Axial velocity vectors in the CFD simulation

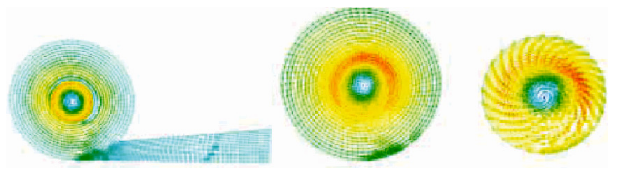


Fig. 8. Velocity vectors

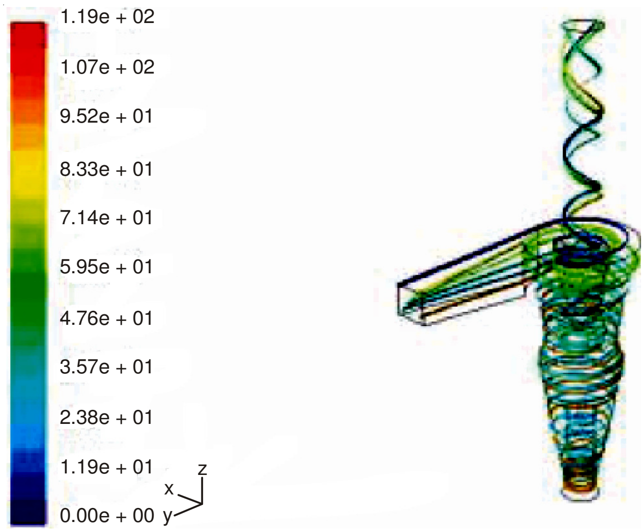


Fig. 9. Path lines showing the spiral flow in a cyclone

Fig. 10 shows the comparison of calculated and measured collection efficiency curves as function of particle size for the case of 18 °C and 1.2 bar. As shown in the graph, it could collect smaller dust particles in the numerical calculation result, which is deemed to be from the fact that the numerical analysis did not consider the phenomenon of the fraction of dust particles into smaller particles and creating more fine particles as well as its re-entrainment that occurs in an actual experiment.

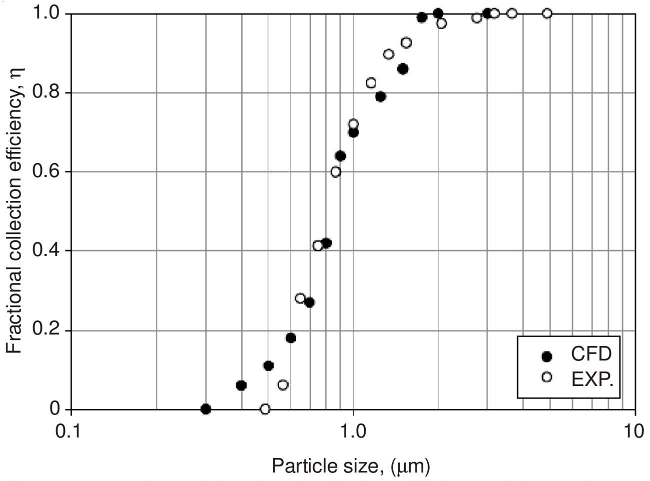


Fig. 10. Comparison of fractional collection efficiency with experimental and numerical calculation data

Conclusion

We have adapted that the collection efficiency can be calculated directly from the counted particle numbers. Based on a series of experimental and numerical investigation by the cyclone we obtained useful results. The results are as following:

- Measurement of pressure drop shows that it influenced by temperature. The increasing of temperature can be explained by show decreasing of pressure drop.
- Collection efficiency for high temperature conditions shows that it also influenced by temperature. The increasing of temperature shows decreasing of collection efficiency.
- Cyclone will be applying (the first step removal process because it decrease high concentrated dust) IGCC, PFBC systems as its removal range fully enough to the limits of G/T inlet conditions under μm.
- The 3-D flow pattern of the cyclone using Fluent S/W shows that well fit relatively experimental results.

ACKNOWLEDGEMENTS

This work was supported by the Human Resources Development of the Korea Insitute of Energy Technology Evaluation and Planning(KETEP) grant funded by the Korea Government Ministry of Trade, Industry and Energy

REFERENCES

1. C.J. Stairmand, *Trans. Instn. Chem. Engrs.*, **29**, 356 (1951).
2. H.S. Bryant, R.W. Silverman and F.A. Zenz, *Hydrocarbon Process.*, **62**, 87 (1983).
3. J. Dirgo and D. Leith, *Filter. Sep.*, **22**, 199 (1985).
4. M.U. Bhatia and P.N. Cheremisinoff, in ed. P.N. Cheremisinoff, Cyclones, In: Air Pollution Control and Design for Industry, Marcel Dekker, New York (1993).
5. R. Xiang, S.H. Park and K.W. Lee, *J. Aerosol Sci.*, **32**, 549 (2001).
6. C.H. Kim and J.W. Lee, *J. Aerosol Sci.*, **32**, (2000).
7. M. Modigell and M. Weng, *Chem. Eng. Technol.*, **23**, 753 (2000).
8. M.A. Silva and S.A. Nebra, *Drying Technol.*, **15**, 1731 (1997).
9. M. Bohnet, Cyclone Separation for Fine Particles and Difficult Operating Conditions, KONA Powder and Particles, No. 12, pp. 69-76 (1994).
10. M. Morweiser and M. Bohnet, Design Calculation of Aerocyclones for Extreme Operating Conditions, 12th International Congress of Chemical and Process Engineering, pp. 55-66 (1996).
11. M. Morweiser and M. Bohnet, Influence of Operating Conditions on Grade Efficiency and Pressure Drop of Aerocyclone, 3rd International Conference on Multiphase Flow, ICMF98, pp. 1-8 (1998).