Review on Technologies Advancement for Particulate Emission Reduction in Palm Oil Mill

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INTRODUCTION

The Malaysian palm oil industry is a large sector contributing to the economic growth of the country. As the world's second largest palm oil producer with millions of hectares of plantations, approximately 20 million tonnes of crude palm oil (CPO) was produced in 2014 from 439 palm oil mills (MPOB, 2014). As a result, the palm oil industry is identified as a major contributor to water and air pollution. The sources of air pollution in the palm oil mills are mainly from boilers using fibres and shells as fuel, and incinerators burning empty fruit bunches (Abdullah *et al.*, 2007).

The main pollutants in boiler exhaust emission are particulates together with small amount of carbon monoxide (CO), nitrogen oxide (NO) and traces of sulphur gases, which are harmful to the environment and community's health. Therefore, monitoring and control of these pollutants particularly particulates are of great concern for the country. Particulates exist in the form of smoke and dust emissions originated from incomplete combustion of solid waste materials (DOE, 1999).

Particulate emission has gained serious attention from local authorities since most of the palm oil mills in Malaysia are constructed in rural areas. As time goes on, the residential areas gradually expand to the suburbs until these areas spread to the vicinity of the industrial area. With the formation of a phenomenon called urban heat island, the emission of particulate matter from the palm oil mills remained suspended within the low level of air turbulence and thus hindering vertical motion for pollutants dissipation. Under this blanket layer, the accumulated particulate matter begins to grow in size. As relative humidity is more than 70%, the coagulated particles start to scatter sun rays which in turn impair visibility causing opaque atmosphere known as haze. Apart from that, particulate matter is also capable of damaging respiratory system of animals and human being.

According to the record obtained from the Department of Environment (DOE) for the entire country between 1993 until 1998, it was found that the emission of particulate from industrial processes were the largest contributors to pollution. In those six years, the highest amount of particulate emission from industrial processes was recorded in

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1994 at 85.54% of total particulates produced in that year which is equivalent to 153 890 metric tonnes. The second highest emission of particulate matter came from industrial fuel used in palm oil mills (Abdullah *et. al*. 2007).

The main objective of the Environment Quality (Clean Air) Regulations 1978 was to prevent, abate and control air pollution as well as to enhance the quality of the environment while allowing development to progress in an environmentally friendly way. The control of black smoke emission comes under Regulations 15 and 16, while the maximum limit for dust emission/ particulate is 0.4 g Nm^{-3}. This limit remained unchanged for the last 30 years, and the DOE is currently in the process of implementing more stringent regulations regarding particulate emission not exceeding 0.15 g Nm^{-3}. The existing dust control system such as multicyclone, can only cope with the existing boiler operation and managed to control particulate matter in the range of 0.32 to 0.46 g Nm^{-3}. Therefore, it is essential to study the palm oil mill management control, combustion and boiler control, and more efficient dust control system in order to comply with the stringent regulation on particulate matter emission.

Existing Technologies in Palm Oil Mills to Control Particulate Matter Emission

Boilers and incinerators are the two sources of particulate emission from palm oil mills. Boilers utilise palm oil fibres and shells as fuels, while incinerators burn empty fruit bunches (EFB) for recovery and use of potash as fertiliser substitute (DOE, 1999). Boilers air emission mainly appear as dark smoke due to the presence of soot following the incomplete combustion of biomass fuels. Several degrees of control of fuel combustion and smoke emission are currently accomplished for steady-state conditions for boilers.

There are a few control measures comprising the use of appropriate indicative boiler instrumentations, automated fuel feed, and boiler modifications. These modifications involve prevention of air leakage from the boiler furnace door, large capacity of draught fans to increase air injection, installation of air nozzles for secondary air supply, replacement of manual with automated fuel feed and improved pollutant dispersion by increasing stack height. The reduction of particulate emission is also feasible through utilisation of control devices and dust collectors.

Among the control devices used in the palm oil mills as shown in *Figure 1* are (a) cyclone separators, (b) bag filters and (c) wet scrubbers. Each device applies different mechanical means of collecting dust in the air emission system before being released into the environment. The most commonly applied technology in the mills is cyclone separators which is more reliable in the long run for palm oil mill operations, with high efficiency and less maintenance (PlasTEP, 2011).

Cyclone and multi-cyclones are the most basic form of external particulate emission control for combustion chamber and heat exchanger of boiler. Particulates are removed through centrifugal forces and gravity (Wakefield, 2013). On the other hand, flue gases pass through fine woven media inside the bag filters where particulates are retained by impingement and located in local exhaust ventilation systems. Wet scrubbers, however, have different mechanism in operation unlike the two dry collectors. They filter particulates via impingement with water droplets (Dauber *et al*., 2017).

Cyclones or multi-cyclones are popular devices used in the industry primarily because they occupy relatively small spaces compared to other devices, and able to tolerate high-temperature exhaust flue gas compared to bag filters which have certain limitations depending on the type of fabric made (Turner, 1998). Besides that, bag filters are usually additional devices added after a pre-cleaning device like the cyclone. They also require additional fan power due to

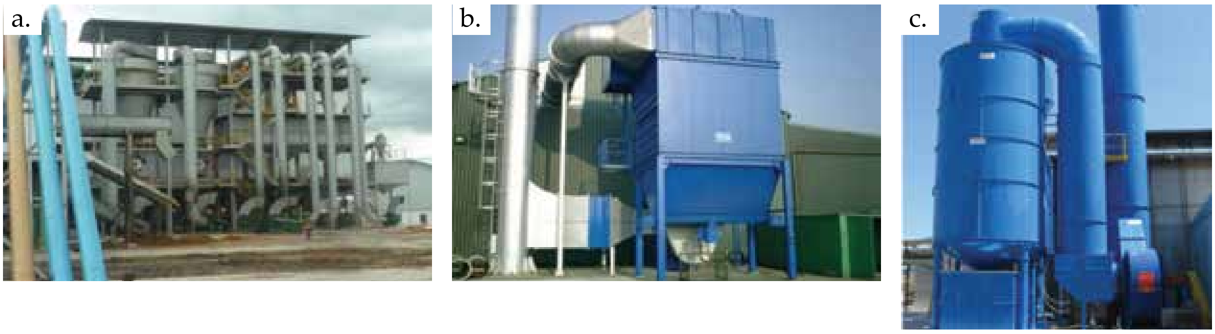


Figure 1. Types of particulate/dust control devices: (a) Cyclone separators, (b) Bag filters and (c) Wet scrubbers.

high pressure drop across the filter media, and occupy a large space area. However, fine-dust-removal efficiency of cyclones is typically below 70%, whereas electrostatic precipitator (ESP) and bag filters can have removal efficiency of more than 99.9% (World Bank Group, 1998). Hence, cyclones are generally used as the first-stage cleaning device before subsequent processes are done to further improve the final exhaust emissions.

Technologies Advancement

Recent years have seen numerous technologies advancements in relation to particulate reduction. Some reuse the fundamental principle of technology such as hurricane/recyclone, while others come up with latest process such as electrostatic precipitator (ESP) to facilitate the reduction of harmful emission.

Cyclone-based Technology

Dry particulate reduction technology, such as cyclone, utilises the fundamental idea of gravity and vortex to separate the particles from flue gas stream. The flue gas is forced to change direction through a cylinder casing which creates a centrifugal force drawing particles towards the wall of the cyclone. Inertia of the particles causes them to remain in the original direction and be separated from the gas stream. When particulate matter hit the wall, it loses velocity and lifted, and thus falls into a collection hopper at the bottom of the cylinder unit (Habib, 2017). Clean air exits the top of the unit flowing upward in a spiral vortex.

Palm oil mills utilise this technology as basis for the application of multi-cyclone units to reduce particulates emissions. The multi-cyclones incorporate many cyclones in one device for successive reduction of particulates through each unit of cyclone until the targeted air quality is achieved. However, the device is still very inefficient in reducing particulate matter compared to more expensive method such as bag filters.

A modification of the existing multi-cyclones was carried out by Chong *et al.* (2013) as shown in *Figure 2*, which focused on recirculation of duct partially extracted flue gas from the bottom of the multi-cyclones by means of an external induced (ID) fan. The fan was utilised to create a slightly negative pressure at the dust hopper, and thus increase the collection of particulates. It also extracted part of the particulates back into the inlet of the multi-cyclones Chong *et al.* (2013).

A new technology called Hurricane or ReCyclone has been introduced and explored. This system is said to be contrary to the traditional claim that cyclones are inefficient dust collectors and able to replace bag filters in many demanding operating processes (Advanced Cyclone Systems, 2014). It is also more efficient than the common multi-cyclone systems, and has lower operational costs compared to bag filters. Researchers have been investigating how cyclones work, culminating on how particle agglomeration affect the efficiency of particle collection (Paiva *et al.*, 2010).

This system assists in building efficiency

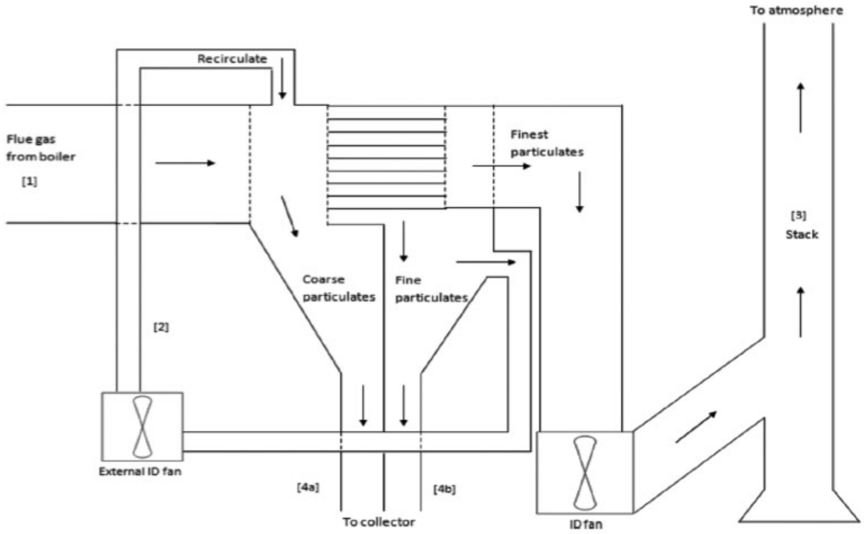


Figure 2. Modified multi-cyclones unit.

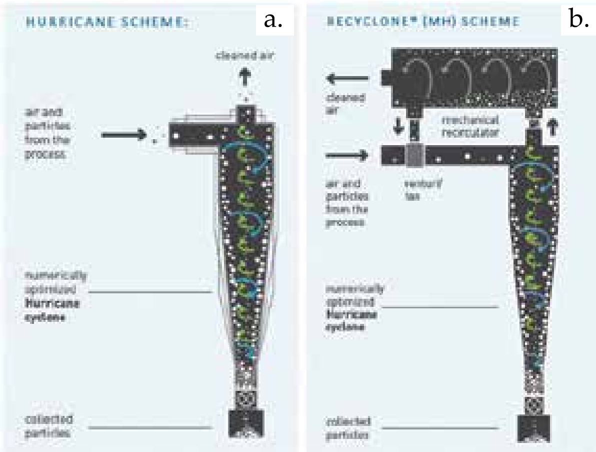
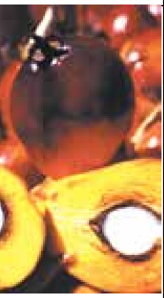


Figure 3. Cyclone-based technology; (a) Hurricane system and (b) ReCyclone.

prediction model, and capable of explaining why sub-micrometer particles are often captured with higher efficiency than expected. Fine particles tend to form larger agglomerates or clusters with higher efficiency than those of the original particles. Agglomeration increases in the presence of wide particle size distributions, long residence times in the cyclone and high inlet particle concentrations (Paiva, 2010; Advanced Cyclone Systems, 2014).

Hurricane system as portrayed in *Figure 3(a)* features higher efficiency than traditional cyclones, down to 10%-20% of the emissions of cyclones, very low emissions (25-45mg Nm^{-3}) with no temperature restriction while maintaining the robustness and low cost of the cyclone system. Meanwhile, ReCyclone as shown in *Figure 3(b)* showcases a system made up of a hurricane and a particle separator in the form of a straight-through cyclone which is placed at the downstream of the cyclone called recirculator.

Hurricane has been invented to give insights on particle agglomeration, while ReCyclone system has been built based on the technology. The main purpose of the recirculator in a ReCyclone system is to reintroduce the fine particles that are not captured back into the cyclone after they have been driven to the outer walls of the recirculator by centrifugal forces. This is accomplished through an additional fan since the tangential gas stream is enriched in



particles which means the axial gas stream exhaust to the stack is free from particles (Advanced Cyclone Systems, 2014).

Since recirculation system only separates instead of collecting dust, the particles are exclusively collected in the cyclone and the need of rapping mechanisms is thus avoided. The ReCyclone system has very high efficiency due to recirculation and agglomeration of very small particles with larger particles coming directly from the process. It decreases the emissions of Hurricane cyclones by 40% to 60%. The system is robust with almost zero maintenance and downtime cost as well as low in operational and investment cost due to absence of temperature restriction and moving part that requires frequent replacement.

Electrostatic Precipitator (ESP)

An electrostatic precipitator (ESP) is a particle control device that uses electric fields to separate particles from the gas stream to the collector plates from which the particles can be removed (Biomass Energy Resource Center, 2011). The first commercial ESP was a wet ESP installed in 1907 for acid mist control, while the first dry ESP was commercialised in 1910's in non-ferrous metals and cement industry (Seetharama *et al.*, 2013). While the wet and dry ESP retain similar high voltage and collection system and also share similar physical characteristics, there are many inherent differences attributed mainly to the existing design of technology for various size particles. *Figure 4(a)* shows the wet ESP, while *Figure 4(b)* illustrates the dry ESP. The wet ESP uses similar working principle as the dry ESP, but it is specifically developed to achieve high yield for water-soluble aerosols, which are more difficult to separate using dry ESP (EMIS-VITO, 2015). *Table 1* summarises the differences between these two types of ESPs.

Research performed by Yang *et al.* (2000) incorporated a wet tubular ESP which has perforated plates to ensure even distribution of gas flow across the entire cross section of the wet tubular ESP tower. *Figure 5* shows the schematic layout of the system (Yang *et. al.*, 2000). Results from the setup and testing showed 63% reduction in particulate matter.

Another study reported by Manuzon *et al*. (2014) used CFD simulation to design and develop an optimised ESP based on previous studies. The ESP unit was tested in a mechanically ventilated poultry layer facility housing 200 000 layer hens and the resulting particulate matter showed reduction of more than 80%. *Figure 6* illustrates the optimised ESP design and ESP module.

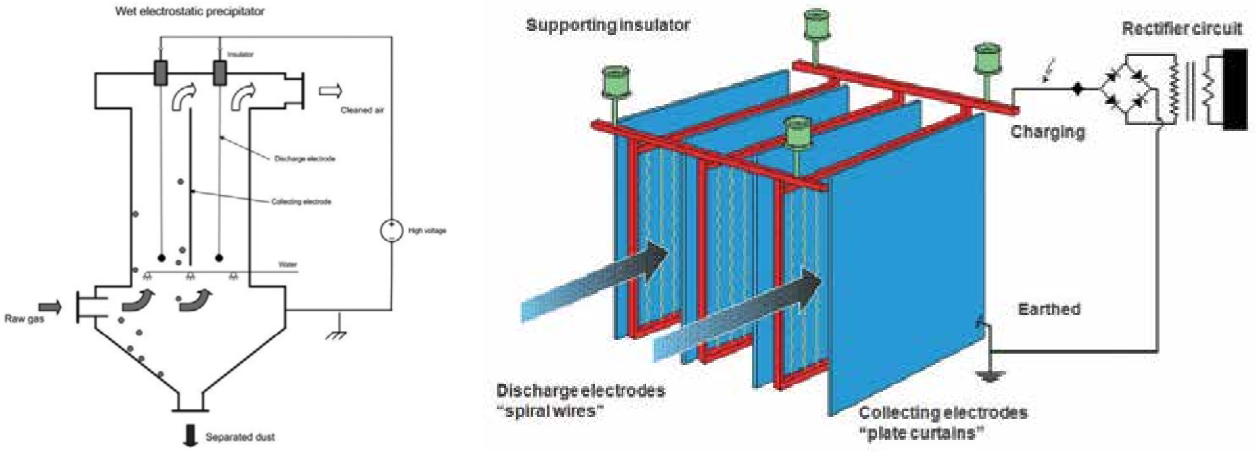
RESEARCH RECOMMENDATIONS

Even with the advancement in technologies, there is still lack of sufficient experimental data to show the effect of utilising these devices in palm oil mills. There are many factors that may affect the final emission from these devices if and after implementation. While Hurricane and ReCyclone system are perceived to reduce particulate emission, real data in application of these systems in palm oil mills to support the claims are not yet available. This is similar with ESP where most studies are only involved in coal power plants or similar systems. In fact, ESP is the dominant technology currently applied in coal-fired power plants in Alberta which achieve 99.9% particulate removal (Chambers, 2006).

It is of interest to set up, test and further improve current technologies so that palm oil mills may achieve the new emission standards to be imposed by the DOE. It would even be more appealing to combine the two technologies for the palm oil industry in Malaysia to achieve that goal.

CONCLUSION

Several technologies have been discussed in this article and it is found that bag filters and scrubbers are able to achieve high particulate removal from flue gas emission. On the other hand, the selection of cyclone systems is due to robustness and low costs.



a. b.

Figure 4. Electrostatic precipitator; (a) Wet ESP and (b) Dry ESP.

TABLE 1. DIFFERENCES BETWEEN DRY AND WET ESP

Parameter	Dry ESP	Wet ESP
Purpose	Primary PM control device	Polishing device
Location	First APC device	Last APC device
Configuration	Horizontal plate	Vertical tubular or Horizontal/ vertical plate
Humidity	5-20%	100%
Temperature	120°C-425°C	<150°F (<65°C)
High PM loading	Yes	No
FPM10 removal	High	Limited
FPM2.5 removal	Moderate	High
PM condensable removal	No	High
H_2SO_4 removal	No*	High
Mercury removal	No*	Moderate
SCA	300-800	50-200
Gas velocity	3-5 feet/sec	6-10 feet/sec
	0.9-1.5 m/sec	1.8-3.0 m/sec
Pressure drop	< 2 in.w.c. (0.5 kPa)	< 2 in.w.c. (0.5 kPa)
Water usage	No	Yes
Waste water treatment	No	Yes
Resistivity issue	Yes	No
Back corona	Possible	No
Re-entrainment	Possible	No
Materials of construction	Carbon steel	Stainless steel, minimum
Cost	Low/moderate	Moderate/high

Note: Unless treated with sorbent injection; PM = particulate matters; APC = air pollution control.

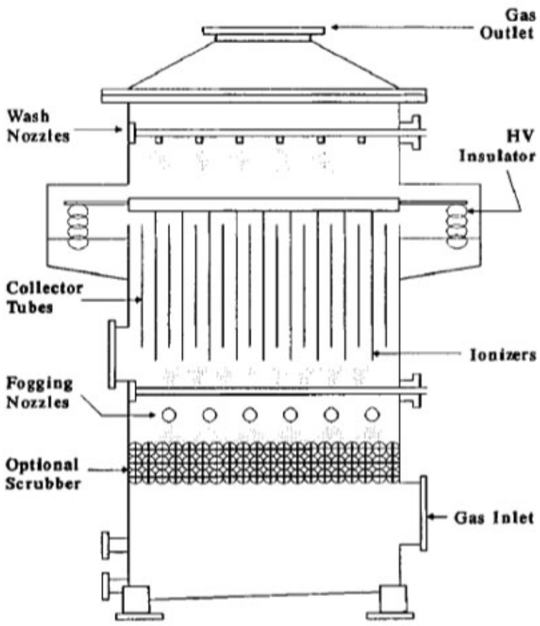
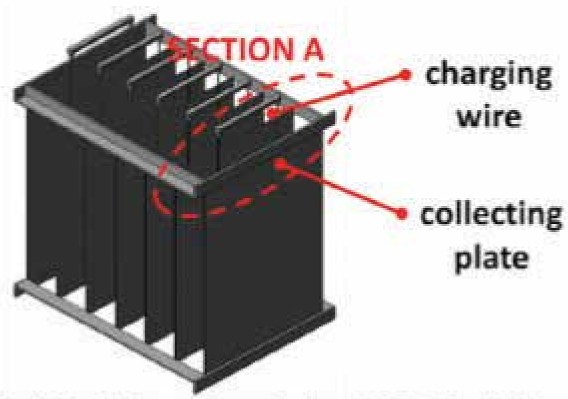
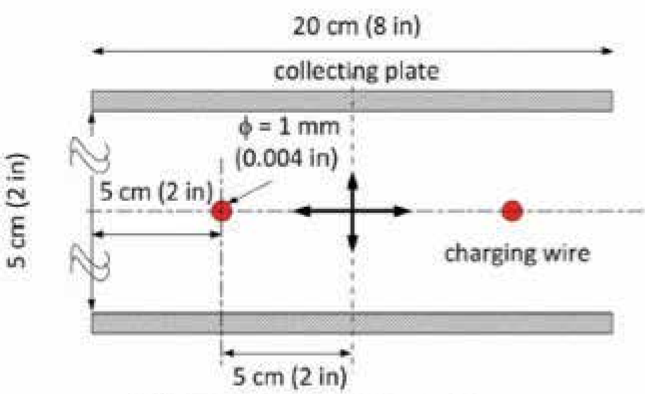


Figure 5. Schematic layout of wet tubular electrostatic precipitator.

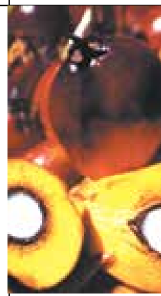


(a)



(b)

Figure 6. (a) Optimised wire-plate ESP design, and (b) ESP module.



Nevertheless, new design of cyclones has been invented to overcome the low efficiency of existing cyclones compared to other technologies based on research that have been done. Electrostatic precipitator (ESP) is also found to remove dust and ashes significantly between 60% to 90% from the particulate emission.

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