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Design and performance evaluation of vacuum cleaners using cyclone technology

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Abstract−A cyclone technology for a vacuum cleaner--axial inlet flow cyclone and the tangential inlet flow cyclone--to collect dusts efficiently and reduce pressure drop has been studied experimentally. The optimal design factors such as dust collection efficiency, pressure drop, and cut-size being the particle size corresponding to the fractional collection efficiency of 50% were investigated. The particle cut-size decreases with reduced inlet area, body diameter, and vortex finder diameter of the cyclone. The tangential inlet twin-flow cyclone has good performance taking into account the low pressure drop of 350 mmAq and the cut-size of 1.5 μm in mass median diameter at the flow rate of 1 m^3/min. A vacuum cleaner using tangential inlet twin-flow cyclone shows the potential to be an effective method for collecting dusts generated in the household.

Key words: Cut-size, Cyclone, Dust Collection Efficiency, Pressure Drop, Vacuum Cleaner

INTRODUCTION

A large fraction of our time is spent in houses, workplaces, or other buildings; therefore, indoor spaces should be comfortable both emotionally and hygienically. But indoor air contains more than twice the pollutants of outdoor air because of air tightness, poisonous chemicals, food smells, and ticks which are generated by the use of new materials and equipment in buildings. The vacuum cleaner is the representative home appliance for removing harmful materials from floors or carpets. The commercial vacuum cleaners used in houses consist of the paper filter, pre-filter, and exhaust filter through which the clean air discharges to the atmosphere. Though vacuum cleaners are convenient in use, the suction pressure decreases rapidly in proportion to the time of cleaning, and the paper filter also should be replaced periodically due to pressure drops, odors, and bacteria by the residual dust inside the paper filter [Cueno et al., 1997; Oh et al., 2004; Park et al., 2005; Yoa et al., 2001].

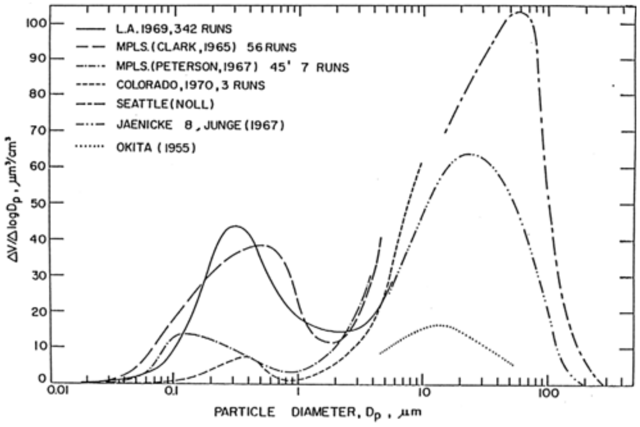

Fig. 1. The bi-modal size distribution of atmospheric aerosols [Liu and Pui, 1991; Whitby, 1978].

Table 1. Typical parameters of atmospheric and diesel aerosols [Knight et al., 1983; Lundgren et al., 1984; Whitby, 1983]

Particle type	Mass mean diameter, μm	Geometric standard deviation	Mass concentration, μg/m^3
Fine mode	0.18-0.36	1.66-2.16	2.07-38.4
Coarse mode	5.7-25	-2	6.2-205
Diesel aerosol	0.15-0.5	1.62-2.1	3.85-36.3

Fig. 1 shows that the size distribution of atmospheric aerosols is usually bi-modal in shape with particles in the coarse (>2.0 μm) mode being primarily of external sources, such as wind blown dust, sea salt sprays, volcanoes, and direct emission from industrial plants and vehicular emission, and those in the fine particle mode consisting of products of combustion or photochemical reaction [Liu and Pui, 1991; Whitby, 1978]. Table 1 shows the modes, mass median diameter, and mass concentration of the typical atmospheric aerosols measured by many investigators. Fine mode in the 0.18 to 0.36 μm size range and coarse mode in the 5.7 to 25 μm size range were measured. Mass concentration ranged from 2 to 205 μg/m^3 for atmospheric aerosols and 3.85 to 36.3 μg/m^3 for diesel aerosols [Knight et al., 1983; Lundgren et al., 1984; Whitby, 1983]. Indoor dusts are affected directly by atmospheric aerosols and many fibers, which are separated from carpets, clothes, bedclothes, papers, and fur of pets, are contained additionally. Most indoor dusts from floors and carpets are coarse particles larger than 2 μm and these particles can be removed easily by using inertial forces. Generally, cyclones are used to collect coarse particles effectively by using centrifugal forces

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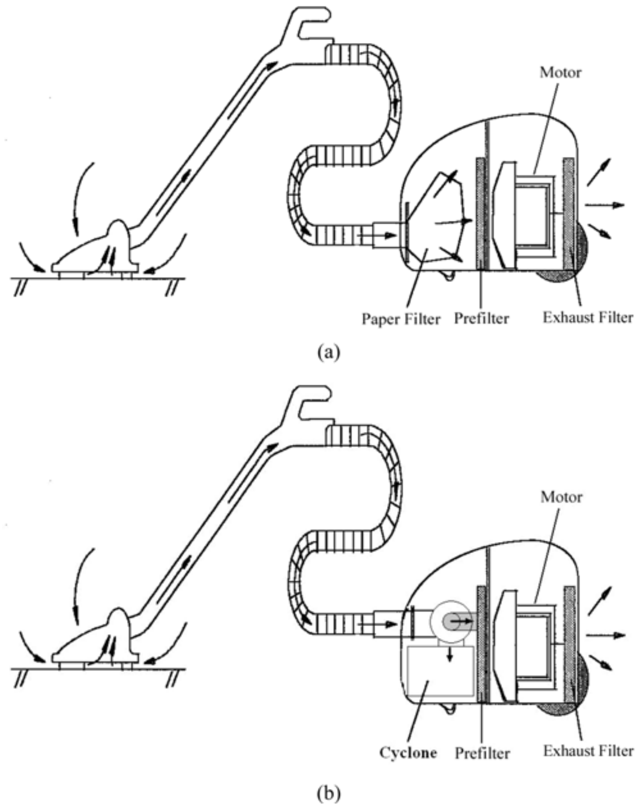

Fig. 2. Schematic diagram of the conventional bag vacuum cleaner and the cyclone vacuum cleaner for this study.
(a) Bag vacuum cleaner, (b) Cyclone vacuum cleaner

which are a kind of inertial force. Therefore, it would be more desirable to change the paper filter to cyclone because it has low pressure drop and clean emission.

This paper describes how to design and evaluate vacuum cleaner performance by using cyclone technology to meet the constant suction power, hygienic exhaust, and a reduction of maintenance cost, and to replace paper filters used in the conventional vacuum cleaner.

PRINCIPLE OF THE VACUUM CLEANER

Fig. 2(a) shows a schematic diagram of the commercial vacuum cleaner. The dust laden air inhaled by the vacuum cleaner is filtered through the paper filter for collecting large particles and fibers, followed by the pre-filter and the final filter for removing fine particles [Lee, 1999]. Sequentially, the cleaned air is exhausted to the atmosphere. High efficiency filters in conventional vacuum cleaners have been developed for better dust removal. But the residual dusts inside the paper filter of the conventional vacuum cleaner make some odors and germs unless the paper filter is replaced in a certain period. Therefore, the vacuum cleaner using the cyclone collector as shown in Fig. 2(b) by replacing paper filters used in the conventional vacuum cleaner is developed to prevent the problems of the conventional vacuum cleaners. The cyclone cleaner has constant suction power compared with the conventional vacuum cleaner of which suction power is rapidly decreased by accumulation of dusts in the paper filter. And the vacuum cleaner using cyclone technology can prevent odor problems by removing the dusts in the cyclone instantaneously.

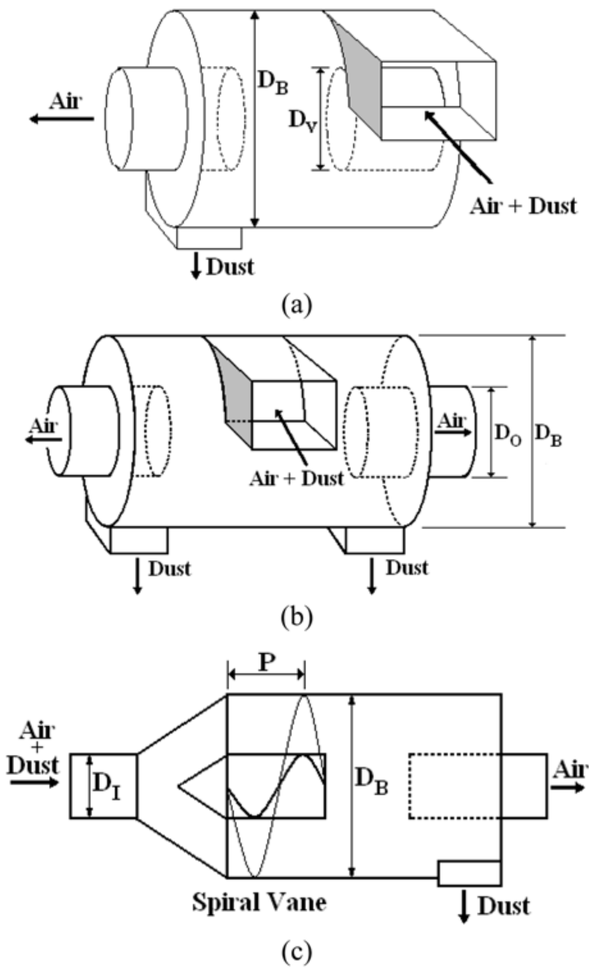

Fig. 3. Schematic diagram of the cyclone design for the vacuum cleaner.
(a) Tangential inlet flow cyclone, (b) Tangential inlet twin-flow cyclone, (c) Axial inlet flow cyclone

CYCLONE VACUUM CLEANER

Fig. 3 shows the schematic diagrams of the cyclone design for the vacuum cleaner such as the tangential inlet flow cyclone, the tangential inlet twin-flow cyclone, and the axial inlet flow cyclone. In the tangential inlet flow cyclone in Fig. 3(a), the dust laden gas rotates by flowing from the tangentially connected inlet pipe into the cyclone body, and dusts are separated by centrifugal force, while the tangential inlet twin-flow cyclone has the inlet flow in the center of the cyclone body and the dust laden gas flows bi-directionally as shown in Fig. 3(b). A tangential inlet twin-flow cyclone being capable of the treatment of high flow rate is designed to decrease pressure drop through the cyclone.

In the axial inlet flow cyclone in Fig. 3(c), the dust-laden gas in the cyclone body is rotated by the spiral vanes and the dust or solid particles are separated by centrifugal force. The clean gas flows to the atmosphere through the exit pipe. For improving the collection efficiency, the axial inlet flow cyclone can be attached with spiral vanes. Those cyclones include a dust box primarily removing the high density and large size materials like papers or plastics. In general, the axial inlet flow cyclone is used in parallel so as to deal with a large volume of gas at a low pressure drop, but the collection efficiency is not as high. A cyclone dust collector should have small and compact dimensions to fit inside the vacuum cleaner. The suction air flow rate of vacuum cleaner for residential use is normally in the range of 1-2 m^3/min. It is a somewhat high volume flow rate with the consideration of applicable size of cyclone collectors. Therefore, axial inlet flow cyclone with a spiral vane is designed to meet with the high volume flow rate.

EXPERIMENTAL RESULTS AND DISCUSSION

The performance evaluations of the tangential inlet flow cyclone, the tangential inlet twin-flow cyclone, and the axial inlet flow cyclone are conducted by measuring the fractional dust collection efficiency, the pressure drop across the cyclone and the cut-size (d_c) which is the particle size corresponding to the fractional collection efficiency with 50%. The collection efficiency and the cut-size are measured with a particle counter (Mastersizer Microplus, Malvern), and the pressure drop is measured with a manometer (FC012-4, Furness Controls Limited). Spherical fly ashes are used as the test particles with particle sizes under 25 μm and mass concentration of 1 g/m^3.

1. Tangential Inlet Flow Cyclone

Fig. 4 shows the effects of the airflow inlet area to affect the fractional dust collection efficiencies as a function of the ratio of the inlet area (A_I) and the cross sectional area (A_B) of the cyclone body. Centrifugal forces created by the change of flow direction move particles to the wall and separate particles from the air stream in the cyclone [Ogawa, 1984]. The centrifugal force increases with increasing flow velocity being inversely proportional to the inlet area. Inlet air velocities range from 11.1-55.6 m/s at the suction flow rate of 1 m^3/min. The cut-size and the pressure drop through the cyclone at the A_I/A_B ratio of 0.16 are approximately 2.3 μm and 450 mmAq, respectively. The most penetrating particle size which shows the minimum collection efficiency is about 2 μm. It is believed that the dust collection efficiency of fine particles smaller than 2 μm increases due to agglomeration between fine particles and coarse particles in spite of decreasing the particle size.

Fig. 5 shows the effects of the size of a vortex finder to the fractional dust collection efficiency. The ratio between the diameter of the vortex finder (D_V) and the diameter of the body (D_B) ranges from 0.275 to 0.475. The vortex finder creates circular flow streams and makes strong centrifugal forces. Especially, the small diameter of vortex finder causes stronger centrifugal forces. Therefore, the fractional dust collection efficiency increases with decreasing D_V/D_B ratio. The design of the vortex finder is very important because the

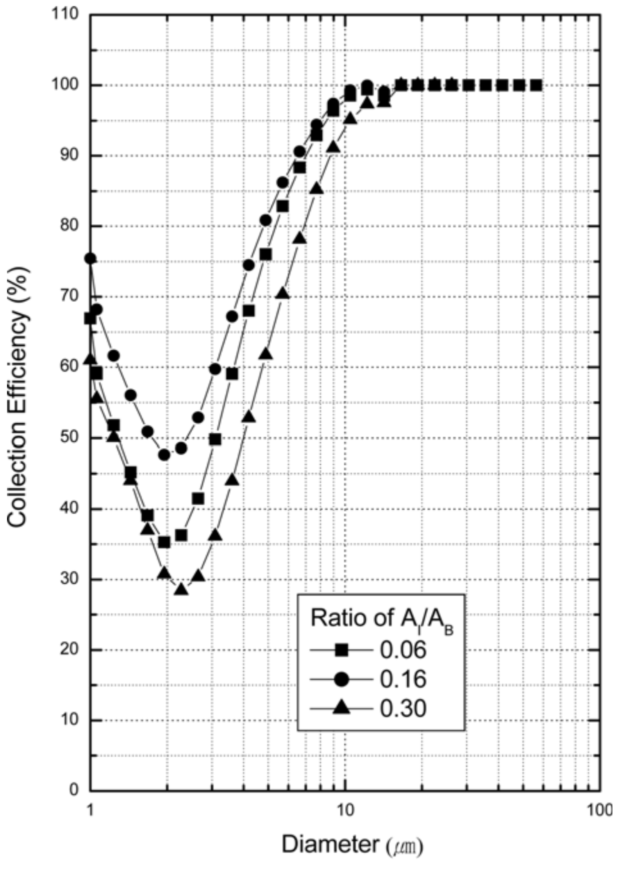

Fig. 4. Effects of the ratio between the inlet area (A_I) and the cross sectional area of the cyclone body (A_B) in the tangential inlet flow cyclone for the dust collection efficiency (Flow rate: 1 m^3/min).

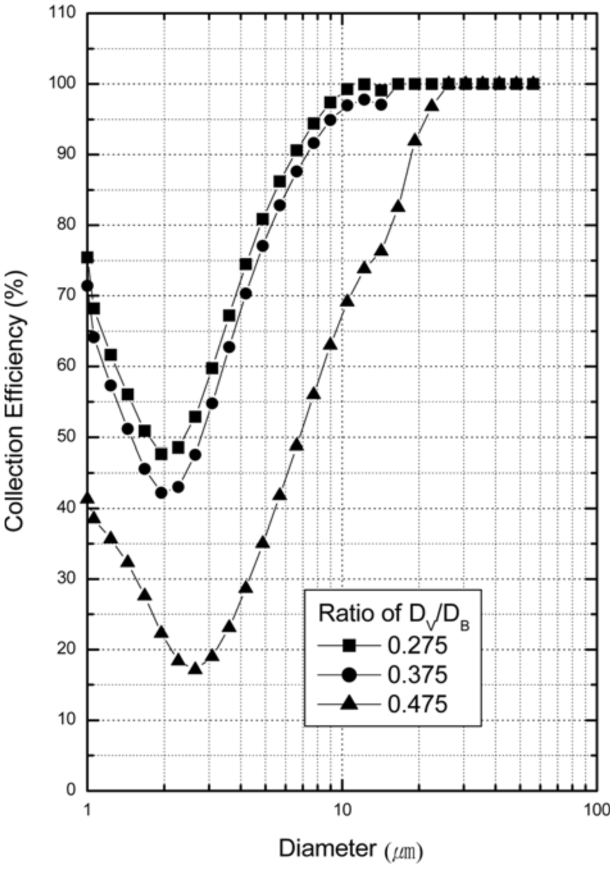

Fig. 5. Fractional dust collection efficiency of the tangential inlet flow cyclone as a function of ratio between diameter of vortex finder (D_V) and diameter of body (D_B) (Flow rate: 1 m^3/min).

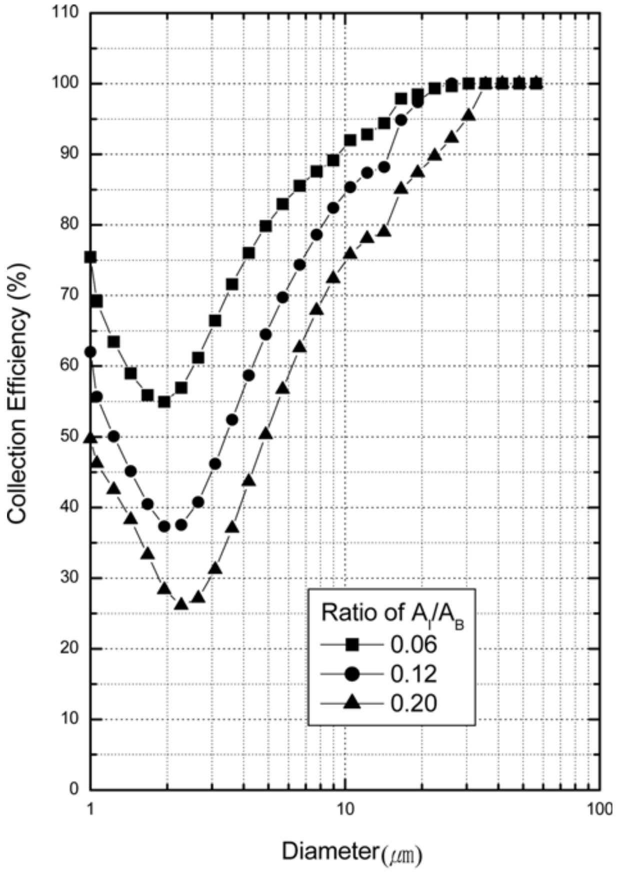

Fig. 6. Effects of the ratio between the inlet area (A_I) and the cross sectional area of the cyclone body (A_B) in the tangential inlet twin-flow cyclone for the dust collection efficiency (Flow rate: 1 m^3/min).

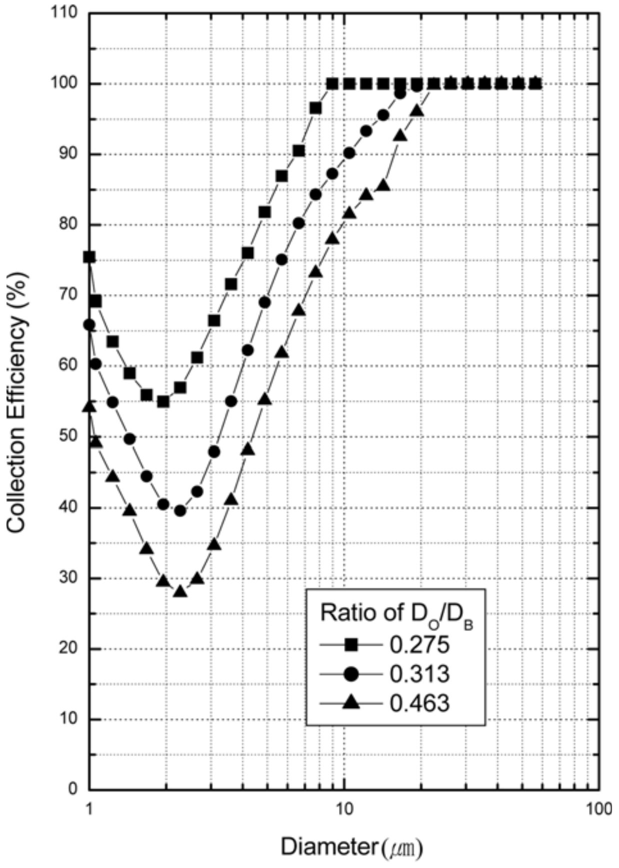

Fig. 7. Fractional dust collection efficiency of the tangential inlet twin-flow cyclone as a function of ratio between diameter of outlet pipe (D_O) and diameter of body (D_B) (Flow rate: 1 m^3/min).

fractional dust collection efficiency decreases abruptly if the ratio of D_V/D_B exceeds a certain limit.

2. Tangential Inlet Twin-Flow Cyclone

Fig. 6 represents the effects of the ratio between the inlet area (A_I) and the cross sectional area of the cyclone body (A_B) in the tangential inlet twin-flow cyclone for the dust collection efficiency at the flow rate of 1 m^3/min. The experiments are performed at an inlet area of 300, 600, and 1,000 mm^2 and are correlated with 55.6, 27.8, and 16.7 m/s, respectively. The cut-size and the pressure drop through the cyclone at the A_I/A_B of 0.06 are approximately 1.4 μm and 350 mmAq, respectively.

Fig. 7 shows the fractional dust collection efficiency of the tangential inlet twin-flow cyclone as a function of ratio between the diameter of the vortex finder (D_O) and the diameter of cyclone body (D_B). The ratio of D_O/D_B ranges from 0.275 to 0.463. The diameter of the vortex finder has an effect on the residence time of the dust laden air stream. The small diameter of the vortex finder causes long residence time and provides enough time to separate the dusts from air stream due to the long lasting centrifugal forces. Therefore, better fractional dust collection efficiency can be obtained at the D_O/D_B ratio of 0.275.

3. Axial Inlet Flow Cyclone

Fig. 8 shows the fractional dust collection efficiency of the axial inlet flow cyclone as a function of the ratio of spiral vane pitch (P) divided by the body diameter (D_B) at the flow of 1 m^3/min. effect of the pitch of the spiral vane to the fractional dust collection efficiency. The ratio of P/D_B ranges from 0.50 to 0.88. The cut-size and the pressure drop through the cyclone at the P/D_B ratio of 0.88 are approximately 2.6 μm and 300 mmAq, respectively. The spiral vane creates circular flow streams and makes strong centrifugal forces but it can transport air and dust to the rear side of the cyclone when they pass through the spiral vane. The air and the dust move faster to the rear side when the pitch of the spiral vane is longer, whereas, since they still have still strong centrifugal forces, most of dusts are collected and clean air is exhausted.

Fig. 9 represents the fractional dust collection efficiency of the axial inlet flow cyclone as a function of ratio between diameter of inlet pipe (D_I) and diameter of body (D_B). Inlet air velocities range from 17.3-34.0 m/s when the suction flow rate of vacuum cleaner is 1 m^3/min. The fractional dust collection efficiency of the axial inlet flow cyclone increases with decreasing inlet area due to more strong centrifugal forces at the small inlet area.

Fig. 10 represents a comparison of the fractional dust collection efficiency of the cyclone cleaners used in this study in their optimized dimensions. The most penetrating particle size of the tangential inlet flow, the tangential inlet twin-flow, and the axial inlet flow cyclones range approximately 2.0 μm. The smallest cut-size of 1.4 μm is obtained at the pressure drop of 350 mmAq for the tan-

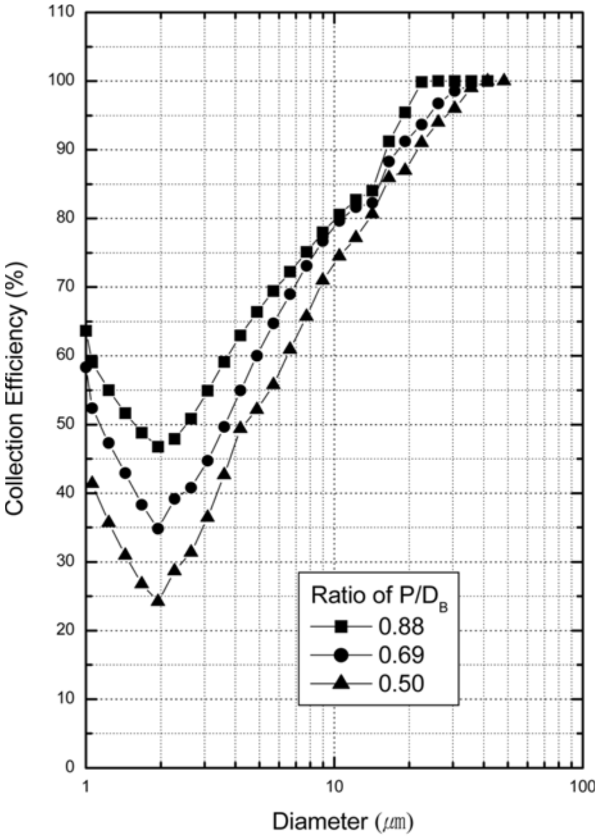

Fig. 8. Fractional dust collection efficiency of the axial inlet flow cyclone as a function of ratio between pitch of spiral vane (P) and diameter of body (D_B) (Flow rate: 1 m^3/min).

gential inlet twin-flow cyclone. Table 2 shows the results of the performance evaluation for cyclone cleaners developed in this study. The cut-size and the pressure drop through the cyclone range from 1.4 to 2.6 μm and 300 to 450 mmAq, respectively. The tangential inlet twin-flow cyclone has the smallest cut-size of 1.4 μm at the pressure drop through the cyclone of 450 mmAq and the flow rate of 1 m^3/min, while the tangential inlet flow cyclone shows highest pressure drop of 450 mmAq and the cut-size of 2.3 μm. It is believed that the tangential inlet twin-flow cyclone can be capable of the treatment of high flow rate and decrease pressure drop through the cyclone. Therefore, the tangential inlet twin-flow cyclone shows the potential to be an effective vacuum cleaner taking into account the cut-size and pressure drop through the cyclone.

CONCLUSIONS

In this paper, commercial design and performance evaluation of the tangential inlet flow cyclone, the axial inlet flow cyclone and the tangential inlet twin-flow cyclone for vacuum cleaners are conducted to meet the constant suction power, hygienic exhaust, and a reduction of maintenance cost, and to replace paper filters used in the conventional vacuum cleaner. The tangential inlet twin-flow cyclone has good performance, taking into account the low pressure drop of 350 mmAq and the cut-size of 1.4 μm in mass median diameter at the flow rate of 1 m^3/min. A vacuum cleaner using the tangential inlet twin-flow cyclone shows the potential to be an effec-

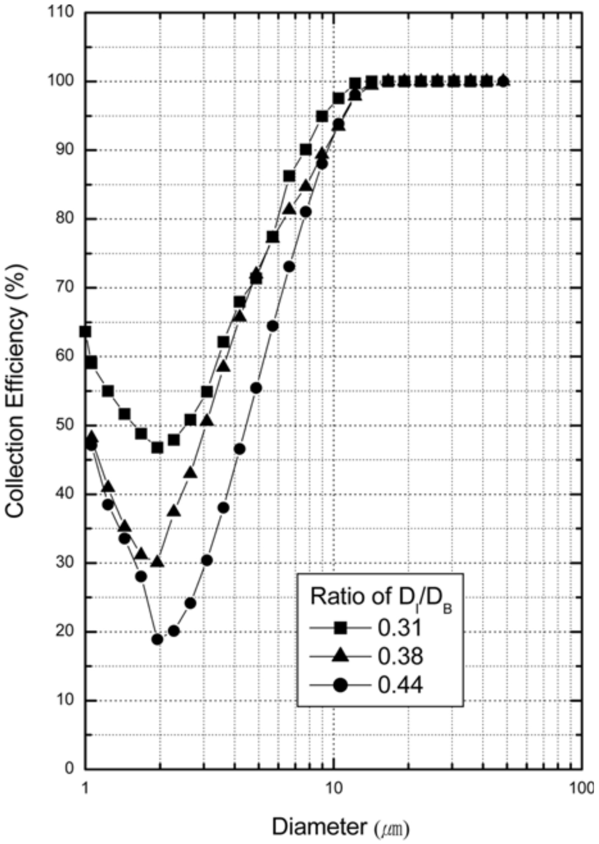

Fig. 9. Fractional dust collection efficiency of the axial inlet flow cyclone as a function of ratio between diameter of inlet pipe (D_I) and diameter of body (D_B) (Flow rate: 1 m^3/min).

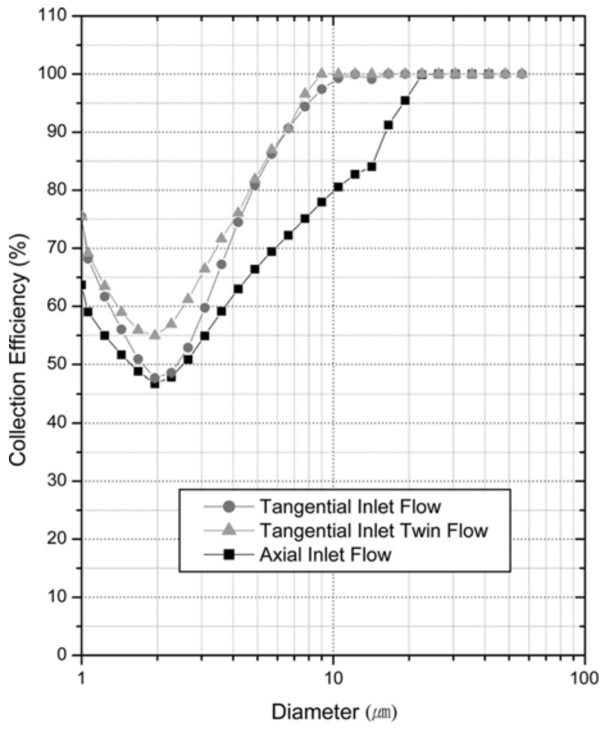

Fig. 10. Comparison of fractional dust collection efficiency of the various cyclone cleaners in their optimized dimensions (Flow rate: 1 m^3/min).

Table 2. Performance evaluation for various cyclone cleaners

Model	Cut-size (μm)	Pressure drop (mmAq)	Noise (dB)
Tangential inlet flow cyclone	2.3	450	65
Tangential inlet twin-flow cyclone	1.4	350	65
Axial inlet flow cyclone	2.6	300	62

tive method to collect dusts generated in the household.

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REFERENCES

Cueno, M. E., Menge, P. R., Hanson, D. L., Fowler, W. E., Bernard, M. A., Ziska, G. R., Filuk, A. B., Pointon, T. D., Vesey, R. A., Welch, D. R., Bailey, J. E., Desjarlais, M. P., Lockner, T. R., Mehlhorn, T. A., Slutz, S. A. and Stark, M. A., "Results of vacuum cleaning techniques on the performance of LiF field-threshold ion sources on extraction applied-B ion diodes at 1-10 TW," *IEEE Transactions on Plasma Science*, **25**, 229 (1997).

Knight, G., Bigu, J., Mogan, P. and Stewart, D. B., "Size distribution of airborne dust in mines, in aerosols: In the mining and industrial work environments," V. A. Marple and B. Y. H. Liu, ed. *Ann. Arbor. Science Publishers*, **2**, 419 (1983).

Lee, J. K., *Performance improvement and optimal design of a household vacuum cleaner using cyclone technology*, Final Report, LG Electronics Inc. (1999).

Liu, B. Y. H. and Pui, D. Y. H., "Aerosols," *Encyclopedia of Applied Physics*, **1**, 415 (1991).

Lundgren, D. A., Hausknecht, B. J. and Buton, R. M., "Large particle size distribution in five U.S. Cities and the effect on a new ambient particulate matter standard (PM10)," *Aerosol Science and Technology*, 467 (1984).

Ogawa, A., *Separation of particles from air and gases*, CRC Press Inc. (1984).

Oh, J. S., Choi, Y. H., Park, J. B. and Zheng, Y. F., "Complete coverage navigation of cleaning robots using triangular-cell-based map," *IEEE Trans. Ind. Elec.*, **51**, 718 (2004).

Park, Y., Yun, C. Y., Yi, J. and Kim, H., "Numerical simulation of the effects of the design feature of a cyclone and the inlet flow velocity on the separation of CO_2 particles from a CO_2-COF_2 mixture," *Korean J. Chem. Eng.*, **22**, 697 (2005).

Whitby, K. T., *The physical characteristics of sulfur aerosols*, in Sulfur in the Atmosphere, ed. Pergamon (1978).

Whitby, K. T., "Size distribution of airborne dust in mines, in aerosols: In the mining and industrial work environments," V. A. Marple and B. Y. H. Liu, ed. *Ann. Arbor. Science Publishers*, **2**, 363 (1983).

Yoa, S. J., Cho, Y. S., Choi, Y. S. and Baek, J. H., "Characteristics of electrostatic cyclone/bac filter with inlet types (lab and pilot scale)," *Korean J. Chem. Eng.*, **18**, 539 (2001).