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Development of the Dual Cyclone System for a High Efficient Vacuum Cleaner

(사이클론 집진 원리를 적용한 진공청소기 개발에 관한 연구)

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Key Words: Vacuum Cleaner, Cyclone, Dust Collection Efficiency, Cut Size, Pressure Drop

Abstract

A new cyclone system for the vacuum cleaner to collect dusts has been studied experimentally and numerically to meet the constant suction power, hygienic exhaust, and a reduction of maintenance cost. The cyclone system of the vacuum cleaner consists of twin cyclones for improving dust collection efficiency. The first cyclone catches large dust particles and the second one having two separated flows to decrease pressure drop collects small dust particles. The optimal design factors such as dust collection efficiency, pressure drop, and cut-size are investigated from the experimental results by the Taguchi method. Cyclone cleaner systems designed in this study has a good performance taking into account the dust collection efficiency of 93% and the cut-size of 1.6㎛ in mass median diameter at the flow rate of 1 CMM. The cyclone vacuum cleaner showed the potential to be an effective method to collect dusts generated in the household.

1. Introduction

A large fraction of our times is spent in either our homes, the workplace, or other buildings. Therefore, the interior of a room should be comfortable place emotionally and hygienically, and it should become a place to stimulate human beings for recreative activities. But indoor air quality contains pollutants more than 2 times that of outdoor because of airtight, the poisonous chemicals, food smell, and ticks which are generated by the use of new materials and equipment in buildings. The vacuum cleaner is the representative of home appliances to remove harmful materials on the floor or carpet. The commercial vacuum cleaner used in home consists of paper filter, prefilter, and exhaust filter through which the clean air discharges to the atmosphere. Though vacuum cleaners are convenient in use, the suction pressure deceases rapidly as the use of air cleaner and paper filters also should be replaced periodically because of the pressure drop, odor, and bacteria by the residual dust in paper filters. Indoor dusts can be classified coarse particles and fine particles by the 1 ㎛. Most

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indoor dusts are coarse particles larger than 1 ㎛ and these particles can be removed by the inertial impaction. The cyclone can be applied to collection of coarse particles by the centrifugal force, and replace the paper filters which generate the secondary pollution.

In this paper, the principle of cyclone is applied to meet the constant suction power, hygienic exhaust, and a reduction of maintenance cost. And the cyclone cleaner is developed to replace the conventional paper filters in vacuum cleaner.

2. Vacuum Cleaner

2.1 Principle of the Vacuum Cleaner

Fig. 1 shows the schematic diagram of the commercial vacuum cleaner. The dust laden air inhaled by the vacuum cleaner is filtered by the paper filter, the pre-filter, and the final filter, sequentially, and the cleaned air is exhausted to the atmosphere.

General vacuum cleaner used up to date have the principle to remove indoor dusts by using various step filters and high efficiency filters have been developed for better dust removal. But the conventional vacuum cleaner must be replaced the paper filter after a certain period, and has a point at issue arising odor and germ by the residual dusts inside of the paper filter.

Therefore, the vacuum cleaner using a cyclone technology was developed to solve the problems of the conventional vacuum cleaner. The cyclone cleaner has a high and constant suction power comparing with the conventional cleaner of which suction power is rapidly decreased by accumulating the dusts in the paper filter. And the cyclone vacuum cleaner can solve the odor problem by removing the dust in the dust box instantaneously.

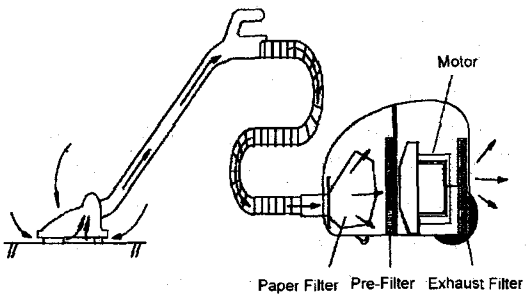


Fig. 1 Schematic Diagram of the Vacuum Cleaner (Lee, 1999)

2.2 Principle of the Cyclone

A dust laden air enters tangentially near the top of the cyclone, as shown in Fig. 2. The air is forced into a downward spiral simply because of the cyclone's shape and the tangential entry. Centrifugal force and inertia cause the particle to move outward, collide with the outer wall, and then slide downward to the bottom of the device. Near the bottom of the cyclone, the air reverses its downward spiral and moves upward in a smaller inner spiral. he cleaned air exits from the top through a 'vortex finder' tube, and the particles exit from the bottom of the cyclone.

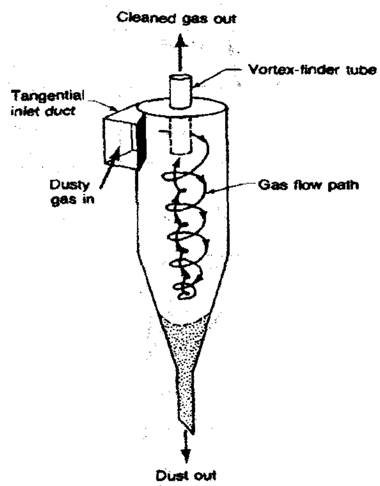
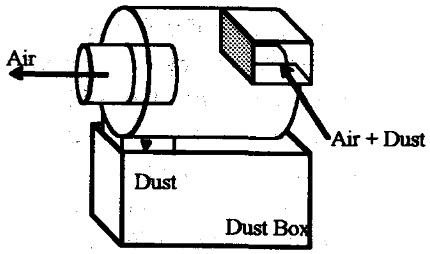


Fig. 2 Principle of a Cyclone Collector (Cooper and Alley, 1994)

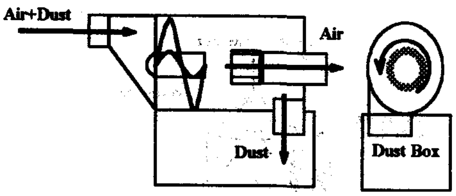
3. Cyclone Vacuum Cleaner

3.1 Cyclone Cleaner

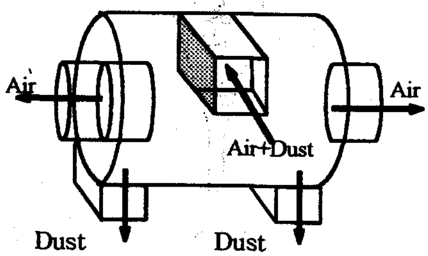
Fig. 3 shows the schematic diagrams of the uni-type, spiral-type, and twin-type cyclone, respectively. The uni-type cyclone is the cyclone of general tangential inlet flow and spiral-type cyclone is the cyclone of axial inlet flow, generates the rotational flow by the spiral located at the inlet. For the higher efficiency, the spiral-type cyclone is attached with a blade. The twin-type cyclone is combined two uni-type cyclones. The twin-type cyclone includes the dust box primarily removing the low density materials like the paper or plastic bags.



(a) Uni-Type Cyclone



(b) Spiral-Type Cyclone



(c) Twin-Type Cyclone

Fig. 3 Schematic Diagram of Cyclone for the Vacuum Cleaner

3.2 Evaluation of the Cyclone Cleaner

An efficiency of the cyclone is evaluated by measuring the dust collection efficiency, and the pressure drop. The collection efficiency is the most important parameter to evaluate the cyclone efficiency evaluation, and express the cleaning efficiency of the cleaner and by measuring the removal quantities of the cut size(d_c) that have 50 % removal efficiency utilizing the particle counter (Mastersizer, Malvern). And the dust collection efficiency and the pressure drop is contrary to each other, the increase of the dust collection efficiency increase the pressure drop dramatically. The pressure drop is measured by Micromanometer at the entrance and the exit of the cyclone.

Table 1 shows the comparison of three types of the final products and commercial products (A, B, C, D). As shown in the table, the dust removal efficiencies are in the range of 88~93% and the cut size diameter is in the vicinity of 1.6~3.2 ㎛ for the cyclone cleaners developed in this study, while the commercial products show the particle removal efficiencies of 69~83%, and the cut size of 1.2~4.2㎛.

Table 1. Evaluation of the Cyclone Vacuum Cleaner (1 CMM Flow Rate)

Model	Efficiency (%)	Cut Size (㎛)	ΔP (mmAq)
A	77.6	3.5	400
B	73.4	4.2	600
C	69	1.2	280
D	83	3.5	220
Uni-Type	88	3.2	450
Spiral-Type	85	3.3	300
Twin-Type	93	1.6	345

4. Empirical Equation of the Cyclone Cleaner

4.1 Deduction of the Empirical Equation

As the method to show cyclone's efficiency, cut size (d_c) and efficiency curve (η) are used, and the cyclone efficiency as a function of the particle size(d) is described as equation (1).

$$\eta(d) = 1 - \exp[-0.693(\frac{d}{d_c})^m] \qquad (1)$$

Here, m is the slope of cyclone efficiency curve, and the cyclone generally has 0.8 ~ 1.5 values.

There are two types of cyclone, the tangential and axial type cyclone. And the cut size of the each cyclone can be calculated with the equations (2), (3) (Ogawa, 1982).

Tangential Type Cyclone

$$d_c = 3.4\sqrt{\frac{g\mu}{\gamma_s u_0}}\frac{r_2}{\sqrt{h_i}} \qquad (2)$$

where, r_2 is a outlet radius , h_i is a body length, γ_s is a specific gravity of particle, and u_0 is a Inlet velocity.

Axial Type Cyclone

$$d_c = 3\frac{r_1}{\sqrt{H_s}}[1-(\frac{r_0}{r_1})^2]\tan\beta\sqrt{\frac{\mu}{\rho_s u_0}} \qquad (3)$$

where, r_0 is a guide axis diameter, r_1 is a outer body length, β is a guide angle, H_s is a height, and u_0 is a inlet velocity.

4.1.1 Empirical Equation of Uni-Type Cyclone

The deduction of empirical equation of the cyclone proceeds two kinds of methods. The first is to obtain m value of cyclone efficiency curve and the second is to obtain the calculation equation of cut size. The m value of cyclone efficiency curve is a value that participates in the slope of cyclone efficiency curve and according to increase m, the slope will increase.

As a result of Uni-type cyclone test data is analyzed, E (exit tube projection length), D (exit tube diameter), F (guide length), and Q (flow rate) is appeared as important variables of cut size (d_c). Using the cut size equation of typical tangential inlet type that mentioned equation (2), the correlation with E (exit tube projection length), D (exit tube diameter), F (guide length), and Q (flow rate) is proved.

$$d_c = 3.4\sqrt{\frac{g\mu}{\gamma_s u_0}}\frac{r_2}{\sqrt{h_i}} = K\ D\ E^a\ F^b / \sqrt{Q} \qquad (4)$$

At equation (4), the study affirmed that unknown quantity becomes a+b=1 through the dimensional analysis with the proportional constant k and index a, b. The experimental results is compared with the result equation (4) for the acknowledgement of the proportional constant k, and index a, b. Equation (5), (6) is an empirical equation of uni-type cyclone that obtained from this study.

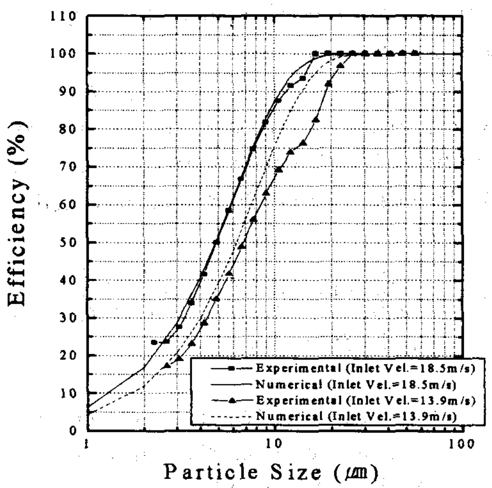


Fig. 4 Comparison of Experimental and Numerical Result for the Uni-Type Cyclone (1 CMM Flow Rate)

Fig. 4 shows the experimental result of cyclone efficiency is compared with the empirical equation, and shows that the result is similar with each other.

Cut Size of the Uni-Type Cyclone

$$d_c = 3.6\times10^{-2} D\ E^{-0.1}\ (5 - F/70)^{1.1}/\sqrt{Q} \quad (5)$$

Efficiency of Uni-Type Cyclone

$$\eta = [1 - \exp(-0.693\ (d/d_c)^m)]\times100 \quad (6)$$

where, m=1.5 (empirical value)

4.1.2 Empirical Equation of Spiral-Type Cyclone

The Spiral-type cyclone is an axial inlet type and this study performed experiment for the various spiral pitch (A) and distance (B) between spiral exit and air exit.

In order to obtain the m value that determines the slope of the cyclone efficiency curve of the spiral-type, the m value of uni-type cyclone is 0.9 by comparing the slopes of the experimental results. This value is much dull to compare with uni-type cyclone slope of the tangential inlet type, and accordingly m is also small to compare with uni-type cyclone.

By using the cut size equation of the typical axial cyclone that are referred at the equation (3), relation with the A (spiral pitch), B (distance), and Q (flow rate) is proved.

$$d_c = 3\frac{r_1}{\sqrt{H_s}}[1-(\frac{r_0}{r_1})^2]\tan\beta\sqrt{\frac{\mu}{\rho_s u_0}} \quad (7)$$
$$= K\ A^a\ B^b\ /\ \sqrt{Q}$$

At the equation (7), the unknown quantity is proportional constant k, index a, b. The distance, B is equal with Hs at the equation (7), and the index b is the same as -0.5. As a variable for the spiral pitch (A) and the distance (B), on the basis of 10 times test

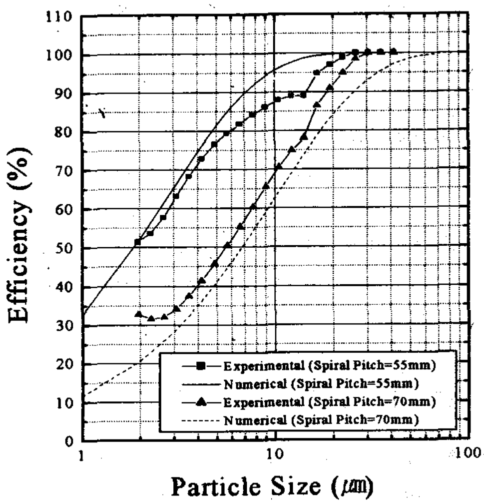


Fig. 5 Comparison of Experimental and Numerical Result for the Spiral-Type Cyclone (1 CMM Flow Rate)

results according to the conditions, relation with the proportional constant k of equation (7), A and B is completed equation (8) of the spiral-type cyclone using trial and error. Fig. 5 is the comparison with the experimental cyclone efficiency, and the results are similar with each other.

Cut Size of Spiral-Type Cyclone

$$d_c = 107.64\times\sqrt{(1.04 - A/46.4)^2}/\sqrt{BQ} \quad (8)$$

Efficiency of Spiral-Type Cyclone

$$\eta = [1 - \exp(-0.693\ (d/d_c)^m)]\times100 \quad (9)$$

where, m=0.9 (empirical value)

4.1.3 Empirical Equation of Twin-Type Cyclone

Twin-type cyclone is the tangential inlet type and has the parameters of A (outer tube diameter), F (air exit diameter), G (air exit height), Q (flow rate), inlet area, area of dust collector. In order to obtain the m of cyclone efficiency curve, compared with the slope of the experimental results, the m value of twin-type cyclone is 1.2.

Using the cut size equation of typical tangential inlet type cyclone that has mentioned at the equation (2), the correlation with A (outer tube diameter), F (air exit diameter), G (air exit height), and Q (flow rate) is proved.

$$d_c = 3.4\sqrt{\frac{g\mu}{\gamma_s u_0}\frac{r_2}{\sqrt{h_i}}} = K\,A^a\,F^b\,G^c\;/\sqrt{Q} \quad (10)$$

In the equation (10), it is certificated that the unknown quantity becomes a+b+c=2 through dimensional analysis as a proportional constant k, and index a, b, c. The equation (11) and (12) are empirical equation of twin-type cyclone that this study has obtained. Fig. 6 was compared with experimental cyclone efficiency curve and the empirical equation, so that this study can understand that each shows similar results.

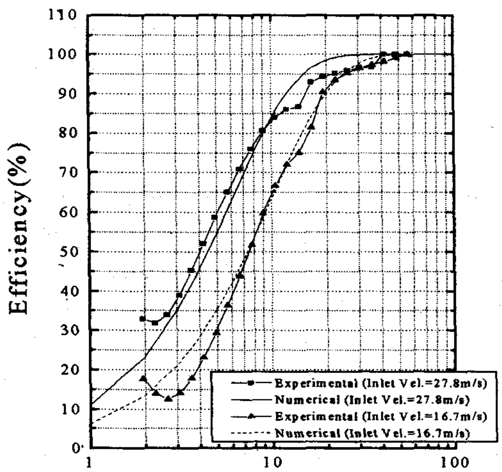


Fig. 6 Comparison of Experimental and Numerical Result for the Twin-Type Cyclone (1 CMM Flow Rate)

Cut Size of Twin-Type Cyclone

$$d_c = (0.704\times10^{-2}\times F^{1.8}\times G^{0.3})\;/\;(\sqrt{Q}\times A^{0.1}) \quad (11)$$

Efficiency of Twin-Type Cyclone

$$\eta = [1-\exp(-0.693\;(d/d_c)^m)]\times100 \quad (13)$$

where, m=1.2 (empirical value)

5. Conclusions

(1) The cyclones designed through this research are uni-type, spiral-type, and twin-type models. Performance evaluation involves the dust removal efficiency, the pressure drop, the noise level, and the cut size diameter. And optimal design parameters are determined by the use of Taguchi method.

(2) Cyclone cleaner systems designed in this study has a good performance taking into account the dust collection efficiency of 93% and the cut-size of 1.6㎛ in mass median diameter at the flow rate of 1 CMM.

(3) The empirical equations for determining the cut size and dust collection efficiency of cyclones are determined based on the experimental result.

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