TEMPORAL RELATIONSHIP BETWEEN PARTICULATE MATTER (PM_{10}) AND SULPHUR DIOXIDE (SO_2) IN DEVELOPING TOWN IN NORTH MALAYSIA

Oleh

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Disertasi ini dikemukakan kepada

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ABSTRAK

Udara merupakan komponen yang sangat penting kepada kehidupan benda hidup seperti manusia, haiwan dan tumbuhan. Namun pencemaran udara yang berlaku semakin serius apabila kandungan bahan pencemar meningkat dalam udara. Terdapat pelbagai jenis bahan pencemar seperti karbon monoksida, nitrogen dioksida, hidrokarbon, sulfur dioksida dan partikel terampai. Bahan pencemar ini disebarkan daripada pelbagai sumber seperti kenderaan bermotor, industri dan pembakaran terbuka. Skop kajian projek ini adalah tertumpu kepada jenis bahan pencemar iaitu partikel terampai bersaiz kurang daripada 10µm dan sulfur dioksida di kawasan Prai,Pulau Pinang. Prai merupakan salah satu kawasan perindustrian di Malaysia dan sektor perindustrian memberi sumbangan yang besar terhadap pencemaran di kawasan ini. Kajian dijalankan terhadap kepekatan partikel terampai bersaiz kurang daripada 10µm melalui data daripada bulan Januari sehingga Ogos dan sulfur dioksida berdasarkan data dari bulan Januari sehingga Jun. Bagi partikel terampai bersaiz kurang daripada 10µm, nilai purata adalah dalam lingkungan 61$\mu g/m^3$ sehingga 93$\mu g/m^3$, nilai tertinggi adalah 540$\mu g/m^3$ dan nilai terendah adalah 7$\mu g/m^3$. Bagi Sulfur dioksida pula nilai purata adalah dalam lingkungan 0.014ppm sehingga 0.025ppm, nilai tertinggi adalah 0.147 ppm dan nilai terendah adalah 0 ppm. Nilai r^2 bagi PM_{10} dan SO_2 adalah 0.0097 bagi hari biasa dan 0.2927 untuk hujung minggu. Ini menunjukkan perubahan SO_2 tidak mempengaruhi perubahan PM_{10}.

ABSTRACT

Quality of air is a very important component to human beings, animals and plants. But, nowadays air has become polluted seriously and the amount of the air pollutants increasing in the air. There are many types of air pollutants such as carbon monoxide, nitrogen dioxide, hydrocarbon, sulphur dioxide and particulate matter. These air pollutants are contributed by many sources such as motor vehicles, industry, and open burning. The scope of this research is about particulate matter up to 10µm and sulphur dioxide in Prai, Pulau Pinang. Prai is one of the industrial areas in Malaysia and this sector contributed large effect to the pollution of this area. These studies are done on the concentration of particulate matter (PM_{10}) by analysis the data from January till August and for sulphur dioxide (SO_2) the data given from January till Jun. For PM_{10} the mean values ranging from 61µg/m^3 up to 93µg/m^3, maximum value is 540µg/m^3 and minimum value is 7µg/m^3 and for SO_2 the mean values ranging from 0.014 ppm up to 0.025 ppm, maximum value is 0.147 ppm and minimum value is 0 ppm. The value of correlation (r^2) between PM_{10} and SO_2 is 0.0097 for weekdays and 0.2927 for weekends which indicates that there is poor correlation between PM_{10} and SO_2.

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CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION

Malaysia has enjoyed one of the least polluted urban environments in Asia. The goal of achieving industrial country status by the year 2020 and the associated rapid economic growth have started to impose costs in terms of industrial pollution and the degradation of urban environment. Depletion of fisheries, air and water pollution, and contamination by industrial wastes has become more serious in Malaysia in recent years. Among them, air pollution is the major issue that has been affecting human health, agricultural crops, forest species, and ecosystems.

Monitoring data and studies on ambient air quality show that some of the air pollutants in several large cities are increasing with time and are not always at acceptable levels according to the national ambient air quality standards. (www.sciencedirect.com/science?_ob=ArticleURL&_aset=V-WA-A-W-Z, 20th February 2005).

The three major sources of air pollution in Malaysia are mobile sources, stationary sources, and open burning sources. For the past 5 years, emissions from mobile sources (i.e., motor vehicles) have been the major source of air pollution, contributing to at least 70–75% of the total air pollution. Emissions from stationary sources generally have contributed to 20–25% of the air pollution, while open burning and forest fires have contributed approximately 3–5%. In 1996, the percentages, of the air emission load by type were motor vehicles, 82%; power stations, 9%; industrial fuel burning, 5%; industrial production processes, 3%; domestic and commercial furnaces, 0.2%; and open burning at solid waste disposal sites, 0.8%.

Mobile sources include motor vehicles such as personal cars, commercial vehicles, and motorcycles. By the end of 2000, there were 10.6 million vehicles registered in Malaysia, compared to 7.7 million in 1996, an increase of almost 2.9 million vehicles or 26% (Department of the Environment, Malaysia, (2001). The federal territory of Kuala Lumpur has the highest vehicle population followed by Johor, Selangor, Perak, and Pulau Pinang. These conditions have caused severe congestion in almost all parts of the highway network and corridors, especially in the central business areas, and inevitably the environment in these areas has deteriorated due to exhaust emissions from motor vehicles.

Stationary sources are related to industry, power stations, industrial fuel burning processes, and domestic fuel burning. Most of the stationary sources in Malaysia reside in Selangor, followed by a significant number of sources in Sarawak, Johor, Sabah, Perak, and Pahang. Increased activity from the industrial sector has been accompanied by an increased use of energy and commodities traffic. Most of the small and mid-sized industries do not install pollution control equipment. This increases the emission of pollutants, especially in the industrial areas, which in some cases contributes specific pollutants to the air.

Open burning sources of air pollution in Malaysia include the burning of solid wastes and forest fires. This is common at some poorly managed disposal sites and results in smoke and fly ash problems.

Ambient air quality standards identify individual pollutants and the concentrations at which they become harmful to the public health and the environment. The standards are typically set without regard to economic feasibility for attainment. Instead, they focus on public health, including the health of "sensitive" populations such as asthmatics, children and the elderly and public welfare, including protection against decreased visibility and damage to animals, crops, vegetation, aquatic resources, and buildings. The Malaysian air pollution index (API) is obtained from the measurement of fine particles and several gases which are carbon monoxide, sulfur dioxide, and nitrogen dioxide.

In Malaysia, few studies have been conducted on air pollution. In anticipation of the potential severity and magnitude of the problem, the government enacted into law the Environmental Quality Act in 1974; subsequently, the Division of the Environment was established and the Clean Air Regulations were formerly gazette in 1978. In April 1995, Alam Sekitar Malaysia Sdn Bhd (ASMA) was awarded a 20-year privatization concession to install, operate, and maintain a network of 50 continuous air quality monitoring stations throughout Malaysia for the DoE. Alam Sekitar Malaysia Sdn Bhd (ASMA) also manages the Environmental Data Center, which provides environmental data to the DoE and other interested parties. In 1996, 10 new fully automated ambient air quality monitoring stations with telemetric systems were installed, bringing the total number of stations up to 31. Table 1.1 lists the The Malaysian Air Pollution index.

Table 1.1 The Malaysian Air Pollution index

Source: [Department of the Environment ,1996].

API	**Diagnosis**
0-50	Good
50-100	Moderate
101-200	Unhealthy
201-300	Very Unhealthy
301-500	Hazardous

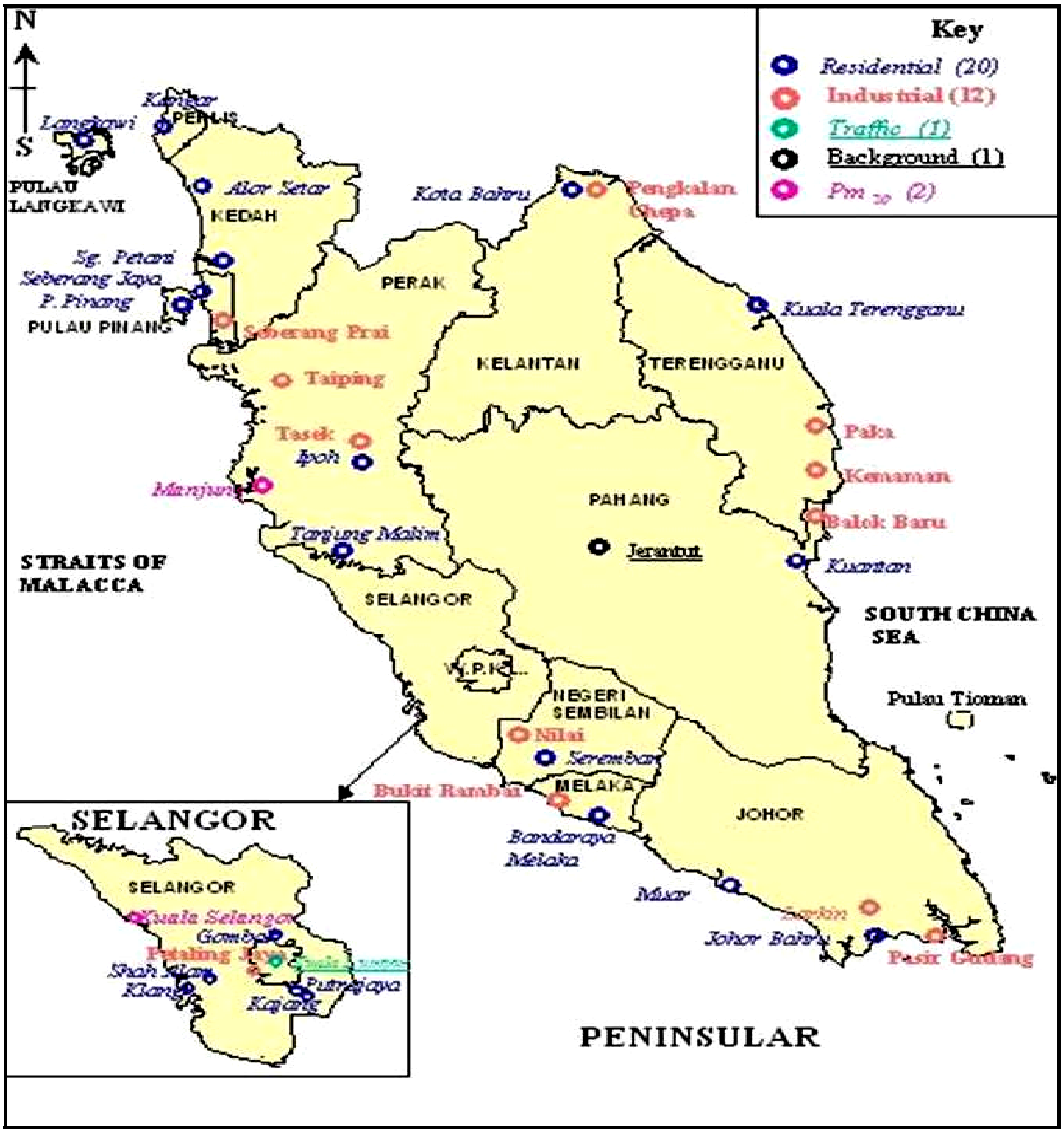

Figure 1.1: Location of Continuous Air Quality Monitoring Station, 2002 for Peninsular Malaysia

Source: (www.jas.sains.myjasAir Data Monitoringstation.htm, 25th January 2005)

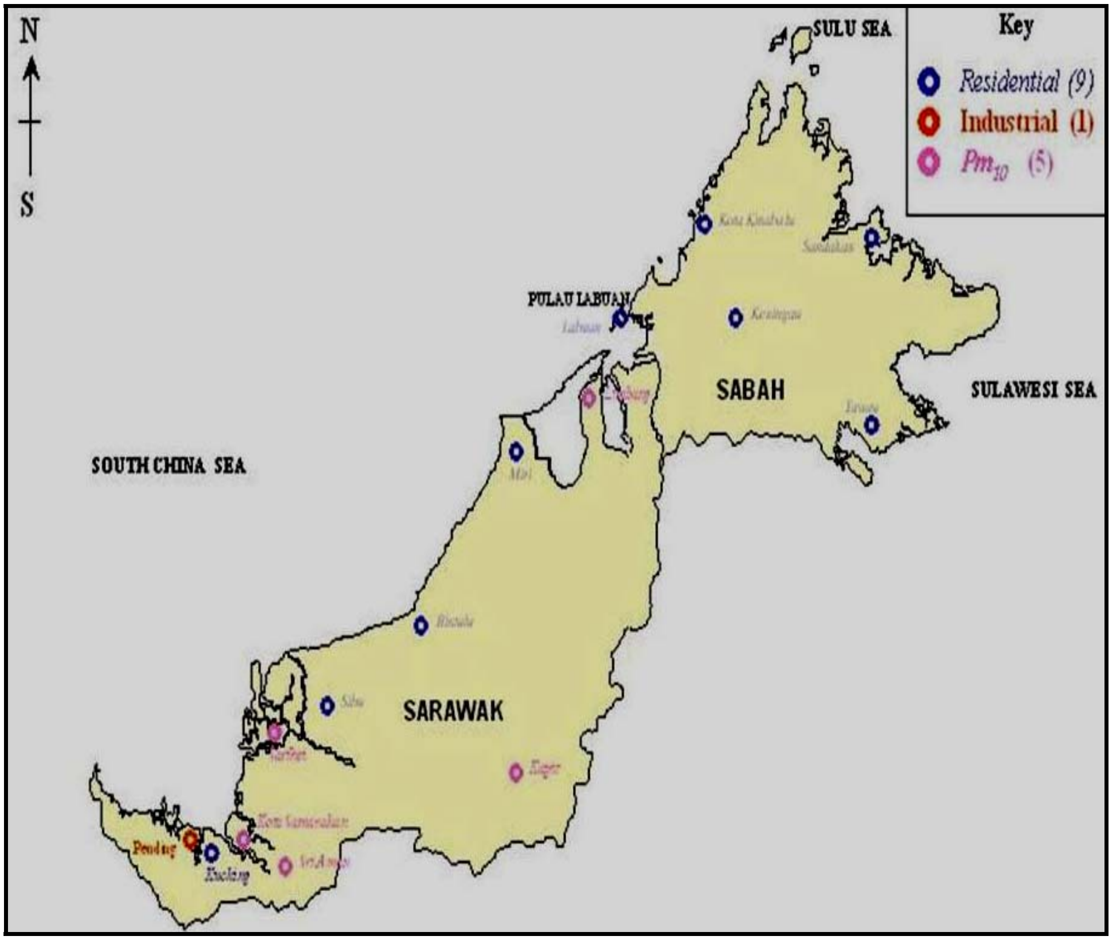

Figure 1.2: Location of Continuous Air Quality Monitoring Station, 2002 for Sabah and Sarawak

Source: (www.jas.sains.myjasAir Data Monitoringstation.htm, 25th January 2005)

1.2 OBJECTIVES

In this thesis, there are three main objectives to meet:

- To determine the relationship between PM_{10} and SO_2 in developing town in Prai.
- To identify the sources of emission.
- To analyze PM_{10} and SO_2 data

1.3 SCOPE

This study will be carried out at Prai, Pulau Pinang which located at:

Lat (DMS)	5° 22' 60N
Long (DMS)	100° 22' 60E
Longitude	100.3833
Latitude	5.3833

According to (http://www.env.upm.edu.my/Yana2.txt, 21st February 2005), urban air pollution is now a cause of major concern due to rapid industrialization. In the northern region of west coast of Peninsular Malaysia, comprising the State of Perlis, Kedah, Pulau Pinang and Perak, the overall air quality ranged between good and moderate most of the time except Prai. Prai is situated at Pulau Pinang, Malaysia and one of developing town in north Malaysia. As Prai is a heavily industrialized area with several petrochemical complexes, the air quality remained at the moderate level more than 90 percent of the time (Malaysia Environmental Quality Report, 2002). The main pollutant of concern is based on 5 parameters namely, Particulate Matter below 10 micron diameter (PM_{10}), Carbon Monoxide (CO), Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_3) and Ozone (O_3) caused by industrial fuel.

Emission data of Particulate Matter below 10 micron diameter (PM_{10}), and sulphur dioxide for the year 2001 is used in this thesis. This study is consisting both of the pollutants since both are major pollutants in this area.

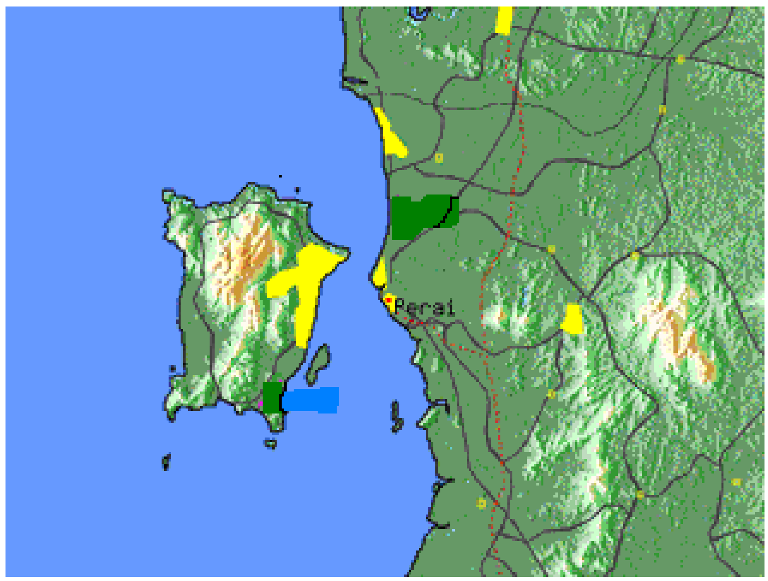

Figure 1.1 Location of Prai, Pulau Pinang

Source: (http://www.fallingrain.com/world/MY/9/Perai.html 23rd January 2005)

CHAPTER 2 LITERATURE REVIEW

2.0 AIR POLLUTION

2.1 DEFINITION

According to (http://www.smkb.edu.my/dtd2003/whatair.htm,20thFebruary 2005). Air pollution can be defined as gases, liquid, or molecules contained in the air are undergoing changes which will affect life form and/or other things. Referring to (http://www.ozoneservices.com/glossary/a/airpollution.htm, 20thFebruary 2005), air pollution can be defined as the contamination of the atmosphere by any toxic or radioactive gases and particulate matter as a result of human activity.

Air pollution occurs when air impurities in the form of gaseous or particles are emitted into the atmosphere. It is important to recognize that air pollution is not a single entity but an alphabet soup of foregoing materials mixed with the normal constituents of air.

Air pollutant comes from a variety of natural and man-made sources. Man made sources include emission from industrial activities, emissions from motor vehicles and burning of fossil fuels and biomass.
(http://www.jas.sains.my/jas/Air+Point/air+point+index.htm, 20th February 2005).

2.1.1 THE SOURCES OF AIR POLLUTION

Based on (www.answers.com/topic/air-pollution, 19th January 2005) the sources of air pollution are divided in two groups: anthropogenic (generated by human activity) and natural.

Natural sources include:

- Volcanic activity, which produce sulphur, chlorine, and ash particulates.
- Dust from natural sources, usually large areas of land with little or no vegetation.
- Methane, emitted by the digestion of animals, usually cattle .
- Smoke and carbon monoxide from wildfires.
- Radon gas from earth minerals.

Anthropogenic sources are mostly related to burning different kinds of fuel . They include:

- Combustion-fired power plants .
- Vehicles with internal-combustion engines, especially diesel .
- Devices powered by Two-stroke cycle engines.
- Stoves and incinerators, specially coal ones.
- Wood fires, which usually burn inefficiently.
- Farmers burning their crop waste.

Sources not directly related to burning fuel include:

- Industrial activity in general.
- Oil refining .
- Waste deposition in land fills, which generate methane.
- Fumes from paint, varnish, and other solvents.
- Arsenic and chlorine found in drinking water and inhaled in bathroom showers.
- Dust and chemicals from farming, especially of erodible land.
- Military actions, including the use and testing of nuclear bombs, poison gases, and germ warfare.

2.1.2 THE POLLUTANTS

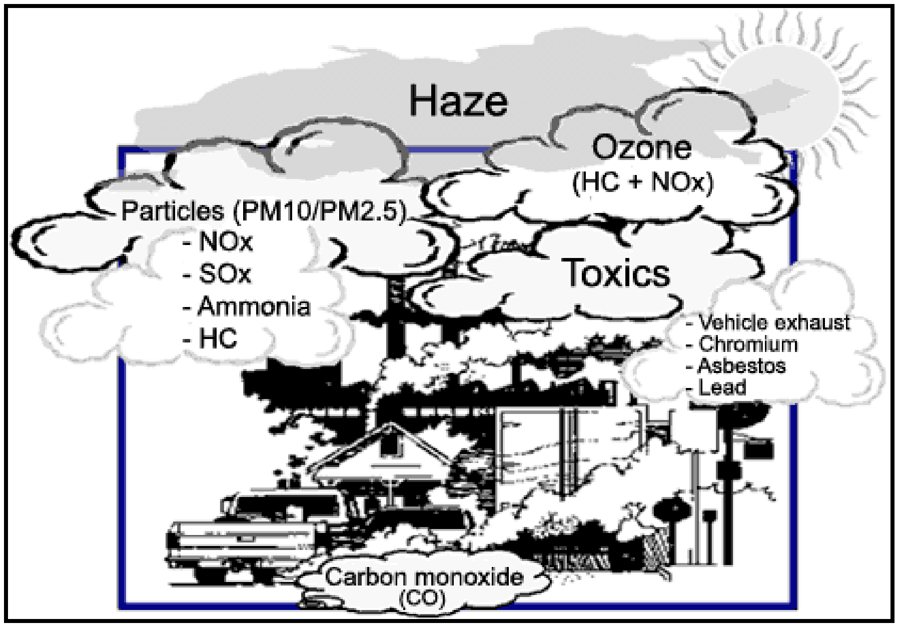

Figure 2.1: Main air pollutants in Malaysia

Source: (http://www2.gtz.de/malaysia/projects/air_pollution_control_pollutants.htm 21st February 2005)

From the many substances and groups of substances that are pollutants of concern to one degree or another, six are presently considered major, in the sense that they have been known longest and studied most, and they are the ones toward which the most control effort is being directed. This distinction has been formalized by the federal government; under the terms of the Clean Air Act of 1972, the Environmental Protection Agency (EPA) has legally established National Ambient Air Quality Standards for these six pollutants, standards that reflect the concentration levels of the pollutants that are believed to be safe (Lynn, 1976).

1. Sulphur dioxide (SO_2)

Definition: Corrosive, poisonous gases produced when fuel containing sulfur is burned.

Examples: SO_2 in gaseous form or sulfurous acid (H_2SO_4) in liquid form, a component of acid rain.

Sources: Electric utilities, industrial boilers, copper smelters, petroleum refineries, mobile sources, residential and commercial heating

Effects: Breathing difficulty when dissolved in the nose and upper air passages; chronic coughing and mucous secretion; acid rain destroys plant life, fish; contributes to lowered visibility as sulfate portions of suspended particulates. (Alley, 1998).

2. Carbon Monoxide

Definition: A colorless, odorless, poisonous gas, lighter than air, produced by incomplete combustion of carbon in fuels.

Sources: Stationary fuels burning sources; mobile fuel burning sources (internal combustion engines, preliminary gasoline engines)

Effects: Can be fatal in a short time in an enclosed area; react with the hemoglobin in blood to prevent oxygen transfer (Alley, 1998).

3. Particulate matter

Definition: Any finely divided solid or liquid material other than uncombined water

Examples: Dust, smoke, fumes, oil droplets, beryllium, asbestos

Sources: Kilns, crushers, mills, grinders, dryers, furnaces, boilers, incinerators, conveyors, textiles finishing, mixers and hoppers, chemical processing equipment, spray booths, forest fires

Effects: Decreased visibility; smoke and dust effect on human health; chronic diseases of the respiratory tract; lead poisoning, soiling of homes and clothing; destruction of plant life and agriculture; effects on climate (Alley, 1998).

4. Nitrogen oxides

Definition: Seven oxides of nitrogen:

NO, NO_2, NO_3, N_2O, N_2O_3, N_2O_4, N_2O_5. Air pollution work generally refers to NO and NO_2, nitric oxide and nitrogen dioxide. Both are colorless gases. Excessive concentrations in air cause brownish color due to light absorption in the blue-green area of area the spectrum.

Sources: Produced by burning fuel at very high temperatures from nitrogen in the air. Also produced from organic nitrogen in coal and heavy oils: large power generators, large industrial boilers, internal combustion engines, nitric acid plants.

Effects: Reduced visibility; nose and aye irritation, pulmonary edema, bronchitis and pneumatic (Alley, 1998).

5. Ozone

Definition: Ozone is a molecule that serves both good and bad functions. In the lower atmosphere, the troposphere, ozone is a major component of smog. This is what people call "bad" ozone because of its harmful effects on people, materials, and ecosystems. It is created when sunlight reacts with hydrocarbons and nitrogen oxides that are emitted by automobiles, auto body shops, gas stations, organic solvents and dozens of other sources. The concentration of ozone in the air also strongly correlates to many meteorological characteristics including temperature, wind speed and atmospheric stability.
(www.cleanairstlouis.com/Airinstl.htm, 23rd January 2005)

Sources: Unlike most other pollutants, ozone is not significantly emitted directly into the air by specific sources. Ozone is generated when heat and sunlight "cook up" Nitrogen Oxides and Volatile Organic Compounds (VOC) to create ozone. (http://www.cleanair-stlouis.com/O3sourc.htm, 23rd January 2005)

Effects: High concentrations of ground-level ozone can cause shortness of breath, coughing, wheezing, headaches, nausea, and eye and throat irritation. There have been studies where healthy adults are exposed to various levels of ozone. The results show that even healthy adults can experience decreased function of their lungs when exposed to ozone. People who suffer from lung diseases like emphysema, bronchitis, pneumonia, asthma and colds have even more trouble breathing when the air is polluted. These effects can be worse in children, the elderly and exercising adults.
(http://www.cleanair-stlouis.com/health.htm ,
23rd January 2005)

6. Hydrocarbons:

A precursor of ozone in addition to oxides of nitrogen. Hydrocarbons are also known as Volatile Organic Compounds (VOC) or Reactive Organic Gases (ROG). They may be emitted into the air by natural sources (e.g., trees) and as a result of fossil and vegetative fuel combustion, fuel volatilization, and solvent use. Hydrocarbons are a major contributor to smog.
(http://tpd.az.gov/air/pdf/Glossary.pdf , 23rd January 2005)

2.2 Malaysian Air Quality Guideline

In 1989, the Department of Environment (DoE) formulated a set of air quality guidelines, termed Recommended Malaysian Air Quality Guidelines (RMG) for air pollutants, defining the concentration limits of selected air pollutants which fight adversely affect the health and welfare of the general public. Based on the MG, the Department subsequently developed its first air quality index system, known as the Malaysian Air Quality Index (MAQI) in 1993. An index system lays an important role in conveying to both decision-makers and the general public the status of ambient air quality, ranging from good to hazardous. Application of the index system, particularly in industrialized countries, has demonstrated its useful role in providing a sound basis for both the effective management of air quality, as well as the effective protection of public health. (http://www.jas.sains.my/jas/air%20data%20monitoring/intro.htm,
20th September2005)

In line with the need for regional harmonization and for easy comparison with countries in the region, the Department revised its index system in 1996, and the Air Pollutant Index (API) was adopted. The API system of Malaysia closely follows the Pollutant Standard Index (PSI) system of the United States.

Referring to the (http://www.jas.sains.my/jas/Air+Data+Monitoring/Api.htm ,
20th September 2004), an air pollution index system normally includes the major air pollutants which could cause potential harm to human health should they reach unsafe levels. The pollutants included in Malaysia's API are ozone (0^3), carbon monoxide (CO),

nitrogen dioxide ($N0^2$), sulphur dioxide ($S0_2$) and suspended particulate matter less than 10 microns in size (PM_{10}).

Generally, an air pollution index system is developed in easily understood ranges of values, instead of using the actual concentrations of air pollutants, as a means for reporting the quality of air or level of air pollution. To reflect the status of the air quality and its effects on human health, the ranges of index values could then be categorized as follows: good, moderate, unhealthy, very unhealthy and hazardous. The index values may also be categorized according to episode or action criteria, such as air pollutant levels within stipulated standards, or levels signifying conditions for alert, warning, emergency and significant harm. The key reference point in these air pollution index systems is the index value of 100 (the "safe" limit), which is based on the National Air Quality Standards or Guidelines for the specific air pollutants concerned.

The averaging time, which varies from 1 to 24 hours for the different air pollutants in the RMG, represents the period of time over which measurements is monitored and reported for the assessment of human health impacts of specific air pollutants. As such, the air pollution indices are normally monitored and reported for the same averaging times as those employed for the air quality standards / guidelines.

2.2.1 Recommended Malaysian Air Quality Guideline

Referring to the (http://www.jas.sains.my/jas/Air+Data+Monitoring/Api.htm , 20th September 2004), API system closely follows the PSI system of the United States. As such, the API breakpoints; at 100 for the various air pollutants correspond to the respective RMG concentrations regarded as being "safe levels". In other words, air quality with API values exceeding 100 are considered likely to cause health effects to the general public. Further, a linear correlation is assumed from API 0 to API 100, with the breakpoint at API 50 corresponding to 50% of the RMG concentration standards for the various air pollutants.

Breakpoints at API 200, 300, 400 and 500 directly mirror those of the PSI system of the United States. Following the requirements of the RMG from the standpoint of human health implications, the API values are reported for varying averaging time as follows: PM_{10} and $S0_2$ on 24-hour running averages, CO on 8-hour running averages and $N0_2$ on 1-hour running averages. The API for PM_{10} (based on a 24-hour period running average), reflects specifically levels of suspended particulate matter pollution and it may not be linked directly to visibility factors, as visibility often determined by results of semi-quantitative observations over relatively shorter time periods.

2.2.2 Calculation of the Air Pollutant Index

Referring to the (http://www.jas.sains.my/jas/Air+Data+Monitoring/Api.htm, 20th September 2004), to determine the API for a given time period, the sub-index values (sub-API) for five air pollutants included in the API system are first calculated using the above mentioned sub-index functions for the air quality data collected from the Continuous Air Quality Monitoring Stations. The corresponding air quality data subjected to the necessary quality control processes and quality assurance procedures, prior to the sub-index calculations.

The API value reported for a given time period represents the highest API value among all the sub-APIs calculated during that particular time period. The predominant parameter contributing towards a particular API value is normally indicated alongside the API value. For example, during the 1997 haze episode, the predominant air pollutant parameter was PM_{10} and hence the API values ported were primarily based on the PM_{10} sub-index.

This approach is also adopted by the PSI system of the United States, and is also commonly followed by other countries in an effort to promote a uniform and comparable API system. Ideally, all sub-API values exceeding the API 100 threshold limit should also be reported in addition to the predominant API value per second.

The following is an outline of the procedures involved in calculating the API values:

I. Collect continuous air quality data for the five air pollutants in the API system for sufficient averaging time periods;

II. Conduct the necessary calibration, validation, quality control and quality assurance in the process of data collection;

III. Calculate average concentration of the specific air pollutants for the specified averaging time periods;

IV. Calculate sub-index value for each of the five air pollutants based on the

V. Report the API at a given time for the preceding averaging period (taking the common end point of 1-hour, 8-hour or 24-hour for all five pollutants) in terms of the highest sub-index value obtained; i.e.

API = Max {sub-indices of all five air pollutants}

State the specific air pollutant responsible for the API value as the predominant parameter along with the index;

State the relevant health effect category of the API reported;

Report also other sub-indices, if any, which exceed 100 (thereby indicating violation of an RMG).

2.3 PARTICULATE MATTER

Based on (http://www.pca.state.mn.us/gloss//fu//Def, 18thSeptember 2004), particulate matter is a collective term used for very small solid and or liquid particles found in the atmosphere. While individual particles cannot be seen with the naked eye, collectively they can appear as black soot, dust clouds or grey hazes. Particulate matter may be generated by natural processes (e.g., pollen, bacteria, viruses, fungi, mold, yeast, salt spray, soil from erosion) or through human activities, including diesel trucks, power plants, wood stoves and industrial processes .

Particulate matter has large variance in shape and size, each with its own set of physical and chemical properties. The most significant property of particulate pollution is the size of the particles (Lynn, 1976).

The size of the particles will almost totally determine the way in which the particles behave in the air, how far the wind will carry them, and what affect they will have, either in lungs of someone breathing the air, or on plants, buildings, and so on. The size attributed to a particle is actually its aerodynamic equivalent diameter, that is, the diameter of a sphere that would have the same aerodynamic settling behavior in the air that particle has.
(Lynn, 1976).

The pollutant particles in terms of their size are dividing into three groups, with dividing lines at sizes 0.1 and 10 microns. The dividing lines are not really that sharp, but generally the particles in these three different size ranges tend to come from different size

The pollutant particles in terms of their size are dividing into three groups, with dividing lines at sizes 0.1 and 10 microns. The dividing lines are not really that sharp, but generally the particles in these three different size ranges tend to come from different sources and to stay in the air for different lengths of time. The size ranges labeled as dust fall, suspended particulate matter and suspended particles (Lynn, 1976).

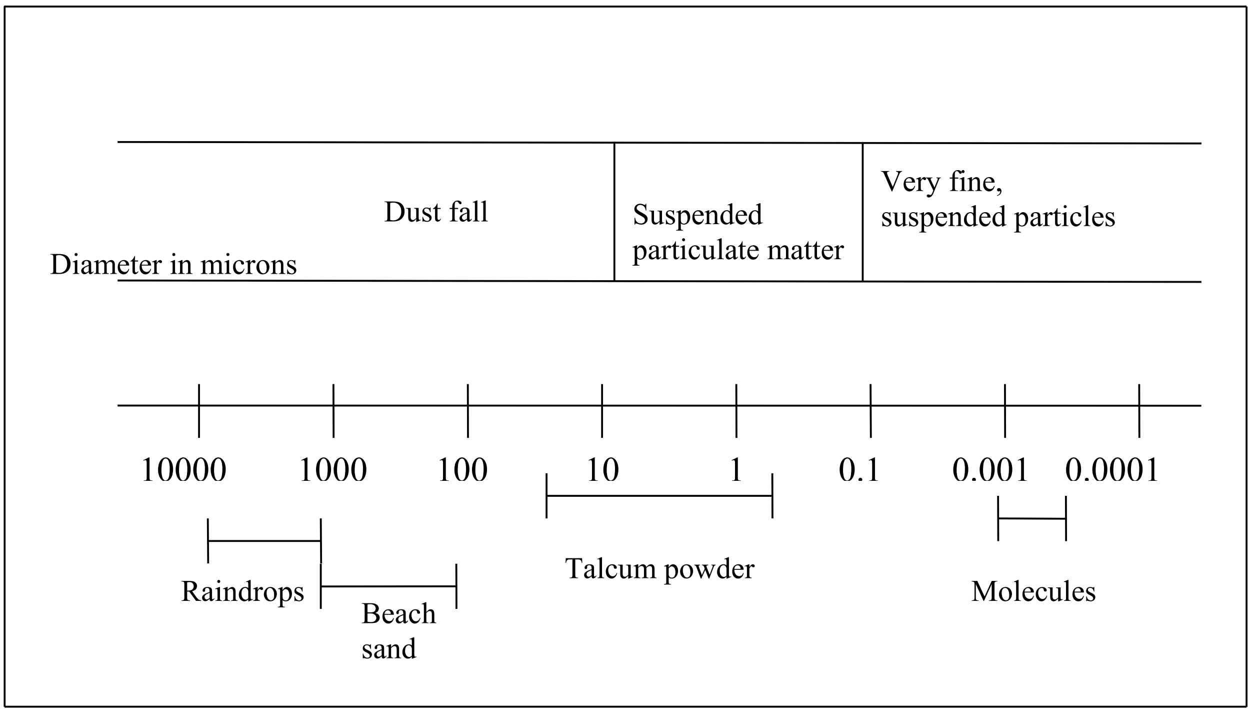

Figure 2.2: The spectrum of atmospheric particle size
(Source: Lynn, 1976)

Referred to (http://www.airinfonow.org/html/ed_particulate.html 25th September 2004), particles are divide into two major groups. The coarse particles, PM_{10} and the fine particles, $PM_{2.5}$.

The fine particles are lighter and they stay in the air longer and travel farther. PM_{10} (coarse) particles can stay in the air for minutes or hours while $PM_{2.5}$ (fine) particles can stay in the air for days or weeks. PM_{10} particles can travel as little as a hundred yards or as much as 30 miles. $PM_{2.5}$ particles go even farther; many hundreds of miles.

2.3.2 PARTICULATE MATTER SOURCES

According to the (http://www.pca.state.mn.us/gloss//fu//Def, 18th September 2004), particles are either emitted directly into the atmosphere or produced in the atmosphere from the physical and chemical transformation of other vaporous or gaseous pollutants.

The major sources of atmospheric particulates are fossil-fuel combustion (which produces ash and soot), industrial processes (involving metals, fibers, etc.), transportation, wind and soil erosion (producing fugitive dust), and photochemical reactions (complex chain reactions between sunlight and gaseous pollutants). Fugitive dust and particles from industrial processes tend to be larger in size (> 1 μm). Particles from combustion and photochemical reactions are usually smaller in size (< 1 μm).

Because of the large number of sources, particulate matter may contain hundreds of different chemical elements. Fine particles (PM_{10}) may contain substantial quantities of sulfate, ammonium, nitrate, elemental carbon and condensed organic compounds. Carcinogenic compounds and heavy metals such as arsenic, selenium, cadmium and zinc are also concentrated in these particles. Larger particles, such as soil particles, fly ash, road aggregate, wood ash, soot and pollen are composed primarily of minerals, including silicon, aluminum, potassium, iron, calcium and other alkaline elements .