Utilising formulated filter aids for toluene removal in filtration plant

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Abstract. Filtration together with dry sorbent injection of activated carbon is widely used for VOCs removal in contaminated flue gas in incineration process. In addition, the sorbent acts as filter aids to the fabric media that enhance the efficiency of the filtration process. This study introduced a newly three in one formulated filter aids known as PrekotAC, which is a combination of PreKot™ and activated carbon. Similarly, a four in one filter aids known as TrikotAC, a combination of three materials PreKot™, activated carbon and lime is also introduced in this study. The adsorption of the formulated PrekotAC10:90 and TrikotAC10:5:85 on toluene was investigated in this study. The results showed that PrekotAC10:90 was able to adsorbed more toluene compared to TrikotAC10:5:85. However, formulated filter aids TrikotAC10:5:85 able to reduce the pressure drop across the filtration plant compared to PrekotAC10:90. The ability to reduce pressure drop in fabric filtration system means that the formulated material able to prolong the cleaning cycle of the filter plant which simultenously preserve the life span of the filter bag.

1. Introduction

Air pollution released from municipal solid waste incineration is becoming of a public concern [1]. It is reported that each tonne of the municipal solid waste burnt releases approximately 5000 cubic metres of gases containing pollutants such as acid gases, particulate matter, heavy metals and organic compounds.

The new Malaysia Ambient Air Quality Standard adopts six air pollutants criteria that include five existing air pollutants which are particulate matter with the size of less than 10 micron (PM10), sulfur dioxide (SO2), carbon monoxide (CO), nitrogen dioxide (NO2), and ground level ozone (O3) as well as one additional parameter which is particulate matter with the size of less than 2.5 micron (PM2.5). In addition, volatile organic compounds (VOCs) are recognized as significant primary pollutants because of their role in the formation of ozone in the ambient air [2 and 3].

Incomplete oxidation during incineration process of waste leads to the generation of VOCs in the flue gas emissions [4]. However, even with a trace amount of VOCs causes severe health effect to the human being [5]. Prolonged exposure to VOCs has been shown to induce eye and throat irritation, cause damage to the liver and central nervous system and increase relative rates of leukaemia and lymphoma [6]. Because of this, the Clean Air Regulation [7] imposed strict regulation on VOCs emission from 20 to 10 mg/Nm³. Therefore, the removal of VOCs emission is crucial in preserving the environment.
The emission of VOCs in the flue gas is treated using powder activated carbon sprayed onto the fabric filters collector as the air pollution control system. The adsorbent also acts as filter aids to ease the process of filtration. However, the problem arises where the activated carbon injected forms a compact filter cake layer on the fabric media that immediately increase the pressure drop across the system. Therefore, pre-coating material which acts as filtration aids is introduced to create a barrier of protection as well as to allow a uniform air flow passing through the filter media [8].

Hajar et al. [9] introduced a newly formulated filter aids known as PrekotAC (combination of PreKot™ and activated carbon) and found that the material was able to improve the filtration characteristics in terms of its pressure drop and reduced the ability of the penetrated particles across the filter cake and the filter media. However, the study was limited to these parameters and there was no report made on the adsorption property of the material on VOCs removal.

Thus, in this study the physical characteristics and adsorption performance of the newly formulated filter aids material PrekotAC and TrikotAC (combination of filter aids PreKot™, activated carbon and lime) were investigated. It is hope that the formulated material presents better filter aids which simultaneously acts as a flue gas cleaning agent for VOCs. This study aims to investigate the performance of three or four in one formulated filter aids in terms of adsorption capacity and breakthrough time in a pilot plant scale fabric filtration system.

2. Methodology

2.1 Filtration Plant

Figure 1 presents the schematic diagram of the fabric filter pilot plant unit used to test the adsorption performance of the formulated filter aids in this study. The unit consists of sixteen (16) cylindrical shape fabric bags (200mmD x 700mmL), toluene injection point, feeder for formulated filter aids, hopper, an induced draft (ID) fan, sampling point and a stack. The air volumetric flow rate through the unit was manipulated by the ID fan.

![Figure 1. The experimental set-up for toluene adsorption test in pilot plant unit](image)

The filtration plant was operated according to the conditions listed in Table 1. The filtration velocity passing through the fabric media was calculated based on the air volumetric flow rate divided by the total area of the filter media. Meanwhile, the pressure drop across the unit was measured using pressure gauge (Series 2000 Magnehilic® Differential Pressure Gauge) installed at the pilot plant.
Table 1. Experimental conditions of the study

| Description                        | Value      | Unit       |
|------------------------------------|------------|------------|
| Toluene gas concentration          | 50, 40, 33 | ppm        |
| Formulated filter aids loading     | 0.2, 0.4, 0.6 | mg/mm² |
| Filtration velocity, $V_f$         | 4, 5, 6    | m/min      |
| Filter bags                        | 16 unit    | -          |
| Filter media                       | P84        | -          |

2.2 Calibration of the pilot plant
Preliminarily, the air volumetric flow rate was calibrated through determining the stack gas velocity according to US-EPA Method 2 – ‘Determination of stack gas velocity and volumetric gas flow rate (Type S-pitot tube)’. A S-pitot tube attached to a digital manometer was used in this case where the stack gas velocity, $V_s$ was calculated using Equation 1.

$$V_s = K_p C_p (∆P)^{0.5}(T_s/P_{stat}M_s)^{0.5}$$

(1)

Where $V_s$ = stack velocity, (m/s); $K_p$ = constant, 34.97; $C_p$ = pitot tube coefficient, 0.84; $∆P$ = average velocity pressure, mmH₂O; $T_s$ = absolute stack gas temperature, °K; $P_{stat}$ = stack static pressure, 760mmHg and; $M_s$ = molecular weight of stack gas, 29g/g-mole. The value of stack gas velocity obtained in Equation 1 was then used to calculate the corresponding air volumetric flow rates of the stack gas based on Equation 2.

$$Q_s = V_s × A_s$$

(2)

Where $Q_s$ = volumetric airflow rates, m³/s; $V_s$ = velocity of stack gas, m/s; and $A_s$ = area of the stack at sampling point, m². The filtration velocity of the fabric filter was calculated using Equation 3;

$$V_f = Q_s/A_T$$

(3)

Where $V_f$ = filtration velocity of the fabric filter, m/s; $A_T$ = the total surface area of the sixteen fabric bags in the pilot plant unit. At this point, no filter aids was introduced during the dry run and the operating conditions were controlled by varying the speed of ID Fan based on the magnitude of frequency controlled by an inverter. The performance of the formulated filter aids on toluene adsorption was then tested once the pilot plant had been calibrated.

2.3 The experimental in the Pilot Plant
As depicted in Figure 1, a 300 mL of concentrated toluene solution was bubbled and introduced directly into the pilot plant and the concentration of toluene was measured at the stack using a portable VOC analyzer (Tiger V3.9). The concentration of toluene generated at 4, 5, and 6 m/min filtration velocity was 50, 40 and 33 ppm, respectively. The formulated filter aids was introduced to the pilot plant at various mass loadings and at different filtration velocities as presented in Table 1. The experiment was carried out until the concentration of toluene at the stack was similar to its initial concentration, which indicates that the breakthrough time has been achieved.

3. Results and Discussions

3.1 Calibration of Filtration Plant
Initially, the calibration of filtration plant was performed to determine the air volumetric flow rates and its effective inlet velocity. Thus, the system was dry run prior to introduction of toluene gas into it.
Figure 2 presents filtration velocity as a function of the volumetric air flow rate of the fabric filter which showed a direct linear relationship between these two parameters as presents in Equation 4, where \( V_i \) is filtration velocity (m/min) and \( Q \) is air volumetric flow rate (m³/s) of the unit.

\[
V_i = 0.21Q 
\]  

(4)

The filtration velocity was calculated based on the volumetric air flow rate divided by the total area of the 16 fabric bags type P84 installed in the pilot plant. In general, filtration velocity is one of the most important factors determining the adsorption of toluene in such unit.

3.2 Toluene Adsorption Performance

The performance was investigated in terms of ratio of toluene adsorbed and pressure drop across the filtration plant. Ratio of toluene adsorbed is defined as the capability of formulated filter aids as an adsorbent for VOCs. In addition, the pressure drop across the filtration plant was also determined as this directly affects the operating cost or energy consumption of the system.

3.2.1 Effect of Filtration Velocity on Toluene Adsorption

Figure 3 depicts the effect of different filtration velocity against the adsorption of toluene by the formulated PrekotAC\(_{10:90}\) and TrikotAC\(_{10:5:85}\) filter aids which generally showed that the higher the velocity the lower the amount of toluene adsorbed. As expected that the adsorption of toluene by PrekotAC\(_{10:90}\) was much more than TrikotAC\(_{10:5:85}\) as the former constitutes a higher amount of activated carbon in the formulation.

PrekotAC\(_{10:90}\) is characterized having large surface area compared to TrikotAC\(_{10:5:85}\) resulted in high number of active sites exist in PrekotAC\(_{10:90}\) hence contribute to the higher amount of toluene adsorbed in the sample.
Based on Figure 3, filtration velocity affects the adsorption of toluene by the formulated filter aids PrekotAC10:90 where the amount of adsorption decreases as filtration velocity increases with descending order 4 > 5 > 6 m/min. As for TrikotAC10:5:85, the trending is quite different where unexpectedly, 5 m/min velocity gives the highest adsorption compared to 4 and 6 m/min velocities. The homogeneity of the material during mixing may be one of the reasons for this finding.

The findings may also be due to the material characteristics of TrikotAC10:5:85 in terms of particle size, where the presence of lime in the formulation leads to the increasing of particle size, hence required a higher filtration velocity. The fact was supported by Malcorm [10] where the author claimed that in hot mix asphalt industry, the filtration velocity applied in fabric filtration system is based on particle size of dust where fine dust normally operates at 1.2 m/min of filtration velocity while coarse particles optimally filtered at 1.8 m/min. In this case, it seems like adsorption of toluene gas by TrikotAC10:5:85 can be optimally obtained at 5 m/min filtration velocity.

Lawrence et al. [11] stated that in general, at low velocities the gas flow through the adsorbent is slower, providing sufficient time for adsorbent-adsorbate adsorption. However, higher filtration velocity reduces the residence time available for gas adsorption. This reduces the number of toluene gas adsorbed onto the formulated filter aids. This situation explained the results observed for PrekotAC10:90 while for TrikotAC10:5:85, the appearance of the deviation is probably related to the unsteady adsorption process around the surface of dust cake and filter media.

Filtration velocity is also called air to cloth ratio which plays an important role in fabric filtration system affecting its efficiency. High velocity embedding particles too deeply in the fabric media thus causes blinding which reduces the gas permeability passing through the filter media. Furthermore, excessive gas velocity also can blow particles through the fabric bag that would not pass through at lower gas velocities. Therefore, the filtration velocity normally depending upon dust particle size and a good choice of air to cloth ratio is usually in the range of 4:1 to 6:1 which equal to 1.22 to 1.83 m/min [10]. Nevertheless, the results showed that the adsorption performance was good even at high velocity, thus it is expected that a better adsorption performance will be observed at lower filtration velocities.
3.2.2 Effect of Filtration Velocity on the Pressure Drop across Fabric Filter

Besides adsorption, the pressure drop across the filter plant is another crucial to be determined as an indicator of its performance. Figure 4 presents the relationship between pressure drop across the filter media against the filtration velocity which showed that pressure drop is directly proportional to the filtration velocity.

Figure 4. Relationship between filtration velocity and pressure drop

It can be seen that the lowest pressure drop across the filter cake was obtained at the lowest filtration velocity of 4 m/min with PrekotAC\textsubscript{10:90} exhibit higher pressure drops compared to TrikotAC\textsubscript{10:5:8}. This means that more energy is required passing through PrekotAC\textsubscript{10:90} compared to TrikotAC\textsubscript{10:5:85}.

Lower pressure shown by TrikotAC\textsubscript{10:5:85} is due to the physical characteristics of the formulated material that has higher porosity (62\%) compared to PrekotAC\textsubscript{10:90} (59\%) which can form porous filter cake on the fabric bag and directly reduces the pressure drop in fabric filtration system [12].

3.2.3 Effect of Filter Aids Loading on Adsorption of Toluene

In this study, material loading is defined as the mass of formulated filter aids introduced to the fabric filtration system. Filter aids introduced does not pass through the fabric bag walls and accumulated on the outside of the bags. Figure 5 presents the effect of filter aids loading on the ratio of toluene adsorbed which showed both PrekotAC\textsubscript{10:90} and TrikotAC\textsubscript{10:5:85} showed similar trending where the toluene adsorbed increases with increasing in filter aids loading.

The decrease in the ratio of toluene adsorbed indicates that more toluene is adsorbed by the formulated filter aids. Obviously, as filter aids loading increases, the amount of cake formation on the fabric filter will increase for a given volumetric flow rate of a gas thus provides larger active sites for adsorption to take place.

Figure 6 presents the graphical presentation of the different of filter cake formation between filter aids loadings of 0.2, 0.4 and 0.6 mg/mm\textsuperscript{2} which showed that filter cake becomes thicker with the increasing of filter aids loading. This provides more surface area of contact between the toluene and the active sites of the adsorbent material for better removal.
3.2.4 Effect of Filter Aids Loading on the Pressure Drop across Filtration Plant.
In this study, the relationship between pressure drop and filter aids loading was monitored at specific velocity and the results showed that pressure drop across the filtration plant increases with filter aids loading from 0.2 to 0.6 mg/mm² as depicted in Figure 7.
Figure 7. Effects of filter aids loading on pressure drop in fabric filtration system

In a continuous application, as the flue gases being filtered and adsorbed, the porosity of the cake decreases and consequently the resistance between cake formation and fabric filter increases thus increases the pressure drop. Besides, the main cause of increasing pressure drops due to the fact that at higher filter aids loading means more of the particles arrive at one pore simultaneously, which leads to the thicker filter cake and consequently reduces the volumetric air flow that passes through the filter cake resulting in higher pressure drop across the filter cake.

Cleaning of the fabric filter is initiated at a specific pressure drop across the system. Cleaning is usually controlled by a timer or a pressure switch set at the selected maximum pressure drop and a typical value of pressure drop range from about 4 to 8 inchH₂O. The cleaning is accomplished by row so that, while one part is being cleaned, the rest of the filter is still in operation. Under these conditions, the gas flow through the device and the overall pressure drop across the device are essentially constant with time. In this case, it is important to maintain the pressure drop as lower as possible to avoid frequent cleaning of fabric which later leads to the problem of wear and tear [13].

Hajar et al. [9] stated that the particle size distribution plays a substantial role in decreasing the pressure drop due to the wider range of non-uniform particle size distribution. In this study, PrekotAC₁₀:₉₀ and TrikotAC₁₀:₅:₈₅ were characterized with a wider range of non-uniform particle size distribution compared to activated carbon alone. Therefore, the application of PrekotAC₁₀:₉₀ and TrikotAC₁₀:₅:₈₅ seems promising for longer life span of fabric filter and simultaneously maintaining designated pressure drop at various filter aids loading before its cleaning cycle.

The results clearly showed that TrikotAC₁₀:₅:₈₅ exhibits lower pressure drop than PrekotAC₁₀:₉₀ due to the difference in compactness of filter cake formation on fabric filter. Previously, TrikotAC₁₀:₅:₈₅ was characterized to be more porous than PrekotAC₁₀:₉₀ which help to form less compact of filter cake thus allow better uniformly air passing through fabric filter compared to PrekotAC₁₀:₉₀, hence gives lower the pressure drop across the fabric filter. However, a higher pressure drop is expected in actual industrial application where the amount of filter cake is not merely contributed by the filter aids but also by the dust material generated in the process. Nevertheless, a high material load increases the adsorption performance due to the presence of more adsorbent in the system.

4. Conclusions

Based on this study, it was observed that PrekotAC₁₀:₉₀ give a better toluene adsorption performance compared to TrikotAC₁₀:₅:₈₅ in all conditions which indicates that PrekotAC₁₀:₉₀ is a better filter aids adsorbent. However, the pressure drops of PrekotAC₁₀:₉₀ is slightly higher than TrikotAC₁₀:₅:₈₅ and it is important to minimize the amount of formulated filter aids PrekotAC₁₀:₉₀ used to avoid high pressure drop. In addition, TrikotAC₁₀:₅:₈₅ also able to adsorb toluene gas and could be apply in real industry as it is continuously injected onto the fabric filtration system over a long period of time before the designated pressure is reached for cleaning and maintain at lower pressure drop.
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