Annual Concentration Report and
Emission Sources Analysis of the Air Pollutants
Measured by the Air Quality Monitoring Station

P. Khaemkaew, S.Raksawong, K.Wongsorntam,
S. Khuntong, P. Iamraksa and T. Wutikhun

Department of Basic Sciences and Physical Education,
Faculty of Resources and Environment,
Kasetsart University, Si Racha Campus, 20230, Thailand.
International Maritime College,
Kasetsart University, Si Racha Campus, Chonburi, 20230, Thailand.
Development National Science and Technology Agency,
111, Thailand Science Park, Phahonyothin Road,
Klong Luang, Phathumthani, 12120, Thailand.

Abstract: Problem statement: Air Quality Monitoring (AQM) station at Kasetsart University, Si Racha Campus, Thailand, was established since 2007. AQM station plays an important role in monitoring the situation of air pollution around industrial areas such as Si Racha and Laem Chabung industrial estate, where the Si Racha Town was established since 2007. AQM station plays an important role in monitoring the situation of air pollution around industrial areas such as Si Racha and Laem Chabung industrial estate, where the Si Racha Town

Keywords: Air quality monitoring, Si Racha, heavy metal, Scanning Electron Microscopic (SEM), heavy metals, emission sources, spherical shape, wind direction, elemental compositions

INTRODUCTION

Air Quality Monitoring (AQM) station at the Kasetsart University, Si Racha campus, Chonburi, Thailand was established since 2007. AQM station plays an important role in monitoring the situation of air pollution around industrial areas such as Si Racha and Laem Chabung industrial estate, where the Si Racha Town
Municipal and LaemChabung City Municipal have received the complaining about the air pollution more than 100 times since 2006 (OSOS, 2009).

Air pollution is the serious problems around the world, especially in less-industrialized countries where the early stages of industrial growth are often pursued without much investment in environmental protection, leading to heavy air pollution in urban areas (Florig et al., 2002). In many developing countries including Thailand one factor related to atmospheric pollution originated from urban contribution where is directly resulted of uncontrolled emission from motor vehicular and other anthropogenic activities (Kim and Hopke, 2008).

Si Racha Metropolitan Area (SRMA), Chonburi province is located at the east of Thailand. The major sources of air particulate include transportation, stationary fuel combustion, processes and agricultural waste and others. From Si Racha Public Health records, population in Si Racha got sick in the respiratory syndrome 21 cases (diseases of respiratory system). The numbers of patients were 46163, 56593, 65139, 59030 and 58016 in the year of 2005, 2006, 2007, 2008 and 2009, respectively Report Sheet 504.

Up to now, the concentration levels of air pollutants in the area are routinely monitored by the Pollution Control Department (PCD) Ministry of Natural Resources and Environment. Air quality was monitored using a standard method for ambient air pollution. Although 53 AQM stations are distributed around the whole country, only 4 stations are located in the industrial area, Chonburi province. The results of pollutant annual concentration from PCD are very close to the limit level of (Notification of National Environmental Board No. 28, B.E. 2007, Table 1) (CD, 2010). These levels may cause high risk on population health in the area. Particularly, particulate matters can cause coughing, wheezing and overall decreased lung function in children and adult (Zanobetti et al., 2000; Limbach et al., 2005).

However, it is very important to characterize airborne particulate matters especially morphology, chemical compositions and their origins in relation to health and environmental impact (Baulig et al., 2004; Areekijeree et al., 2009). It is very important to measure not only the levels of fine particles in and around major cities and industrial area but also to identify the sources of these particles.

The aims of this research are: (1) To quantify the average concentrations of CO, SO2, NOx, O3, PM10 and TSP in ambient air around Si Racha area. (2) To measure the heavy metal accumulated in the particulate matter, elemental composition and microstructure of PM10 and TSP (3) To identify the possible emission sources of the air pollutants with the meteorological data. Identifying the source of airborne particles and their composition, physical and chemical properties will help to provide a clear connection to their impact on the environment and the human health (Brook et al., 2004).

**MATERIAL AND METHODS**

**Sampling location:** The Si Racha Metropolitan Area has a surface area of approximately 616.4 km2 and about 228,717 inhabitants. The atmospheric aerosol has been studied since 2006 (Pollution Control Department (PCD). There are basically three seasons in SRMA: a rainy (June to August), a winter and dry (November to February) and a summer (March to May) season. The air quality monitoring is located in Kasetsart University Si Racha Campus (13°07´15.42´´N, 100°55´09.28´´E) where is about 15 m closed to Sukumvit Road (Fig. 1a-c). The station unit is situated within an urban commercial/residential and industrial area.

**Sampling technique:** Tempered Element Oscillating Microbalance (Model TEOM 1400ab Ambient Particulate Monitor) has been used as a standard method for continuous of PM monitoring in the AQM station. The 1400ab series TEOM (Thermo Scientific) is equivalent to US EPA method (US EPA equivalency designation number EQPM-1090-079) which provides an almost real-time PM10 masses from a 16.67, lmin−1 air flow (1.002 m3 h−1). Atmospheric air was pump though the sampling head with the flow rate of 16.67 lmin−1 and then divided into filter flow (3 lmin−1) and auxiliary flow (13.67 lmin−1).

Another pollutant such as CO, SO2, NOx and O3 were also measured and real-time reported. Their technique, range, accuracy and their low limit detection are shown in Table 2.
Fig. 1: The location of the sampling site (a) Chonburi province (b) Kasetsart University Si Racha Campus and (c) the Air quality monitoring station.

Table 2: Pollutants, techniques, range, accuracy and low detection limit (TEOM 1400ab data sheet)

| Pollutants analyzer | Technique          | Range              | Accuracy (%) | Low limit detection |
|---------------------|--------------------|--------------------|--------------|---------------------|
| SO\(_2\)            | UV Fluorescence    | 0-500 ppb to 0-20 ppm | 1            | 0.5 ppb             |
| NO(NO\(_2\))/NO\(_x\)| Chemiluminescence | 0-500 ppb to 0-20 ppm | 1            | 0.5 ppb             |
| CO                  | Non-dispersive infrared detection | 0-50 ppm to 0-200 ppm | 1  | 0.05 ppm           |
| O\(_3\)             | UV absorption      | 0-500 ppb to 0-10 ppm | 1            | 0.5 ppb             |

In order to measure the concentration of TSP, Teflon fiber filters were accurately pre-weighted with analytical balance (Metler Toledo AG 204±0.0001 g). Sample filters were collected from stack filter unit twice a month as located in the manifold tube with a flow rate of \(\approx\) 1 L min\(^{-1}\). Meteorological data (temperature, wind speed and wind direction, dew point used to compute relative humidity data) have been provided by the facilities in the AQM station.

Chemical compositions of heavy metals analysis in particulate matters: Teflon fiber filters and a 16 mm PTFE-coated glass fiber filter (PM\(_{10}\)) were collected (twice a month) to measure the heavy metals accumulated in the particulate matter. Heavy metals adsorbed on particulate matters were determined by digesting the filter paper with 20 mL deionizer water (purified by Millipore Simplicity 185) in Sonorec ultrasonic bath (Super RK 514 BH). The extract solutions were analyzed by injection to inductively coupled plasma atomic emission spectrometry (ICP-AES, Jobin Yvon JY2000) via nebilizing system (Khaenamkaew et al., 2010). The instrument was well calibrated with standard reference material (SpexCertiprep) of heavy metals.

Morphology and elemental composition analysis: The shape and physical structure of particles in the filter samples were observed using a Scanning Electron Microscope equipped with Energy Dispersive Spectrometer (Phillips: XL30 and EDAX). The filter samples were cut onto the area of 0.5×0.5 cm\(^2\). Gold and carbon were coated on the filter samples with a Pirani501 device for the SEM and ED’s analysis, respectively. Analytical conditions were fit to 15 kV accelerating voltage and 100s of effective counting time.

Besides ED’s analysis, the electron beam was spot over the selected area. Elements with atomic numberless than 11 cannot be determined due to insufficient accuracy and presence of carbon in the substrate. The morphologies and spotted elemental compositions of the reference samples were shown in Fig. 7 and 8.

RESULTS AND DISCUSSION

Average concentrations of pollutants from AQM: The average concentrations of pollutants measured by AQM from July, 2007-2008 are provided in Table 3. Average concentration of ozone is higher than the standard level (100 ppb) in July 2007 and April 2008 (Table 3).

O\(_3\) concentration and their possible source: Ozone is a molecule made up of three oxygen atoms (O\(_3\)), Avery reactive gas and even at low concentrations it is irritating and toxic.

When ozone is present at ground level and in the troposphere (10-18 km above earth’s surface), it is considered as a pollutant and a greenhouse gas (Mason et al., 2001). The ozone concentrations are higher than the limit level in July 2007 and April 2008. Moreover, the concentrations of ozone were found relatively high in December 2007-March 2008. In this period, wind roses are indicated the ozone comes from the southwest, south and southeast direction (Fig. 2 and 3) Southern of the AQM station are the petrochemical industry and the sea side area. Ozone is readily formed in the atmosphere by the reaction of Volatile Organic Compounds (VOCs) and NO\(_x\) in the presence of heat and sunlight, which are most abundant in the summer (Mason et al., 2001; Crutzen and Lelieveld, 2001).
Table 3: Air quality and PM$_{10}$ concentration from AQM

| Month | Average | CO (1 h) | NO$_x$ (1 h) | SO$_2$ (1 h) | O$_3$ (1 h) | PM$_{10}$ (24 h) | TSP (24 h) |
|-------|---------|----------|-------------|-------------|-------------|----------------|-----------|
| Jul-07 | Min     | 0.23     | 3.9         | 0.3         | 0.6         | 18             | 54.40     |
|       | Max     | 1.43     | 64.0        | 76.3        | 109.0       | 64             | 43.10     |
| Aug-07 | Min     | 0.27     | 1.9         | 0.4         | 0.1         | 27             | 50        |
|       | Max     | 3.08     | 52.6        | 55.8        | 7.3         | 50             | 50        |
| Sep-07 | Min     | 0.78     | 0.0         | 0.0         | 0.1         | 22             | 41.30     |
|       | Max     | 2.54     | 37.5        | 91.3        | 20.3        | 76             |           |
| Oct-07 | Min     | 0.74     | 0.3         | 2.2         | 0.4         | 24             | 7.40      |
|       | Max     | 2.48     | 42.2        | 41.7        | 47.7        | 114            |           |
| Nov-07 | Min     | 0.73     | 1.3         | 2.3         | 1.1         | 24             | 9.30      |
|       | Max     | 2.49     | 56.0        | 10.2        | 47.0        | 129            |           |
| Dec-07 | Min     | 0.44     | 1.7         | 2.5         | 0.9         | 30             | 9.00      |
|       | Max     | 2.31     | 66.7        | 39.4        | 91.5        | 101            |           |
| Jan-08 | Min     | 0.55     | 0.0         | 2.6         | 1.8         | 37             | 13.80     |
|       | Max     | 2.76     | 80.3        | 84.2        | 96.7        | 123            |           |
| Feb-08 | Min     | 0.68     | 0.0         | 0.8         | 0.4         | 24             | 151.00    |
|       | Max     | 2.47     | 67.2        | 62.9        | 90.2        | 100            |           |
| Mar-08 | Min     | 0.72     | 0.0         | 0.8         | 0.0         | 29             | 9.70      |
|       | Max     | 2.14     | 73.3        | 81.3        | 95.8        | 125            |           |
| Apr-08 | Min     | 0.40     | 0.0         | 0.2         | 1.3         | 18             | 55.10     |
|       | Max     | 1.70     | 40.1        | 41.7        | 114.3       | 56             |           |
| May-08 | Min     | 0.46     | 0.6         | 0.8         | 0.4         | 21             | 8.50      |
|       | Max     | 1.56     | 33.7        | 49.2        | 37.8        | 61             |           |
| Jun-08 | Min     | 0.38     | 0.4         | 0.7         | 0.5         | 26             | 4.70      |
|       | Max     | 2.27     | 47.3        | 58.1        | 47.5        | 53             |           |
| Jul-08 | Min     | 0.00     | 0.2         | 0.8         | 0.0         | 23             | 54.40     |
|       | Max     | 1.52     | 22.7        | 61.2        | 21.7        | 46             |           |
| PCD Standard unit | 30 ppm | 170 ppb | 300 ppb | 100 ppb | 120 µg.m$^{-3}$ | 330µg.m$^{-3}$ |

VOCs are emitted from variety of sources, including motor vehicles, chemical plants, refineries, factories and natural (biogenic) sources (Florig et al., 2002). Nitrogen oxides (a precursor to ozone) are emitted from motor vehicles, power plants and other sources of combustion, as well as natural sources including lightning and biological processes in soil (CEPA, 2011). Figure 2 are also shown the concentration level of NO$_x$. Although the levels are lower than standard values (170 ppb, as seen in Table 1), but the concentration are relatively high in December 2007, January 2008, February 2008 and March 2008.

Figure 2 and 3 are the wind roses of the ozone sources. In July 2007 and April 2008, the wind direction came from the southwest, south and southeast.

These result indicated that ozone possibly come from the sea spray, petrochemical industry and other factories in southern of AQM station.

PM$_{10}$ concentration and their possible source:
Particulate matter is the generic term for a broad class of chemically and physically diverse substances that exist as discrete particles (liquid droplets or solids) over a wide range of sizes. The concentration of TSP and PM$_{10}$ are shown in Table 3. The concentrations of PM$_{10}$ are higher than the limit of standard level (120µg.m$^{-3}$, Table 1) in November 2007, January 2008 and March 2008 with the value of 129, 123 and 125µg.m$^{-3}$, respectively.

Particulate matter may be emitted directly or formed in the atmosphere by transformations of gaseous emissions such as sulfur oxides, nitrogen oxides and VOCs. The chemical and physical properties of particulate matters are greatly varied with time, location, meteorology and source category, thus complicating to assessment of health and welfare...
effects (Paoletti et al., 2002). However, the wind roses of the PM$_{10}$ can be also measure and carefully considered. Figure 4-6 show the wind speed and wind direction of the PM$_{10}$ during the level are exceed than those standard level. November 2007 and January 2008 wind direction came from the northeast and the results indicated that PM$_{10}$ possibly come from the industry estate area. While March 2008 wind direction came from the southwest direction that is transportation activity. The possible sources of particulate matter collected from this site are: commercial and residential heating, road transportation, petrochemical industry and industrial estate area. There is also a possibility that some of these airborne particulates may have migrated to this region from elsewhere (Paoletti et al., 2002).

**Morphologies and elemental compositions:** The surface texture of PM$_{10}$ and TSP filter sample were illustrated in Fig. 7 and 8, respectively. The elemental compositions of selected PM$_{10}$ and TSP were given in Table 4. Both images provided spherical particles with 10 µm-diameters in TSP and less than 10 µm for PM$_{10}$.

In agreement with the results from SEM observations and EDS analysis (Table 4), it could be concluded that soil and rock dust represented a large proportion of particles adsorbed onto the glass and quartz filters (Han et al., 2009). Particles from anthropogenic sources and the marine environment were also found in filter samples (Khaenamkaew et al., 2010).

**Chemical compositions of heavy metals in particulate matters:** The amounts of selected heavy metals which were calculated in terms of mass of metals per mass of particle per unit air volume ($\mu$g g$^{-1}$ m$^{-3}$). Among all metals, zinc was the most probable among all metals with the value of $1.3891\pm1.6198$ µg g$^{-1}$ m$^{-3}$ in TSP. The weighted mean concentrations were $0.4200\pm0.4381$, $0.4293\pm0.5276$, $1.3891\pm1.6198$, $0.6577\pm0.8702$ and $0.7069\pm0.7186$ µg g$^{-1}$ m$^{-3}$ for Ni, Cu, Zn, Pb and Se, respectively. Amounts of heavy metals in PM$_{10}$, Cu was dominated with $0.5374\pm0.8084$ µg g$^{-1}$ m$^{-3}$, the others were almost in the same levels and much lower than in TSP (Table 5). However, all of heavy metals are not exceeding than the national standard level (13 mg g$^{-1}$ m$^{-3}$) (PCD).

**Correlation between amounts of PM$_{10}$ and various kinds of pollutants:** As mentioned in the previous paragraph, O$_3$ and NO$_2$ show strong correlation. It is confirmed that the NO$_2$ is the precursor of O$_3$ (19). Beside O$_3$ and NO$_2$, the strong correlation between PM$_{10}$ and NO$_2$ is shown in Table 6. It is possible that the NO$_2$ is a precursor of PM$_{10}$. NO$_2$ and other chemical substances can form to be aerosol or particle-bound to water and show a particulate property.
Table 4: Elemental composition of PM$_{10}$ (spectrum 1, 2 and 3) and TSP (EDS spot)

| PM$_{10}$ Spectrum 2 | PM$_{10}$ Spectrum 3 | PM$_{10}$ Spectrum 4 TSP (xEDS spot) |
|---------------------|---------------------|-------------------------------------|
| Elem                | Wt (%)              | Elem | Wt (%) | Elem | Wt (%) |
| C                   | 19.71               | C    | 22.54  | C    | 28.34  |
| O                   | 34.50               | O    | 38.91  | O    | 24.09  |
| Na                  | 0.52                | Na   | 0.71   | Na   | 0.82   |
| Al                  | 1.89                | Al   | 6.03   | Al   | 3.61   |
| Si                  | 5.76                | Si   | 19.20  | Si   | 12.68  |
| Cl                  | 0.98                | Cl   | 6.72   | Cl   | 4.23   |
| K                   | 1.61                | K    | 7.25   | K    | 1.87   |
| Ca                  | 18.46               | Ca   | 1.34   | Ca   | 2.21   |
| Fe                  | 1.21                | Fe   | 18.80  | Fe   | 4.12   |
| Mg                  | 0.80                | Mg   | 1.18   | Mg   | 1.18   |

Table 5: Amounts of heavy metals in PM$_{10}$ and TSP

| PM$_{10}$ Collecting time | PM Weight (mg) | Ni   | Cu   | Zn   | Pb   | Se   |
|---------------------------|----------------|------|------|------|------|------|
| July 07                   | 0.0739         | 0.2032| 1.7345| 0.6318| 0.2422| 0.3900|
| October 07                | 0.0313         | 0.1874| 0.3195| 1.0121| 0.1082| 2.3122|
| March 08                  | 0.0778         | 0.1310| 0.0587| 0.2242| 0.0000| 1.0915|
| June 08                   | 0.0764         | 0.0728| 0.0367| 0.1859| 0.0542| 0.2627|
| Geometric mean            | 0.0648         | 0.1486| 0.5374| 0.1011| 1.0141|
| Standard deviations       | 0.0224         | 0.0593| 0.8048| 0.1039| 0.9390|
| TSP                       |                |      |      |      |      |      |
| July 07                   | 0.0431         | 0.1350| 0.1346| 0.3761| 0.3396| 0.4523|
| August 07                 | 0.0413         | 0.0509| 0.1952| 0.1027| 0.3765| 0.4837|
| September 07              | 0.0413         | 0.0509| 0.1952| 0.1027| 0.3765| 0.4837|
| October 07                | 0.0074         | 0.6303| 0.5803| 4.7325| 2.6281| 1.4313|
| November 07               | 0.0093         | 0.5615| 0.2098| 0.5518| 1.6675| 2.0320|
| December 07               | 0.0090         | 1.3053| 1.9758| 1.7891| 0.8250| 0.2861|
| January 08                | 0.0138         | 0.2313| 0.3292| 1.6080| 0.2110| 0.7866|
| February 08               | 0.1510         | 0.0253| 0.2677| 0.3268| 0.1290| 0.1280|
| March 08                  | 0.0997         | 0.3852| 0.3035| 1.2991| 1.6832| 0.0000|
| April 08                  | 0.0551         | 0.1047| 0.0670| 0.4250| 0.0000| 0.0000|
| May 08                    | 0.0085         | 0.3218| 0.3281| 0.8191| 0.0000| 1.8210|
| June 08                   | 0.0047         | 1.2116| 0.7402| 4.5523| 0.0000| 1.0124|
| Geometric mean            | 0.0339         | 0.4200| 0.4293| 1.3891| 0.6577| 0.7069|
| Standard deviations       | 0.0417         | 0.4381| 0.5276| 1.6198| 0.8702| 0.7186|

Table 6: The Pearson correlation between amounts of PM$_{10}$ and various kinds of air pollutants

| PM$_{10}$ | CO    | NO$_2$ | SO$_2$ | O$_3$ | PM$_{10}$ |
|-----------|-------|--------|--------|-------|-----------|
| CO        | 1.000 |        |        |       |           |
| NO$_2$    | 0.400 | 1.000  |        |       |           |
| SO$_2$    | 0.008 | 0.219  | 1.000  |       |           |
| O$_3$     | -0.276| 0.635  | 0.107  | 1.000 |           |
| PM$_{10}$ | 0.421 | 0.649  | -0.109 | 0.348 | 1.000     |

Fig. 8: SEM Micrograph of TSP sample collected from AQM
It is the secondary form of particulate matter namely artifact particulate matter (Turpin et al., 2000). Artifacts in the measurement of particle mass concentrations also arise from the adsorption of semi-volatile organic gases onto or from collected particulate matter and filter media (Tsai and Huang, 1995) and the neutralization of acid or basic gases on either filter media, or collected particulate matter (Turpin et al., 2000). Table 6 The Pearson correlation between amounts of PM$_{10}$ and various kinds of air pollutants

As Ni is strongly correlated with Cu (Table 7 and 8), it may be assumed that they originated from the same source. For the TSP, the strong correlation coefficient between Cu, Ni and Zn (Table 8) suggest be the same origin of these elements (Spotar and Sorokin, 2010). It could be assumed that Cu, Ni and Zn partially originated from same origin due to the correlation.

**CONCLUSION**

The annual concentrations of O$_3$ are higher than the limit of standard level in July 2007 and April 2008. The PM$_{10}$ concentrations are higher those level in November 2007, January 2008 and March 2008. Emission sources of the O$_3$ possibly estimate from the wind speed and wind direction. The result indicated that O$_3$ came from the southwest, south and southeast direction where the petrochemical and others industries. PM$_{10}$ came are also analyzed, the possible sources of PM$_{10}$ are the industry estate and the transportation activities in SukumvitRoad. Strong correlations between NO$_2$ with O$_3$ and between NO$_2$ with PM$_{10}$ were found. These results show that NO$_2$ is the precursor of the photochemical reaction and generate O$_3$. Among the amounts of selected heavy metals, Zn was the most probable among all metals with the value of 1.3891±1.6198 µg.g$^{-1}$.m$^{-3}$ in TSP. Amounts of heavy metals in PM$_{10}$, Cu was dominated with 0.5374±0.8084 µg.g$^{-1}$.m$^{-3}$, the others were almost in the same levels and much lower than in TSP. The microscopic structures of TSP provided various shapes and dimensions from 0.1 to greater than 100 µm, while the microstructures of PM$_{10}$ presented the needle-like and spherical shape. SEM-EDS analysis was able to detect some element (C, O, F, Na, Al, Si and K), while the ICP-AES showed that there were other heavy metals present in the filter sample (Ni, Cu, Zn, Pb and Se). Correlation coefficient between each metal can be estimate the emission source of their particulate matter together with the wind speed and wind direction.

**ACKNOWLEDGEMENT**

The researchers would grateful to thank Assoc. Prof. Dr. Nipon Tangkananuruk for his suggestions. The AQM station received the maintenance budget from Faculty of Resources and Environment. This research project was financially supported by the Kasetsart University Research and Development Institute (KURDI: Code No. RM 24.53) and partially supported by Kasetsart University, Si Racha Campus.

**REFERENCES**

Areekijeree, M., K. Panishkan, N. Sanmanee and K. Swangjang, 2009. Microanalysis by SEM-EDX on structure and elemental composition of soils from different agriculture areas in the western region of Thailand. J. Micro. Soc. Thai., 23: 152-156.

Baulig, A., J.J. Poirault, P. Assuet, R. Schins and T. Shi et al., 2004. Physicochemical characteristics and biological activities of seasonal atmospheric particulate matter sampling in two locations of Paris. Environ. Sci. Technol., 38: 5985-5992. DOI: 10.1021/es049476z

Brook, R.D., B. Franklin, W. Cascio, Y. Hong and G. Howard et al., 2004. Air Pollution and Cardiovascular Disease: A Statement for Healthcare Professionals from the Expert Panel on Population and Prevention Science of the American Heart Association. Circular, 109: 2655-2671. PMID: 15173049

CEPA, 2011. Annual monitoring network report. California Environment Protection Agency.

Crutzen, P.J. and J. Lelieveld, 2001. Human Impacts on Atmospheric Chemistry. Ann. Rev. Earth Planet Sci., 29:17-45. DOI:10.1146/annurev.earth.29.1.17

Florig, H.K., G. Sun and G. Song, 2002. Evolution of particulate regulation in China-prospects and challenges of exposure-based control. Chemosphere, 49: 1163-1174. DOI: 10.1016/S0045-6535(02)00246-1

Han, Y.M., J.J. Cao, Z.D. Jin and Z.S. An, 2009. Elemental composition of aerosols in Daihai, a rural area in the front boundary of the summer Asian monsoon. Atmos. Res., 92: 229-235. DOI:10.1016/j.atmosres.2008.10.031

Khaenamkaew, P., P. Iamraksa, S. Raksawong, K. Wongsorndham and S. Khuntong, 2010. SEM/EDS morphological and chemical composition identification of particulate matter emission from shipping activities around Si Racha Bay, Si Chang Island, Chonburi, Thailand. J. Micro. Soc. Thai., 24: 37-41.

Kim, E. and P.K. Hopke, 2008. Source characterization of ambient fine particles at multiple sites in the Seattle area. Atmos. Environ., 42: 6047-6056. DOI: 10.1016/j.atmosenv.2008.03.032
Limbach, L.K., Y. Li, R.N. Grass, T.J. Brunner and M.A. Hintermann et al., 2005. Oxide nanoparticle uptake in human lung fibroblasts: Effects of particle size, agglomeration and diffusion at low concentrations. Environ. Sci. Technol., 39: 9370-9376. DOI: 10.1021/es051043o

Mason, N., P. Hughes and R. McMullan, 2001. Introduction to Environmental Physics: Planet Earth, Life and Climate. 1st Edn., Tylor and Francis, USA., ISBN-10: 0748407650, pp: 463.

OSOS, 2009. Office of Natural Resource and Environmental Policy and Planning. One Start One Stop Investment Center.

Paoletti, L., B.D. Berardis and M. Diociaiuti, 2002. Physico-chemical characterization of the inhalable particulate matter (PM10) in an urban area: an analysis of the seasonal trend. Sci. Total Environ., 292: 265-271. DOI: 10.1016/S0048-9697(01)01134-2

Spotar, S.Y. and A.L. Sorokin, 2010. Focusing of the flow capture for local exhaust ventilation systems. Am. J. Applied Sci., 7: 732-738. DOI: 10.3844/ajassp.2010.732.738

Tsai, C.J. and H.Y. Huang, 1995. Atmospheric aerosol sampling by an annular denuder system and a high-volume PM10 sampler. Environ. Int., 21: 283-291. DOI: 10.1016/0160-4120(95)00024-F

Turpin, B.J., P. Saxena and E. Andrews, 2000. Measuring and simulating particulate organics in the atmosphere: problems and prospects. Atmos. Environ., 34: 2983-3013. DOI: 10.1016/S1352-2310(99)00501-4

Zanobetti, A., J. Schwartz and D.W. Dockery, 2000. Airborne particles are a risk factor for hospital admissions for heart and lung disease. Environ. Health Persp., 108: 1071-1077.