Development of decontamination equipment to remove hot particulates contaminated in hot cell at KAERI

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Summary

A new approach has been adopted to remove the hot particulates from nuclear facilities, KAERI, South Korea, by using the new compact cyclone train, made of steel ness steel, with optional vortex finder length. Flow rate results showed a dramatic change in removal efficiency, performance was changed with the change of exit tube length. The 15 m/s flow rate was found suitable one for new equipment with the 49 mm optimum exit tube length for 76 mm cyclone body diameter. Results shows the removal efficiency for 1 μm was more than 65% and for 10 μm was seen ~97%. Over 15 m/s flow rate, was not shown much different in removal efficiency. The removal efficiency increased with the flow rate, and pressure drop. Cut size diameter decrease with the inlet flow rate. Cut size diameter found lowest with 49 mm exit tube length and 15 m/s flow rate. For filters the performance decreased with the inlet velocity increased.

Introduction

The decontamination technologies to clean the nuclear facility by easiest and economical way cause a strong impetus to develop new equipment. A cyclone is considered as one of advantageous tools for hot particulates removal. Although, there are several ways and some instruments are available for this purpose but due to their limitations, these instruments are not good enough for Korea Atomic Energy Research Institute, Taejeon nuclear facilities. Due to using stainless steel materials and convenient methods of construction new compact equipment may be adapted for use in extreme operating conditions such as high flow rate, high pressure, and high temperature. The major disadvantage of the industrial-scale cyclone is its relatively low efficiency for particles smaller than 5 μm in diameter [1,2]. Therefore, the objective of this study is to construct the equipment to remove the hot particulates, size smaller than 5 μm, however, we have suggested design and built a new instrument (Figure 1). This compact cyclone train have two major parts, one is cyclone separator, another is filters.

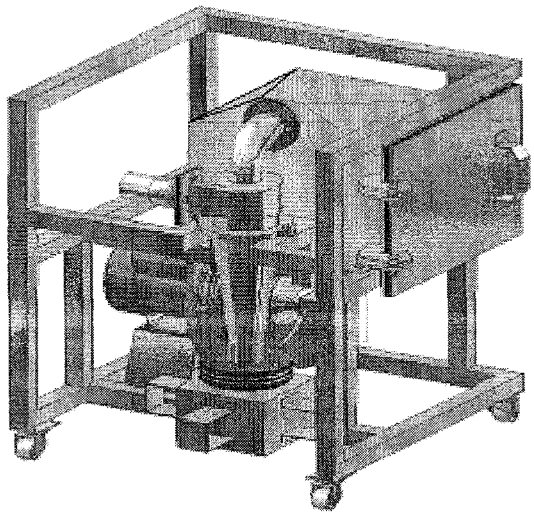


Fig. 1. Three-dimensional view of compact cyclone train.

In recent years, more stringent environmental regulations require improved hot particulates collection efficiency in nuclear facilities installations creating a need for further research aimed at improving the efficiency of industrial-scale cyclones for particles smaller than 5 μm. Moreover, it is desirable in some nuclear facilities, to capture an extra fraction of the hot particulates from the wall-surface in order to decrease the loss of the valuable products in secondary waste removal units such as filters. In this work experiments under controlled conditions were carded out with cyclones of dimensions greater than the usual laboratory range in order to elucidate the flow rate and particles collection mechanism by vortex-finder. A commercially available CFD program was used to calculate the flow profiles and grade efficiency curves for the cyclone, both individually and in combination, and the results were compared with the experimental data. This study describes the hot particulates removal performance with the use of compact cyclone train at various flow rates, the effects of changing size of the vortex finder length, pressure and temperature effects.

Experimental

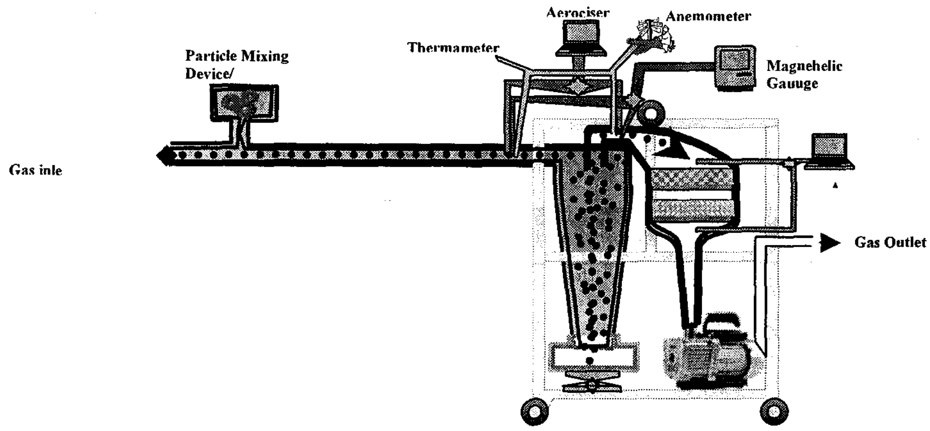


Fig 2. Perspective view of new Cyclone train.

A perspective diagram of the installation and the details experimental apparatus is shown in Fig. 2. Stairmand [3] 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 designing a high efficiency cyclone. So far several scientist [4-8] study focused on the radial dimensions such as cyclone body diameter as well as the inner diameter of exit tube. But still these studies are not sufficient for evaluating the effects of flow rates on the mechanisms responding to particle deposition in cyclones. The cyclone dimensions are given in figure 3.

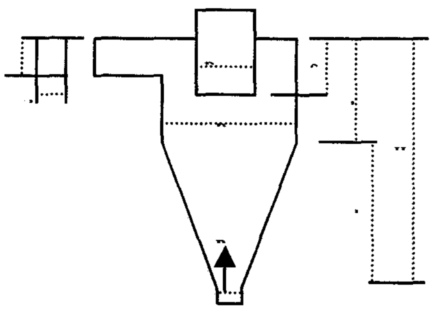


Fig. 3. Cyclone dimensions.

The cyclone used in this study was a standard Alexander [9] high-efficiency geometry with a diameter of 76 mm and height of 125 mm. The vortex finder length of the cyclone was varied from 28 to 75 mm by adjusting the position of a vane in the exit. The width of the tangential inlet was 15 mm and inlet height was 30 mm. The dust outlet diameter was similar the exit tube diameter. The instrument was made by stainless steel. The experiments were conducted with the Al_2O_3 particles. The test particles consisted mostly with the sizes of 0.3, 1.0, 2.0- 3.0, 5.0 and 10 μm (Sigma-Aldrich Inc.,). An Aerociser measured the size distribution of this particle. The particles were premixed and an electric vibratory feeder was used to introduce at rates in the range of 12.00 to 18.00 g/min to the inlet through a nozzle. The air supply to the nozzle was at different pressure of 8 to 20 cm aqueous. The particle-laden air was drawn through the cyclone; bag filter and the HEFA filter by a blower with desired flow rate and pressure. However, the gas from the cyclone passed through the bag filter and to the top of a high-efficiency HEFA filter before being released.

Table 1. Dimensions and operation conditions for the tested cyclone

Dimensions	Values (mm)
Cylinder height (h)	125
Cyclone height (H)	336
Exit tube length (S)	28, 49, 75
Cyclone body diameter (D_c)	76
Gas exit diameter (D_e)	38.1
Inlet height (a)	35.5
Inlet width (b)	15
Dust outlet diameter (B)	38.1
Cyclone cone height (k)	211

The operational parameters of the cyclone were varied to evaluate the performance of the cyclone and filters. The vortex finder diameters and lengths of the cyclone were prepared for use in the experiments, with various flow rate combinations. The flow rates were measured and controlled by a mass flow controller, and pressure drop by a Magnehelic gauge and temperature was measured by thermometer. The particle size distributions of mock samples from the inlet, the cyclone hopper, bag filter, and HEFA filter were analyzed by Aerociser. The air for isokinetic sampling by the cyclone train was drawn by an air pump. It was possible to measure distributions of 0.3 to 10 μm particles at various flow rates by optional choice of suction nozzles in the cyclone train. At high particles concentrations can affect performance [10]. For example Stern et al. [11] state that the overall mass efficiency of a cyclone increased drastically for increase in particles concentration. Wheeldon and burnard [12] found that the shape of the fractional efficiency curve did not change with the increased loading but that the curve shifted toward higher efficiency for particles of all sizes.

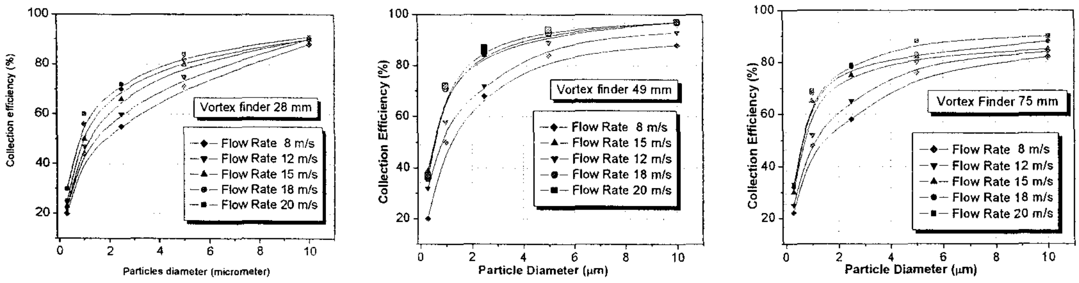
Results and discussions

Initially the test cyclone was characterized by varying the inlet velocity, and particles concentration. Varying the pressure of the cyclone chamber varied the inlet velocity from 8 to 20 m/s. The varying the length of vortex finder or cyclone cylinder height varied the pressure drop. The overall efficiency of the cyclone at different inlet velocities varied from 20 to 97% for 0.3 to 10 μm particles size.

Table 2. Cut size (μm) of tested cyclone at different flow rates (m/s)

Vortex finder	Flow rates				
	8	12	15	18	20
28	2.30	1.50	1.25	1.00	0.82
49	1.22	0.85	0.60	0.58	0.55
75	1.50	1.15	0.75	0.68	0.65

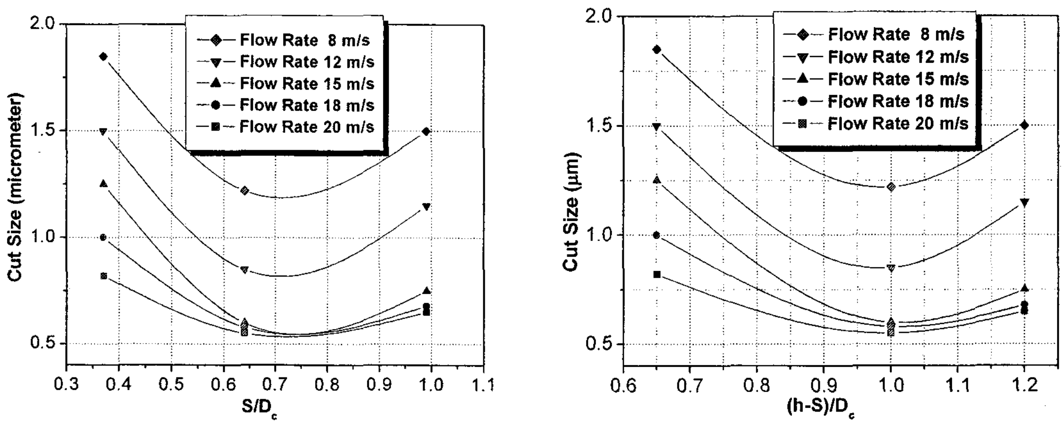
The collection efficiency data obtained for the tested cyclone with different exit tube heights at different flow rates are presented in Fig. 4a, 4b, and 4c. Exit tube S as designated in Fig. 3. The dimensions and operation conditions are listed in Table 1. The inlet velocity of the cyclone was varied from 8 to 20 m/s. The performance of the cyclone increased with the increasing velocity as shown in Fig. 5. At an inlet velocity of 8 m/s, the total cyclone efficiency was only 88 %, whereas the inlet velocity of 20 m/s, the total cyclone efficiency was found 97 %. The marked increase in cyclone efficiency at low inlet velocity is probably due to the availability of a greater amount of relatively coarser particles to be separated because of the lower efficiency of the cyclone. Thus at 8 m/s, the cyclone receives a higher fraction of bigger particles than at 20 m/s; this may also aid in removing smaller particles by agglomeration.



a) b) c)

Fig. 4. Measured collection efficiency as a function of particle size for a) Vortex finder 28mm b) Vortex finder 49 c) Vortex finder 75, at different flow rates.

To evaluate the effect of mock particles concentration on cyclone performance, the mock particles concentration was varied from 12 to 18 g/min. As expected, the efficiency of the cyclone increased with the increase in particle concentration from 78 to 85%. The efficiency of the filters also appears to increase slightly. For higher concentrations of feed particles, the smaller particles are better removed in the cyclone, either due to a limited carrying capacity of the gas or the sweeping effect of the larger amount of mock particles.



a) b)

Fig. 5. Cut size as a function of the ratio of a) exit tube length to body diameter (S/D_c), b) the difference of the cyclone cylinder height and the exit tube length to body diameter ($(h\text{-}S)/D_c$) for tested cyclone.

In spite of the fact the swirl velocity decreases with the increase in particles concentration. Considering the axial dimension effects discussed before, the cyclone which has h/D_c of 2.0 and S/D_c of 1.0, or more accurately, $(h\text{-}S)/D_c$ of 1.0 would be the best design. It is noted that although there are some discrepancies between experimental results and Stairmand's design regarding either h/D_c or S/D_c, the ratios of $(h\text{-}S)/D_c$ are essentially the same. This is different from what happened on the collection efficiency discussed above. Given a higher flow range, the increase in the efficiency as the flow rate increases becomes less significant.

Table 3. Pressure drop (cm water) across the tested cyclone at different flow rates (m/s)

Vortex finder	Flow rates				
	8	12	15	18	20
28	6	8	11	13	15
49	7	11	14	16	19
75	8	14	17	20	25

Except for the collection efficiency, the pressure drop across the cyclone is another important concern from the point of view of energy consumption. In this study, pressure drops were measured between two pressure taps on the cyclone inlet and outlet tube by means of a Magnehelic gauge. To evaluate the feasibility of operating cyclones at high flow rates, the pressure drops for the entire test at different flow rates were measured and the results are listed in Table 3.

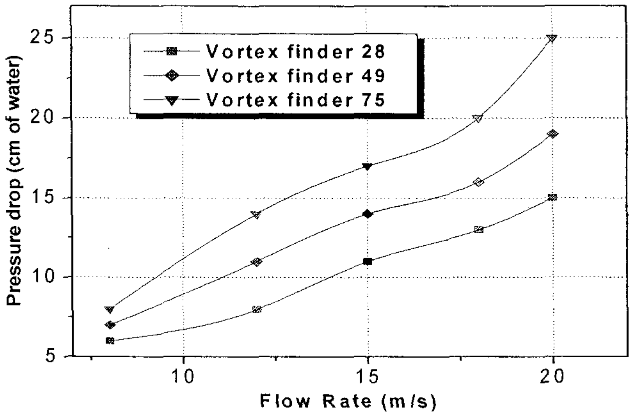


Fig. 6. Pressure drop of the cyclone.

It is well known that higher-pressure drop is associated with higher flow rate for a given cyclone. However, it should be noted that the extent to which the pressure drop increases as the flow rate increases does not become smaller at a higher flow rate range or the pressure drop decreases substantially as the cylinder height is lengthened or as the exit tube becomes shorter. As expected, the pressure drop is seen to become larger as the flow rate is higher. As a result, the greatest pressure drop occurs at 20 m/s. Since the pressure drop is a measurement of energy consumption during cyclone operation, it is not advisable to operate cyclones at an excessively high flow rate.

The evaluation of the mock particles separator resulted in the cut-size characteristics as shown in Fig. 6 and 8 and listed in table 2. This figure shows that cutoff diameters are dependent on both the exit tube lengths and the flow rates. The 50% cut diameter decreased as the flow rate increased as shown in the table and figure. The figure also revealed that the 49 mm exit tube length cyclone had a smaller 50% cut diameters than those of the 28 mm and 75 mm. It is believed that cutoff diameters decrease and collection efficiencies increase as the inertial force is increased. At the high flow rates (18 and 20 m/s), however, the decreasing slope of cutoff diameters are not sharp, compared to those at low flow rates (8 and 15 m/s) as shown in Fig. 8. It is expected that inertial force less influence small particles than large particles.

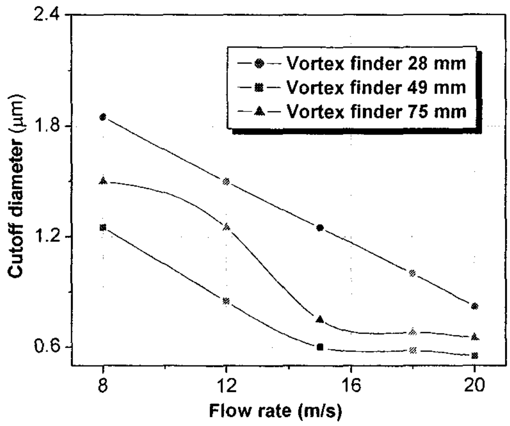


Fig. 7. Cutoff diameters for different flowrates.

The performances of filters (Bag and HEPA) used in this equipment were very good to control the fine particle dispersed in the air. The Figure 9 shows the more than 95 % collection efficiency for fine particle size 0.3 μm and 1 μm, but 100 % collection efficiency for more than 5 μm particles were measured.

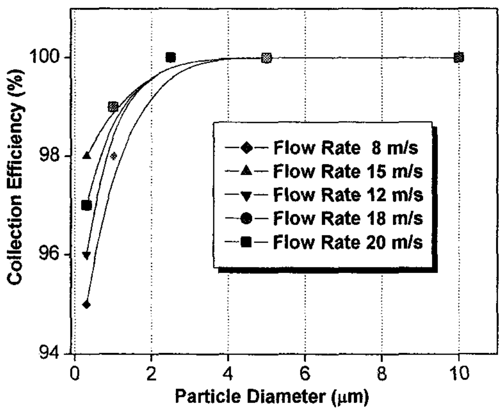


Fig. 8. Collection efficiency for filters as a function of particle size at different flow rates.

Conclusions

A compact cyclone was developed and fabricated in this study as a hot particulate separator. This new hot particulate separator produced satisfactory results; the performance was much better when the inlet velocity of the cyclone was lower than 18 m/s. such as a small 50% cutoff diameter and the sharp slope. The two axial dimensions, cylinder height and exit tube length, were covered and high flow rates were employed to evaluate the particle collection efficiency in cyclones. The results drawn from the experiment of developed equipment can be summarized as follows.

a) Removal efficiency of the developed cyclone was greater than 65% of mock particulate, size of which has more than 1 ㎛, and more than 90% of mock particulate, size of which has 5~10 ㎛ at inlet velocity more than 15m/sec.

b) Cyclone had the highest removal efficiency on vortex finder length of 7.5 cm.

c)Removal efficiency of Bag/HEPA filter box for 1 ㎛ was found greater than 97%.

d) The pressure drop measurements indicate that lengthening cylinder height or shortening exit tube length will both help to reduce pressure drop to some extent.

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