Relationship between total suspended particulates and particulate matter of 10 microns

Partha Kumar Gupta
University of Wollongong

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RELATIONSHIP BETWEEN TOTAL SUSPENDED PARTICULATES AND PARTICULATE MATTER OF 10 MICRONS

A dissertation submitted in partial fulfilment of the requirements for the award of the degree of

Master of Engineering (Honours) in Environmental Engineering

UNIVERSITY OF WOLLONGONG

by

Partha Kumar Gupta

DEPARTMENT OF CIVIL & MINING ENGINEERING
DEDICATED TO MY PARENTS AND MY BROTHER
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ABSTRACT

The greatest challenge for the industries, nowadays, is to provide products and services that provide a very high standard of living without degrading the environment. The role of an engineer has changed drastically over the years, since, he/she has not only to provide the existing living standards but also has to upgrade the standards, without harming the quality of the environment. In the past, scientists and engineers were oriented towards the concepts of industrial growth and expansion, increased efficiency in production and exploitation of resources. This gave very little room for concern about the long range effects of the pollution and harmful side effects of the products. This was driven by the conventional economic criteria and concepts of optimum design which has resulted in global pollution.

The air we breathe for our survival is being polluted and has reached intolerable proportions in many countries. It has been found that the total emission of all contaminating gases and particulate matter into our atmosphere, including natural sources such as plant life and volcanoes, is estimated to be $10^{12}$ tonnes/yr. Only 500 million tonnes, or 0.05%, result from man’s activities, but since these tend to remain concentrated near urban and industrial sources, they are held responsible for many problems.

In this project, particulate matter generated from a steel plant has been studied. Generally, particulate matter having less than 100 microns in diameter, is called fine solid. They have important light scattering properties, leading to smog and haze. They may be corrosive, toxic, or merely a source of dust and soiling. The total suspended particulates (TSP) which are 50 microns or less in diameter do not enter the lungs but may enter the digestive tract via the nasal passages. They are considered heavier particles. Particulate matter being less than 10 microns (PM10) in diameter are a matter of concern because they enter the lungs and cause respiratory problems.

This study focussed on the relationship between TSP and PM10 as generated from a steel plant. The results showed that for the ratio of TSP to PM10 is 0.50, irrespective of wind velocity and wind direction. The relationship was determined using high volume air samplers in order to measure TSP, and PM10 and then using some statistical tools to arrive at such a relationship.
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CHAPTER 1

INTRODUCTION, AIM AND SCOPE

1.1 INTRODUCTION

Air pollutants are divided into two main categories: a) common, and b) toxic. The common air contaminants are the cause of most well-known air pollution-related concerns, and are the ones that are monitored at ambient air monitoring stations. Normally included in this group are: sulphur dioxide, nitrogen oxides, suspended particulate matter, ground level ozone and carbon monoxide. Another contaminant that might be added to this list, given its role as the pre-eminent “greenhouse gas”, is carbon dioxide.

Most air pollutants are toxic, given sufficiently high concentrations. However, some pollutants are toxic even at relatively low levels. These “toxic air pollutants” number in at least the hundreds, and are generated from a multitude of sources, particularly in the industrialized countries and as well as in the developing countries. Included in this group of contaminants are lead, mercury, asbestos, polycyclic aromatic hydrocarbons (such as benzo(a)pyrene), pesticide residues (such as DDT), and other chlorinated organic compounds (such as dioxins and furans) (Still, 1990).

1.2 SUSPENDED PARTICULATE MATTER

Suspended particulate matter is composed of solid or liquid particles of a size and shape that allows them to become airborne once emitted. At its worst, this is one of the most obvious kinds of air pollution because it impairs visibility, causes soiling (of clothing, cars, houses, etc.), and can cause respiratory health problems in humans. However, exposure to the very fine particulates that predominate in air pollutants transported over a long distances are now considered to be of more importance from a health point of view. These particles are not visible.
Particulate matter in the atmosphere is composed of a mixture of natural soil and organic matter, and anthropogenic aerosols including sulphates, nitrates, organics and trace metals. These substances can reduce visibility and solar radiation and contribute a variety of acids, toxic metals, and organics to forest and aquatic ecosystems through wet and dry deposition processes. Large particles are composed primarily of natural soil material, and are not usually transported over a long distances. A majority of acidic substances, potentially toxic trace metals and organics are contained in small particles which can be transported over hundreds of kilometres on prevailing winds.

The health effects of exposure to elevated levels of suspended particulate matter potentially include restricted lung function, aggravation of existing lung and heart disease, interference with mucous clearing, damage to lung tissue and possibly even death in some extreme cases. Where death have occurred, such as in London and New York in the 1950s and early 1960s, high levels of airborne particulate matter have coincided with elevated oxides of sulphur levels. Those in the highest risk categories from exposure to elevated particulate levels include pre-school and school-aged children, the elderly, and asthmatics, those with heart problems and arteriosclerosis, individuals suffering from influenza and bronchitis and smokers. Airborne particulate matter ranges in size from 0.005 to 100 microns, but it is the particles of 10 microns or less that are of particular concern to human respiratory health problems. Particles of this size can enter the thoracic region of the lung where the greatest toxic response from airborne particulate matter can be elicited. This size fraction is referred to as inhalable particulate.

Air quality has improved substantially with respect to many air contaminants where they have been measured since early 1970s. Pollution control legislation and regulations have resulted in major reductions in contaminant emissions, particularly from industrial and automotive air pollution sources, during this period. Anecdotal evidence also gives the distinct impression that the air of our cities is much cleaner now than it was when coal was in popular use from the early to mid-1900s until well after the middle part of the century. It is on the basis of this assessment to conclude that, where air quality is concerned, we have been moving towards a higher degree of environmental sustainability, over at least the last two decades. Unfortunately, however, a number of serious air quality problems are still outstanding. Table 1.1 (USEPA, 1979) shows air quality objectives for suspended particulate matter.
Table 1.1 Air Quality Objectives for Suspended Particulate Matter (USEPA, 1979)

<table>
<thead>
<tr>
<th>Exposure Period</th>
<th>Maximum Desirable Concentration</th>
<th>Maximum Acceptable Concentration</th>
<th>Maximum Tolerable Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>One hour</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>24 hour</td>
<td>-</td>
<td>120 µg/m(^3)</td>
<td>400 µg/m(^3)</td>
</tr>
<tr>
<td>One year</td>
<td>60 µg/m(^3)</td>
<td>70 µg/m(^3)</td>
<td>-</td>
</tr>
</tbody>
</table>

The study of particulate matter can be classified into two categories: a) suspended matter, and b) depositable matter. This division is not clear cut and is dependent upon such factors as meteorological conditions and the size, density and terminal velocity of the particles. Figure 1.1 shows the relative proportion of suspended particulate matter in the atmosphere.

![Figure 1.1 Measures of Particulate Matter in the Atmosphere (USEPA, 1979).](image)

Figure 1.1 Measures of Particulate Matter in the Atmosphere (USEPA, 1979).
This figure shows the overlaps in the different measures, but is not drawn to scale in terms of typical relative proportions in the atmosphere. Such proportions vary from place to place and time to time. The term acid aerosols has been used to refer to acid present in the atmosphere in the vapour phase such as nitric acid. Such vapours fall outside the definition of any of these particulate measures. In rare circumstances, such as in the information of acid fogs, acid aerosols can become larger than PM10.

### 1.2.1 EMISSION OF PARTICULATE MATTER

There are few industrial processes which do not emit particulate matter and the amounts emitted vary considerably from process to process as well as in different parts of any particular process. Formulae exist for estimating the behaviour of pollution emitted from discrete sources such as coke heaps, or from materials handling processes such as grabs, excavators or conveyor belts. Methods of estimating overall emissions are more difficult and have to be designed for each individual case. It is true that a conveyor belt can be regarded as a line source of pollution, and a mechanical grab, unloading cargo from ship's hold, as generator of discrete puffs of pollution. Formulae do exist for estimating ground level concentrations from such sources but in practice it is seldom possible to apply them because such industrial sources are generally installed in heavily congested areas where nearby buildings affect dispersion of the pollution and make any accurate estimation of likely concentrations from these sources almost impossible to carry out.

### 1.2.2 HISTORY OF PARTICULATE MATTER STANDARDS

According to the National Ambient Air Quality Standard (NAAQS) review, USEPA (United States Environment Protection Agency), has set an annual average and 24-hour NAAQSs for TSP and PM10. Table 1.2 shows the historical overview of particulate matter standards. As seen from the Table 1.2 (Wolff, 1996), between 1971 and 1987, it was realised that the most important particulate matter (PM), from a health perspective, were those deposited in the thoracic region of the respiratory system. Maximum PM penetration to the thoracic region occurs during mouth breathing and deposition is restricted to those PM equal to or less than 10 μm in diameter. In nasal breathing, thoracic deposition is limited to particles less than or equal to about 1 μm in diameter. Consequently, in 1987 USEPA replaced the TSP NAAQSs with 24-hour and annual PM10 NAAQSs. Operationally, PM10 is defined by the Federal Reference Method and sampler.
In terms of sampler collection efficiency, the 10 μm cut point represents the size of the particle that is collected with a 50% collection efficiency.

Table 1.2 Historical Overview of PM NAAQSs

<table>
<thead>
<tr>
<th>YEAR</th>
<th>MEASURE</th>
<th>24-HR (µg/m³)</th>
<th>ANNUAL (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971</td>
<td>Total Suspended Particulates (TSP)</td>
<td>260</td>
<td>75</td>
</tr>
<tr>
<td>1987</td>
<td>PM10 (particulates with diameters ≤ 10µm)</td>
<td>150</td>
<td>50</td>
</tr>
<tr>
<td>1996</td>
<td>USEPA Staff recommendation :</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>i)  PM10</td>
<td>150</td>
<td>40-50</td>
</tr>
<tr>
<td></td>
<td>ii) PM2.5 (particulate with diameters ≤ 2.5µm)</td>
<td>18-65</td>
<td>12.5-20</td>
</tr>
</tbody>
</table>

The PM NAAQS is the only NAAQS that is not chemically specific, although it is understood that the toxicity of individual particles are not equal. Further, it is understood that the potential for biological responses varies with particle size. As mentioned above, for normal nasal breathing, the particle sizes of concern are generally 1 µm in diameter or less, while for mouth breathing, particles less than 10 µm in diameter are of concern. In addition, the sources of the fine particles (PM10 or PM2.5) are generally different from the sources of the coarser particles (particles ≥ 2.5µm in diameter). For example, particles less than 2.5 µm in diameter are formed primarily by combustion or secondary chemical reactions in the atmosphere whereas particles ≥ 2.5µm in diameter are formed primarily by mechanical processes such as construction, demolition, unpaved roads, and wind erosion. For these reasons, many have felt that fine and coarse particles should be treated as separate pollutants because different control strategies are required to address both size ranges. This logic and the health effects led USEPA staff to recommend the separate PM2.5 and PM10 NAAQSs listed in Table 1.2 (Wolff, 1996).
1.2.3 EMISSION FACTORS FOR PARTICULATE MATTER

Since different industrial processes emit differing qualities of particulate pollutants, data relating to such pollution are best presented as mass of particulate matter per unit weight of finished product. Most industrial processes employ different methods for reducing emissions and efficiencies of these will vary from process to process and industry to industry. The particulate emission factor is given by the mass of particulate matter emitted per tonne of raw material, which is used to assess the average efficiency of the control techniques in place (Buonicore, 1992). According to the Air & Waste Management Association, USA, the emission factor can be estimated using the following empirical expression:

\[
E = k(0.0016) \left( \frac{U}{2.2} \right)^{1.3} \left( \frac{M}{2} \right)^{1.4} \text{ (kg/Mg)}
\]  \hspace{1cm} (1.1a)

\[
E = k(0.0032) \left( \frac{U}{5} \right)^{1.3} \left( \frac{M}{2} \right)^{1.4} \text{ (lb/ton)}
\]  \hspace{1cm} (1.1b)

where

- \( E \) = emission factor;
- \( k \) = particle size multiplier (dimensionless);
- \( U \) = mean wind speed, m/s; and
- \( M \) = material moisture content (%).

The particle size multiplier, \( k \), varies with aerodynamic particle diameter, as shown in Table 1.3.
Table 1.3 Aerodynamic Particle size Multiplier (k) (Buonicore, 1992)

<table>
<thead>
<tr>
<th>&lt;30 micrometre</th>
<th>&lt;15 micrometre</th>
<th>&lt;10 micrometre</th>
<th>&lt;5 micrometre</th>
<th>&lt;2.5 micrometre</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.74</td>
<td>0.48</td>
<td>0.35</td>
<td>0.20</td>
<td>0.11</td>
</tr>
</tbody>
</table>

In the iron & steel industry, the emission factor depends upon the efficiency of the control techniques applied for particulate emission. This in turn helps to show whether the process is meeting the regulations. However, emphasis cannot be placed solely on the selection and efficiency of the control device for criteria pollutants, it is also necessary to consider the full range of air pollutants that may be emitted. There are other factors that also need to be considered, ie., capture efficiency of the entire system, and the energy efficiency, cost effectiveness, and ease of maintenance and reliability of the control system.

1.3 HEALTH EFFECT STUDIES

Although individual particulate matter (PM) health effect studies have focussed on a variety of end-points, the epidemiological studies that focused on human mortality are primary focus of this discussion. There were two types of PM-mortality studies that have been cited by USEPA (Wolff, 1996). The first were the short-term, acute mortality studies which compared the daily PM and mortality time series in various locations around the United States. After filtering out or accounting for the effects of such things as seasonality, day of the week, meteorology, etc., on mortality, the remaining statistical relationship between daily PM and daily mortality was quantified. Although this relationship varied from location to location, the average value was on the order of a 4% increase in daily mortality with a 50 \( \mu g/m^3 \) increase in PM10 concentrations and there appeared to be no evidence for a threshold concentration (USEPA 1995, 1996a, and 1996b).

The second type of epidemiological study was the long-term prospective cohort studies where the health status of certain groups (cohorts) of individuals was followed for a number of years in various locations in the United States. In these studies, the annual mortality rate in a given location was related to the annual average PM10 or PM2.5 concentrations after the mortality rates have been adjusted for smoking and some other potential confounding variables. Of the three studies, two showed a positive relationship to annual mortality and PM, and attribute two to three times the number of deaths to PM as the short-term acute effect.
studies. The third study showed no PM-mortality relationship but the USEPA dismissed this study for a number of reasons including its lower statistical power (smaller sample size). USEPA used the higher mortality estimates from the two studies to conclude that there are premature deaths due to chronic exposure to PM, in addition to the deaths due to acute exposure identified in the time-series studies. In addition, USEPA also concluded that the mortality was due to PM2.5 rather than the coarse fraction of the PM10 (Public Health Service, 1969).

1.4 ANALYSIS OF PARTICULATE MATTER

Airborne particles may be collected by impingers, electrostatic precipitators or filters. Filters are preferable because of their ease of use and high efficiency of collection for small particles. Glass fibre filters allow very fast passage of air and are used with high volume air samplers. Sampling of particulate matter from gas streams such as stack gases should be isokinetic, but for sampling relatively stagnant ambient air this is not essential and generally not feasible as wind velocity and direction are seldom constant.

1.5 AIM OF THESIS

The aim of this study is to determine the relationship between Total Suspended Particulates (< 50 μm) and Particulate Matter with an aerodynamic diameter of 10 μm and less, which are considered as inhalable particles. This will determine the percentage constituent of PM10 in TSP, so that when TSP is measured, one can know the constituent of PM10 in TSP, when generated. The results of this study has shown that these particulates are highly correlated, irrespective of wind velocity and direction. An overview has been presented with respect to the iron & steel industry located at Port Kembla, NSW, Australia.

1.6 SCOPE OF THE THESIS

This project was conducted in association with BHP Steel, Australia, with their Port Kembla division. The concentrations of TSP and PM10 were studied as generated from a typical steel plant. In the thesis, as discussed in Chapter 2, an intensive search have determined that such a relationship study had not been carried out earlier. However, there have been some studies on the relationship between PM10 and PM2.5 (aerodynamic diameter of 2.5 microns) in the USA. In Chapter 3, a brief description on the instrument used for measurement of
concentrations of TSP and PM10 is outlined. Procedural details of the experiments are also
discussed. In Chapter 4, results obtained in the field are indicated. A detailed analysis of the
data obtained is given, followed by a brief discussion on the results. In Chapter 5,
conclusions are drawn from the study and further recommendations are made to improve the
analysis so that when compared with similar conditions, it does produces similar results.
CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

This chapter focuses on the work undertaken on particulate matter with an aerodynamic diameter of 10 microns (PM10), total suspended particulates (TSP), and related particulates such as coarse particulates ($2.5\langle d_a \rangle 10\mu m$) and particulate matter with an aerodynamic diameter of 2.5 microns (PM2.5). An attempt has been made to determine the relationship between them. However, it has been found that so far, no such relationship has been developed between TSP and PM10. Nevertheless, related works have been explored and discussed in this chapter.

Firstly, it describes briefly on particulate matter, its sources, sampling and air pollution with respect to particulate matter in Sydney, and then it is followed by description on the related topics. In addition, attempt has also been made to describe the particulate matter generated by a steel plant.

2.2 SOURCES AND DISTRIBUTION

There are basically three main sources of particulates: natural continental aerosols, natural oceanic aerosols, and man made aerosols. Natural continental aerosols arise from natural sources and include the following (Stern Vol. I & III, 1976):

i) Particles from dust storm and desert area, with sizes ranging above $0.3 \mu m$ in radius.

ii) Particles from photochemical gas reactions between ozone and hydrocarbons that are derived in plants with sizes ranging less than $0.2 \mu m$ in radius.
iii) Particles from photochemical reactions between trace gases such as SO₂, H₂S, NH₃ and O₃ or atomic oxygen. The reactions depend upon humidity and the presence of other particulates.

iv) Particles from volcanic eruptions which emit particles of all sizes in addition to trace gases, especially SO₂, which may become a particulate in the atmosphere.

Natural oceanic aerosols are particles that arise from evaporation of ocean water thrown into the atmosphere in the form of spray. They have the same composition as sea salt, with sizes ranging above 0.3 \( \mu m \).

Man made aerosols arise from combustion processes, either from stationary sources or mobile sources, such as automobiles, railroads, etc., and can be characterized as follows (Still, 1990):

i) Particulates from smoke i.e., solid particles resulting directly from combustion.

ii) Particulates from photochemical gas reactions between unburned or partially burned organic fuel and oxides of nitrogen in the atmosphere.

iii) Particles from photochemical reactions between SO₂ and ozone or atomic oxygen in the atmosphere.

The number of small particles (less than 0.1 \( \mu m \)) per unit volume falls off with increasing altitude, while concentration of large particles (0.1-1 \( \mu m \)) shows a maximum at about 18 km, indicating that these particles are formed in the stratosphere. It is believed that these particles originate from the oxidation of gaseous SO₂ and formation of sulphuric acid mists.

It is interesting to note that large particles (with radius between 0.1-1 \( \mu m \)) are involved in scattering visible radiation because their dimensions are of the same order as wavelengths in the visible region. These particles and as well as for particles having radii of less than 0.1 \( \mu m \), are sufficiently small to be influenced by Brownian motion of air molecules and thus may remain suspended for long times and travel over large distances. Particles larger than 10 \( \mu m \) rapidly settle out of the air by sedimentation, a process best described by Stokes’s law.
The diameters of airborne particles range from about $6 \times 10^4 \, \mu m$, to about $10^3 \, \mu m$. According to Stokes’s law, the terminal velocity or settling velocity is given by (Cheremisinoff et al., 1978):

$$V \ (cm/s) = \frac{2ga^2(d_1 - d_2)}{9\eta}$$

(2.1)

where,
- $a =$ particle radius, cm;
- $d_1 = d_2 =$ the sphere and medium densities, g/cm$^3$;
- $\eta =$ the medium viscosity in poises (dynes/cm$^2$); and
- $g =$ acceleration due to gravity, cm/sec$^2$.

For a particle density of 1, at $10 \ \mu m$ diameter, the settling rate is significant, 0.3 cm/sec, and at $1000 \ \mu m$ it is substantial, 390 cm/sec, relative to normal turbulence of air masses (Cheremisinoff and Morresi, 1978).

### 2.3 PARTICULATE MATTER SAMPLING

The collection of an accurate and adequate sample from a gaseous medium is a complicated process. The design of the sampling programme so that the best possible samples are collected is one of the foremost steps in evaluating air pollution and monitoring the control programme.

#### 2.3.1 STEPS IN SAMPLING

Four important steps should be followed for determining particulate matter. They are described as follows (Instrumentation for Monitoring Air Quality, 1974):

a) Size of sample: The size of the particulate matter need to be determined since airborne particulates or aerosols consist of either liquid or solid particles in diameter from 0.001 $\mu m$ or less, up to about 100 $\mu m$. 


b) Rate of sampling: The sampling rate is determined by the collecting equipment employed. The instruments and sampling rates are selected to meet the requirements of the project. The final criterion in selecting the sampling rate is the efficiency of collection at the rate required to provide an adequate sample.

c) Duration of sample: The duration of sampling is usually for 24 hours. Factors which affect the minimum possible duration include: i) the significant concentration that will be encountered, ii) permissible rate of sampling, and iii) lower limit used for analytical procedure.

d) Collection limitations: The collection efficiency of a sampling system is usually determined on the basis of either; a) the weight of particles collected; b) a count of the particles removed; or c) the changes in colour of a filter. If particulate matter measured is high in the number of large particles, the efficiency of its removal on a weight basis may be very high. Efficiency on a count basis usually gives much lower results if large particles are present. It may be possible to give an efficiency of 99.99% on a weight basis and only 50 or 60% on a particle count basis. The method of determining the efficiency will depend upon the ultimate use of the data. If fine particles are of significance, a count analysis may be indicated, but if only the total weight of the particulate matter is of interest, a weight analysis should be made (Torvella, 1994).

The above steps are followed in all the development of a sampling programme for particulate matter.

2.4 AIR POLLUTION IN NEW SOUTH WALES, AUSTRALIA

Problems of air pollution, like dust fall-out, suspended particles and acid gases, have improved to levels which fall consistently below World Health Organization’s long-term goals. However, other pollution, like photochemical smog and brown haze are matter of concern for metropolitan Sydney. The control of odour and toxic emissions requires immediate attention and has got to go a long way as far as EPA’s standards are concerned (WHO 1976, and McGuinness, 1985).
2.4.1 PARTICULATES IN SYDNEY

Sydney’s brown haze is caused by very fine particles suspended in the atmosphere. These particles scatter and absorb light to produce brown-coloured haze which is prevalent during the colder months from May to September. It has been found that the sources of these fine particles are 45% from motor vehicle exhausts, 35% from domestic refuse burning, and 20% from industrial combustion (McGuinness, 1985). There has been reduction of particulate emissions from motor vehicles in the Sydney region after introduction of catalytic converters and the use of unleaded petrol. Figure 2.1 shows the suspended matter concentration in Sydney (McGuinness, 1985).

Now the EPA and local councils favour a total ban on all domestic waste burning, but this would mean upgrading domestic waste collection, and greater expense for councils. Industrial combustion has been controlled by utilising expensive control measures. The soot emissions from coal-burning units were much higher than those from units using gas or oil. Accordingly, any widespread return to burning coal as cheaper source of energy would significantly worsen fine particulate pollution.
2.5 DISCUSSION ON RELATED TOPICS

Even though exact relationship study between TSP and PM10 has not been found in the open literature, there have been some studies which are related to this project, and which highlight some interesting results obtained from such studies. They are briefly described below.

2.5.1 RELATIONSHIP BETWEEN PM2.5, COARSE PARTICULATE AND PM10 CONCENTRATIONS.

The study to determine the relationship between PM2.5 (particulates with a diameter of 2.5 microns), coarse particulate \(2.5 \langle d_\alpha(10\mu m)\rangle\), and PM10 (dia of 10 microns) concentrations was carried out by the USEPA's Atmospheric Research and Exposure Assessment Laboratory, and School of Public Health, Harvard University, during the summers of 1992 and 1993 (Burton et al., 1996). They also analysed the spatial variation of these particulates and compared their findings with those made in an earlier study of sulphate ion \((SO_4^{2-})\) concentrations. The particle mass concentrations were measured at eight sites located within metropolitan Philadelphia, USA. They found that PM2.5 and PM10 concentrations were uniform across Philadelphia, which suggested that concentrations measured at a single monitoring site were able to characterize particulate concentrations across a large area.

The parameters that were taken into consideration were wind direction, relative humidity, and temperature. These were measured hourly at all sites. Sites were selected based on their population densities. The purpose of this kind of selection was to ascertain the level and concentration of the particulates in residential areas in order to understand their affect on health. As per EPA guidelines, the samples were collected for a 24-hour period and samplers were placed at a height (as specified by EPA) to collect the particulates. The flow rates were 10 L/min using inertial impactors. All filter papers were weighed using electronic microbalances, and in order to ensure consistent values for mass, the filters were weighed under controlled temperature \((18 - 24^\circ C)\) and relative humidity \((40\pm 5\%)\) conditions. However, in order to eliminate the effects of static charge, filters were passed over polonium sources \((\alpha\text{-rays})\) prior to weighing (Burton et al., 1996).
In this research, it was found that the coarse particulate concentrations were found to vary spatially with population density within Philadelphia. Coarse particulate levels also varied by day of the week, as weekday levels were higher than weekend levels. Statistical analysis using Pearson Correlation Coefficients, one-way analysis of variance (ANOVA) and univariate regression, show the following results:

1) Wind speed and temperature were found to differ by wind direction using ANOVA and Tukey HSD procedures. Figure 2.2 shows the concentrations stratified by day of week.

![Graph showing PM2.5, PM10, coarse particulate concentrations stratified by day of the week.](image)

**Figure 2.2.** PM2.5, PM10, coarse particulate concentrations stratified by day of the week, respectively. Samples collected were at eight sites located in Philadelphia, PA, USA, during the summer of 1992 and at seven of these sites during the summer of 1993 (Burton et al., 1996).

2) Neither population density nor distance from the city centre were correlated to PM 2.5, coarse particulates, or PM 10 concentrations.

3) Particulate concentrations were found to differ significantly with respect to wind direction using ANOVA and Tukey HSD procedures.
4) When stratified by wind direction, mean PM2.5 concentrations did not vary by site or population density as regression of mean PM2.5 showed insignificant slopes. Similar results were also for PM10. Regression of mean PM10 concentrations on population density for all wind directions showed insignificant slopes for southerly and westerly winds. However, regression of mean PM10 concentrations on population density yielded significant slopes from east and north winds. For these wind directions, PM10 concentrations increased by 4 \( \mu g/m^3 \) with every 10,000 persons/mi\(^2\). Coarse particulate concentrations were different for different wind directions as concentrations were highest when winds were from the south and west. Figure 2.3 shows the regression lines of PM2.5, PM10, and coarse particulate concentrations on population density.

![Figure 2.3a. Regression lines of mean summertime, PM2.5 fine particle (d<sub>0</sub>\( \leq 2.5\mu m \)) concentration on population density. Mean concentrations stratified by wind direction. Data collected in Philadelphia, PA, during the summers of 1992 and 1993 (Burton et al., 1996).](image-url)
Figure 2.3b. Regression lines of mean summertime PM10 \( (d_a<10\mu m) \) concentrations on population density. Mean concentrations stratified by wind direction. Data collected in Philadelphia, PA, during the summers of 1992 and 1993 (Burton et al., 1996).

Figure 2.3c. Regression lines of mean summertime coarse particle \( (2.5<d_a<10\mu m) \) concentrations of population density. Mean concentrations stratified by wind direction. Data collected in Philadelphia, PA, during the summers of 1992 and 1993 (Burton et al., 1996).
5) PM10 comprises approximately 75% of PM2.5 and thus the results indicated a strong correlation between PM10 concentrations and PM2.5 concentrations. Coarse particulates comprises the remaining 25% of PM10 and were less strongly correlated with PM10 concentrations. It was important to note that factors such as day of the week, population density and location did not affect PM2.5 concentrations. Correlation coefficients for pairwise comparison showed PM10 and PM2.5 concentrations to be highly correlated for all eight sites. Correlation between the sites’ coarse particulates concentrations were weaker. PM2.5, PM10 and coarse particulates concentrations were found to be uniform within Philadelphia but were found to vary with wind direction. Figure 2.4 shows the composition of PM10 concentration in Philadelphia, USA (Burton et al., 1996). In this figure, sulphate-related fine particles represented a fraction of PM10 that was comprised of sulphate ions, ammonium ions and hydrogen ions or 48%, while non sulphate fine particles represented the fraction of PM10 that was comprised of non sulphate ions fine particles or 26%. Coarse particles consisted of 26% of PM10. This data represented averages for the two summers.

![Pie chart showing PM10 composition](image)

Figure 2.4. Composition of PM10 in Philadelphia, PA, during the summers of 1992 and 1993 (Burton et al., 1996).

In the above study, emphasis was on PM10, PM2.5, and coarse particle concentrations rather than on the total suspended particles liberated in the city of Philadelphia.
2.5.2 PRESENCE OF METALS IN AIR PARTICULATES - KUWAITI OIL FIRES.

A study of the presence of nickel and vanadium in air particulates during and after the Kuwaiti oil fires of 1991 and 1992 was undertaken by Water Resources and Environment Division, The Research Institute, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia (Sadiq and Mian, 1994). Both TSP and PM10 air particulates were collected during and after the Kuwait oil fires from March 1991 to July 1992 using high volume air samplers. This study indicated the presence of nickel and vanadium metals in the air particulates and because of their biotoxicity potentials, the determination of these metals helped to understand the adverse ecological effects due to the Kuwaiti oil fires.

The method adopted for collecting the samples was same (including the instrument) as used in section 2.5.1, except, there was an addition of a few chemical reagents for metal determination to the sample paper after running it through the High Volume Air Sampler. Analysis of the findings were not as exhaustive as pictured above, however, the results showed some interesting features of TSP and PM10. They are described as follows:

a) The data collected showed that on volume basis, the TSP contained slightly higher concentration of nickel and vanadium than the inhalable fraction PM10, of total air particulates sampled.

b) The monthly mean concentrations both on volume and weight basis of nickel in the air particulate samples are shown in Figure 2.5.
Figure 2.5a. Monthly mean concentrations (on volume basis) of nickel in the air particulate samples (Sadiq and Mian, 1994).

Figure 2.5b. Monthly mean concentrations (on weight basis) of nickel in the air particulate samples (Sadiq and Mian, 1994).

c) The monthly mean concentrations both on a volume and a weight basis of vanadium in the air particulate samples are shown in Figure 2.6.
Figure 2.6a. Monthly mean concentrations (on volume basis) of vanadium in the air particulate samples (Sadiq and Mian, 1994).

Figure 2.6b. Monthly mean concentration (on weight basis) of Vanadium in the air particulate sample (Sadiq and Mian, 1994).
The data revealed a high correlation between TSP and PM 10. Thus the mean monthly concentrations of nickel and vanadium in the PM 10 particulate samples followed a similar trend to that of the TSP samples. It is interesting to note that on the monthly mean concentration on a weight basis, the concentration of PM10 was higher than TSP for both the nickel and vanadium metals. Figure 2.7 shows a comparison of concentrations of nickel and vanadium during those months of the years 1982, 1991 and 1992, when they are considered to be the highest.

Figure 2.7a. A comparison of nickel concentrations in air particulate samples collected during 1982, 1991 and 1992 (Sadiq and Mian, 1994).

Figure 2.7b. A comparison of vanadium concentrations in the air particulate samples collected during 1982, 1991 and 1992 (Sadiq and Mian, 1994).
This study states that both nickel and vanadium, if inhaled in large quantities and for a prolonged period, can adversely affect human health (WHO, 1976). Repeated exposure to nickel oxide above 4 g m\(^{-3}\) air produces pulmonary inflammation and fibrosis. Exposure to insoluble nickel compounds is controlled at 50 \(\mu g/m^3\) air. Vanadium, if occurring at high concentrations in air particulate (as vanadium pentoxide), could produce acute irritation of the eyes and respiratory tract. Exposure in excess of 0.5 mg/m\(^3\) air to vanadium particles of respirable size, PM10, has caused conjunctivitis, nasopharyngitis, and signs of pulmonary irritation and broncospasm, lasting in some cases for several days (USEPA, 1976, and USEPA, 1977). Long term exposure to vanadium concentrations higher than 1 \(\mu g/m^3\) air may induce adverse health effects, according to World Health Organization (Cordoasco et al., 1995).

From this study, it was found that concentrations of nickel and vanadium were below the limits and therefore, it can be anticipated that these elements in air particulates were not a health concern during and after the Kuwaiti oil fires.

### 2.5.3 PARTICULATE MONITORING - KUWAITI OIL FIRES

Another study on particulate monitoring during the Kuwaiti oil fires was done by the Water Resources and Environment Division, The Research Institute, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia (Husain and Amin, 1994). This research was assisted by the U.S. Air Team and the Meteorology and Environmental Protection Administration (MEPA), Saudi Arabia. This study dealt with the determination of the statistical trend of the inhalable PM10 and the suspended particulate matters in the air during the Kuwaiti oil fires in the Eastern Province of Saudi Arabia. They also did a comparison on the particulate concentration. An attempt was also made to correlate the PM10 concentrations and TSP.

It was carried out at various locations in Saudi Arabia and in Kuwait, where the frequency of monitoring was done on a daily basis at some places. The purpose was once again, to study the adverse effect on human health since these PM10 sized particles can easily penetrate the lower region of the respiratory tract and can cause severe health problems. The method used for particulate monitoring and the procedure adopted were similar to the method as discussed above in sections 2.5.1 and 2.5.2.
Some interesting results were obtained which are discussed below:

a) About 50% of the PM10 and TSP values were above 200 and 500 μg/m³, while the permissible limit set by MEPA was 340 μg/m³. This occurred in May 1991. In June 1991, 50% of the PM10 and TSP were above 250 and 800 μg/m³ respectively, which again exceeded the permissible limit (Husain and Amin, 1994).

b) Particulate data was classified with wind speed between 2.5 m/s and 6.5 m/s. It then indicated that for wind speed greater than 5.5 m/s, the PM10 concentrations were in the range of 450 - 500 μg/m³, while for wind speed between 2.5 and 5.5 m/s, the concentrations were in the range of 100 - 150 μg/m³. Thus, for high wind speed, the concentrations of inhalable particulates were high, which was definitely an area of concern. Figure 2.8 shows the mean particulate concentration with respect to wind velocity (Husain and Amin, 1994).

![Figure 2.8. Mean particulate concentration of PM10 in relation to wind speed in Dhahran in 1991. The mean values varied from 25 percentile to 75 percentile (Husain and Amin, 1994).]
c) Particulates were also classified with the wind direction. In one particular place in Dhahran it was found that the concentrations were high when the wind was from the north, north-northwest, and northwest. The concentrations were lowest when wind was from the east and southeast directions. Figure 2.9 shows the variation of PM10 concentration with respect to wind direction.

![Figure 2.9](image-url)

**Figure 2.9.** Concentration of inhalable particulate matters (PM10) in relation to wind direction in Dhahran in 1991 (Husain and Amin, 1994).

d) Particulate concentrations were measured during and after the Kuwaiti oil fires and the data showed that in May 1992, which was after the oil fires, the concentrations decreased by 10-15% while in June and July it decreased in the range of 5-10%. This shows that there was very little decrease in the concentrations of particulates which indicated that most of the inhalable particulate concentrations were not related to oil fires.
e) Organic and inorganic constituents were also analysed and it was observed that the concentrations of metals and hydrocarbons were usually low. Metals such as lead and nickel and the organic matters such as benzo(a)pyrene were found to be high but below the permissible limits.

f) On comparing the results between TSP and PM10, it was found that the concentration of TSP was around 600 $\mu g/m^3$, which was beyond the permissible limit, while the concentration of PM10 was 250 $\mu g/m^3$. Figure 2.10 (Husain and Amin, 1994) shows the comparison between PM10 and TSP values and Figure 2.11 (Husain and Amin, 1994) indicates the mean values of inhalable particulate concentration.

![Figure 2.10. Comparison between PM10 and TSP values in Dhahran (May-December 1991) (Husain and Amin, 1994).](image)
Figure 2.11. Mean values of PM10 concentration in Dhahran (April - November 1991). The mean values varied from 25 percentile to 75 percentile (Husain and Amin, 1994).

The above study was inclined towards the particulate concentration generated due to oil fires, rather than on the generation of particulate matter on a daily basis. The relationship between TSP and PM10 was limited to the value of the concentration and whether these values were above or below the permissible limit. The quantitative relationship was not determined nor there was derivation of any mathematical relationship. However, the study did reflect on the particulate matter generated, especially the inhalable particulates, PM10, when the situation like oil fires occurred. The study of this parameter during such incident was really significant in that part of the world.
2.5.4 PM10 SOURCE APPORTIONMENT STUDY

The Desert Research Institute, Nevada, USA, carried out a PM10 apportionment study at Bullhead City, situated near a 1,580 MW coal-fired power plant. In this study, it was found that the major contributors to primary PM10 were geological dust, coal dust, mobile vehicle exhaust, secondary sulphates and nitrates, and coal-fired power plant emissions. This region experienced elevated particulate concentrations from unknown sources. Due to close proximity, it was assumed that aerosols were being transported over long distances, such as from Los Angeles, California. Based on the infrequency of plume contact at sites in the valley, as determined by SO₂ measurement, it was believed that the contribution of the power plant to primary PM10 was minimal, and that fugitive dust was the primary source of ambient particulate matter (Gertler et al., 1996).

To evaluate the magnitude of source contributors, PM10 measurements were made using a medium-volume sampler for a period of more than one year. The aerosol filter samples were analysed for mass, elements, ions, and carbon. Source apportionment using the Chemical Mass Balance receptor model was performed and following results were obtained (Gertler et al., 1996):

a) On average, geological dust was the major contributor to PM10 (79.5%), followed by primary motor vehicle sources (16.7%), secondary ammonium sulphate (3.5%), secondary ammonium nitrate (0.1%), and primary coal-fired power plant emissions (0.1%).

b) The average PM10 concentration was 43.8 μg/m³ and the maximum was 148.9 μg/m³. Neither the annual nor the 24-hour PM10 standards were exceeded during the monitoring programme.

c) Concentrations of nitrate, sulphate and ammonium were low, averaging 0.75, 1.73, and 0.43 μg/m³, respectively. Concentrations of organic carbon and elemental carbon were higher, averaging 6.00 and 1.94 μg/m³, respectively.

d) Concentrations of the crustal elements Al, Si, and Fe were quite high, averaging 2.61, 8.27, and 1.23 μg/m³, respectively. Selenium, which was used as a marker of coal combustion emissions, was detected in 24 of 64 samples.
In this study, a Chemical Mass Balance (CMB) receptor model was used, which solved a set of linear equations, each expressed as a chemical concentration measured at a receptor as the sum of the products of the chemical’s source compositions (profile) and source contributions. The source profiles consisted of the fractional abundances with respect to PM10 mass of ions, carbon, and elements in the source emissions. The solution for the source contributions was obtained from a weighted, least squares multiple regression. The weighting was by effective variances, which were calculated from the measured uncertainties in the receptor concentrations and source compositions. This approach provided a realistic estimate of the source contributions (Gertler et al., 1996).

However, in most cases, the primary aerosol contributions of local and distant mobile sources and distant coal-fired power plants could not be distinguished by CMB using a single sampling site. Profiles for pure compounds of ammonium sulphate, ammonium bisulphate, and ammonium nitrate were also included to account for secondary sulphate and nitrate, which were not represented by the primary source profiles. Figure 2.12 shows the source contribution of PM10.

![Figure 2.12](image)

**Figure 2.12.** Average CMB source contributions to PM10 in Bullhead City, USA (Gertler et al., 1996).
In this study, CMB source contribution estimated were similar for all but periods with the lowest PM10 concentrations. Fugitive dust from sources dominated the PM10 aerosol. Further, relative source contribution for sample periods with the highest PM10 concentrations were similar to those estimated on average.

2.6 PARTICULATE EMISSION FROM AN IRON & STEEL INDUSTRY

Particulate emission sources in the iron and steel industry can be generally classified as: a) process stack emission sources, b) process fugitive emission sources, and c) open dust sources. Process stack emissions are any emissions exhausted to the atmosphere through a stack, duct or flue. Process fugitive emissions and open dust sources are both defined as any emissions not entering the atmosphere from a duct, stack or flue (Englund, and Berry, 1976). Open dust sources traditionally have included a) vehicular traffic on paved and unpaved roads, b) raw material handling outside of buildings, and c) wind erosion from storage piles and exposed terrain, while all other nonducted sources have been classified as process fugitive emissions (Parker, 1978).

The major processes which contribute to particulate emission are described below (Cuscino, 1979). These particulate emissions results in total suspended particulates (TSP), particulate matter of 10 microns (PM10), coarse particulates, and particulate matter of 2.5 microns. The parameters like, TSP, and PM10, which were studied in this project, are usually generated from these processes. A brief description of the processes are mentioned in order to elucidate the exact sources of TSP, and PM10, so that when these processes are analysed closely, the exact relationship between the two parameters can be examined.

By-product coke oven process: Coking is the process of heating coal in an atmosphere of low oxygen content, i.e., destructive distillation. During this process, organic compounds in the coal break down to yield gases and a residue of relatively nonvolatile nature. The integrated iron and steel plant produces coke using the by-product process. This process will not be found at plants which produce steel only via the electric arc furnace process. Plants producing steel via the basic oxygen furnace or open hearth furnace process will normally have a coke plant. The by-product process is oriented toward the recovery of the gases produced during the coking cycle (Buonicore, 1992).
Sintering process: Sintering provides a method of agglomerating the fine-sized raw materials that are input to the blast furnace. This reduces the occurrence of "bridging" in the blast furnace and the subsequent occurrence of blast furnace slips. In this process fine iron ores are fused with coke and flue dust at temperatures between 1300\(^\circ\) and 1480\(^\circ\) C. The sinter bed is ignited on the top surface in the furnace. The fused sinter is discharged from the end of the sinter machine where it is crushed and screened. The larger material is cooled and screened again before being input to the blast furnace (Buonicore, 1992).

Iron manufacturing process: Iron is produced in blast furnaces, which are refractory-lined chambers into which iron in the form of natural ore, or agglomerated products such as pellets or sinter, coke, and limestone are charged and allowed to react with large amounts of hot air to produce molten iron. Slag and blast furnace gases are by-products of this operation. The production of 1 unit weight of iron requires an average charge of 1.7 units of iron bearing charge, 0.55 units of coke, 0.20 units of limestone, and 1.9 units of air. Blast furnace by-products consists of 0.3 units of slag, 0.05 units of flue dust, and 3.0 units of gas per unit of pig iron produced. The coke used in the process is produced in the by-product coke ovens. The flue dust and other iron ore fines from the process are converted into useful blast furnace charge via sintering operations (Buonicore, 1992).

Basic Oxygen Furnaces: The basic oxygen process is employed to produce steel from a furnace charge composed. On average, 70% molten blast furnace metal and 30% scrap metal by use of a stream of commercially pure oxygen to oxidise the impurities, principally carbon and silicon. Cycle time for the basic oxygen process ranges from 25 to 45 minutes. There is much carbon monoxide (CO) produced by the reactions in the furnace. This CO can be combusted at the mouth of the furnace and then vented to gas cleaning devices as in the case with the open hood, or the combustion can be suppressed at the furnace mouth as in the case with the closed hood (Buonicore, 1992).

Open-hearth furnaces: In this process, a mixture of scrap iron and steel, and hot metal (molten iron) is melted in a shallow rectangular basin or 'hearth'. Burners producing a flame above the charge provide the heat necessary for melting. This process may or may not be oxygen lanced and this effects the process cycle time which is approximately 8 hr or 10 hr, respectively (Buonicore, 1992).
Scarfing: Scarfing is a method of surface preparation of semi-finished steel. A scarfing machine removes surface defects from the steel billets, blooms, and slabs before they are shaped or rolled by applying jets of oxygen to the surface of the steel which is at orange heat thus removing a thin layer of the metal by rapid oxidation (Cuscino, 1979).

Miscellaneous combustion sources: Iron and steel plants require energy in the form of heat or electricity for every plant operation. Some energy intensive operations that produce particulate emissions on plant property are boilers, soaking pits and slab furnaces burning such as fuels as coal, fuel oil, natural gas, coke oven gas, or blast furnace gas. In soaking pits, ingots are heated such that the temperature distribution across the cross-section of the ingots is acceptable and the surface temperature uniform for further rolling into semi-finished products such as blooms, billets, and slabs. In slab furnaces, a slab is heated before being rolled into finished products such as plate, sheet or strip (Cuscino, 1979).

Open dust source processes: As discussed above, vehicular traffic consists of plant personnel and visitor vehicles, plant service vehicles, and trucks for hauling raw materials, plant deliveries, steel products, and waste materials. Raw material is handled by clamshell buckets, bucket-ladder conveyors, rotary railcar dumps, bottom railcar dumps, front-end loaders, truck dumps, and at conveyor transfer stations. All these activities disturb the raw materials and expose the fines to the wind. Even fine materials resting on flat areas or in storage piles are exposed to the wind. It is not unusual to have several million tons of raw material stored at a plant nor is it unusual to have in the range of 10 to 100 acres of flat exposed area at plant. These types of sources are subject to wind erosion (Cuscino, 1979).

Thus from the above manufacturing processes, it was observed that generation of both PM10 and TSP concentrations were inevitable. However, an in-depth study of these processes will help to control their generation. Once the sources are known, their behavioural study from the source to the point where they are liberated into the atmosphere can be studied. Further, alteration of some of the processes can bring down the concentration level to a great extent. This requires an extensive study on the above manufacturing processes.
CHAPTER 3

EXPERIMENTAL PROCEDURE AND APPARATUS

3.1 INTRODUCTION

The experiment to determine the relationship between TSP and PM 10 was conducted in accordance with the Australian Standard for “Ambient Air - Particulate Matter”, AS 2724.3-1984. According to AS 2724.3-1984, Part 3, Total Suspended Particulates (TSP) and Particulate Matter with aerodynamic diameter of 10 microns (PM10) are determined by using the High Volume Air Sampler Gravimetric Method. Hence, in this experiment the apparatus used was a high volume air sampler (HVAS) for measurement of TSP and PM10 concentrations.

3.2 THEORY

The Total Suspended Particulates are the particles with an equivalent aerodynamic diameter (EAD) of less than approximately 50 \( \mu m \). The definition of EAD is that it is the diameter of a spherical particle of density 1000 kg/m\(^3\) which exhibits the same aerodynamic behaviour as the particle in question. As the name implies, PM10 are the particles with an EAD of 10 microns.

3.2.1 PRINCIPLE

Ambient air is drawn at a known flow rate through a prepared filter mounted in the specified equipment (HVAS) during a 24-hour sampling period. The sampler flow rate and the geometry of the shelter favour the collection of particles with an EAD of range, 50 and 10 \( \mu m \) depending upon wind velocity and direction. The filter is weighed (after moisture equilibration) before and after use to determine the net weight (mass) gain. The total volume
of air sampled, corrected to EPA standard conditions (25 °C, 760 mm Hg), is determined from the measured flow rate and the sampling time. The concentration of TSP and PM10 in the ambient air is computed as the mass of collected particles divided by the volume of air sampled, and is expressed as micrograms per standard cubic metre ($\mu g/m^3$). For samples collected at temperature and pressure significantly different than standard conditions, these corrected concentrations may differ substantially from actual concentrations, particularly at high elevations. The actual particulate matter concentration can be calculated from the corrected concentration using the actual temperature and pressure during the sampling period.

### 3.2.2 SCOPE AND APPLICATION

The Australian Standard sets out a gravimetric method for determining the suspended particulate matter in ambient air. The particles collected are of EAD of less than approximately less than 50 microns and 10 microns. The upper limit of the particulate matter depends upon sampling conditions, especially wind velocity and direction.

The method provides a measure of mean concentration over the sampling period employed. The sampling period is normally of 24-hour duration to account for diurnal variations. Provided that the mass of the filter is determined under carefully controlled laboratory conditions, concentrations of $1 \mu g/m^3$ and above may be determined using a 24 hour sampling period (AS2724.3-1984).

### 3.2.3 RANGE

According to the USEPA, the approximate concentration range of the method is 2 to 750 $\mu g/m^3$ for TSP. The upper limit is determined by the point at which the sampler can no longer maintain the specified flow rate due to the increased pressure drop of the loaded filter. This point is affected by particle size distribution, moisture content of the collected particles and variability from filter to filter, among other things. The lower limit is determined by the sensitivity of the balance and by inherent sources of error.

At wind speeds between 1.3 and 4.5 m/sec, the HVAS has been found to collect particles up to 25 to 50 $\mu m$, depending on wind speed and direction. For the filter specified below (see 3.3.1), there is effectively no lower limit on the particle size collected.
Similarly for PM10, the lower limit of the mass concentration range is determined by the repeatability of filter tare weights, assuming the nominal air sample volume for the sampler. For samplers having an automatic filter-changing mechanism, there may be no upper limit. For samplers that do not have an automatic filter-changing mechanism, the upper limit is determined by the filter mass loading beyond which the sampler no longer maintains the operating flow rate within the specified limits due to increased pressure drop across the loaded filter. This upper limit cannot be specified precisely because it is a complex function of the ambient particle size, distribution and type, humidity, filter type and perhaps other factors. Nevertheless, all samplers should be capable of measuring 24 hour PM10 mass concentrations of at least 300 \( \mu g/m^3 \) while maintaining the operating flow rate within the specified limits (USEPA, 1987, 1996).

3.2.4 PRECISION

Based upon collaborative testing, the relative standard deviation (coefficient of variation) for TSP for single analyst precision (repeatability) of the method is 3.0%. The corresponding value for interlaboratory precision (reproducibility) is 3.7%.

The precision of PM10 samplers must be 5 \( \mu g/m^3 \) for PM10 concentrations below 80 \( \mu g/m^3 \) and 7% for PM10 concentrations above 80 \( \mu g/m^3 \). Continual assessment of precision via collocated samplers is required for PM10 samplers used in certain monitoring networks. This is per the USEPA regulations (USEPA, 1987, 1996).

3.2.5 DETERMINATION OF TSP AND PM10 AS PER AS 2724.3

The apparatus used for the determination of TSP and PM10 is a high volume sampler as shown in Fig 3.1. As per the standard, the sampler shall be capable of passing ambient air through an approximate 40,000 mm\(^2\) portion of a clean filter having a dimension of 200 X 250 mm at a maximum air flow rate of 1.6 m\(^3\)/min. The air flow rate should not fall below 1.0 m\(^3\)/min.
Figure 3.1. High volume air sampler (HVAS).
The sampler shall be capable of continuous operation for at least 24 hours over the range of expected environmental conditions. The air flow measurement device shall be capable of being calibrated, and of providing the basis for measuring the flow rate through the filter, and subsequent calculation of the air volume sampled. Typical devices include a mass flowmeter or an orifice located in the sample air stream or a bypass rotameter. Some samplers have automatic flow control to maintain constant flow and correct for filter loading, line voltage changes, temperature and pressure. A time clock capable of controlling the operation of the sampler to within 2% of the selected time period may be used. A seven day time clock is useful for operating the sampler on pre-set days in unattended conditions (Air Pollution Measurement Manual, 1990).

A differential manometer having a range of at least 4.0 kPa (approximately 400 mm of water), graduated in 0.01 kPa divisions is used to determine the pressure. An orifice flow rate calibration unit is given a temporary connection to the system to calibrate the instrument flow measuring device. It shall consist of an orifice unit with an adaptor which connects to the inlet of the sampler, a manometer or other device to measure the orifice pressure drop and a means to vary the flow through the sampler unit (Air Pollution Measurement Manual, 1990).

The sampling site shall be selected to obtain the information required, e.g. air quality of the area or the investigation of a specific source. When the results are to be used to determine the air quality of an area, the sampling site should be representative of that area. This will basically determine the location of the instrument.

### 3.2.6 CALCULATIONS

a) Volume of air sampled: Calculate the volume of air sampled from the following expression:

\[
V = \frac{(Q_i + Q_f)}{2} \times t \times \frac{273}{T} \times \frac{p_i}{101.3}
\]  

(3.1)
where
\[ V = \text{air volume sampled, in cubic meters corrected to } 0^\circ C \text{ and } 101.3 \text{ kPa} ; \]
\[ Q_i = \text{initial flow rate, in cubic meters per minute} ; \]
\[ Q_f = \text{final flow rate, in cubic meters per minute} ; \]
\[ t = \text{sampling time, in minutes} ; \]
\[ T = \text{estimated mean, ambient temperature, in kelvins} ; \text{ and} \]
\[ p_i = \text{estimated mean, ambient barometric pressure, in kilopascals}. \]

b) TSP and PM10 concentration: Calculate the TSP concentration for each sample from the mass of particles collected on the filter and the respective volume of air sampled, from the following expression:

\[ C = \frac{(W_f - W_i) \times 10^3}{V} \]  
\( (3.2) \)

where
\[ C = \text{mass concentration of TSP and PM10, in micrograms per cubic metre} ; \]
\[ W_i = \text{initial mass of filter, in milligrams} ; \]
\[ W_f = \text{final mass of filter in milligrams} ; \text{ and} \]
\[ V = \text{volume of air sampled (from equation 3.1)}. \]

3.2.7 ACCURACY

The major sources of error are from variations in flow, wind velocity and direction relative to the orientation of the location of the instrument. The absolute accuracy of the method is undefined because of the complex nature of atmospheric particulate matter and the difficulty in determining the 'true' particulate matter concentration.

Similarly for PM10 because the size of the particles making up ambient particulate matter varies over a wide range and the concentration of particles varies with particle size, it is difficult to define absolute accuracy of PM10 samplers. It is however, believed that the accuracy is within ± 20% (USEPA, 1987, 1996).
3.2.8 INHERENT SOURCES OF ERROR

According to the USEPA, there are some inherent sources of error which need to be taken into account before the measurements are made. Some of the important sources of error are described below briefly:

a) Airflow variation: The error resulting from the nonconstant flow rate depends on the magnitude of the instantaneous changes in the flow rate and in the particulate matter concentration. Normally, such errors are not large, but they can be greatly reduced by equipping the sampler with an automatic flow controlling mechanism that maintains constant flow during the sampling period (USEPA, 1987, 1996). In the event the sampler is not equipped with a constant flow controller, use of continuous flow recorder is recommended.

b) Humidity: The collected particulate matter may be hygroscopic, therefore, moisture conditioning procedures may be necessary, which may eliminate error due to moisture.

c) Filter handling: Careful handling of the filter is necessary to avoid errors due to loss of fibres or particles from the filter. A filter paper cartridge or cassette used to protect the filter can minimize handling errors.

d) Timing errors: Errors in the nominal 1440 minutes sampling period may result from a power interruption during the sampling period or from the discrepancy between the start or stop time recorder on the filter information record and the actual start or stop time of the sampler. Such discrepancies may be caused by i) poor resolution of the timer set-points, ii) timer error due to power interruption, iii) missetting of the timer, or iv) timer malfunction. In general, digital electronic timers have much better set-point resolution than mechanical timers, but require a battery back-up system to maintain continuity of operation after a power interruption. A continuous flow recorder or elapsed time meter provides an indication of the sampler run-time, as well as indication of any power interruption during the sampling period and is therefore recommended (USEPA, 1987, 1996).
3.2.9 METHOD FOR CALIBRATING AIR FLOW MEASURING DEVICE

The following apparatus are required to calibrate the air flow measuring device in order to determine TSP and PM10 in ambient air:

a) A differential manometer, and
b) An orifice flow rate calibration unit with adaptor.

The procedure shall be as follows:

a) Operate the high volume sampler with a clean filter for at least 5 minutes.
b) Remove the filter and attach the flow measuring device, and read the indicator.
c) Operate the high volume sampler for four different but constant air flows.
d) Record the reading of the differential manometer on the orifice calibration unit and simultaneously record the readings of the flow measuring device at each flow.
e) Measure the atmospheric pressure and temperature.
f) Convert the differential manometer readings to the cubic meter per minute, $Q_1$ at $0^\circ\text{C}$ and 101.3 kPa.
g) Calculate the corrected flow rate from the following expression:

$$Q_2 = Q_1 \left( \frac{T_1 P_1}{T_2 P_2} \right)$$

where

- $Q_2$ = corrected flow rate, in cubic meters per minute at $0^\circ\text{C}$ and 101.3 kPa;
- $Q_1$ = flow rate during high volume sampler calibration, in cubic meters per minute;
- $T_1$ = absolute temperature during orifice unit calibration, in kelvin;
- $T_2$ = absolute temperature during high volume sampler calibration, in kelvin;
- $P_1$ = barometric pressure during orifice unit calibration, in pascals; and
- $P_2$ = barometric pressure during high volume sampler calibration, in pascals.
3.2.10 METHOD FOR CALIBRATION OF ORIFICE FLOW RATE

The procedure shall be as follows:

a) Draw air through the unit and using the manometer, measure the differential pressure across the orifice plate for a range of resistances applied sequentially.

b) Determine the flow rate corresponding to each resistance either by referring to the calibration graph of differential pressure versus air flow rate or by means of the following equation:

\[
Q = 60 \left[ \frac{YFA\sqrt{2g_e\rho\Delta p}}{\rho} \right] \tag{3.4}
\]

where

- \( Q \) = flow rate of air in cubic meters per minute;
- \( Y \) = expansion factor which for the conditions applying in this calibration may be taken to have a value of 1.0;
- \( F \) = flow coefficient which for the range of orifice diameters and for the flow rates typical of this calibration, may be taken to have a value of 0.62;
- \( A \) = area of orifice, \( m^2 \);
- \( g_e = 1.0 \frac{kg \cdot m}{Ns^2} \) This is a factor which serves the purpose of providing dimensional consistency when using a 4-fold system of dimensions, namely force, mass, length and time. (It is not a gravitational term either in numerical value or in dimensional units);
- \( \rho \) = density of ambient atmosphere, in kilograms per cubic metre, which is calculated from the following equation; and
- \( \Delta p \) = differential pressure across the orifice plate as measured by the U-tube manometer, in pascals (10 mm of water = 98.03 Pa.).
Since in the Equation (3.4), \( Y=1.0 \) and \( F=0.62 \) and \( g_c \) has a numerical value of 1.0, it can rewritten in the following form:

\[
Q = \frac{37.2A\sqrt{2\rho \Delta p}}{\rho} \tag{3.5}
\]

In this experiment only the flow measuring device was calibrated.

### 3.3 EXPERIMENTAL APPARATUS

The apparatus used in this experiment are: a) filter papers, b) high volume air samplers, c) 10 \( \mu \text{m} \) size selective inlet, d) dessicator box, e) weighing pan, f) plastic bags, and g) labels.

#### 3.3.1 FILTER PAPERS

The filter papers used are called ‘Glass Fiber Filters’, manufactured by Gelman Sciences, USA. The dimension of these papers is 8”x10” (203 mm X 254 mm) and comply with the AS 2724.3 standards. These filter papers have a collection efficiency of at least 99\% for particles of 0.3 \( \mu \text{m} \) EAD and permit an air flow rate of at least 1.0 m\(^3\)/min. at all times. They are free from pinholes and other defects and are able to withstand one crosswise crease without cracking or material separation. Because of these features, glass fibre filters are commonly used.

#### 3.3.2 HIGH VOLUME AIR SAMPLERS (HVAS)

The HVAS used in this experiment was manufactured by Wedding & Associates, Inc., USA for PM10, and Eco-tech Inc., USA for TSP. Even though the HVAS are of different makes, their principle of operation, components and other internal devices are quite similar. The major difference was that in a HVAS for TSP, the clock used was automatic and digital whereas in that for PM10, the clock used was manual and hand wound. There has been some error in recording time with the HVAS using the manual clock which has been shown in the next Chapter in Results and Discussion.
The sampling efficiency of a HVAS is affected by environmental wind velocity and direction. Higher velocity air retains larger particles in suspension than slower air, and can have a diameter of up to 50 \( \mu \text{m} \). These then appear on the sample filter paper, producing variable results.

The HVAS consists of two major components a) High volume shelter, and b) Critical flow device.

a) **High Volume Shelter**: It is fabricated utilizing one-piece construction, and thus adding strength and providing a dust-free, field rugged unit. A blower outlet baffle plate is installed and air exists through six side exhaust ports eliminating filter contamination due to re-aerosolized dust.

b) **Critical Flow Device**: It implicitly utilizes the effect known as ‘choking’. The critical state requires that the reference velocity is such that the Mach number is unity. The maximum value in the curve of flow rate per unit area is uniquely related to the choking effect. For a given flow area, there is in subsonic flow a maximum initial Mach number which can be maintained steadily and the flow is then said to be ‘choked’. When this condition occurs, a stable shock wave is created and maintained within the throat portion of the critical flow device. By maintaining a sufficient vacuum potential downstream of the throat, the presence of the shock wave limits the flow of air through the device to an absolute maximum. The flow rate is unique and predictable function of the stagnation pressure and temperature, and said flow rate is unaffected by changes in the exit condition such as motor/blower speed or exit pressure. The unique energy recovery system of the critical flow device enables the usage of an inexpensive motor/blower. Thus to operate the system, simply, plug in the motor/blower assembly to line voltage and the flow remains constant in the choked condition with no adjustment required, and no detailed calibration required. During a typical 24-hour sampling cycle, the volumetric flow rate will be known to within 0.75% using the calibrator. Figure 3.2 shows the critical flow device in a HVAS.
Figure 3.2. Critical flow device in a high volume air sampler.
3.3.3 10 μm SIZE SELECTIVE INLET

The 10 μm size selective inlet is a separate unit that fits easily on a standard HVAS by replacing the existing canopy. The principle of operation employs a rapid directional change in sampled air. This causes larger particles, with greater mass, and therefore momentum, to impact the flat horizontal surface and come to rest. The smaller particles remain suspended in the air and continue with the flow to be collected on the filter-cassette. Air velocity through the selective inlet is fairly critical. The selective inlet is circular to operate independent of wind direction and is unaffected by environmental wind speeds of up to 24 km/hr. The top is detachable to necessitate the periodic removal of waste particles greater than ten microns, which if allowed to accumulate will eventually impair selective efficiency. Figure 3.3 shows the 10 μm size selective inlet unit.

3.4 PROCEDURE

The procedure adopted for conducting the experiment is same for both TSP and PM10. However, there is some modification in the apparatus used which is described in section 3.3 above. In general, it is essential to calibrate HVAS before conducting the experiment. The calibration procedure is described below and then followed by experimental procedure.

3.4.1 CALIBRATION PROCEDURE

The calibration and subsequent periodic audits of the volumetric flow rate of ambient aerosol samplers has been time consuming and consequently an expensive but necessary task required in the field. The normal approach has been to utilize a flow transfer standard to provide an on-site flow rate calibration of the sampler. This has necessitated the dismantling of the flow control system, the removal of the inlet, a calculation procedure to correct for the temperature and pressure conditions of the day, and then final adjustment of the flow control system for set-point operation.
Figure 3.3 10 \( \mu m \) Size selective inlet flow diagram.
The HVAS has the critical flow device which has a unique flow control system. Using an EPA traceable pressure standard, a relationship is determined between the sampler volumetric flow rate $Q_0$, the ambient temperature $T_0$, and the ratio of the sampler stagnation pressure $P_1$ downstream of the filter to the ambient pressure $P_0$. This relationship is then incorporated into a simple look-up table given in the Appendix III for use in the field. To calibrate the sampler either in the laboratory or in the field, there is a provision for an in-situ measurement pressure $P_1$. Utilizing a 20” water manometer for the single-point audit or 0-8” Hg manometer for the multi-point check and a barometer or the pressure transfer standard which is incorporated in the calibrator, values for $P_1 (V_1)$ and $P_0 (V_0)$ are realized in the field in-situ while the sampler is operating, requiring less than 1 minute to perform. By noting the ambient temperature and proceeding to the look-up table, it is possible to know exactly the volumetric flow rate of the system, accurate to within 0.75%. Thus this method has been adopted for calibration at all the three different sites.

3.4.2 EXPERIMENTAL PROCEDURE

The experimental procedure is outlined briefly. This procedure is follows the manufacturer’s operating manual and meets the Australian Standard AS 2724.3.

a) All the glass fibre filter papers are kept in the dessicator box. The filter paper that will be used in the sampler should be kept in the box for at least one day.

b) Weigh the filter paper on the weighing scale. This is to determine the weight of the clean filter paper.

c) The weighed filter paper is loaded into the filter cassette.

d) The timer is now set as per the sampling time required.

e) The elapsed time indicator is wired to start when the motor/blower is started. The instrument will automatically and cumulatively register the elapsed time.

f) After the sampling period is over, carefully remove the filter paper from the filter cassette and put it in the plastic bag and label it.
g) Note the timer clock and check whether the sampler ran for exactly 24-hours.

h) Weigh the filter paper again, to determine the weight of the particulate collected on the filter paper.

j) Equation (3.2) is used to calculate the concentration of the particulate collected.

The above procedure is adopted to determine the concentrations of both TSP and PM10.
CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

Samples were collected for both TSP and PM10 analysis at three different sites located at Port Kembla. The first site, Scouts Hall, was an urban area, while the other two sites were within the steel plant complex. This chapter outlines the calculations used to determine the volume of air sampled and the concentrations of TSP and PM10 during the experiment. This is followed by the results obtained at three different sites with respect to wind velocity and wind direction. Some statistical analysis of the data obtained has been shown; this includes the correlation coefficient and regression analysis. Finally, a discussion is made on the results obtained.

4.2 CALCULATIONS

The calculations are per Australian Standard, AS 2724.3 - 1984. This guideline is also followed by the EPA, New South Wales, Australia. Equation (3.1) is used for calculating the volume of air sampled. The volume obtained from this equation is used for calculating the TSP and PM10 concentrations in Equation (3.2).

4.3 RESULTS AND ANALYSIS

The results obtained from each of the three sites at which samples were taken are shown separately. Since statistical analysis provides one of the best tools to determine the validity of the apparent relationship between TSP and PM10, it was used here. An analysis has been performed for each site and then on the combined data collected from the three separate locations.
4.3.1 Monitoring site: Scouts Hall

The data obtained at this site are indicated in Table 4.1. The detailed observational data are shown in Appendix I. As discussed in Chapter 3, the flow rates were obtained during calibration, air volume were obtained by using Equation (3.1), and concentrations were obtained by using Equation (3.2).

Table 4.1. Observational data at Scouts Hall

<table>
<thead>
<tr>
<th>Monitoring Date</th>
<th>Flow rate TSP (m³/hr)</th>
<th>Flow rate PM10 (m³/hr)</th>
<th>Air volume TSP (m³)</th>
<th>Air volume PM10 (m³)</th>
<th>Concentration TSP (µg/m³)</th>
<th>Concentration PM10 (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.07.96</td>
<td>69.8</td>
<td>69.36</td>
<td>1576.99</td>
<td>1567.50</td>
<td>58.36</td>
<td>15.88</td>
</tr>
<tr>
<td>23.07.96</td>
<td>69.8</td>
<td>69.36</td>
<td>1576.99</td>
<td>1567.50</td>
<td>51.30</td>
<td>22.51</td>
</tr>
<tr>
<td>25.07.96</td>
<td>69.5</td>
<td>69.36</td>
<td>1570.21</td>
<td>1567.50</td>
<td>26.87</td>
<td>12.50</td>
</tr>
<tr>
<td>26.07.96</td>
<td>69.5</td>
<td>69.36</td>
<td>1570.21</td>
<td>1567.50</td>
<td>52.66</td>
<td>35.08</td>
</tr>
<tr>
<td>29.07.96</td>
<td>69.5</td>
<td>69.36</td>
<td>1570.21</td>
<td>1567.50</td>
<td>21.90</td>
<td>12.69</td>
</tr>
<tr>
<td>31.07.96</td>
<td>69.5</td>
<td>69.36</td>
<td>1570.21</td>
<td>1567.50</td>
<td>16.49</td>
<td>8.42</td>
</tr>
</tbody>
</table>

**Wind velocity and wind direction**

The wind rose diagrams are given in Appendix II which indicates the wind velocity and wind direction of the sample taken at the Scouts Hall site. Table 4.2 indicates the percentage of samples with respective wind velocity and wind direction at Scouts Hall.
### Table 4.2a. Wind rose data for 19.07.96

<table>
<thead>
<tr>
<th>Wind velocity (m/sec)</th>
<th>Wind Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>North</td>
</tr>
<tr>
<td>0-1.38</td>
<td>1.5%</td>
</tr>
<tr>
<td>1.38-2.77</td>
<td>4.5%</td>
</tr>
<tr>
<td>2.77-4.16</td>
<td></td>
</tr>
<tr>
<td>4.16-5.55</td>
<td>16%</td>
</tr>
<tr>
<td>5.55-8.33</td>
<td></td>
</tr>
<tr>
<td>&gt; 8.33</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4.2b. Wind rose data for 26.07.96

<table>
<thead>
<tr>
<th>Wind velocity (m/sec)</th>
<th>Wind Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>North</td>
</tr>
<tr>
<td>0-1.38</td>
<td>2%</td>
</tr>
<tr>
<td>1.38-2.77</td>
<td>4%</td>
</tr>
<tr>
<td>2.77-4.16</td>
<td></td>
</tr>
<tr>
<td>4.16-5.55</td>
<td>10%</td>
</tr>
<tr>
<td>5.55-8.33</td>
<td></td>
</tr>
<tr>
<td>&gt; 8.33</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4.2c. Wind rose data for 29.07.96

<table>
<thead>
<tr>
<th>Wind velocity (m/sec)</th>
<th>Wind Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>North</td>
</tr>
<tr>
<td>0-1.38</td>
<td></td>
</tr>
<tr>
<td>1.38-2.77</td>
<td></td>
</tr>
<tr>
<td>2.77-4.16</td>
<td>6%</td>
</tr>
<tr>
<td>4.16-5.55</td>
<td>15%</td>
</tr>
<tr>
<td>5.55-8.33</td>
<td></td>
</tr>
<tr>
<td>&gt; 8.33</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4.2d. Wind rose data for 31.07.96

<table>
<thead>
<tr>
<th>Wind velocity (m/sec)</th>
<th>Wind Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>North</td>
</tr>
<tr>
<td>0-1.38</td>
<td></td>
</tr>
<tr>
<td>1.38-2.77</td>
<td></td>
</tr>
<tr>
<td>2.77-4.16</td>
<td></td>
</tr>
<tr>
<td>4.16-5.55</td>
<td></td>
</tr>
<tr>
<td>5.55-8.33</td>
<td></td>
</tr>
<tr>
<td>&gt; 8.33</td>
<td></td>
</tr>
</tbody>
</table>

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4.3.1a Analysis at Monitoring Site: Scouts Hall

As seen from Table 4.1, it was found that the concentrations of both TSP and PM10 were high on 23rd of July and on 26th of July. The correlation coefficient was used to determine the degree of relationship present between the variables TSP and PM10, and it was found to be 0.89. Figure 4.1 shows TSP and PM10 data for the location at Scouts Hall. The relationship between TSP and PM10 is expressed in Figure 4.2.

![Figure 4.1. Concentrations of TSP and PM10 obtained at Scouts Hall site.](image-url)
Figure 4.2. Relationship between TSP and PM10 at Scouts Hall site.

The Regression Analysis of the two variables determines the predicted change in one variable when another variable varies. Amongst the two variables, it was found that PM10 is a dependent variable, while TSP is independent. Therefore, a regression equation was made, which would determine the predicted change in PM10, when the TSP varied. This is expressed in Equation (4.1). In Equation (4.1), ‘Y’ is denoted as a dependent variable, PM10, and ‘X’ is denoted as an independent variable, TSP. The regression equation of Y on X is given as:

\[ Y = a + bX \]  \hspace{1cm} (4.1)

where:
- Y = Dependent variable, PM10;
- X = Independent variable, TSP; and
- a & b = constants.
The Equation (4.1) is an equation of a straight line, where ‘a’ can be considered as an Y - intercept and ‘b’ as a slope. However, in the regression equation, ‘b’ is considered as a “Regression Coefficient” and ‘a’ as a constant. Since the values of Y and X are known from the experimental observations, the values for constants ‘a’ and ‘b’ can be determined from Equations (4.2) and (4.3) (Edwards, 1984).

The regression coefficient, b, is determined from Equation (4.2), which is expressed as,

\[
b = \frac{\sum XY - \sum X \sum Y}{\sum X^2 - \left(\frac{\sum X}{n}\right)^2}
\]  

(4.2)

where:

\[n = \text{the sampling number} ;\]
\[\sum X = \text{sum of X variables} ; \text{and}\]
\[\sum Y = \text{sum of Y variables}.\]

On substituting the values of X and Y from Table 4.1 into the Equation (4.2), the value of ‘b’ is determined.

\[
b = \frac{4363.8644 - \frac{(207.58)(107.04)}{6}}{8349.7822 - \frac{(207.58)^2}{6}} = 0.5655
\]
Chapter 4

Results and Discussion

The constant 'a' is determined from the Equation (4.3) (Edwards Allen, 1984).

\[ a = \bar{Y} - b\bar{X} \]  \hspace{1cm} (4.3)

where:

\[ \bar{Y} = \text{Mean value of the variable } Y ; \text{ and} \]
\[ \bar{X} = \text{Mean value of the variable } X. \]

The mean values of X and Y are substituted from Table 4.1 into the Equation (4.3), and the value of 'a' is determined.

\[ a = 17.84 - 0.565 \times 34.59 = -1.7 \]

The constants 'a' and 'b' are substituted into the Equation (4.1), in order to arrive at the regression equation of Y on X.

\[ Y = -1.7 + 0.565X \]  \hspace{1cm} (4.4)

In order to predict a value of Y corresponding to the mean of the X values, Equation (4.4) was used. It was found from Equation (4.4), that, for a mean value of X = 34.59, the value of Y obtained was, 17.84, which was equal to the mean value of the Y values. The regression line would, therefore, pass through the point established by the means of the X and Y values or, in other words, the point with coordinates (\( \bar{X}, \bar{Y} \)). This will be true for any linear regression line fitted by the method of least squares. The predicted values of Y, when X = 21.9, and 38.36, are 10.67, and 19.97. The regression line will therefore pass through the points (34.59, 17.84), (21.9, 10.67), and (38.36, 19.97). Figure 4.3 shows the regression line of Y on X.
Figure 4.3. Regression line of Y (PM10) on X (TSP).

It was observed from Figure 4.3 that the Equation (4.4) was valid only when $X \geq 3$, otherwise this equation gave negative results which was impractical. On comparing the results obtained from Table 4.1 and 4.2, it was observed that the wind velocity and direction played negligible role on the relationship between TSP and PM10. As seen from both the tables, 40% of TSP and PM10 concentrations on 19.07.96, were flowing in the direction of north west at an average velocity of 7 m/s. But this did not affect the relationship between TSP and PM10, and therefore Equation (4.4) remains unchanged due to wind velocity and direction.

4.3.2 Monitoring site: AQMS (Near Blast Furnace # 2)

The data obtained at this site are indicated in Table 4.3. The detailed observational data are shown in Appendix I. The volume of air sampled, and the concentrations of TSP and PM10 were calculated by using Equations (3.1) and (3.2).
Table 4.3. Observational data at AQMS

<table>
<thead>
<tr>
<th>Monitoring Date</th>
<th>Flow rate TSP (m³/hr)</th>
<th>Flow rate PM10 (m³/hr)</th>
<th>Air volume TSP (m³)</th>
<th>Air volume PM10 (m³)</th>
<th>Concentration TSP (µg/m³)</th>
<th>Concentration PM10 (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.08.96</td>
<td>69.9</td>
<td>69.66</td>
<td>1570.99</td>
<td>1565.60</td>
<td>164.35</td>
<td>80.99</td>
</tr>
<tr>
<td>14.08.96</td>
<td>69.9</td>
<td>69.66</td>
<td>1570.99</td>
<td>1565.60</td>
<td>36.6</td>
<td>18.77</td>
</tr>
<tr>
<td>15.08.96</td>
<td>69.9</td>
<td>69.66</td>
<td>1570.99</td>
<td>1565.60</td>
<td>40.16</td>
<td>19.8</td>
</tr>
<tr>
<td>18.08.96</td>
<td>69.9</td>
<td>69.66</td>
<td>1570.99</td>
<td>1565.60</td>
<td>16.35</td>
<td>7.28</td>
</tr>
<tr>
<td>20.08.96</td>
<td>69.9</td>
<td>69.66</td>
<td>1570.99</td>
<td>1565.60</td>
<td>17.5</td>
<td>9.58</td>
</tr>
</tbody>
</table>

Wind velocity and wind direction

The wind rose diagrams are given in Appendix II, which indicates the wind velocity and wind direction of the sample taken near blast furnace # 2. Table 4.4 indicates the percentage of samples with respective wind velocity and wind direction.

Table 4.4a. Wind rose data for 13.08.96

<table>
<thead>
<tr>
<th>Wind velocity (m/sec)</th>
<th>North</th>
<th>North East</th>
<th>East</th>
<th>South East</th>
<th>South</th>
<th>South West</th>
<th>West</th>
<th>North West</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1.38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.38-2.77</td>
<td>2%</td>
<td>1%</td>
<td></td>
<td></td>
<td>4%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.77-4.16</td>
<td>15%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.16-5.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>5.55-8.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;8.33</td>
<td>48%</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>
### Table 4.4b. Wind rose data for 14.08.96

<table>
<thead>
<tr>
<th>Wind velocity (m/sec)</th>
<th>North</th>
<th>North East</th>
<th>East</th>
<th>South East</th>
<th>South</th>
<th>South West</th>
<th>West</th>
<th>North West</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1.38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>40%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.38-2.77</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>40%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.77-4.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>60%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.16-5.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.55-8.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;8.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 4.4c. Wind rose data for 15.08.96

<table>
<thead>
<tr>
<th>Wind velocity (m/sec)</th>
<th>North</th>
<th>North East</th>
<th>East</th>
<th>South East</th>
<th>South</th>
<th>South West</th>
<th>West</th>
<th>North West</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1.38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.38-2.77</td>
<td>1%</td>
<td>3%</td>
<td></td>
<td>10%</td>
<td></td>
<td></td>
<td>4%</td>
<td></td>
</tr>
<tr>
<td>2.77-4.16</td>
<td>5%</td>
<td>5%</td>
<td></td>
<td></td>
<td>6%</td>
<td></td>
<td>7%</td>
<td></td>
</tr>
<tr>
<td>4.16-5.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6%</td>
<td>15%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.55-8.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>18%</td>
<td>20%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;8.33</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

### Table 4.4d. Wind rose data for 18.08.96

<table>
<thead>
<tr>
<th>Wind velocity (m/sec)</th>
<th>North</th>
<th>North East</th>
<th>East</th>
<th>South East</th>
<th>South</th>
<th>South West</th>
<th>West</th>
<th>North West</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1.38</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.38-2.77</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.77-4.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.16-5.55</td>
<td>5%</td>
<td>4%</td>
<td></td>
<td></td>
<td>15%</td>
<td>8%</td>
<td>7%</td>
<td>22%</td>
</tr>
<tr>
<td>5.55-8.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>28%</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>&gt;8.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 4.4e. Wind rose data as on monitoring date 20.08.96

<table>
<thead>
<tr>
<th>Wind velocity (m/sec)</th>
<th>North</th>
<th>North East</th>
<th>East</th>
<th>South East</th>
<th>South</th>
<th>South West</th>
<th>West</th>
<th>North West</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1.38</td>
<td>3%</td>
<td>2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.38-2.77</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.77-4.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.16-5.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.55-8.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;8.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.3.2a Analysis at Monitoring Site : AQMS (Blast Furnace # 2)

Table 4.3 shows that the concentration on 13th of August was very high, while for rest of the days it remained low. The correlation coefficient at this site was found to be 0.99. Figure 4.4 shows the TSP and PM10 data for the location at AQMS. The linear relationship between them is expressed in Figure 4.5.

![Graph showing concentrations of TSP and PM10](image)

Figure 4.4 Concentrations of TSP and PM10 obtained at Blast Furnace # 2.
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Figure 4.5 Relationship between TSP and PM10 at Blast Furnace # 2.

The regression analysis of the two variables, TSP, and PM10, were determined from Equations (4.2), and (4.3). The regression coefficient, ‘b’, was found to be 0.491, and the constant ‘a’ was found to be 0.253. On substituting these values in Equation (4.1), the regression equation of Y on X was determined. Equation (4.5) is the regression equation at blast furnace # 2.

\[
Y = 0.253 + 0.491X
\]  

(4.5)

From Equation (4.5) it was found that for a mean value of X = 54.99, the value of Y obtained was 27.25, which was equal to the mean value of the Y values. The regression line, would therefore, pass through the coordinates (54.99, 27.25), (17.50, 8.84), and (40.16, 19.97). Figure 4.6 shows the regression line of Y on X.
Figure 4.6. Regression line of Y on X.

On comparing the results obtained from Table 4.3, and 4.4, it was once again observed that wind velocity and direction played negligible role on the relationship between TSP and PM10.

4.3.3 Monitoring Site: Printery

The data obtained at this site are indicated in Table 4.5. The detailed observational data are shown in Appendix I. The volume of air sampled, and the concentrations of TSP and PM10 were calculated by using Equations (3.1) and (3.2).
Table 4.5. Observational data at Printery

<table>
<thead>
<tr>
<th>Monitoring Date</th>
<th>Flow rate TSP (m³/hr)</th>
<th>Flow rate PM10 (m³/hr)</th>
<th>Air volume TSP (m³)</th>
<th>Air volume PM10 (m³)</th>
<th>Concentration TSP (µg/m³)</th>
<th>Concentration PM10 (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.08.96</td>
<td>68.9</td>
<td>69.84</td>
<td>1536.17</td>
<td>1557.58</td>
<td>25.77</td>
<td>10.65</td>
</tr>
<tr>
<td>26.08.96</td>
<td>68.9</td>
<td>69.84</td>
<td>1536.17</td>
<td>1557.58</td>
<td>40.75</td>
<td>24.58</td>
</tr>
<tr>
<td>27.08.96</td>
<td>68.9</td>
<td>69.84</td>
<td>1536.17</td>
<td>1557.58</td>
<td>76.55</td>
<td>44.17</td>
</tr>
<tr>
<td>28.08.96</td>
<td>68.9</td>
<td>69.84</td>
<td>1536.17</td>
<td>1557.58</td>
<td>37.75</td>
<td>18.61</td>
</tr>
<tr>
<td>30.08.96</td>
<td>68.9</td>
<td>69.84</td>
<td>1536.17</td>
<td>1557.58</td>
<td>35.08</td>
<td>17.84</td>
</tr>
</tbody>
</table>

Wind velocity and wind direction

The wind rose diagrams are given in Appendix II which indicates the wind velocity and wind direction of the sample taken at Printery site. Table 4.6 indicates the percentage of samples with respective wind velocity and wind direction.

Table 4.6a. Wind rose data for 24.08.96

<table>
<thead>
<tr>
<th>Wind velocity (m/sec)</th>
<th>Wind Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>North</td>
</tr>
<tr>
<td>0-1.38</td>
<td></td>
</tr>
<tr>
<td>1.38-2.77</td>
<td></td>
</tr>
<tr>
<td>2.77-4.16</td>
<td></td>
</tr>
<tr>
<td>4.16-5.55</td>
<td></td>
</tr>
<tr>
<td>5.55-8.33</td>
<td></td>
</tr>
<tr>
<td>&gt;8.33</td>
<td></td>
</tr>
</tbody>
</table>
As seen from Table 4.5, it was found that the concentration was high on 27th of August. The correlation coefficient between TSP and PM10 at this site was also found to be 0.99. Figure 4.7 shows TSP and PM10 data for the location at Printery. The relationship between them is expressed in Figure 4.8.
Figure 4.7. Concentration of TSP and PM10 obtained at Printery.

Figure 4.8. Relationship between TSP and PM10 at Printery.
Equations (4.2), and (4.3) were used once again to determine the regression equation. The regression coefficient, ‘b’, was found to be 0.647, while the constant, ‘a’, was found to be -4.80. The regression equation is arrived at by substituting these values in Equation (4.1). Equation (4.6) indicates the regression line of $Y$ on $X$.

\[ Y = -4.80 + 0.647X \]  

(4.6)

Equation (4.6) indicates that for a mean value of $X = 43.18$, the value of $Y$ obtained was 23.13, which was equal to the mean value of the $Y$ values. The regression line, would therefore, pass through the coordinates (43.18, 23.13), (35.08, 17.89), and (40.75, 21.56). Figure 4.9 shows the regression line of $Y$ on $X$. 

![Figure 4.9. Regression line of Y on X.](image)
Chapter 4  

Results and Discussion

It was observed from Figure 4.9, that the Equation (4.6) was valid only when $X \geq 7.4$, otherwise this equation gave negative value of $Y$ which was impractical. Once again, on comparing the results obtained from Table 4.5 and 4.6, it was found that the wind velocity and direction had little or no effect on the relationship between TSP and PM10.

4.4 TOTAL ANALYSIS

In this section, all the data are combined from the three separate sites and then analysed by using the same statistical tools. The result obtained from the analysis were quite similar to the result obtained at each separate site. Table 4.7 shows the data combined from all the sites. Correlation coefficient was used to determine the degree of relationship and it was found to be 0.984. Figure 4.10 shows TSP and PM11 for all the combined data and Figure 4.10 shows their relationship.

Table 4.13. Concentration of TSP and PM10 combined from all the sites.

<table>
<thead>
<tr>
<th>Monitoring Date</th>
<th>TSP ($\mu g/m^3$)</th>
<th>PM10 ($\mu g/m^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.07.96</td>
<td>38.36</td>
<td>15.88</td>
</tr>
<tr>
<td>23.07.96</td>
<td>51.30</td>
<td>22.51</td>
</tr>
<tr>
<td>25.07.96</td>
<td>26.87</td>
<td>12.5</td>
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<tr>
<td>26.07.96</td>
<td>52.66</td>
<td>35.08</td>
</tr>
<tr>
<td>29.07.96</td>
<td>21.90</td>
<td>12.69</td>
</tr>
<tr>
<td>31.07.96</td>
<td>16.49</td>
<td>8.42</td>
</tr>
<tr>
<td>13.08.96</td>
<td>164.35</td>
<td>80.99</td>
</tr>
<tr>
<td>14.08.96</td>
<td>36.60</td>
<td>18.77</td>
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<tr>
<td>15.08.96</td>
<td>40.16</td>
<td>19.80</td>
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<td>16.35</td>
<td>7.28</td>
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<td>20.08.96</td>
<td>17.50</td>
<td>9.58</td>
</tr>
<tr>
<td>24.08.96</td>
<td>25.77</td>
<td>10.65</td>
</tr>
<tr>
<td>26.08.96</td>
<td>40.75</td>
<td>24.58</td>
</tr>
<tr>
<td>27.08.96</td>
<td>76.55</td>
<td>44.17</td>
</tr>
<tr>
<td>28.08.96</td>
<td>37.75</td>
<td>18.61</td>
</tr>
<tr>
<td>30.08.96</td>
<td>35.08</td>
<td>17.84</td>
</tr>
</tbody>
</table>
Figure 4.10. Combined concentrations of TSP and PM10.

Figure 4.11. Relationship between the combined TSP and PM10 data.
Equations (4.2), and (4.3) were used to determine the regression equation. The regression coefficient ‘b’ was found to be 0.506, and the constant ‘a’ was found to be 0.344. On substituting these values in Equation (4.1), the regression equation was determined. Equation (4.7) indicates the regression line of Y on X.

\[ Y = 0.344 + 0.506X \quad (4.7) \]

Equation (4.7) shows that for a mean value of \( X = 43.65 \), the predicted value of \( Y \) was 22.45, which was equal to the mean value of the \( Y \) values. Figure 4.12 shows the regression line of \( Y \) on \( X \).

![Figure 4.12. Regression line of Y on X by taking the combined values.](image)
From the above analysis it was found that a definite relationship exists between TSP and PM10. Figure 4.14 justifies this statement, as it is seen that the regression line fits the data very well. This relationship between TSP, and PM10 can also be denoted by the ratio 1:0.5. This is discussed further in the next section.

4.5 DISCUSSION

In this experiment an attempt was made to determine the relationship between TSP and PM10. From the above results and analysis it was found that PM10 concentration constituted 50% of that of TSP concentration. This means that of the Total Suspended Particulate matter liberated at BHP Steel at Port Kembla, 50% was that of Particulate Matter of 10 microns. Local factors such as the day of the week, monitoring site (location), and, sampling time did not appear to have a significant affect on PM10 concentration and its relationship with TSP. From the above findings, it was clear that PM10 concentrations were closely linked to TSP concentrations.

The concentrations of all particle measured were not influenced significantly by wind direction and wind velocity. It was difficult to determine at which direction, concentrations were highest. At the first site, which was relatively an urban area, the highest concentration was found to be $52.72 \text{ pg/m}^3$ while PM10 was $35.08 \text{ pg/m}^3$, which was nearly 67% of that of TSP. This was an area of concern since it was an urban area compared to the remaining two sites, located within the steel plant complex. The highest concentration observed at the second site was $164.35 \text{ pg/m}^3$ while PM10 was $80.99 \text{ pg/m}^3$, at the third site TSP was $76.55 \text{ pg/m}^3$ while PM10 was $44.17 \text{ pg/m}^3$. Even though the concentrations of PM10 were 48.8% of TSP and 60.4% of TSP, quantitatively, the figures were quite high for both.
In the above analysis, an attempt was also made to formulate an equation on the relationship using regression analysis, by considering PM10 concentration as a dependent variable and TSP concentration as an independent variable. From the above Equations (4.4), (4.5) and (4.6), it was observed that the value of PM10 could easily be predicted once the value of TSP was known. From Equation (4.7), it was clear that a change of one unit in TSP resulted in a predicted change of 0.506 units in PM10, as this was the value of the regression coefficient. The regression coefficient of 0.506 represented that PM10 would vary by 50.6% of every unit variation in TSP. Further, the correlation coefficient between TSP and PM10 was 0.985, which indicated a very high degree of relationship present between them. Thus, from the above analysis, it was found that the variables, TSP and PM10 were linearly related, and that the concentration of PM10 was 50% that of TSP.

Another interesting point to be noted was that wind velocity and wind direction played almost negligible role on the relationship between TSP and PM10. It was quite surprising to note that, two instruments such as High Volume Air Samplers would not be required, since a measure of TSP would result in a predicted value of PM10. Before, concluding that only one High Volume Air Sampler (used for measuring TSP) would suffice to determine both TSP and PM10, it is to be noted that the particulate matter generation in a steel plant is highly variable factor and not consistent over a period of time. This is because the source and concentration of particulate matter varies considerably from site to site. A full one year analysis of both TSP and PM10 concentration should be conducted before reaching a conclusion. It must be noted that all the above observations and analysis were based on a typical Iron and Steel plant and on the particulate matter generated from this industry. It is also important to note that if a similar type of experiments were conducted at other plants and the relationships were similar, it could be concluded that the Equation (4.7) was valid.
CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The following comments are made in order to conclude the work on this project:

a) It has been found that in a typical iron & steel plant situated in the south-coast of Australia, the concentration of PM10 is 50% of that of the concentration of TSP.

b) The correlation coefficient between TSP and PM10 was 0.89-0.99 at all sites selected in the experiment. Thus, it was found that the behaviour of PM10 depends entirely upon the behaviour of TSP. The linear regression analysis between TSP and PM10 justified the similarity in their behaviour.

c) The concentration of PM10 was consistently 50% of the concentration of TSP during the study. The wind rose diagrams indicated that wind velocity and direction had no significant impact on the relationship between TSP and PM10 in this study.

d) The concentration of PM10 exceeded the 50% mark for three of the sixteen samples. The highest ratio of PM10 to TSP was 0.67:1 at site #1 (Scouts Hall) which is relatively urban area. The highest concentration of PM10 was 80.99 \( \mu g/m^3 \), at site #2 (Blast furnace no. 2), which was well below the guideline set by USEPA of 150 \( \mu g/m^3 \) for a 24-hour sampling period (see Table 1.2).
From the linear regression analysis of TSP versus PM10, it has been found that the slope of the line is 0.506. This positive slope indicates that an increase in TSP is accompanied by an increase in PM10 and a decrease in TSP is accompanied by decrease in PM10.

5.3 CRITICAL DISCUSSION

As seen from the detailed observational data in Appendix I, there has been an error in timing with the high volume sampler used to measure PM10. This is because there has been some discrepancy between the start or stop time recorder on the filter information, and the actual start or stop time of the sampler. This has happened due to poor resolution of the timer set-points and timer malfunction. This resulted in having a sampling time of more than the stipulated 24 hours. On some monitoring dates, wind velocity and direction were not recorded due to the failure of the weather station. However, since it was determined that wind velocity and direction had no significant impact on the ratio of PM10 and TSP, this failure had little bearing on the project.

There may be some loss of volatile particles during shipment and/or storage of the filter paper prior to post-sampling weighing. This would have resulted in errors in at most, two samples. The experiment was conducted for a period of five months, which is an insufficient time to estimate the annual concentration of TSP and PM10. Further, the experiment was conducted during autumn and winter months, and therefore, there may be a seasonal affect due to differing weather patterns. The number of sites selected was low, however, the consistency of the collected data makes it unlikely that additional locations would significantly alter the results.

5.3 RECOMMENDATIONS

In order to avoid the timing errors, it is essential to have a digital electronic timers since they have a better set-point resolution than mechanical timers. However, they require a battery back-up to maintain the operation in the event of power failure. A connection to a microprocessor-based recorder would provide an indication of the sampler run-time, flow rate, pressure, temperature, and as well as an indication of any power interruption during the sampling period. Therefore it is highly recommended.
Careful handling of filter papers during presampling and postsampling is essential. Effort must be made to fit the paper in the filter paper cartridge properly so that cracking of filter papers does not occur. It is also necessary to carefully handle filter papers between presampling and postsampling weighing, in order to avoid errors due to loss of particles from the filter. This will also prevent loss of volatile particles during shipment and/or storage of the filter paper.

It may be necessary to select sites in an urban area close to the steel plant so that the concentration of PM10, the inhalable particulates, can be determined, and any health effect checked immediately. The experiment should be conducted throughout the year to take care of all the seasonal variations in wind velocity and direction. This will also help to provide annual data for TSP and PM10 concentrations, according to the EPA guidelines. Additionally, it may produce interesting results on the relationship between TSP and PM10 concentrations.

It would be worthwhile to study the concentrations of coarse particulate (having diameter between 2.5 and 10 \( \mu m \)), and PM2.5 (having diameter of 2.5 \( \mu m \)) along with PM10 and TSP. The USEPA has now emphasised both PM10 and PM2.5 as a standard measurement for particulate matter. They are gradually phasing out TSP (having diameter of less than 50 \( \mu m \)) as one of the measurement standard for particulate matter. Therefore, a study on the relationship between PM2.5, coarse particulate, and PM10 will provide interesting results, which may modify the steel making processes so that future air pollution legislations can be met. Once PM10 is known, TSP can easily be determined. Further, the relationship study may contribute as one of the main criteria in achieving a certification of ISO 14000 in steel manufacturing process at BHP, Australia.
REFERENCES


APPENDIX I
### Monitoring Site: Scouts Hall

<table>
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<tr>
<th>Monitoring Date</th>
<th>Time Started (Hours)</th>
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<th>Total Time (Hours)</th>
<th>Flow Rate for TSP Initial (cubic meters per hour)</th>
<th>Flow Rate for PM 10 Initial (cubic meters per hour)</th>
<th>Mass on the filter TSP (grams)</th>
<th>Mass on the filter PM 10 (grams)</th>
<th>Concentration of TSP µg/m³</th>
<th>Concentration of PM 10 µg/m³</th>
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<th>Flow Rate for PM 10 Initial (cubic meters per hour)</th>
<th>Mass on the filter TSP (grams)</th>
<th>Mass on the filter PM 10 (grams)</th>
<th>Concentration of TSP µg/m³</th>
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APPENDIX II
26 JULY 96

Station: BHP WEATHER STATION  
Parameter: channel 1

Magnitude (Kmh)
0% calm
29 July 96
Station: BHP WEATHER STATION
Parameter: channel 1

29-07-1996 11:00:00 to 30-07-1996 11:00:00

Magnitude(Kmh)
0% calm
13 AUGUST 96
Station: BHP WEATHER STATION
Parameter: channel 1

Magnitude (Kmh)
0% calm
14 AUGUST 96
Station: BHP WEATHER STATION Parameter: channel 1

Magnitude(Kmh)
0% calm
15 AUGUST 96
Station: BHP WEATHER STATION Parameter: channel 1

Magnitude(Kmh)

0% calm
18 AUGUST 96
Station: BHP WEATHER STATION Parameter: channel 1

Magnitude(Kmh)
0% calm

18-08-1996 to 19-08-1996
20 AUGUST 96
Station: BHP WEATHER STATION
Parameter: channel 1

20–08–1996 08:45:00 to 21–08–1996 08:45:00

Magnitude (Kmh)

0% calm
24 AUGUST 96

Station: BHP WEATHER STATION  Parameter: channel 1

Magnitude(Kmh)

0% calm
26 AUGUST 96
Station: BHP WEATHER STATION
Parameter: channel 1

Magnitude (Kmh)

0% calm
28 AUGUST 96
Station: BHP WEATHER STATION
Parameter: channel 1

Magnitude (Kmh)
0 km/h calm
30 AUGUST 96
Station: BHP WEATHER STATION  Parameter: channel 1

Magnitude(Kmh)

0% calm
19 JULY 96
Station: BHP WEATHER STATION Parameter: channel 1

Magnitude (Kmh)
0% calm

19-07-1996 to 20-07-1996
APPENDIX III
To use the look-up table, locate the column containing the measured value of \( P_i/P_o \) and \( T_0 \) value (either operating or average for the sampling period). Read the \( Q_0 \) value in (m\(^3\)/min).

### Look-up Table

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<th>( P_i/P_o = 0.951 )</th>
<th>( P_i/P_o = 0.952 )</th>
<th>( P_i/P_o = 0.953 )</th>
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