Reduction of PM10 Emission from A Retrofitted Multicyclone

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Abstract. Multi-cyclone is one of the particulate control systems commonly used in the industry due to its low capital, operating, and maintenance cost as well as its reliability under a wide range of operational conditions. Unfortunately, it has low performance in collecting fine particulate especially of less than 10 μm in diameter or PM10. Thus, this limitation motivated a cost-effective retrofit of the existing conventional multi-cyclone. The retrofit was performed by creating a more negative pressure at the dust hopper of a conventional multi-cyclone, by drawing out a small portion of the air using an Induced Draft Fan. The particulate emission concentration and overall collection efficiency of the unit at various effective inlet velocities ranging from 6.2 to 19.8 m/s with particulate loading of 30 mg/m³ of 100 μm sample size diameter of Palm Oil Mill Boiler Fly Ash were investigated in this study. Interestingly, the introduction of suction increased the overall performance of the multi-cyclone by 10 to 20%. The finding suggests that a simple retrofit managed to increase the overall performance of the conventional multi-cyclone even for PM10.

1 Introduction

Air pollution is defined as an introduction of particulate matter (hereinafter PM), chemicals or biological materials that cause harm or discomfort to humans and other living organisms. These discomforts are damaging to the natural and built environment as the PM is released into the atmosphere [1]. PM is a by-product of industrial processes such as combustion, grinding, crushing and many more, which needs to be controlled and removed from being emitted into the atmosphere as it creates adverse effects to human.

There are many types of particulate control systems available in the market such as cyclone, electrostatic precipitator, bag house filters and scrubber. Generally, cyclone is the most common among all, and it is used for removing particulates from contaminated flue gas due to its low capital, operating, and maintenance cost and as well as its reliability under a wide range of operational conditions [2].

In industry, conventional multi-cyclone (hereinafter CMC) which is comprised of several small-diameter cyclones arranged in parallel with a common gas inlet and outlet is widely used commercially.
It is preferred due to its capability of handling massive volumetric flow of contaminated flue gas which cannot be handled by a single cyclone [3], [4].

Unfortunately, multi-cyclone is more efficient in collecting coarse PM rather than fine particulate. Thus, in many cases, multi-cyclone is used merely as a pre-cleaner unit upstream of a more efficient air pollution control system as it is not effective in meeting the stringent particulate emission requirement [5]. Therefore, it is the primary reason for being utilised as a pre-cleaner at the upstream of other devices to reduce dust loading and remove larger particulates from the stream [6].

Thus, the performance of a retrofitted multi-cyclone (from now on refer as, RMC) on the collection of fine particulate size fraction of PM10 was investigated in this study. The experimental findings obtained from a pilot plant unit of the CMC and RMC were compared and presented in this study.

2 Methodology

2.1 Particulate Sample
Palm Oil Mill Boiler Fly Ash (POMBFA) generated from the combustion of palm fiber and shell in the palm oil mill boiler was used as a dust sample in the experiments. The sample collected from a mill was mixed thoroughly to ensure homogeneity and dried for 24 hours at 110 °C to remove moisture. The dried POMBFA was sieved and categorized into size fraction below of below 100 μm via sieving and used for experimental runs. The particulate size distribution of the sample was further determined by using a micro-sieve (Sieve vibrator Model Octagon Endecotts).

2.2 The Pilot Plant
The CMC pilot plant consists of a dust feeder, pressure meter, induced fan (IDC), and stack. It is fitted with four identical miniature cyclones in a single compartment and equipped with a control panel [7]. The speed of the IDC fan, which controls the volumetric airflow rates of MC is regulated by the control panel. Figure 1 presents the schematic diagram of the CMC and its retrofitted part shown in blue, which includes an additional suction inlet pipeline with a suction valve, an ID fan (IDS) connected to a stack with a sampling port. A separate control panel is attached to manipulate the IDS fan as a mean to control the volumetric air flow rate of the suction.

![Figure 1. The schematic diagram of the CMC with its retrofitted component in blue.](image)

2.3 Performance Test
The performance of the CMC and RMC was determined through the total particulate emission concentration measured iso-kinetically at the cyclone stack following the USEPA Method 17: Determination of Particulate Emissions from Stationary Sources In Stack Filtration Method. In addition, the particulate emission and its size distribution at the cyclone stack was determine using GRIMM
Portable Laser Aerosol Spectrometer dust monitor (Model 1.108/1.109). The experiments were conducted at varies volumetric air flow rate ranging between 0.11 to 0.35 m$^3$/s corresponding to effective inlet velocity of 6.2 to 15 m/s with constant mass loading of 30 mg/m$^3$ using POMBFA as the test sample. Similar experimental procedures were repeated on the RMC applying suction by withdrawing a portion of volumetric airflow at the dust hopper of the unit. The percentage suction was from 0 to 20%, representing the ratio of airflow rate extracted from the dust hopper to the total amount of airflow rate passing through the cyclone.

3 Results and Discussion

3.1 Particulate Distributions

Figure 2 presents the mass cumulative percentage of POMBFA sample fed and emitted from the CMC and RMC, which showed a similar pattern between them but shifted apart. The mass cumulative distribution of the sample fed into the cyclone was determined using sieving method while the mass cumulative distribution of the cyclone was based on GRIMM’s readings. It is observed that the particulate emitted from the stack represents smaller size fraction with 50% mass cumulative size 2.7 μm compared to 45 μm of the raw sample. Interestingly, Hasyimah et al., (2017) also found that the particulate 50% cut size of the CMC was 2.5 μm, which is similar to this study. This construes that the existing CMC is efficient in removing fine particulate size fraction. However, introduction of suction has further improved the efficiency of CMC by shifting the cut size to 2.1 μm as shown in Figure 2.

![](image)

**Figure 2.** The comparison particulate distribution for sample fed and the emission concentration from the CMC and RMC (i.e. with 20% suction) at cyclone flow rate 0.11 m$^3$/s with constant mass loading of 30 mg/m$^3$

3.2 Experimental run on CMC

The overall efficiency is equal to the ratio of the difference between the inlet and emitted particulate concentration of the cyclone separator to the inlet particulate concentration [8]. Figure 3 presents the collection efficiency of the CMC with respect to the effective inlet velocity at mass loading of 30 mg/m$^3$, which showed that the collection efficiency increases with effective inlet velocity. The effective inlet velocity is the ratio of volumetric air flow rate by the entry area of the axial cyclone successively means an increase in effective inlet velocity also indirectly increase the volumetric air flow rate.

As in Fig 3 and based on the best-fit curve, the there is an increase in collection efficiency with effective inlet velocity till 14 m/s, thenceforth the collection efficiency started to decline. Hence, the
maximum collection efficiency at 14 m/s was 88% for 30 mg/m$^3$. As the inlet velocity increases, the centrifugal force of the particulate increased contributing to greater efficiency [9]. However, too high inlet velocity decreases the collection efficiency because of increased in turbulence and re-entrainment of particulate.

![Figure 3. Overall collection efficiency of CMC at mass loading 30 mg/m$^3$ at different inlet velocities.](image)

3.3 Experimental run on the RMC

Figure 4 depicts the collection efficiency of the retrofit cyclone at varied cyclone flow rates with different percentage of suctions where similar trend lines are observed in the experiment. As in the figure, the RMC with suction percentage of 10, 15 and 20% showed a positive upward trend representing an increase in collection efficiency with the increase in percentage of suction. The intercept values of 67, 78 and 86 in Figure 4 represent the collection efficiency of the CMC namely at 0% suction, where collection efficiency of the CMC increases with the flow rate of the cyclone. The collection efficiency of the RMC at 20% suction was 83, 93 and 95% for the flow rate of 0.11, 0.15 and 0.19 m$^3$/s, respectively. This affirms that the cyclone’s total overall performance for the fine particulate control has increased with the presence of the retrofit by 9 to 16% compared to the CMC alone. It is observed that the increment is higher at lower cyclone flow rate compared to higher cyclone flow rate, which is represented by the high slope value in Figure 4. Therefore, it is anticipated that suction pull is more effective at lower cyclone flow rate because the suction force needs to overcome lower swirling force of the cyclone at lower flow rate. Huang et al., (2018) stated that the particulate concentration distributions can be roughly classified into two regions in the cyclone where at the cylindrical part of the cyclone, the particulate concentration is lower and follows the gas spiraling downward flow patterns. While at the conical part of the cyclone, the reducing of the cone radius caused the acceleration of the gas tangential velocity. The enhanced centrifugal force by the increasing of the gas tangential velocity moved the particulate toward the conical wall. With the decreased of the conical volume and the increased particulate numbers around the wall region, the particulate concentration was higher at the conical part of the cyclone. Since the retrofit creates a pull of air at the dust hopper by having suction, these particulates along with air will travel further into the dust hopper, creating more collision among particulate, increasing collection at dust hopper which explains the increase in cyclone performance with presence of suction.
As in Figure 4, the suction created at the dust hopper creates a pull of air toward the suction stream line leaving a reduction of mass and enhanced the negativity of pressure in the hopper and the suction duct. Naturally, a negative pressure area would be balanced by flow of air from a higher pressure to a lower to balance the pressure at that point. Similarly, to replace the mass of air that is being pulled, it is anticipated that the air flow in the conical tip would flow downwards into the hopper carrying the vortex further down into the hopper. Higher pull of air due to high flow rate at suction stream which is created by higher suction percentage would create a very high-pressure difference. This phenomenon explains the higher collection efficiency at 20% suction compared to the lower ones.

![Figure 4](image_url)

**Figure 4.** The collection efficiency of retrofitted multi-cyclone at different cyclone flow rate with various suction percentage.

Figure 5 depicts the emission concentration of PM10 sampled at the cyclone stack under influence of varied suction percentage at constant cyclone flow rate 0.11 m³/s with fixed inlet mass loading of 30 mg/m³ which showed the reduction in emissions with increase in suction percentage. This figure clearly depicts that the CMC (i.e. 0%) has higher PM10 emissions compared to RMC for PM10 size fraction. This downward trend affirms that PM10 has reduced by 50% with the presence of 20% suction at the RMC.
3.4 Morphology of Particulate Collected by CMC and RMC

Figure 6 depicts the SEM images of the POMBFA particulates collected on the filter media, scanned for their diameters randomly to determine the particulate cut-size of the cyclone at the respective operating conditions. Moreover, the SEM was used to support and verify the results from GRIMM. Figure 6 (a) displays the image captured on a blank filter while, Figure 6 (b, c, and d) showed particulates on CMC and RMC sampled filter under 10 and 20% suction. These images clearly showed that the particulate size emitted is reduced with RMC compared to CMC. An increased in suction flow rate decreases the amount of fine particulate and its particulate cut-diameter. Smallest particulate diameter 3 μm is measured at volumetric air flow rate of 0.11 m/s at suction 20% while the largest is 9 μm at volumetric air flow rate of 0.11 m/s at zero suction.

![Figure 5. PM10 emission concentration at the cyclone stack under various suction percentage at cyclone flow rate 0.11 m³/s.](image-url)
Figure 6. Filter paper sampled at cyclone stack a) blank filter; b) CMC (0% suction); c) RMC -10% suction and d) RMC - 20% suction.

4 Conclusions
Several conclusions can be drawn from the study and these are;

i. The CMC demonstrated increase in collection efficiency with the effective inlet velocity. However, beyond 14 m/s, the collection efficiency declined due to particulate re-entrainment.

ii. The introduction suction at the RMC has further increased the collection efficiency of the existing CMC by decreasing the cyclone’s cut size from 2.7 to 2.1 μm.

iii. In addition, RMC also demonstrated reduction in PM10 emissions at the cyclone stack by 50% for constant cyclone flow rate of 0.11 m³/s at fixed inlet mass loading of 30 mg/m³.

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