A CFD Analysis on Axial Inlet Cyclone using Realizable *k-ε* Turbulent Model

J.S. Kim*, I.K. Kim and Y.S. Kim

Graduate School of Mechanical Engineering
Pukyong National University
San100 Yongdang-dong, Nam-gu, Busan, 608-739 Republic of Korea
E-mail:kimjs98@pknu.ac.kr.kr

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ABSTRACT

Introduction

The cyclones which employ a centrifugal force generated by a spinning gas stream to separate dusts from the carrier gas are one of the most useful dust collectors. They have the advantages of simple design, low cost and very low maintenance operation cost. However, cyclones directly employ a centrifugal force to separate dusts, so they have the advantages to collect the larger size of particles relatively. These are why they are used as pre-cleaners for more expensive final control devices such as bag houses or electrostatic precipitators.

Inner flows of cyclones have very complicated features such as mechanically strong eddy, cavity region which has backflows in specific case and so on. Thus, experiments on inner flow of cyclone, approaches of many theories, methodology using numerical modeling were performed many times. Research conducted by Zhou & Soo[1] showed 30% improvement of pressure drop, increase of collection efficiency when a special shaped geometric body was employed at center of cyclone inside. Chun & Ohm[2] performed the numerical analyses with several parameters such as vortex finder diameter, effective dust exit diameter, vortex finder length, inlet type and showed that the simulation results with k-ε turbulence model were in good agreement with empirical knowledge. Gimbun & Chuah[3] showed that CFD(Computational Fluid Dynamics) predicted the cyclone cut-off size for all operating conditions with a deviation of 3.7% from the experimental data. It also produced the better result than other empirical models'.

In this study, we present an application of CFD to predict the dust collection efficiency according to various dimensional parameters such as shape of helical guide vanes, length of cylindrical part, dimension of inner diameter. With above numerical results, the experiments are performed to replace the old cyclone model according to KS R 1041 which is identical to ISO 5011.

Cyclone Models

The numerical analyses of inner flow were performed using FLUENT6.0 according to various shapes and trajectories of various particle sizes were calculated with numerical results. Fig. 1 shows one of the cyclones generated with 3 dimensional meshes and Fig. 2 shows the assembly of cyclone dust collector. We changed the geometrical dimensions of cyclone such as helical guide vanes, inner diameter of cyclone, length of cylindrical part indicated as the mark ⓐ, ⓑ and ⓒ in Fig. 1 respectively. Moreover, Table 1 shows the 13 analyzed models with 3 different types according to various shape parameters based one prototype model named 'HJ-Proto'.

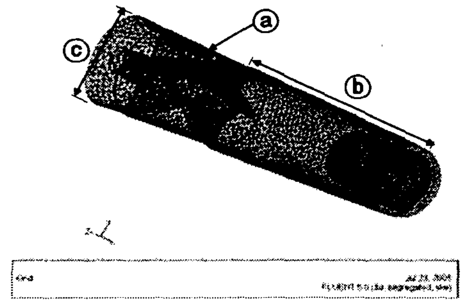

Fig. 1 3-dimensional generated meshes

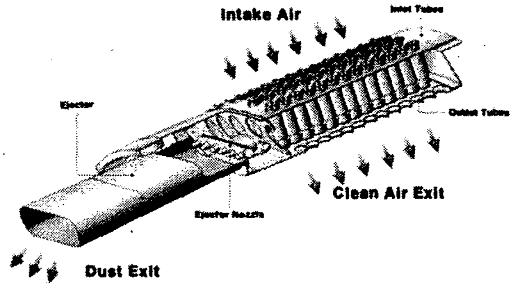

Fig. 2 Assembly of cyclone dust collector

Model No.	Features	Model No.	Features
HJ-Proto	basic model	HJ-165Dg	rotated helical guide vanes by 165
		HJ-72L	cylinder length equal to 72[mm]
HJ-90Dg	rotated helical guide vanes by 90°	HJ-74L	cylinder length equal to 74[mm]
HJ-105Dg	rotated helical guide vanes by 105	HJ-12D	inner diameter equal to 12[mm]
HJ-120Dg	rotated helical guide vanes by 120	HJ-14D	inner diameter equal to 14[mm]
HJ-145Dg	rotated helical guide vanes by 145	HJ-18D	inner diameter equal to 18[mm]
HJ-150Dg	rotated helical guide vanes by 150	HJ-20D	inner diameter equal to 20[mm]

Table 1 Specification of analyzed models

The 3-D models in Table 1 were designed by IDEAS9.0, and exported with IGES file format, which FLUENT6.0 is able to accept, and then we generated surface and volume meshes using GAMBIT2.0 within FLUENT6.0. The number of generated meshes depends on different shape among models, so each model contains about tetrahedral 85,000 cells. We employed realizable k-ε turbulent model to solve turbulent field. Inlet boundary condition is velocity inlet type, outlet boundary condition is outflow and discrete phase modeling is assumed spherical particle to calculate particle trajectory.

Numerical Results

Three different types of cyclones were performed in this study as seen above. Firstly, helical guide vanes are the very important part to generate the centrifugal force in axial inlet cyclone. Therefore, the efficiency depends on the geometric shape. The models with various helical guide vanes were analyzed and Fig. 3 and Fig. 4 show the graph of the distribution graph of particle diameters at dust-exit. We can see that the more the rotate angle of helical guide vane is getting larger, the more the pressure at inlet is getting higher because it blocks up and interrupts the gas flow. Therefore, it induces the pressure drop. Fig. 4 shows that in case of separating the particles of about over 36 ㎛, 'HJ-Proto' is more efficient than others.

Secondly, the length of cylindrical part is one of the shape parameters that have affect to guide the gas flow to dust-exit effectively and if it's length is longer, the efficiency will be higher, but it'll be able to bring out pressure drop. Fig. 5 and Fig. 6 show the graph of the distribution of particle diameters at dust-exit according to length changes. In Fig. 5, the pressure of inlet is getting lower according to increase of that length contrary to above expectation because of extended path to exit dusts. We can judge that the secured exit drives the flow get the proper streamline, velocity gradient.

Lastly, we expect to know the effect on the strength of centrifugal force, path of gas flow according to change of inner diameter. The inlet shape of cyclone is one of the affected parameters on efficiency. Fig. 7 shows that the larger the diameter is, the lower the values of inlet pressure go down. However, Fig. 8 shows that the larger the diameter is, the lower the fraction of big sized particles go down. The reason is that the dimensional changes of inner diameters do not affect the velocity magnitude heavily.

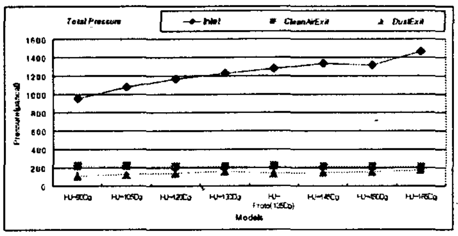

Fig. 3 Graph of pressure distribution(ⓐ)

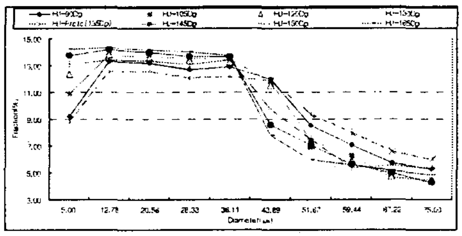

Fig. 4 Graph of particle diameters(ⓐ)

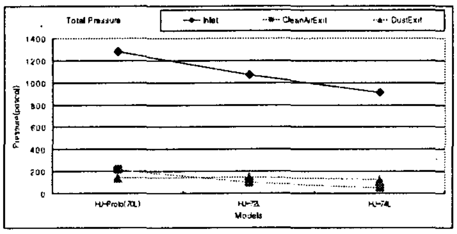

Fig. 5 Graph of pressure distribution (ⓑ)

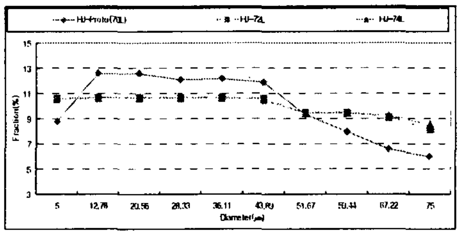

Fig. 6 Graph of particle diameters (ⓑ)

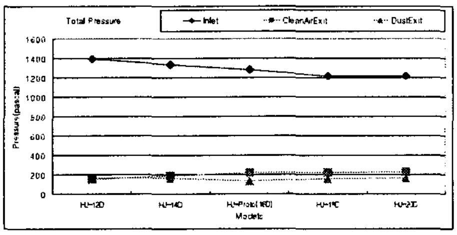

Fig. 7 Graph of pressure distribution (ⓒ)

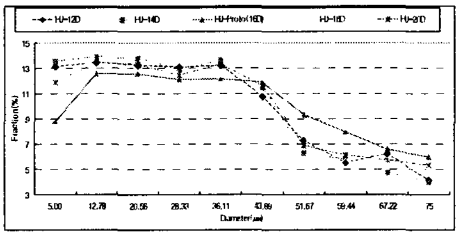

Fig. 8 Graph of particle diameters (ⓒ)

As above numerical results, we recommended 1 model named 'HJ-Proto' because it has the advantages on the collection of over 36 ㎛ particles as well as the acceptable pressure drop. The length changed models such as 'HJ-72L', 'HJ-74L' have the uniform fractions in Fig. 6, thus they can be more efficient cyclones. However, they cannot be accepted because the increase or decrease of length affects the over whole design.

Experimental Results

We performed the test of the clean efficiency as well as ventilation resistance on old model and 'HJ-Proto' model referred to KS R 1041(ISO 5011). Fig. 9 shows the diagram of test unit and Fig. 10 shows photograph of test unit. Table 2 shows the operating conditions for ventilation resistance and Table 3 shows the operating conditions for clean efficiency. As the above test result, Table 4 shows that the performance of 'HJ-Proto' is equal to or higher than the old model.

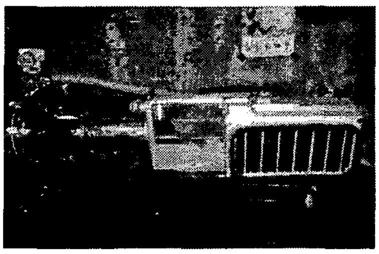

Fig. 9 Photo of test unit

Flow rate (m^3/min)	Rate(%)	Conditions
30.0	50.0	Temp. : 30 0.5℃ Relative humidity : 50%
45.0	75.0	
60.0	100.0	
75.0	125.0	

Table 2 Operating conditions of ventilation resistance

Flow rate (m^3/min)	Dust density(g/m^3)
30.0	1.0±0.05

Table 3 Operating conditions of clean efficiency

Item	New	Old	Result
Ventilation Resistance[mbar]	23.9	24.2	Okay
Clean Efficiency[%]	99.91	99.91	Okay

Table 4 Test results

Conclusions

The numerical analyses and experimental tests were performed in this paper. The results are as follows: the higher the rotate angle of helical guide vane is, the higher the pressure of inlet is. However, when we employed the model with rotate angle of 135°, the clean efficiency of over 36 μm particles is better than others. The dimensional modification of cylinder length affected the pressure of inlet and dust discharge at dust-exit. However, we cannot help excepting these because of the many problems of design modifications. The larger the size of inner diameter is, the lower the value of pressure drop goes down, however the lower the clean efficiency of large particles goes down. As experimental result referred to numerical results, the performance of new model is equal to or higher than the old is in terms of tests of clean efficiency and ventilation resistance.

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