# Theoretical and Experimental Performance of MR-deDuster as an Axial Entry Multi-Cyclone

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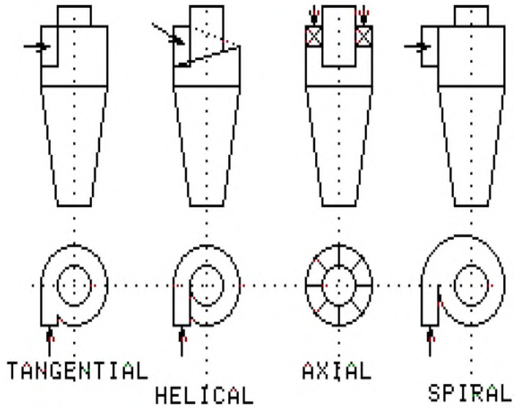
**Abstract.** This paper presents the theoretical and experimental performance of MR-deDuster as an axial entry multi-cyclone system. Collection efficiency and pressure drop across the unit were measured under various operational conditions of inlet velocity and dust loading. Two different diameters of vortex finder of 73 and 90mm were theoretically evaluated using modified version of semi-empirical equations introduced by Lapple in determining its overall collection efficiency. However, only experimental data on 90 mm vortex finder diameter were compared to the theoretical predictions. Both theoretical and experimental results showed that the overall collection efficiency of MR-deDuster increases with inlet velocity.

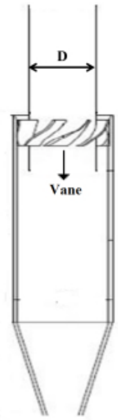
## Introduction

Cyclone has often been considered as a low-efficiency particle collector in the past. However, its collection efficiency varies greatly with cyclone design configurations and operating conditions. Many advanced designed works for the past years had greatly improved the cyclone performance even up to 99% efficiency for particles greater than 5 microns especially at very high dust loading [1, 2]. To date, cyclone separator is an important dedusting device which is widely used in many industries as an air pollution control system due to its simple construction, low manufacturing cost, ease of maintenance, compactness, and lack of moving parts [3].

To meet more stringent emission requirements for a better environment, cyclone performances must be improved unremittingly. Size of vortex finder and inlet velocity are parts of parameters which significantly affect the performance of the cyclone especially in two aspects; collection efficiency and pressure drop [4-6]. Basically, there are four different types of inlet used in gas cyclones (Fig. 1 (a)); tangential, axial, helical, and spiral [7]. Most common conventional cyclone design is the tangential inlet entry, where gas is brought in at the side of cyclone to initiate the swirling action. Meanwhile, for axial entry, the gas is brought in at the top and the swirling action is imparted by stationary vane positioned in path of incoming gases as shown in Fig. 1(b).




(a) Types of inlet entry




(b) Position of vane in axial inlet entry

Fig. 1 Inlet entry of a cyclone.

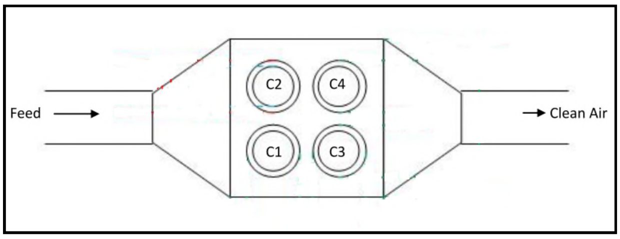
Studies on prediction of MR-deDuster performance as a fine dust emission control system with axial inlet entry multi-cyclone had been reported elsewhere [8-11]. The system is theoretically able to collect as high as 90% of particles between 5 and 10 microns size range with specific area of inlet entry and operating conditions [8]. In this paper, the performance of a pilot plant scale MR-deDuster was investigated theoretically and experimentally to determine the overall collection efficiency and pressure drop across the cyclone using different size of vortex finder subjected to various inlet velocities and dust loadings.

## Pilot Plant Scale of MR-deDuster

There are various cyclone separators with different shapes and configurations. The most generally used one is the reversed flow cyclone which has a cone under a cylindrical body with a tangential inlet [6]. MR-deDuster introduced a new design of four units miniature cyclones with axial inlet entry installed as one system. The unit is designed with replaceable vortex finder pipe of any diameter size (designated as D in Fig. 1 (b)). The design of this new cyclone is based on configurations of the cyclone i.e. diameter and length of the cyclone as well as the area of inlet entry. Changing the inlet size is said to give significant effect especially for the cut-off diameter [12].

Fig. 2 (a) shows the actual image of the pilot unit of MR-deDuster while Fig. 2 (b) shows the schematic arrangement of MR-deDuster which consists of four miniature cyclones in one unit. The pilot plant is equipped with a pressure drop indicator, controller to manipulate the air volumetric flowrate passing through the unit and a feeder where the particle is introduced into the system.


(a) Pilot plant scale of MR-deDuster




(b) Schematic arrangement of MR-deDuster

Fig. 2 Pilot scale and schematic diagram of MR-deDuster.

## Theoretical Performance of MR-deDuster

The performance of MR-deDuster was determined theoretically with two different sizes of vortex finder i.e 73 and 90mm. In this study, the performance of MR-deDuster in term of its collection efficiency had been predicted by using the semi-empirical model which introduced by Lapple [8, 11]. Cut-diameter ($d_{pc}$) is defined as the particle size collected at 50% efficiency. It is an important element of describing efficiency for a particulate control device. The collection efficiency was calculated based on $d_{pc}$ as in the Eq. (1)-(3) as follows:

$$dpc = \left\lfloor \frac{9\mu W}{2\pi NeVi(\rho p-\rho g)} \right\rfloor \tag{1}$$

$$\eta_j = \frac{1}{1+\left(\frac{d_{pc}}{d_{pj}}\right)^2} \tag{2}$$

$$\eta = \sum \eta_j m_j \tag{3}$$

where μ is the gas viscosity (kg/m.hr); W is the particle travel distance from the vortex finder wall to the cyclone wall (m); Ne is the number of effective turns; Vi is the gas inlet velocity (m/s); ρp is the density of particle while $\rho_g$ is the gas density. The grade collection efficiency of the particle size range ($\eta_j$) was calculated as in Eq. (2) where $d_{pj}$ is the diameter of particle size range while the total collection efficiency (η) was calculated by using Eq. (3) where $m_j$ is stand for mass fraction of particles in $j_{th}$ size range.The solid particle used in the study was palm oil mill boiler fly ash (POFA) with particle density of 2388kg/m³ and having wide range of particle size distribution.

### Experimental Performance of MR-deDuster

A set of experiment was performed in order to measure the collection efficiency and pressure drop of MR-deDuster. In this study, the overall collection efficiency of MR-deDuster was determined experimentally based on the particulate emission sampled at stack by introducing known amount of particle before the unit. The particle emission at the stack was sampled following the USEPA Method 17; Determination of Particulate Matter Emissions from Stationary Sources. The sampling was done iso-kinetically using a cellulose thimble type filter as the collection media. The weight of the particle collected was determined gravimetrically. The performance of MR-deDuster in term of its overall collection efficiency was calculated based on Equations in (4):

$$\text{Overall collection efficiency, } \eta_o(\%) = \frac{\text{Mass in-Mass out}}{\text{Mass in}} \text{ x } 100 \quad (4)$$

Meanwhile, the pressure drop across the cyclone was measured by using pressure gauge (Magnehelic® Differential Pressure Gauge) located at the inlet and outlet of the unit. A selected amount of tested particle was screwed feed into the inlet duct and sampled at the stack of the pilot plant. The experiments on the performance of the unit was carried out with vortex finder size 90mm only with different inlet velocities and dust loading ranging from 13 to 17m/s and 11 to 34g/s respectively. Fig. 3 shows the schematic diagram of the pilot plant MR-deDuster of the experimental setup.

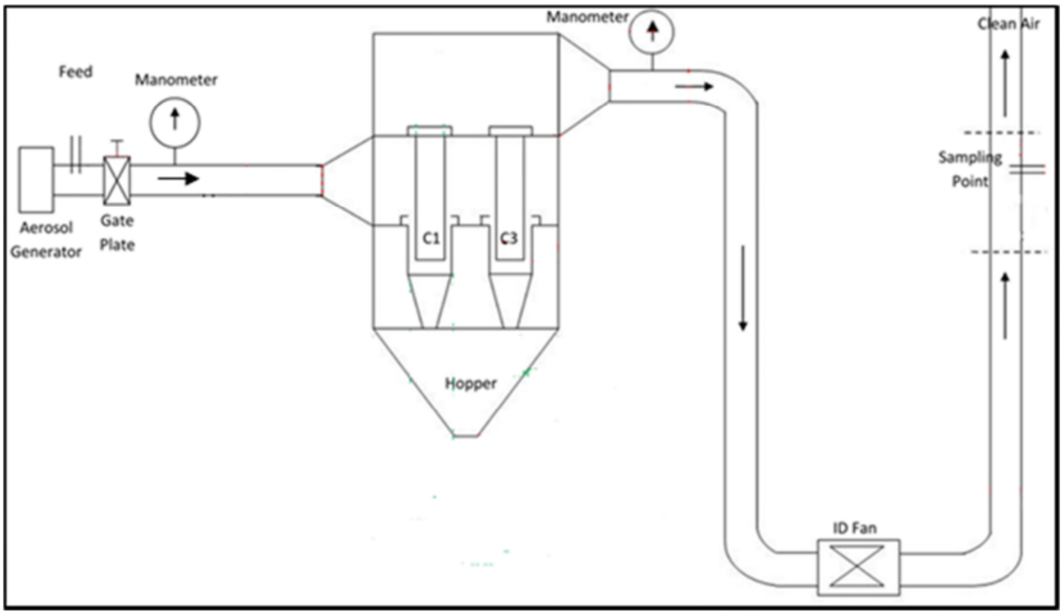



Fig. 3 Schematic of pilot plant MR-deDusterof the experimental setup.

### Results

**Theoretical Performance of MR-deDuster.** Fig. 4 presents the theoretical performance of MR-deDuster for different vortex finder diameter with inlet velocity 13-17m/s which showed that the larger the diameter of vortex finder the higher the overall collection efficiency compared to the smaller vortex finder. This is because, a bigger diameter of vortex finder resulting smaller area of cyclone entry which helps in reducing the distance of particle travelled between vortex finder wall to the cyclone wall. Hence increase the collection efficiency of the system. The size of vortex finder is an especially important dimension, which significantly affects the cyclone performance as it plays a critical role in defining the flow field inside the cyclone [2]. On the other hand, increasing in inlet velocity seems to increase the overall collection efficiency regardless of the diameter size.

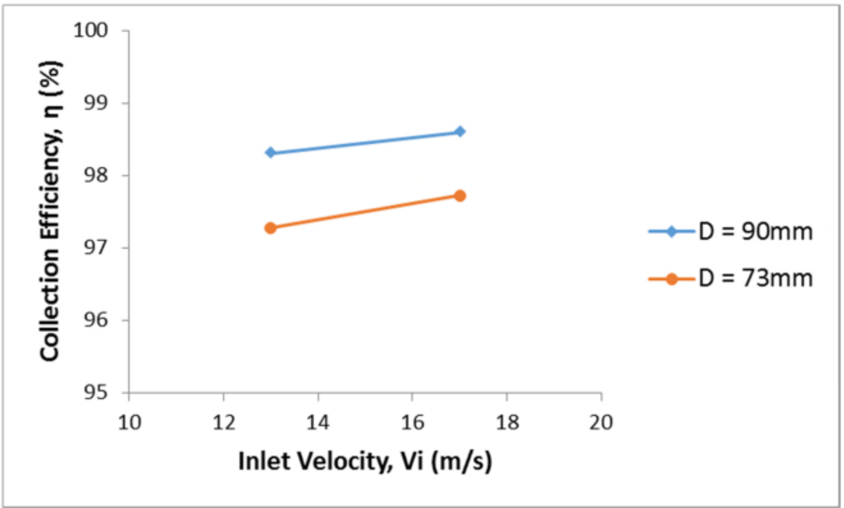



Fig. 4 Predicted overall collection efficiency of MR-deDuster.

**Experimental Performance of MR-deDuster**

Fig. 5 presents the overall collection efficiency against the inlet velocity which showed that there is a good agreement between the theoretical prediction and experimental observation with merely 0.8% difference. As previously found, a higher inlet velocity gives a higher collection efficiency in both cases theory and experiment. The overall collection is proportionally related with inlet velocity regardless of dust loading rate.

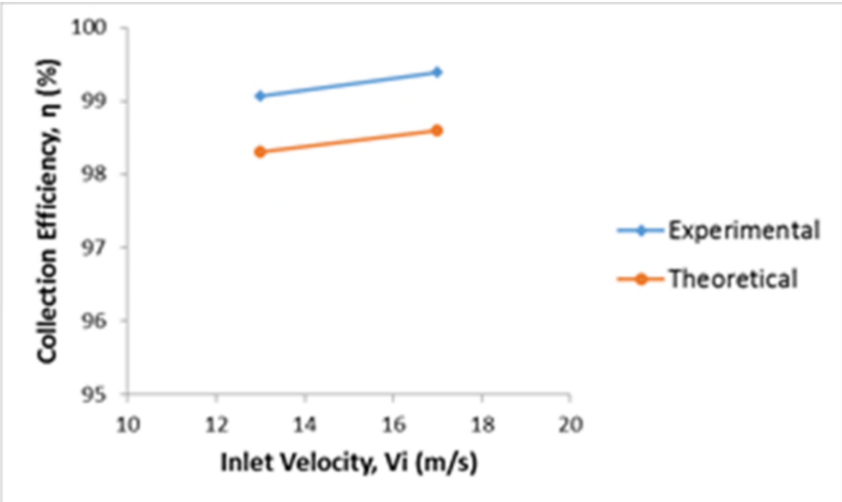



Fig. 5 Comparison of overall collection efficiency between theoretical and experimental.

Fig. 6 showed that increasing inlet velocity not only resulting higher collection efficiency but also increase the pressure drop across the cyclone. However, the pressure drop observed in the experiment i.e 1.8 inch of water,was found to be lower than in theory. A decrease pressure drop means lower the energy consumption of operating the system. Thus, it is important to note that the pressure drop is closely related to inlet velocity which directly influenced the operating cost of the system [13]. In this case, having low pressure drop across the system presents a tremendous benefit.

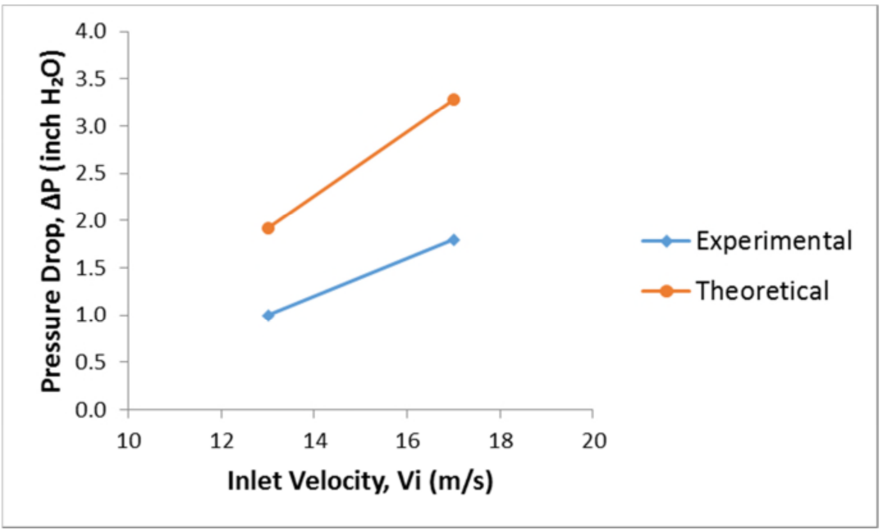



Fig. 6 Comparison of pressure drop across the cyclone between theoretical and experimental.

In general, increase dust load will increase efficiency on cyclone performance [1]. Fig. 7 depicts the effect of increasing dust loading from 11 to 34 g/s and inlet velocity simultaneously. Higher dust loading with higher inlet velocity presents a better overall collection efficiency. In this study, dust loading seems to be significantly correlated with collection efficiency with $r^2=1$ which showed that it is in positive relationship where collection efficiency is proportional to dust loading.

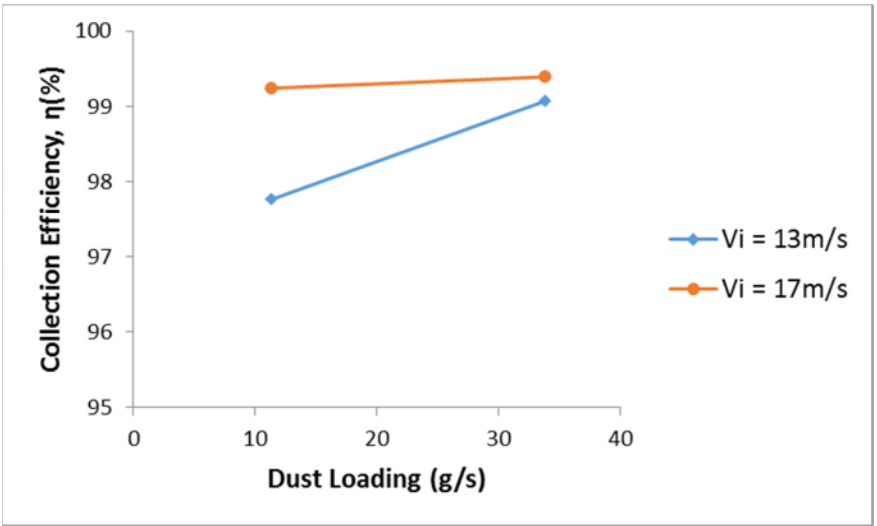



Fig. 7 Effect of dust loading towards overall collection efficiency.

## Conclusion

This study investigated a novel design of axial entry multi-cyclone as a fine dust emission control system. The study found thatlarger diameter of vortex finder givesa higher overall collection efficiency along with increasing of inlet velocity. In addition, the study showed that MR-deDuster has higher collection efficiency with higher inlet velocity but low in pressure drop compared to in theory. The finding also found that dust loading significantly affects the overall collection efficiency of the unit.

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## References


[1] C. D. Cooper and F. C. Alley, Air Pollution Control: A Design Approach, Third Edition, Waveland Press Inc., United States of America, 2002.

[2] F. Ficici, V. Ari and M. Kapsiz, The Effect of Vortex Finder on the Pressure Drop in Cyclone Separators, Int. J. Phys. Sci. 2010, 5(6) (2010) 804-813.

[3] A. C. Hoffmann and L. E. Stein, Gas Cyclones and Swirl Tubes: Principles, Design and Operation, 2008, 1-422.

[4] K. S. Lim, H. S. Kim, K. W. Lee. Characteristics of the Collection Efficiency for a Cyclone with Different Vortex Finder Shapes, J. Aerosol Sci. 35 (2004) 743-754.

[5] J. Yang, G. Sun, M. Zhan. Prediction of the Maximum-Efficiency Inlet Velocity in Cyclones, Powder Technology, 286 (2015) 124-131.

[6] I. Karagoz, A. Avci, A. Surmen, O. Sendogan, Design and Performance Evaluation of a New Cyclone Separator, J. Aerosol Sci. 59 (2013) 57-64.

[7] C. L. Svarovsky, Gas Cyclones, Fine Particle Software Publication, no. 2, 2009.

[8] H. Norelyza and M. Rashid, Performance of MR-deDuster on Particulate Emission Control for a Different Area of Axial Entry, J. Environ. Res. Dev. 7(4) (2013) 1392-1398.

[9] H. Norelyza, M. Rashid, S. Hajar, A. Nurnadia. MR-deDuster: A Dust Emission Separator in Air Pollution Control, J. Technol. 58(20) (2012) 85-88.

[10] H. Norelyza, M. Rashid. Performance of MR-deDuster: A Case Study of a Palm Oil Mill Plant, Adv. Mater. Res. 664 (2013) 133-137.

[11] N. Hasyimah, M. Rashid and H. Norelyza, A Theoretical Performance of MR-deDuster as a Fine Dust Emission Control System, Adv. Mater. Res. 1125 (2015) 317-321.

[12] K. Elsayed and C. Lacor, The Effect of Cyclone Inlet Dimensions on the Flow Pattern and Performance, Appl. Math. Model. 35 (2011) 1952-1968.

[13] W. B. Faulkner and B. W. Shaw. Efficiency and Pressure Drop of Cyclones Across a Range of Inlet Velocities, Appl. Eng. Agric. 22 (2006) 155–161.