PM_1 AS TOXIC AIR POLLUTANT: A REVIEW

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Abstract: Particulate matter (PM) is one of the most common air pollution entities and is known to have significant impacts on environment and human health. PM exposure is commonly monitored as mass concentration of PM_{10} or $PM_{2.5}$, although increasing toxicity with decreasing aerodynamic diameter has been reported. Particulate matter whose aerodynamic diameter is less than1µm is called PM_1 (submicron particulate matter). Up till now, there is huge number of investigations performed to evaluate mass concentrations and chemical profiles of ambient $PM_{2.5}$/PM_{10} particles. There are only few reports on source apportionment studies of PM_1. Data on levels and speciation of PM_1 all over the world is very scarce. Ambient air monitoring needs to be supplemented by studies to quantify the contribution made by different sources and to assess the impacts on damage cost (including public health consequences) in order to prioritize the cost-effective interventions. Present review highlights mass concentration of PM_1 with their possible sources, signifying the need for establishing standards for PM_1.

***Index terms*: Aerosol, PM_1, PAH, Source apportionment, Water soluble inorganic ions**.

I. INTRODUCTION

Ambient aerosol is a suspension of a complex mixture of liquid and solid particles in air that vary greatly in size, composition and concentration, depending on the diverse sources generating the particles, atmospheric processes and factors such as geographic location, season, day and time of day (Tippayawong et al., 2006). The effects of aerosols on the atmosphere, climate, and public health are among the central topics in current environmental research. Moreover, airborne particles play an important role in the spreading of biological organisms, reproductive materials, and pathogens like pollen, bacteria, spores, viruses, etc., and can cause or enhance respiratory, cardiovascular, infectious, and allergic diseases (Finlayson and Pitts, 2000., Bernstein et al., 2009., Hinds, 1999). Many researchers have demonstrated the usefulness of separating the particles in at least three or four categories on the basis of their mean size: coarse (PM_{10}), fine ($PM_{2.5}$), submicron ($PM_{1.0}$) and ultrafine ($PM_{0.1}$) (Casale et al., 2009). PM can be classified as PM_{10}, $PM_{2.5}$ and PM_1 by size with mass median aerodynamic diameter less than 10 µm, 2.5 µm and 1 µm respectively. Size of particles is directly linked to their potential for causing health problems, research evidences that particle size is an important factor which influences how particles deposits in the respiratory tract and affect human health (Anderson et al.,2005., Davidson et al., 2005.,Donaldson et al.,2005a.,Englert.,2004.,Graff et al.,2009). "Inhalable coarse particles" larger than 2.5 micrometers and smaller than 10 micrometers in diameter (PM_{10}), such as those found near roadways and dusty industries are deposited almost exclusively in the nose and throat. Coarse fraction usually remains in upper airways but finer fraction like PM_1 is able to penetrate deep into the human respiratory system. It is reported that fine particles ($PM_{2.5}$ and PM_1) do more harm to human health than the coarse PM. The reason being, fine particles are toxic in nature and they carry reactants and harmful substances (Srimuruganandam and Nagendra, 2010). PM_1 induces cytokine production and lipid peroxidation of human bronchial epithelial cells (Huang et al., 2003). Chemically PM is a complex mixture of organic and inorganic, volatile and involatile, water soluble and insoluble matter possessing a range of morphological, chemical, physical and thermodynamic properties (Bulpitt and Price, 2006). PM_1 particles may be primary (such as diesel soot), or secondary formed from gaseous precursors by nucleation or by condensation on existing particles (Perez et al., 2008). Most anthropogenic pollution sources are combustion-related and generate particles with diameters < 1 µm (Jamriska and Morawska, 2000). Coal and oil combustion facilities produce fine particles in the submicron size range enriched by heavy metals (Jang *et al.*, 2007). PM_1 represent most particle matter that is dispersed in urban environments in terms of particle number concentrations (Nazaroff et al., 1990). The lifetime of coarse particles is short and it decreases with the increasing size of particles (Morwaska et al., 1998).

II. OVERLOOKED PM_1

Several studies (Vallius et al. 2000; Cabada et al. 2004) have indicated that major components of PM_1 and $PM_{2.5}$ originate from the same sources, and those investigations of PM_1 yield little new information when compared with what is obtained from studies of $PM_{2.5}$. On the other hand one could argue that PM_1 may be a better indicator of anthropogenic sources than $PM_{2.5}$, because natural sources have less of an impact on the smaller sized particles than pollution emissions (Lundgren et al., 1996; Lee et al., 2006). Recent studies carried out at different urban areas like at Kaohsiung city led to the conclusion that combustion emissions and the formation of secondary aerosols were the most important sources for ambient PM_1(Lin 2002; Lin and Lee ,2004). Study carried out at Kanpur concluded that Secondary sources and vehicular emissions were the two main sources contributing to PM_1 mass with minor contributions from paved road dust and coal combustion sources. In Phoenix, Arizona, USA, emphasized that $PM_{1.0}$ was a better indicator for a roadside microenvironment than $PM_{2.5}$, because, compared with $PM_{2.5}$ and PM_{10}, it minimized interference from natural sources. (Lundgren et al, 1996) Another study conducted at Hong Kong also supports the above (Lee et al, 2004).

For the purposes of monitoring and regulating, there are two commonly used particle metrics — PM_{10} and $PM_{2.5}$. Mass measurement of ambient PM_{10} and $PM_{2.5}$ size fractions is a rather well established technique. Unavailability of instrument for collecting PM_1 could be the reason for insufficient data leading to pending standard regulation. Earlier study trends of particles were more concentrated on coarse and fine size ranges although now days submicron particle size is the centre of study as smaller the particle, more harm it may cause as it easily penetrates deep into lungs. Therefore, there is growing interest in measuring PM_1.

Table 1, PM_1 Mass Concentration Measured at Different Locations

Sr.No	Country	PM_1 Concentration ($\mu g/m^3$) Mean
1	Kanpur,India	Monsoon 30.1 Post Monsoon 63.8 Winter 199.0 Pre Summer 77.1 Summer 142.3
2	Durg, India	64.7
3	Milan, Italy	Summer 16.4 Winter 41.0
4	Genova, Itly	22
5	Taipei	General site 14 Traffic site 37.6
6	Hong Kong	35.9
7	Kaohsiung, Taiwan	52
8	Tehran, Iran	Winter 53.7 Summer 15.70
9	Helsinki, Finland	4.1
10	Italian towns (Milan, Genoa, and Florence	Winter – Milan 48.8 Winter – Florence 25.3 Winter – Genoa 11.5 Summer- Milan 19.4 Summer- Florence 11.8 Summer- Genoa 17.4
11	Xi china	127.3
12	Melpitz, Europe	12.5
13	Austria	16
14	Xi'an, Northwest China	149.7
15	Tito Scalo — Southern Italy	8
16	Greece	Urban 20.1 Suburban 18.5 Natural background 10.3
17	Hong Kong	44.5
18	Barcelona (Spain)	19
19	Nagpur (India)	Industrial site 53.3

An ambient air quality standard for $PM_{2.5}$ has been implemented recently in some countries. In 2006, the United States Environment Protection Agency (U.S. EPA) executed the 24-hour $PM_{2.5}$ standard 35 ug/m^3. Mass concentration of PM_1 measured at China, India, Iran, Taiwan, Hong Kong and Italian towns were higher. If comparing $PM_{2.5}$ standard with PM_1, it surpass the limitation. Within the Asia-Pacific region, Hong Kong's $PM_{2.5}$ standard, as outlined by the new Air Quality Objectives, is the most lax, more lax than even India's own $PM_{2.5}$ standard.

Table 2. $PM_{2.5}$ Standard

Country/City	$PM_{2.5}$ Standard (24 hourly)
Bangladesh	65
Hong kong	75
India	60
Mongolia	50
Pakistan	35
Singapore	35
Sri Lanka	50

III. Chemical composition of Submicron particulate matter (PM_1)

Knowledge of the chemical composition of atmospheric aerosol is important to assess its impact on the environment and health. PM_1 has been characterized for metals, ions, organic carbon (OC) and elemental carbon (EC). It was reported that $PM_{2.5}$ usually contains a substantial amount of particles usually less than 1 µm in diameter e.g., soot and sulfur particles (Liu et al., 2004). It has been known that OC and EC particles exist mainly in aerodynamic particle diameters of 0.1 to 1 µm (Kleeman et al., 2000; Funasaka et al., 2000). Organic material, habitually referred to as organic aerosol (OA), often represents more than half of the mass for submicron particles (Jimenez et al., 2009). A substantial fraction of that is secondary OA (SOA) which is formed from chemical reactions of gaseous compounds Zhang et al., 2007a, Zhang et al., 2007, Kanakidou et al., 2005, Jimenez et al., 2009). Tobacco smoke and atmospheric transformation products of SO_2, NO_2, and organics (including biogenic organics) are also mostly in the 0.1-1.0 µm aerodynamic diameter range. The chemical composition tends to be sulfates, acids, metal salts, and carbon. Results from recent studies have shown that water soluble inorganic ions and carbonaceous aerosol were the major component of PM_1. In submicron fraction, water soluble anions contribute a significant portion to the overall PM_1 mass (Pérez *et al*., 2008). Ionic species and carbonaceous aerosol were dominant of PM_1, which attributed 46.0% and 27.5% to the total particle mass (Lee and Hopke, 2006, Shen et al.,2010). PM_1 and $PM_{2.5}$ measurements at roadside in Hongkong showed that carbonaceous aerosols were major components in fine particles, constituting 45.7% of PM_1 and 44.4% of $PM_{2.5}$ (Lee *et al*., 2006). Water soluble inorganic anions contributed to almost 35–40% of overall PM_1 mass and among those anions nitrate and sulfate were the two most predominant species (Chakraborty and Gupta, 2010). In Leipzing PM_1 contributes 55% of water soluble ions. Most of the $PM_{2.5}$ mass is PM_1 (Spindler et al., 2012). Study carried out in Durg, India also pointed out that out of the total aerosol mass, water soluble constituents contributed an average of 16.98% (11.14% anions, 5.85% cations) in PM_1 Dhananjay *et al*.,2011). Also study carried out in Nagpur, India water-soluble inorganic ions were dominant chemical species and occupied to 32.5% of PM_1 mass. NH_4^+, SO_4^{2-} and NO_3^- were the major species of ionic compounds, which accounted for 88.6％ of total ions concentration. Metals occupied 7.8 % of PM_1 mass (Talwar and Bharati). Regarding carbon profiles it was observed that mass fractions of total carbon inPM_1 were 58%, in general station and 74%, in the traffic station, respectively (Li and Lin, 2002). The PM_1 fraction mainly comprises OM+EC (45%) with an important fraction of secondary inorganic aerosols (mostly ammonium nitrate and sulphate which were 31% (Pe´ rez *et al.*, 2008,). EC, OM (organic matter), and SO_4^{2-} were the dominant components, accounting for 36%, 26%, and 24% of PM_1 respectively (Cheng *et al*., 2011). PAH with the highest molecular weights are associated with the finest particles, so $PM_{2.5}$ and (mainly) PM_1 inlets should be used more frequently (Daban *et al*., 2005) Crustal elements like Fe, Ca, and Mg also found to be present in higher concentration even in the submicron fraction. (Wang *et al.*, 2006; Srivastava *et al.*, 2008; Balakrishna and Pervez, 2009).

IV. SOURCES OF PM_1

If the sources are known and detailed information on source profiles is available, Chemical Mass Balance (CMB) models can be applied, whereas in case the sources are unknown and there is limited information on source profiles, Principal Component Analysis (PCA) and Positive Matrix Factorization (PMF), UNMIX model methods are preferred

Table 3.SOURCE APPORTIONMENT STUDIES ON PM_1

Source Apportionment Studies	Identified Sources	Receptor Model
Kanpur, India	Road dust, Vehicular emission, Coal Combustion, and Secondary sources.	EPA UNMIX
Durg, India	Anthropogenic Origins and Natural origins.	PCA
Tito Scalo—Southern Italy	Industrial emissions, Traffic and Re-suspension of soil dust.	PCA
Hong Kong	Vehicle exhaust, Secondary aerosols, and Waste incinerator/biomass burning	PMF
Xi'an China	Secondary aerosol and Combustion emissions	PMF
Itly	Mineral dust, Oil combustion/secondary sulphate and Mixed combustion	PMF

Above apportionment results will be useful to the local authorities to regulate ambient air particulate matter for governing PM_1 standards, aiming to

- Indicate the levels of air quality necessary with an adequate margin of safety to protect the public health and vegetation.
- Assist in establishing priorities for abatement and control of pollutant level.
- Provide uniform yardstick for assessing air quality at national level and
- To indicate the need and extent of monitoring programme.

V. CONCLUSION

A significant number of health problems related to atmospheric aerosols is due to particles having diameters less than 1.0 μm, because these particles can penetrate deep into the respiratory system. If comparing $PM_{2.5}$ standard with PM_1, it surpass the limitation. Previous researchers found that $PM_{2.5}$ data were hard to interpret, because they include particles from both mechanical processes and from combustion. PM_1 measurements, however, could be used to distinguish between particles from combustion processes distinct from mechanically generated particles.
In order to design effective programmes and strategies for reduction of PM_1 concentration in the ambient air, it is necessary to have information about the sources and their respective contributions. Monitoring technologies are now available that can measure $PM_{1.}$. Results from recent studies supported the findings that combustion sources and secondary aerosols played major roles in the formation of ambient submicron (PM_1) aerosol particles in the urban areas. Further research on the PAH, Water soluble organic component and metals in urban area needs to be carried out.

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