Performance of a Retrofitted Multicyclone for $PM_{2.5}$ Emission Control

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Abstract. This paper presents on the performance of a retrofitted multicyclone system, which aims to increase the collection efficiency of $PM_{2.5}$ (i.e. particulate size fraction ≤ 2.5 µm) emission. The multicyclone was retrofitted by extracting 15% and 20% of the total volumetric air flow rate at the dust hopper of the unit using an additional Induced Draft Fan. The total collection efficiency with and without the extraction was measured at various air volumetric flow rates and particulate mass inlet concentration. The results showed that there was a reduction of 12% to 54% depending on the inlet concentration of $PM_{2.5}$ emission in the stack with compared to without extraction increasing the collection efficiency of the retrofitted multicyclone. The finding suggests that a simple technique of applying gas extraction at the dust hopper of a multicyclone as reported in this study able to increase the overall performance in fine particulate collection.

1 Introduction

Cyclones are one of the most popular air pollution control device used in separating particulate matter (hereinafter PM) from flue gas in industries. Generally, it is a preferred choice due to geometric simplicity, safety, low maintenance and operating costs, and wide range of operating conditions [1,2]. In industries, since the volumetric flow of contaminated flue gas is large, a multicyclone is used instead of single cyclone whereby it is made up of a number of small-diameter cyclones which are arranged in parallel and have a common gas inlet and outlet [3,4]. These multicyclones remove PM from the contaminated flue gas before emitting to the air, but unfortunately its more efficient in collecting coarse PM rather than fine. The fine PM fractions particularly smaller than 2.5 µm or PM2.5 are harmful to human health especially in relation to respiratory and cardiovascular disease [5,6] hence the emission needs to be addressed earnestly. The conventional multicyclone has limitations of low collection efficiency on fine particulate, therefore it is merely used as pre cleaner rather than as a main air pollution control system in industry [7]. Hence emerging a motivation in increasing its performance especially

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collection of particulate with size fraction of 2.5 µm and below (hereinafter $PM_{2.5}$), the existing conventional multicyclone system was retrofitted at its dust hopper.

2 Methodology

2.1 The retrofitted pilot plant

Fig. 1 presents the experimental setup of the pilot plant scale multicyclone system, which showed the retrofitted section (images inside the dotted box) of an additional extraction stream attached to the dust hopper. The conventional multicyclone system consists of four identical miniature cyclones in a single compartment equipped with a dust feeder and a pressure gauge to determine multicyclone's differential pressure, dust hopper, multicyclone ID fan (designated as ID multicyclone or IDC) and multicyclone stack (CS). The conventional multicyclone was based on the designed done in the previous study [8]. The retrofitted extraction stream is equipped with a valve and an ID Extraction fan or IDS to regulate the air volumetric flow rate of the extraction stream. Similarly, the airflow rate of the IDC is manipulated separately through a control panel attached to the pilot plant. The experiment was performed without and with extraction flow rate created at the dust hopper via the extraction stream by the IDS.

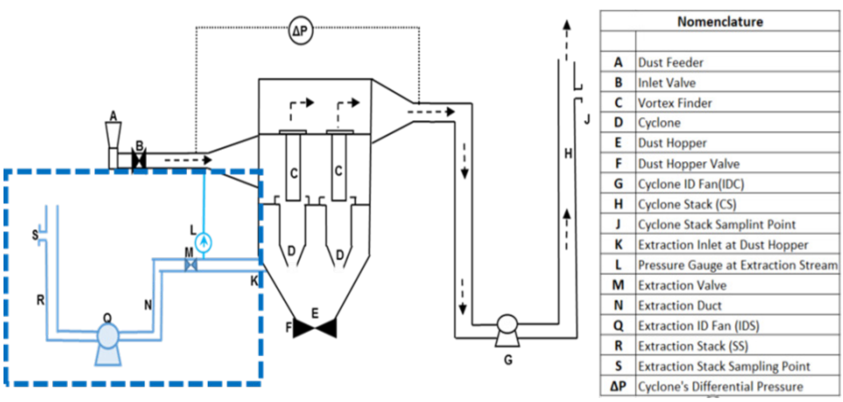

Fig.1. The pilot plant multicyclone system with the retrofitted stream in dotted region.

2.2 The particulate sample

The palm oil mill boiler fly ash (POMBFA) used in the experiments were obtained from two separate mills from the dust hopper of their respective air pollution control system. Each sample was dried in an oven at temperature 105±5ºC for 24hr [9] and then the samples were thoroughly mixed and sieved through a 100um sieving tray (Endecotts Laboratory Test Sieve BS 410-1). The sample passing through the 100µm tray was used in the experiment.

2.3 The experiments on non-retrofitted multicyclone

Initially, the experiments were conducted with and without the multicyclone unit at air volumetric flow rate of $0.19m^3/s$ using two different inlet dusts loading of 0.4 and 0.6 mg/m^3, where the emission concentration of $PM_{2.5}$ was measured at the cyclone stack. Later, the experiments were performed with the multicyclone at two different air volumetric flow rates of 0.11 and 0.19 m^3/s, which corresponds to inlet velocity of 6.0 and 11.0 m/s respectively. A similar inlet dust loading of 0.4 and 0.6 g/m^3 was applied in this case. The emission concentration of $PM_{2.5}$ was measured isokinetically using Dekati® PM_{10} Impactor following the USEPA Method 17: Determination of Particulate Emissions From Stationary Sources -In-Stack Filtration Method. The $PM_{2.5}$ was collected on a filter media placed in the impactor where its particulate mass emission concentration was calculated using Equation 1.

$$C = \frac{M_f - M_i}{Q \times t} \tag{1}$$

where,
C = emission concentration, g/m^3
M_f = mass of filter paper after experiment, g
M_i = mass of filter paper before experiment, g
t = time of sampling, s
Q = isokinetic flowrate of sampling pump, m^3/s

2.4 The Experiments of Retrofitted Multicyclone

The experiments of the retrofitted multicyclone was performed at flow rate of 0.11 m^3/s (corresponding to inlet velocity of 6.0 m/s) at two different inlet dust loading of 0.4 and 0.6 g/m^3 with the air extraction of 15% and 20% of the total air volumetric flow rate of the unit. In this experiment, $PM_{2.5}$ emission concentration was measured at both cyclone and extraction stack sampling point. The emission concentration was obtained from with and without extraction and the results were compared in this study.

3 Results and Discussion

3.1 Performance on the non-retrofitted multicyclone

Fig. 2 presents the $PM_{2.5}$ emission concentration of the pilot plant with and without the presence of multicyclone units at a flowrate 0.19 m^3/s at inlet dust loading of 0.4 and 0.6 g/m^3 which showed that $PM_{2.5}$ emission concentration was reduced at range of 48% – 51% compared to without the multicyclone unit. In addition, the finding suggest that $PM_{2.5}$ constitutes 30-32% of the inlet dust loading.

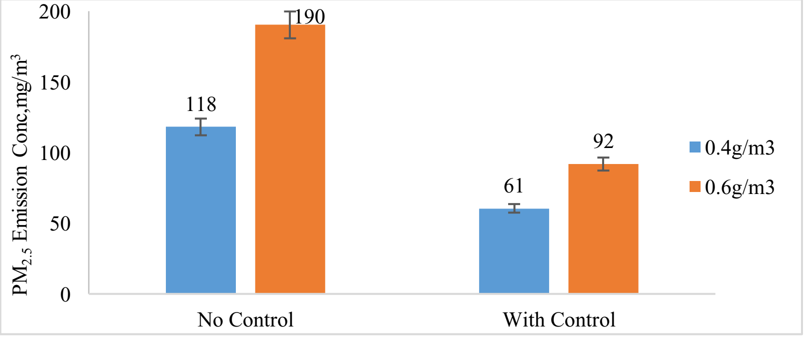

Fig. 2. $PM_{2.5}$ emission concentration with and without multicyclone unit at flow rate of 0.19 m^3/s at the respective inlet dust loading.

Fig. 3 presents the emission concentration of the plant with cyclone at inlet velocities of 6.0 and 11.0 m/s at two different inlet dust loadings of 0.4 and 0.6 g/m^3 which showed that $PM_{2.5}$ emitted from the cyclone increases with inlet dust loading and velocity as per observed in Fig. 2.

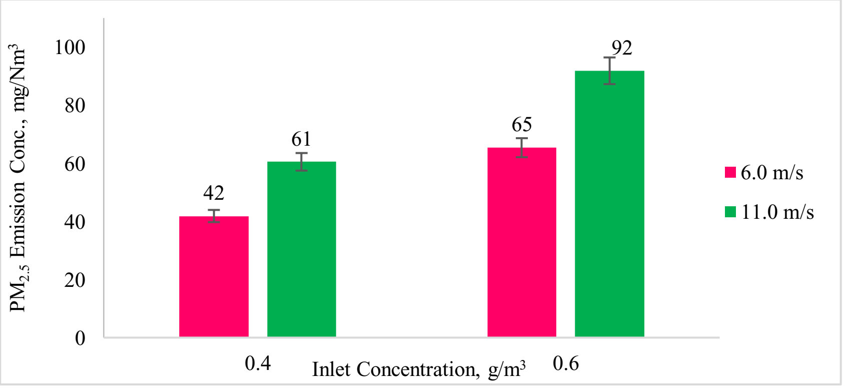

Fig. 3. $PM_{2.5}$ emission concentration of the conventional multicyclone with different inlet velocities and inlet concentration.

Similarly as observed in Fig. 3, a higher inlet concentration contains more of $PM_{2.5}$ therefore as expected more $PM_{2.5}$ would be emitted out from the multicyclone due to the limitations of collecting the overloaded $PM_{2.5}$. It seemed that the cyclone loses some of its swirl intensity in its vortex at high inlet concentration causing a dampening in its gas flow turbulence, which increases the emission concentration. Derksen *et al.* (2005) performed three-dimensional, time-dependent Eulerian–Lagrangian simulations of the turbulent gas–solid flow in a cyclone where through large-eddy representation of the gas flow, solid particles with different sizes were tracked and found that the collection efficiency gets affected in opposite senses: negatively by the loss-of-swirl, positively by the reduced turbulence in a cyclone[10].

In addition at higher inlet velocity of 11.0 m/s, the emission concentration of $PM_{2.5}$ is more compared to lower inlet velocity due to $PM_{2.5}$ re-entrainment where finer particle would easily escape from the cyclone due to the centrifuging out of the particles in tangential velocity field [11].

3.2 Performance on the retrofitted multicyclone

Fig. 4 presents the $PM_{2.5}$ emission concentration of conventional compared to retrofitted multicyclone at various inlet dust loading at constant inlet velocity of 6.0 m/s under 15% and 20% extraction ratio of extraction flowrate to multicyclone flowrate which showed a reduction in $PM_{2.5}$ emission upon applying the retrofit. This proved that the retrofit managed to selectively extract $PM_{2.5}$ out of the multicyclone's dust hopper simultaneously reducing the $PM_{2.5}$ emission concentration by 12 to 54% depending on the inlet concentration. As in Fig. 3, the collection efficiency which shows at extraction 15% for inlet concentration 0.4 g/m^3 the efficiencies are 89.5% and 93.5% and for 0.6 g/m^3 are 89.1% and 95% for conventional and retrofitted multicyclone respectively. On the contrary, the increase in extraction ratio at constant inlet velocity does not seem to contribute the reduction of $PM_{2.5}$ emitted which requires further investigations.

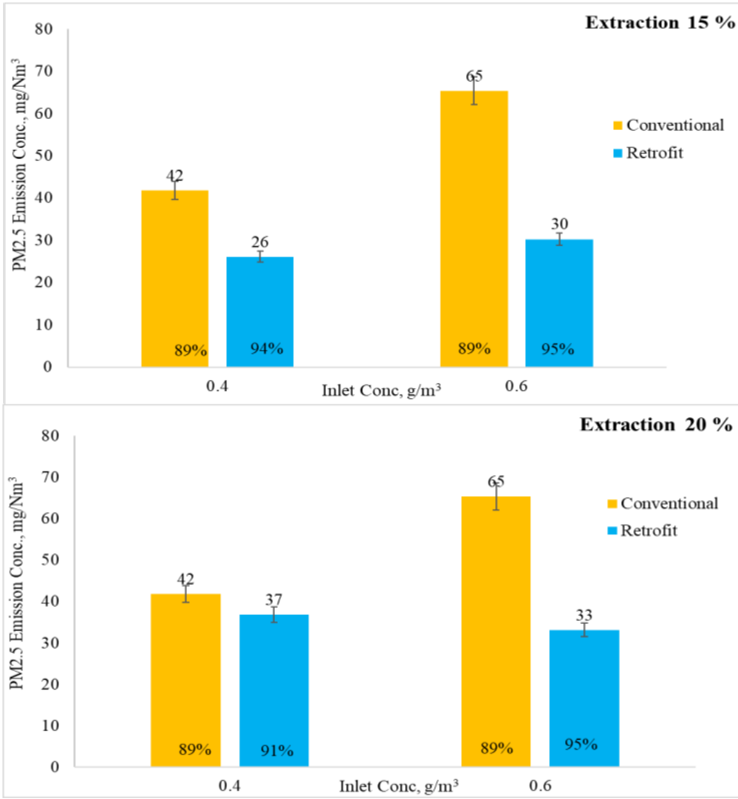

Fig. 4. $PM_{2.5}$ emission concentration at various inlet concentration at constant inlet velocity of 6.0m/s at 15% and 20% extraction ratio of extraction flow rate to multicyclone flow rate.

Based on Obemair *et al*. (2003), separation process in a gas multicyclone can be divided in three steps[12], where one of it is actually happens at the dust hopper therefore by introducing an extraction stream which is operated higher than the terminal falling velocity of $PM_{2.5}$, (0.425 mm/s) would cause more of $PM_{2.5}$ to be extracted out from dust hopper. Table 1 further validates that the extraction stream has selectivity towards $PM_{2.5}$ compared to the bigger size fraction because the ratio of $PM_{2.5}$ to PM_{10} is consistently at 90%. This phenomena is due to the inner vortex of the multicyclone is being extended under the influence of extraction causing fine particulate to be carried along with the extraction stream as modelled by CFD [13].

Table 1. Ratio of $PM_{2.5}$ to PM_{10} in the extraction stream.

Ratio $PM_{2.5}/PM_{10}$	15%	20%
0.4 g/m^3	0.9	0.9
0.6 g/m^3	0.9	0.9

4 Conclusions

The performance of the multicyclone on collection of $PM_{2.5}$ was evaluated by experiments before and upon installing the extraction stream at the dust hopper. Presence of extraction stream at the dust hopper of the multicyclone divides the airflow rates into two where a portion of $PM_{2.5}$ has been selectively extracted out from the dust hopper causing a reduction in $PM_{2.5}$ emitted from the multicyclone. The performance of retrofitted multicyclone in collecting $PM_{2.5}$ increases by at least 12% to 54% depending on the inlet concentration particularly in the collection of $PM_{2.5}$.

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