Supplement of

Overview of Aerosol and Air Pollution in South Eastern Asia Countries

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Fig. S1. Sampling site (7°13'7.5"S, 112°39' 9.75"E) around industrial and warehousing areas in West Surabaya, Indonesia.
Fig. S2. Container.  
Fig. S3. Flow meter.  
Fig. S4. Kestrel.  
Fig. S5. Filters.  
Fig. S6. Cassette filter.
Fig. S7. Daily Concentration of PM$_{2.5}$ and PM$_{10}$. 
Fig. S8. (a) Regression for PM$_{2.5}$; (b) Regression for PM$_{2.5–10}$.
Fig. S9. Factor contributions to (a) PM$_{2.5}$; (b) PM$_{2.5-10}$.
S3.1.3.4 Estimated locations of pollutant sources

Estimating the locations of the pollutant sources is carried out by the CPF method. PM$_{2.5}$ Factor 1 is characterized by Cu, Mg, and K, and may derive from industrial activities using Cu and biomass combustion. Fig. S10a shows an estimate of the location of sources for Factor 1, which are industries from both wind directions. In the north-northwest to the northeast, there are residential areas, while in the south-east there is a wood charcoal industry at a distance of 1 km and wood processing at a distance of 2 km from the study site. The wood charcoal manufacturing industry around this research site processes wood waste into wood charcoal. Emissions containing K are produced from the burning of biomass (smoke), which is the result of an imperfect open combustion process such as burning garbage, forest fires, or cigarette smoke.

The identification of potential sources of pollutants in Factor 2, characterized by its Ni content, suggests that these may have come from the east, south, and southeast (Fig. S10b) showing several metal industries such as the iron industry are potential contributors to this factor. The estimated source location of Factor 3, derived from Zn, comes from the east and south-east (Fig. S10c). Zn is produced by galvanized metal industries, two-stroke engines, and household waste combustion. The potential sources of Zn pollutants may be derived from the nearby industry as well as from vehicular tire wear. At this site, observations show heavy traffic and several likely source industries.

Factor 4, which may come from diesel-fueled vehicles as it is characterized by S, is estimated to come from the east and southeast (Fig S10d). There is heavy traffic on Road Tambak Osowilangun because it is a connecting road between Surabaya and Gresik Regency, and many vehicles travel to the warehousing area as well as to Teluk Lamong Port. This road
is very congested in the morning and evening, caused by many city modes of transport that stop at Jalan Tambak Osowilangun to wait for passengers.

The estimated locations of potential sources of pollutants in Factor 5 are to the northeast, southwest, and southeast (Fig. S10e), characterized by the elements Mn, Fe, and Zn. Mn is commonly used in the steel industry, the production of dry battery cells, and the production of potassium permanganate. Meanwhile, the estimated locations of potential sources of pollutants contributing to Factor 6, marked by their Ca contents, come from the northeast and the southeast (Fig. S10f). From the observations at the study site, construction of toll roads, road repairs, and the construction industry 1–2 km away in those directions are potential contributors to this factor.

The seventh factor, characterized by the elements Al, Si, and Ti, possibly from soil dust, is estimated to come from the east and southeast (Fig. S10g). Open vacant land located in these directions relative to the study site can potentially be a source of these pollutants. The estimated source locations for the Pb-rich Factor 8 lie in the southeast and northeast (Fig. S10h). Glass industry in the area is a potential source of pollutants for this factor. The glass industry usually is characterized by emissions of Pb, As, and Sb, but this remains to be confirmed in Surabaya using other methods to measure these elements.

The estimated locations of the source of pollutants in the first factor of PM$_{2.5-10}$, possibly deriving from the construction as this factor is characterized by Ca, lie to the east and southeast of the study site (Fig. S11a). The second factor, coming from the southeast (Fig. S11b), where open vacant land about 1 km away could contribute soil dust as the source of pollutants for this factor.

The third factor, characterized by the elements S and Na, comes from the northwest to the north and from the southeast (Fig. S11c), contributed by burning coal activities.
The fourth factor is characterized by the elements Zn and Pb. It was estimated to come from the north-northwest, north-northeast and, south-southeast (Fig. S11d). To the southeast of the study site, there are several non-ferrous metal industries within a distance of 0.5 km –3 km. The high concentrations of Zn and Pb in Surabaya are supported by the results of Ahmad and Santoso (2016), which found the highest concentrations of Zn and Pb elements in Surabaya compared to other cities and suggested the steel smelting industry as a source of air pollution emissions in Surabaya.

The fifth factor, characterized by the elements Ni and Cu, is estimated to originate from the northeast and southwest directions (Fig. S11e). Potential sources of pollutants for this factor may be metal industries, including iron, originating from the southwest, but this needs to be further ascertained. The sixth factor, characterized by the element Br, is estimated to originate to the southeast of the study site (Fig. S11f) and is possibly derived from road dust. A warehousing area with many freight transporters to the southeast of the site can be a contributor to this factor. The seventh factor was characterized by Na and Cl and possibly derived from sea salt, likely has potential sources in the south and southeast (Fig. S11g), where there are salt industries and a salt pond in the south. Surabaya has 623 ha of salt farmland, which is processed by salt farmers by draining seawater into swaths of soil to further expedite the evaporation process (Mahdi and Soemardiono, 2019).
Fig. S10. Estimated source areas of PM$_{2.5}$, (a) Factor 1; (b) Factor 2; (c) Factor 3; (d) Factor 4; (e) Factor 5; (f) Factor 6; (g) Factor 7; (h) Factor 8.
Fig. S11. Estimated source areas of PM$_{2.5-10}$, (a) Factor 1; (b) Factor 2; (c) Factor 3; (d) Factor 4; (e) Factor 5; (f) Factor 6; (g) Factor 7.
S4.2 PM Removal by Electrostatic Precipitators

Electrostatic precipitators (ESPs) are electrohydrodynamic (EHD)–based filters commonly used in coal-fired power plants to collect fly ashes because of the low pressure drop and thus high energy efficiency. Fig. S12 shows the schematic of a traditional single-stage ESP that consists of the corona electrode (usually thin wire or needle) and the collector electrode (usually plate). When the electric field applied between the corona electrode and the collector electrode is high enough to induce corona discharge ($> 3.2 \times 10^6 \text{ V m}^{-1}$), particles passing around the corona electrode would get charged. After that, those charged particles would move toward the collector electrode because of the induced electrostatic forces (following the electric field). Particle collection (or precipitation) is the result. It can be seen that the single-stage ESP uses the same electric field to charge and collect particles. Two-stage ESP works exactly the same as single-stage ESP except the electric field designed for particle collection is different from the one designed for particle charge, as shown in Fig. S13.

Fig. S12. The schematic of a traditional single-stage ESP.
The collection efficiency of an ESP is highly particle-orientated (size, dielectric constant, etc.) and can be governed by the Deutsch-Anderson equation (Deutsch, 1922), as shown in (S1) and (S2). For a well-charged particle, the collection efficiency of an ESP increases when the electric field is stronger, the collecting area is bigger, and the airflow rate is lower.

\[
\eta = 1 - \exp \left( - \frac{wA}{Q} \right) 
\]  

(S1)

\[
w = \frac{qEC_c}{6\pi r \mu}
\]

(S2)

where \(\eta\) is collection efficiency, \(w\) is migration velocity, \(A\) is the area of collector electrode, \(\dot{Q}\) is airflow rate, \(q\) is total particle charge, \(E\) is electric field, \(C_c\) is Cunningham correction factor, \(r\) is particle radius, and \(\mu\) is the dynamic viscosity of air.

The greatest advantage of an ESP is that few obstacles impede the flow so the pressure drop of an ESP is low when compared with fibrous filters. As a result, the energy consumption of an ESP-based filtration system (attributed to the energy required to pump the flow) is low. Wen et al. (2015) compared the key energy performance of an ESP (foam-covered and two-stage) and a fibrous filter (3M-E133). The results show that the key energy performance of
such the ESP and the fibrous filter is 6.2 and 0.4, respectively, suggesting that using an ESP-based filtration system can be 15 times more energy efficient than using a fibrous-based one. Besides, the operating cost per unit airflow for a specific classroom building can be lowered by 26.5% when replacing the fibrous filters with the ESPs. On the other hand, the collection efficiency of an ESP depends on the applied voltage and thus corona power (consumption). Thus, the energy consumption of an ESP can be optimized by the management of the electrical system. Prasad et al. (1999) presented that, the energy savings for the ESPs operated in a 500 MW power plant can be up to 754,784 kWh by meeting the minimum collection efficiency required, controlling the current for the optimum sparking rate, adjusting the rapping cycle, and applying the pulse-shaped input corona current. Chai et al. (2009) indicated that the energy consumption per unit particle removal of the newly developed ESP can be as low as 1.1 J mg$^{-1}$ and increases over the applied corona voltage.

The collection efficiency of an ESP can be affected by dust cakes which are the accumulations of collected particles and can either induce back corona (Bacchiega et al., 2006; Mizuno, 2000) or alter the characteristics of the electric field (Wen and Xue, 2020). Thus, cleaning the collector electrode is necessary. One common cleaning process is to dislodge the collected particles by rapping. However, these dislodged particles would have chances of re-entering back the environment and thus lowering the collection efficiency, known as particle re-entrainment. Zukeran et al. (1999) pointed out that the maximum possible particle re-entrainment rate can be up to 60% for ultrafine particles under some extreme conditions. There are several methods proposed to ease the re-entrainment. One is to connect several ESPs in series. When upstream ESPs are performing cleaning, the dislodged particles would be collected by downstream ESPs. This is effective. However, operating many ESPs is costly and highly space-demanding. On the other hand, instead of physically rapping, using water to flush the collector electrode works as well, known as wet-ESP (Chen et al., 2014). By using
continuous scrubbing water, collected particles are unlikely to come off the collector electrode and therefore have minimal chances to go back to the environment. Though, the operation and maintenance of a wet-ESP are not cost-friendly. Other than the above, some creative collector electrodes have been proposed to resolve particle re-entrainment. Yamamoto et al. (2009) presented a new collector electrode that comes with special pockets for single-stage ESPs. Particles are able to enter such pockets with the help of the induced ionic wind, as shown in Fig. S14. The particles collected in the pockets have lower chances to re-enter the environment. Xue and Wen (2020) used the idea of flow recirculation to propose a square-wave collector electrode to reduce the particle re-entrainment rate, as shown in Fig. S15. The results reveal that the particle re-entrainment increases over the airflow velocity. When compared with the traditional flat plate collector electrode, the square-wave collector electrode can lower the particle re-entrainment rate by up to 22.6%. Furthermore, attributed to both the drag and viscous effects (Stokes number), large particles tend to impact and deposit on the upstream side of the square structure, while small particles would follow the flow and circulate to the downstream side of the square structure.

Fig. S14. Yamamoto’s ionic wind assisted and pocket structure (Yamamoto et al., 2009).
Most of the components in the channel of an ESP are metal, offering a great capability for high-temperature applications. Nevertheless, a long-term operation of an ESP can deteriorate performance. One has been mentioned earlier, cleaning the collector electrode is a must but can induce some problems. The other is oxidation, which is natural to metals (particularly to corona electrodes). Wen and Su (2020) showed that the discharge capacity of the cylinder corona electrodes decreases over time, while the oxidation also leads to fluctuations in the discharge processes, as shown in Fig. S16. The SEM photos show that the tip of the cylinder corona electrodes deteriorates a lot over time, depending on the strength of the electric field as well, as shown in Fig. S17. Such longevity issues could be resolved by replacement/cleaning or possibly by using innovative anti-oxidation materials.

ESP-based filtration systems are energy efficient because of the low-pressure drop. Thus, some ESPs have been developed for residential or office applications. However, the byproduct of corona discharge, ozone, is still a concern. Ozone is one of the principal pollutants defined by the United States Environmental Protection Agency. Ozone is a strong oxidant and can be harmful to humans. Viner et al. (1992) showed that the ozone generation of an ESP is proportional to the applied corona current and can be more than 100 ppb (0.01-cm-radius
tungsten wire and 45% relative humidity). Chen and Davidson (2002) confirmed that ozone production increases with the corona current and the diameter of the corona electrode, but decreases over temperature. Awad and Castle (1975) showed that the ozone generation for corona discharge can be lowered by heating the corona electrode. The results demonstrated that the ozone concentration for an unheated configuration can be up to 400 ppb but can be lower than 100 ppb when coming with a 43.4 W heating system (0.63-mm-diameter chromel-A wire and 20% to 25% relative humidity). Alternatively, activated carbon is one of the most common materials used to remove ozone. Poppendieck et al. (2014) claimed that placing an activated carbon filter immediately downstream of a particular ESP can reduce the ozone generation rate from 51.3 mg h\(^{-1}\) to 38.7 mg h\(^{-1}\).

Although there are still a lot of challenges waiting to be addressed as mentioned, the features that ESPs have such as low-pressure drop and high collection efficiency offer ESPs a great chance to be in the off-the-shelf market in Vietnam.

Fig. S16. The stress test for the current-time characteristics (Wen and Su, 2020).
Fig. S17. The SEM photos of the tip of the cylinder electrode (Wen and Su, 2020).
References


