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A STUDY ON THE ATMOSPHERIC QUALITY AND CONTROL IN THE EMIRATE OF ABU DHABI

By

Eng. Sukaina Faisal Al-Wasity

B.Sc. Engineering Management, 1986

A thesis submitted to the Faculty of Science
of the United Arab Emirates University
in partial fulfilment of the requirements
for the Degree of
Master of Science in
Environmental Science

Faculty of Science
UAE University
(June, 1994)


بسم الله الرحمن الرحيم

The Thesis of Sukaina Faisal Al-Wasity for the degree of Master in Environmental Science is approved.

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June 1994

ABSTRACT

Limited data are available on air pollution levels in Abu Dhabi Emirate in general. Therefore, the present study was designed to investigate the level of atmospheric contaminants in the environment of Abu Dhabi Emirate. This includes measurement of suspended particulate matter less than 10 micron (SPM_{10}) in Al Ain City during normal and stormy conditions and measurement of the same air solids besides the gaseous pollutants : ozone, sulphur dioxide, carbon monoxide, nitrogen oxides and methane and non-methane hydrocarbons in Abu Dhabi City and follow up of hourly variation in their concentration. The study further includes collecting sufficient data for the prevailing meteorological factors in Al Ain and Abu Dhabi.

The study was undertaken with a Mobile Air Pollution Laboratory. As the first of its kind in the country, and being equipped with the most advanced monitoring devices, the laboratory can provide accurate measurement of low concentrations of the above air contaminants, besides the meteorological parameters.

The available results contribute much in ascertaining the role of the major man-made activities taking place in contaminating the Emirate atmosphere as well as the natural materials. These results will help also in comparing the pollution levels in Abu Dhabi Emirate with the established air quality standards.

Air pollution legislation and control in Abu Dhabi Emirate has been taken into consideration in the present study.

It is expected that the present study will form an important contribution for air quality management in Abu Dhabi Emirate.

ACKNOWLEDGMENTS

I wish to express my sincere appreciation to the committee members who have supervised my study program. I am specially grateful to my advisor Prof. Kamal Tamer Hindy of the Geology Department for his valuable advises and necessary guidance throughout my study and for reviewing the manuscript.

I also would like to thank the Faculty of Science of the United Arab Emirates University, especially our Dean Prof. Salah El Nahawy for his support and the former Dean Prof. Mohamed Youssef.

A sincere note of appreciation goes to the Faculty of Chemical Engineering in the Higher Colleges of Technology, Abu Dhabi Men's College for training me on Environmental S.A. Mobile Laboratory.

I would like to thank all the members of staff in Al-Dhafra Meteorological Prediction Center, for training me to analyse the meteorological data. Also, the meteorological Department in the Ministry of Communication and the UAE Air Force for providing me with meteorological data.

Special thanks go to the following firms for their cooperation during carrying out the field measurement in Abu Dhabi city: Food and Environmental Control Center and Abu Dhabi National Oil Company (ADNOC).

And finally, sincere thanks go to my family for their support and encouragement especially for my husband for his tangible help and support throughout my study.

The author is specially grateful to a number of friends for their support, encouragement and help.

THIS THESIS IS DEDICATED TO MY FAMILY

To my mother as she's my first teacher in the world and for love and support. To my husband for his support and encouragement

To my son Faisal may the air be cleaner for him.

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CHAPTER I

INTRODUCTION

Our environment is simple as well as complex. It is simple so long as it remains clean. It gets complex when sources of contamination grow. To comprehend this complex nature of environment, we need knowledge of all disciplines of chemical, geological, physical and biological sciences. To devise control measures, we need knowledge of engineering and technology. Thus Environmental Science and Engineering is truly inter-disciplinary in nature.

Amongst the various types of pollution, air pollution is of greatest importance. It is readily noticed and it causes immediate health problems.

As the world's population expands, streets and highways are becoming cooked with more and more automobiles, industries are multiplying and running at peak capacities and the hazard of air pollution has become a more pressing problem than ever before.

The Science of Air Quality Monitoring and Control is a recent one, and it is a field that presents many complex and unanswered questions. While much is yet to be learned, many definite facts about the dangers and economic losses caused by air pollution are evident.

1. COMPOSITION OF THE AIR

Pure air can not be seen or smelled. it is a composed mixture. The typical composition of clean dry air near sea level is shown in Table (1).

TABLE (1)
Typical Composition of Clean Dry Air Near Sea Level*

Component	Formula	Content	
		% by vol.	ppm
Nitrogen	N_2	78.09	789,900
Oxygen	O_2	20.94	209,400
Argon	Ar	0.93	9,300
Carbon dioxide	CO_2	0.033	330
Neon	Ne	18×10^{-4}	18.0
Helium	He	5.2×10^{-4}	5.22
Methane	CH_4	1.5×10^{-4}	1.5
Krypton	Kr	1.0×10^{-4}	1.0
Hydrogen	H_2	0.5×10^{-4}	0.5
Nitrous oxide	N_2O	0.5×10^{-4}	0.5
Xenon	Xe	0.08×10^{-4}	0.08
Ozone**	O_3	0.07×10^{-4}	0.07
Ammonia	NH_3	0.01×10^{-4}	0.01
Iodine	I_2	0.01×10^{-4}	0.01
Nitrogen dioxide	NO_2	0.001×10^{-4}	0.001
Sulphur dioxide	SO_2	0.0002×10^{-4}	0.0002
Carbon monoxide	CO	0 to trace	-

* Data by (Hesketh, 1972).

** Ozone content in winter is 0.02 ppm and in summer is 0.07 ppm.

2. AIR POLLUTION DEFINITION

The Engineers Joint Council, U.S.A. in "Air Pollution and its Control" gives the following definition:-

> "Air pollution means the presence in the outdoor atmosphere of one or more contaminants, such as dust, fumes, gas, mist, odors, smoke, or vapour in quantities of characteristics, and of duration, such as to be injurious to human, plant or animal life or to property or which unreasonably interferes with the comfortable enjoyment of life and property." (Perkins, 1974)

To ease-out this definition, any existence of foreign substance which is not included in Table (1) causes impurity of air. These impurities are better termed air pollutants. Thus, 99% of the air we inhale is gaseous nitrogen and oxygen, we also inhale trace amounts of other gases, minute droplets of various liquids, and tiny particles of various solids. Studies have detected up to 2,800 compounds in urban air. Many of these chemicals are classified as air pollutants. Most of these pollutants come from cars, trucks, power plants, factories, cigarettes smoke, cleaning solvents and other sources related to human activities (Miller, 1991).

3. CLASSIFICATION OF AIR POLLUTANTS

3.1 Particulate Pollutants

Particulate Pollutants are classified as follows:-

a) Dust - Solid particles which are entrained by process cases directly from the material being handled or processed, e.g. coal, ash, and cement; direct offspring of apparent material undergoing a mechanical operation, e.g. sand from sand blasting. Dust from grain elevators and coal-cleaning plants typify this class of particulate. Dust consists of relatively large particles, their size ranges between 0.1 - 75 μm (Vesilind and Perice, 1983).

b) Fume - a solid particles frequently a metallic oxide, formed by the condensation of vapour by sublimation, distillation, calcination or oxide resulting from the condensation and oxidation of metal volatilized in high-temperature process. The particles in fume are quite small, their size ranges between 0.001-1.0 μm (Vesilind and Perice, 1983).

c) Mist - a liquid particles, formed by the condensation from gaseous state, or as dispersion of liquid state. Mists typically range from 0.01 to 10.0 μm (Vesilind and Perice, 1983).

d) Smoke - solid particles formed as a result of incomplete combustion of carbonaceous material. Smoke particles range between 0.1 and 1.0 μm.

e) Spray - a liquid particles formed by the atomization of a parent liquid.

3.2 Gases

Many types of gases are emitted to atmosphere from various industrial processes and combustion of the fuels. These gases may be primary, such as NO, SO_2, CO, ..etc. or secondary pollutants, such as O_3, NO_2, SO_3, and H_2SO_4 vapour.

4. SOURCES OF ATMOSPHERIC POLLUTION

The overall problem of atmospheric pollution arises from various sources of natural and man-made origin. These sources are almostly the same in any living community, but their significance and impact on the trends of pollution levels differ from one area to another depending on many factors :-

a) The strength of each source and how much it contributes to the pollution problem.
b) Meteorological, geographical and topographical features of the area under consideration.
c) Population density and sanitation facilities.
d) Urban and non-urban planning and the zoning of various human operational functions.

4.1 Natural Sources

Nature and natural processes do pollute the atmosphere by volcanic dust and gas, wind-eroded soil, sea-salt nuclei, methane from marshes, and hydrogen sulfide from decaying organic matter.

4.2 Man-Made Sources

Man-made sources are the inevitable consequence of modern science and technology which aims at facilitating life for man. These sources, however, are generally classified into the following :-

a) Combustion of fossil fuels for domestic and industrial purposes.

b) Emissions from transportation equipment in land, sea and air.

c) Pesticides entering the atmosphere from drift during application and by wind erosion and by volatilization (El-Taieb, 1987).

Table (2) summarizes the input pollutants into the atmosphere in the first 15 km layer of atmosphere above the ground.

TABLE (2)
Estimates of the Atmospheric Aerosol Production Rates

SOURCE	PRODUCTION RATE (metric tons/day)	WEIGHT (% of total)
A. Natural Sources		
1. Primary		
wind-blown dust	$2 \times 10^4 - 10^6$	9.3
sea spray	3×10^6	28
volcanoes	10^4	0.09
forest fires	4×10^5	3.8
2. Secondary		
vegetation	$4 \times 10^5 - 3 \times 10^6$	28.0
sulfur cycle	$105 - 10^6$	9.3
nitrogen cycle	2×10^6	14.8
volcanoes (gases)	10^3	00.009
subtotal	10×10^6	94
B. Man-made sources		
1. Primary		
combustion & industrial	$1 \times 10^5 - 3 \times 10^5$	2.8
dust from cultivation	$10^2 - 10^3$ $10^2 - 10^3$	0.009
2. Secondary		
hydrocarbon vapors	7×10^3	0.063
sulfates	3×10^5	2.8
nitrates	6×10^4	0.56
ammonia	3×10^3	0.028
subtotal	6.7×10^5	6
total	10.7×10^6	100

* Data by Hidy and Brock (1970)

5. IMPACT OF AIR POLLUTION

5.1 Human Health

Much of our knowledge of the effects of air pollution on people comes from the study of acute air pollution episodes and laboratory studies with animals which are of some help.

The respiratory system is the main target of air pollution, which can be infected by different chronic diseases such as bronchitis, asthma, emphysema and lung cancer. Extensive studies cited that lung cancer mortality is higher in urban than in rural areas, people living in metropolitan areas have a short life span (Vesilind and Pierce, 1983).

5.2 Plant Injury

Three kinds of injury are commonly considered important. Acute injury, which results from short term exposure to relatively high concentration, the effect is noted within a few days and could show visible marking on the leave due to a collapse and death of the cell, which leads to the death of the tissue. Chronic injury results from long term low level exposure and usually causes chlorosis of leaf abscission. The last form of injury is an effect on growth without visible marking (Perkins, 1974).

5.3 Effect on Domestic Animals

Chronic poisoning usually results from ingesting forage contaminated by the pollutant. Pollutants in this connection are the heavy metals, lead and molybdenum. Lead poisoning of cattle and horses was reported from Germany as recently as

1955. Cattle and horses grazing within a radius of 5 km of each of two lead and zinc foundries were affected, and some had to be slaughtered (Vesilind and Pierce, 1983).

5.4 Effect on Materials

Perhaps the most familiar effect of air pollution is soiling of building surfaces. Soiling results from the deposition of smoke (fine particles of approximately 0.3 μm diameter) on surface (Vesilind and Pierce, 1983).

The deposition accumulates over a period of time and become noticeable as soiling, a discoloring or darkening of the surface. In the case of exterior building materials, sand blasting is often required to clean the surface and part of the surface is removed in the process of cleaning. This is a damage to economy of any country which has highly polluted atmosphere.

Another effect of air pollution is that of accelerating the corrosion of metals. For example, it has been observed that in the presence of sulphur dioxide many materials corrode much faster than they would otherwise. Indeed, the effect of ozone, a principal ingredient of smog, on rubber is so specific that rubber cracking can be used to measure ozone concentrations (Vesilind and Pierce, 1983).

6. AIR QUALITY STANDARDS

An air quality standard means the concentration of a pollutant that should not be exceeded in the atmosphere at the point of measurement (Lund, 1971).

The air quality standards are closely analogous to the tolerance level; labeled "maximum allowable concentration" or "threshold limit value". It is important, however, to recognize the differences and similarities. The maximum allowable concentration (MAC) is time-weighted for 8 hr/day, 5 day/week exposure of healthy adults, who are supposed to breath uncontaminated air for the remainder of the time. These (MAC) values are applied for the industrial workers. The air quality standards, refer to 24-hr, 7 days/week exposure of an entire population, including the very young, the very old, the sick and the infirm and involves exposure of fauna and flora, and the structures and materials used by man.

Air quality standards in a community must be much smaller than those in the working environment. Exposures in the later environment are restricted to a part of the day and to persons of working age. Older, younger, infirm and sick persons are excluded from these exposures. In fact, most of the published 24 hr., mean quality standards for some contaminants, based on consideration of harm to humans, lies between 1/10 and 1/100 of the MAC values for the same substances. For this reason, a value of 1/30 of the MAC value has been suggested by Stern (1962) as a reasonable approximation for the 24 hr. mean atmospheric safe level concentration of substance for which no air quality standards has been set (Hindy, 1977).

7. THE POLLUTION CYCLE

Atmosphere pollution starts with the production of pollutant, often as undesirable or incidental consequence of various industrial processes, this pollutant is followed by transfer through the atmosphere. Its movement with the air will depend upon a number of factors. Particles larger than approximately 1 micron are significantly affected by gravity. In addition to gravity, the movement of pollutants is affected by turbulent diffusion and the wind speed. At substantial wind speeds, pollutants are rapidly removed from the point of origin and turbulent diffusion usually dilutes them below the level of significant effect within a short distance. But under some conditions, turbulence can bring the plume from a stack to the ground in great lapse at a point quite close to the source and before extensive dilution has occurred, resulting in brief, exposure to extremely high concentrations. The cycle is completed by the contact of pollutants with people, livestock, vegetation, and other objects. This contact may result in eliminating pollutants from the atmosphere or it may be followed by the repetition of a similar cycle. In this stage, the atmospheric pollution may cause damage to health and property.

At each stage of an atmospheric pollution cycle, attempts can be made to reduce the dangers, and inconveniences of atmospheric pollution, or to prevent it from reaching such "a magnitude that it becomes a great danger to the population" (Al-Taieb, 1987).

8. METEOROLOGY AND TOPOGRAPHY

The quality of the atmospheric environment, as already cited earlier, is highly influenced by a wide variety of activities of nature and man. The dispersion of contaminants arising from these activities into the atmosphere, not only affects its quality, but is also highly affected by topography and the continuously changing weather elements :-

1. Levels of air pollution at any given areas largely depend upon local weather changes, principally upon the wind speed and direction and the vertical temperature gradient (Abdel Salam, 1978).

2. Concentration of air contaminants vary inversely with the wind speed at and near their points of discharge. The higher the speed, the more rapidly are pollutants carried away from the source and diluted through their dispersion, vertically and horizontally, into greater volumes of air. On the other hand, pollutants are more concentrated near their source during periods of light winds and calms (Abdel Salam, 1978).

3. Local topography has a great influence on local wind direction and speed. For instance, surface winds blowing at an angle across a mountain chain are channeled in the direction of the windward adjacent valley, while winds relatively aloft are partly channeled and partly pass over the ridge. Such effects would create at the leeward

side of the mountain, either a wake of calm or very light winds, or a turbulent zone, depending on the speed of the originally prevailing wind. Winds funneled by this process may also be markedly increased in speed. Effects of topography, therefore, greatly influence both the rate of dispersion of air pollutants and also the direction of air pollutants and also the direction in which they occur (Abdel Salam, 1978).

4. Air temperature as such has little or no effect on pollution levels. However, the vertical change in its value has a profound effect as it determines the degree of atmospheric stability. Temperature in the troposphere normally decreases with increasing height from the earth's surface, at a rate called the "lapse rate". The critical value of this rate, which differentiates between stable and unstable atmospheres is the "dry adiabatic lapse rate" having a value of 1°C/100 m. Under such condition, the atmosphere is said to be "neutral", i.e., in a state where the density of atmospheric layers is independent of height. When the lapse rate exceeds the dry adiabatic value, the atmosphere is unstable and pollutants are carried aloft and dispersed in a relatively deep and extensive layer of air, so that concentrations of pollutants near the earth's surface are unlikely. On the other hand, when the lapse rate is less than 1°C/100 m or when there is an inversion (an increase of temperature with height), the atmosphere is stable and the vertical motion of air is restricted or hindered.

Pollutants discharged into the atmosphere under such conditions are then trapped in a shallow layer near the ground, whereby high concentrations may result.

Stability is the principle and most important factor in occurrences of unusually high or episode levels of air pollution. Three major forces, namely: wind, heating and cooling, cause shifts from stable to unstable condition and back again. Wind, in addition to horizontal motions, usually has vertical eddies: thermal and/or mechanical. These eddies help vertical mixing and dispersion of contaminants discharged into the air. Thermal eddies are principally developed through the solar heating of the ground and are less developed by heat islands formed over urban and industrial centers. Mechanical eddies, on the other hand, are dependent on the ground surface roughness, topographical features impact and the aerodynamic influences of buildings (Abdel Salam, 1978).

5. Moisture factors do also have appreciable effect on pollution levels although not as direct as that of wind and stability. Its direct effect comes through rainfall which has a pretty good washing effect upon gaseous and particulate airborne contaminants in the atmosphere below the rain-making layer. Fairly clear, air is found during, and for some time after, precipitation. By wetting the ground, rainfall also greatly reduces the amount of wind-generated dust. The presence of fog also limits solar heating of the ground and, therefore, affects the degree

of vertical diffusion in the surface layer air (Abdel Salam, 1978).

6. Mountain-valley, urban-rural and land-sea breezes of weak winds when accompanied with periods of calms and light winds in surrounding areas, can cause a parcel of air to pass over a locality twice or more times during the day. If contaminants are continuously discharged into the air, high levels of pollution will be built up (Abdel Salam, 1978).

9. PREVIOUS STUDIES IN ABU DHABI EMIRATE

A short-term measurements (15 days duration) of air quality in Abu Dhabi city were carried out by LSS, London during October, 1990. The measurements programme included a city-wide nitrogen dioxide diffusion tube survey and background measurements of ozone (at three stations), carbon monoxide (at two stations) and sulphur dioxide, suspended particulates and smoke (at one station). The levels of these pollutants were recorded over a one-week period.

During the period of December, 1990 through December, 1991, Food and Environment Control Center (FECC), Abu Dhabi Municipality had continuously monitored air pollution at six locations in the City of Abu Dhabi. The study was mainly concerned with sulphur dioxide and suspended particulate matter.

Results obtained revealed that the daily mean concentrations of sulphur dioxide exceed the World Health Organization (WHO) guideline (125 $\mu g/m^3$) persistently at one location. The other five locations show an incearse in the level of SO_2 with differential scales during the summer time (May, 1991 to November,1991). Throughout the rest of the year, the concentrations of SO_2 at the five locations were below 60 $\mu g/m^3$ conforming to the requirements of the WHO guidelines with exceptions of very short duration peaks.

On the other hand, the study revealed that the monthly mean concentrations of suspended particulate matter at most of the locations are high in comparison with the standard value published by WHO (70 $\mu g/m^3$).

10. AIM OF THE PRESENT STUDY

The main object of this study is to carry out an investigation on the atmospheric quality of Abu Dhabi Emirate. This will be undertaken through the following :-

1. Measurement of suspended particulate matter (less than 10 μm in diameter) and ascertain the degree that they exist in Abu Dhabi Emirate.
2. Measurement of the gaseous pollutants : carbon monoxide, nitrogen oxides, sulphur dioxide, ozone and hydrocarbons and follow up hourly variation in their concentration.

3. Ascertain the degree of contribution of major man-made activities taking place in contaminating the Emirate atmosphere.
4. Comparing the pollution levels in Abu Dhabi Emirate with those of selected cities of the world and established air quality standards.
5. Setting the suitable recommendations for the air quality management in Abu Dhabi Emirate.

This study is of great importance for all who are interested in air pollution and its effects and for different authorities particularly those responsible for human health.

While the object of the investigation is to obtain exact scientific information, it is essential to remember that one of its main purposes is to give assistance to public authorities and to industry in dealing with the air pollution problem and with questions of public health.

CHAPTER II

METHODOLOGY AND EXPERIMENTAL WORK

1. OBSERVATIONAL SITES

1.1 Abu Dhabi

The Emirate of Abu Dhabi lies at the south western corner of the Arabian Gulf between latitudes (22°,50° and 25°) north and longitudes (51° and 55°) east. It is the largest of the seven Emirates with an area of (67,340) square kilometer and amounting to 86,6% of the total area of the Federation (Ghunaim, 1991).

Abu Dhabi Emirate (Fig. 1) is divided into :

1- The group of Islands which include the Abu Dhabi City.

2- The western region which is divided into : Al-Dhafra and Bainuna which contains the onshore oil fields, and the industrial complex of Al-Ruwais-Jebel Dhana on the coast; site of an oil export terminal refinery and other installations. The region also contains the great arc of the Liwa Oasis, which is in reality a group of dozen little oasis.

3- The eastern region, represented nearly by one city, i.e. Al Ain , the capital of the region.

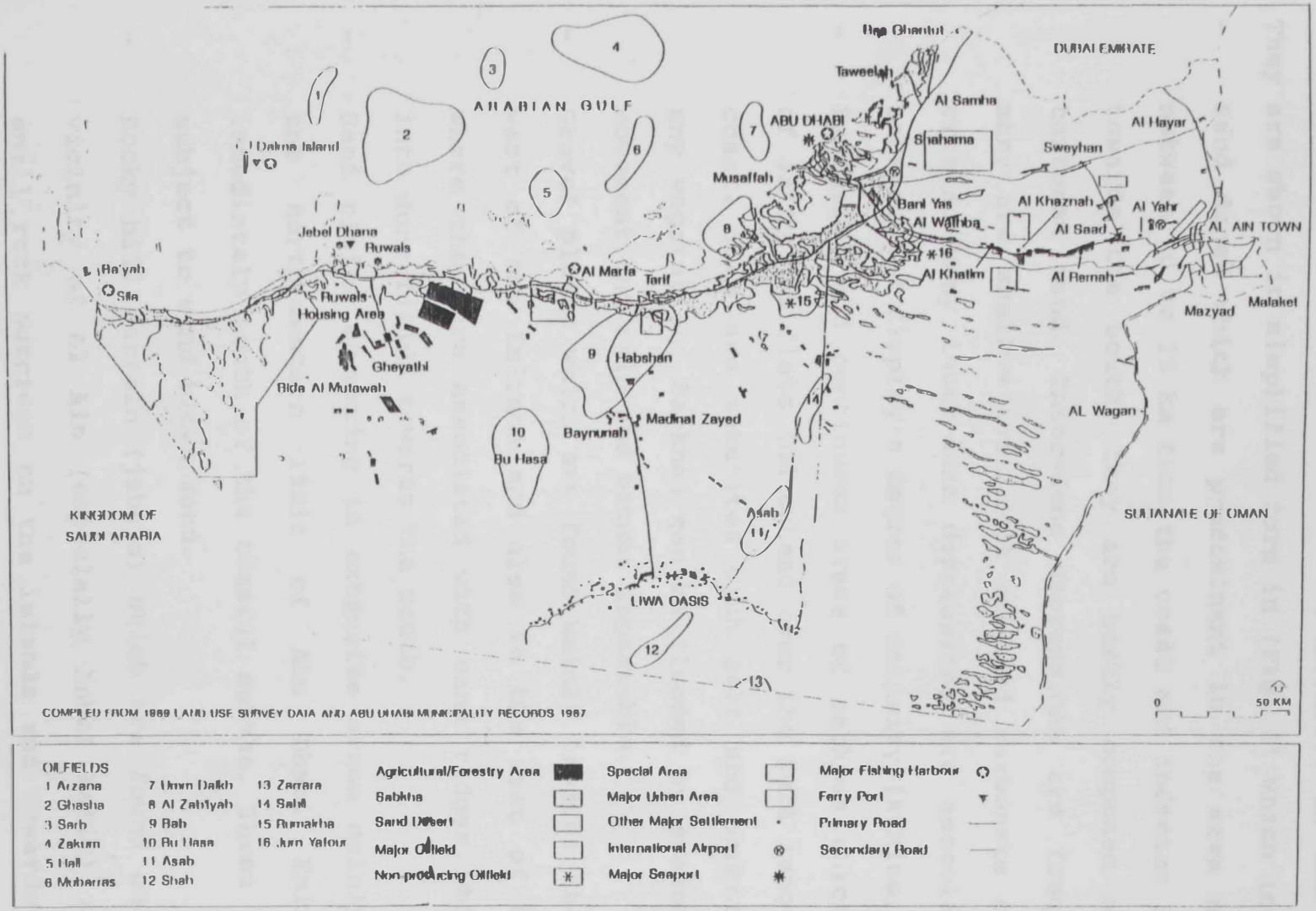


Figure (1) Abu Dhabi Emirate
(After Atkins, 1990)

Land Form and soils

Several land forms have been identified in the Emirate. They are shown in simplified form in (Fig. 2) which includes:

- Sand dunes which are predominant in the area and start between 10 to 15 km from the coast and increase in height towards the south. They are mostly composed of coarse textured sand. Inter-dune depressions are frequent and many are shallow over rock or hard carbonate or gypsic crusts. Many inter-dune depressions are associated with sabkhas and display a degree of salinity (Atkins, 1990).
- Extensive and continuous areas of sabkhas which consist of salty mud flats and extend over the full length of the coast. They are saturated with salt and cannot support any vegetation. Sabkhas can be flooded by seasonal tidal movement and rain and become impassable.
- Gravel plains which are found mainly towards the extreme west of the Emirate and also to the east of Abu Dhabi where they are associated with sand ridges which merge into dune fields towards the south.
- Sand plains occurring in extensive areas mainly towards the north-western limit of Abu Dhabi Emirate and immediately south of the coastal sabkha. These areas are subject to wind blown sand.
- Rocky hill terrain (jebels) which are found only in the vicinity of Al Ain (especially Jebel Hafit) and a few small rock outcrops on the islands and towards the west of the Emirate.

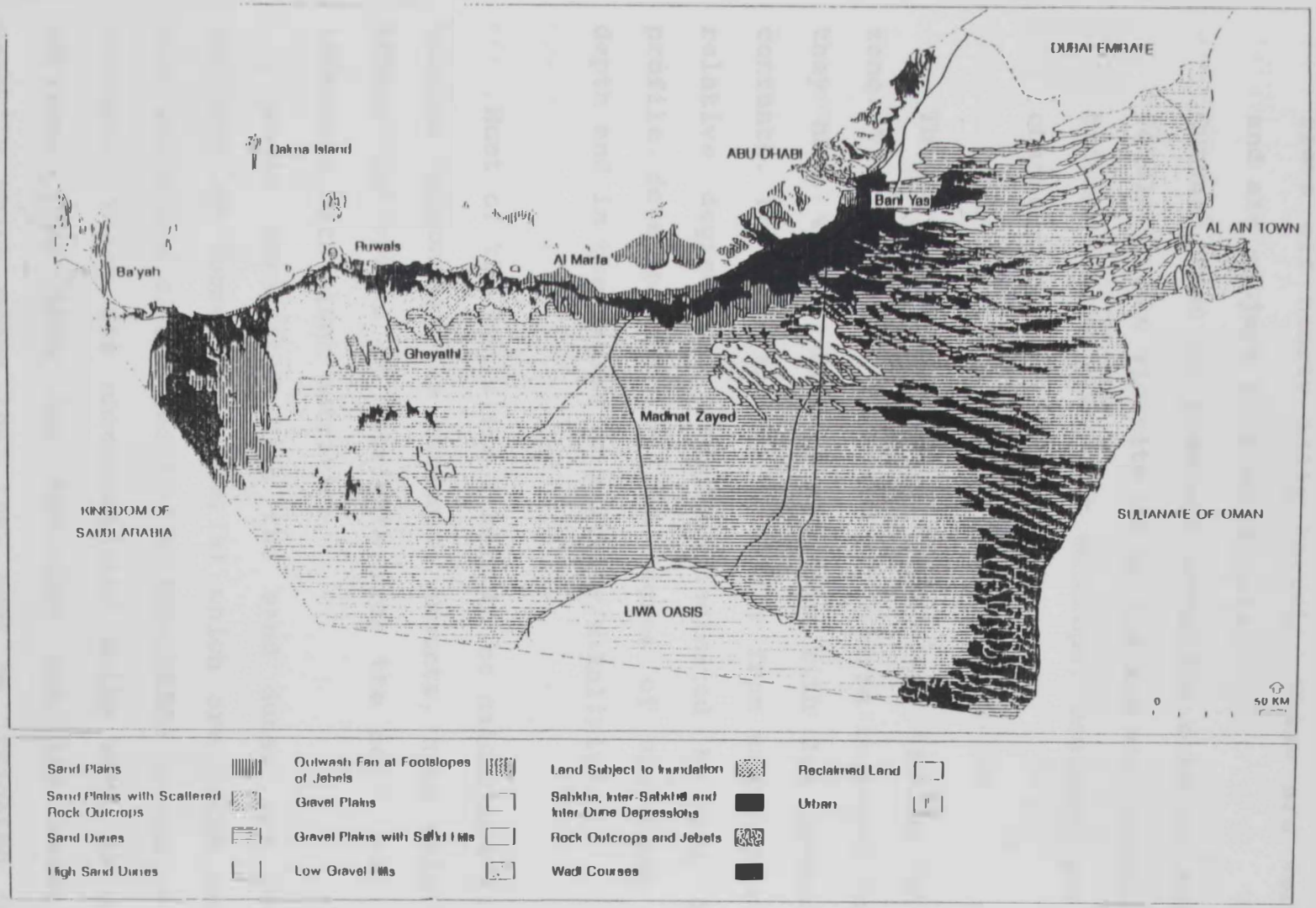


Figure (2) Abu Dhabi Emirate : Geomophological features
(After Atkins, 1990)

- No clearly defined wadi channels exist in the Emirate except for a few in the vicinity of Al Ain where water flows off nearly hilly terrain. These are very boulder and are subject to flash floods.
- Outwash fans or piemonds occurring only on the foot of jebels in the vicinity of Al Ain and are characterized by broken ground with rock outcrops, boulders and drainage channels (Atkins, 1990).

The soils of Abu Dhabi Emirate are typical of the arid zone. Virtually all the soils are coarse textured (sandy) and they have weakly defined topsoils with low organic matter contents. However, the soils differ from each other in their relative degree of maturity (indicated by the degree of profile development), by the degree of stoniness, by soil depth and in the degree of salinity/alkalinity.

Most of the soils are likely to be calcareous (containing calcium carbonate). In excessive amounts, high calcium levels affect the uptake of nutrients from the soil, and therefore interfere with plant nutrition.

Soils associated with the sand dunes are mobile and composed of loose sand material which are often calcareous. Such soils are classified in the FAO-UNESCO system as Calcaric Regosois. These are unconsolidated soils with no diagnostic horizon. They have low fertility and low water holding capacity which means that they must be irrigated frequently with small applications of water to avoid excessive loss to drainage and to avoid plant wilting. Such Calcaric Regosois

Rainfall

Average annual rainfall varies from 58 mm in Abu Dhabi (1971-88) to 88.1 mm in Al Ain (1971-87). Most of the rain falls in the period January to April (90% in Abu Dhabi City and 75% in Al Ain City). Wide variations in the amount of rainfall occur from year to year with substantial standard deviations (Atkins, 1990).

Relative Humidity

Mean relative humidity varies from 55% to 69% in Abu Dhabi City and 37% to 61% in Al Ain City. Humidity sometimes reaches 100% at the coastal regions (Department of Planning,1990).

Insolation and Evaporation

Peak insolation occurs during May, June and July. As a result, evaporation is high. Mean monthly evaporation values are plotted for Abu Dhabi City and Al Ain in Fig. (3). Total annual evaporation is 2858 mm in Abu Dhabi and 3322 mm in Al Ain (Atkins, 1990).

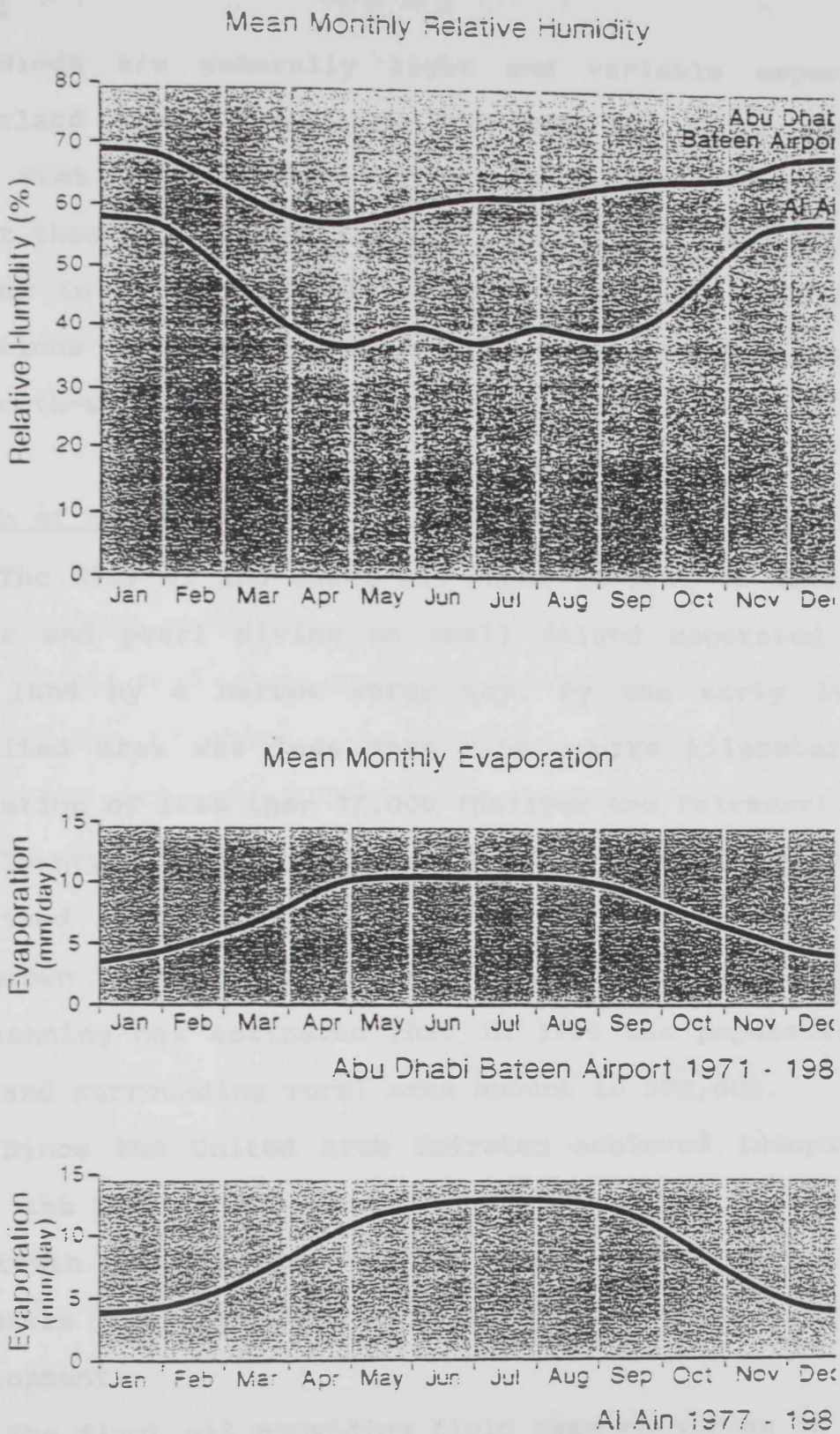


Figure (3) Mean Monthly Relative Humidity and Evaporation for Abu Dhabi City and Al-Ain

Winds

Winds are generally light and variable especially in hinterland areas. Available data for Abu Dhabi and Al Ain shows that wind speed is relatively faster between March and August than the rest of the year. Mean yearly wind speed is 14 km/hour in Abu Dhabi and around 13 km/hour in Al Ain. Wind directions are more frequent from the north-west, south-east and south-west respectively.

Growth of the Emirate

The City of Abu Dhabi was found in 1761 as small fishing center and pearl diving on small island separated from the main land by a narrow water way. By the early 1970's its inhabited area was less than nine square kilometers with a population of less than 25,000 (Hallyer and Fairservi, 1992).

Twenty five years ago the present site of Abu Dhabi City comprised a scattering of huts and a fort. In 1980 the city had grown to a population of 330,000 and today the Department of Planning has estimated that in 1989 the population of the City and surrounding rural area amount to 555,000.

Since the United Arab Emirates achieved independence in 1971, the Emirate has experienced a dramatically rapid process of growth becoming one of the world's most significant oil producers and emerging as a model of economic and social development.

The first oil providing field came on stream in 1962, and the ensuing oil boom transformed the Emirate. In 1988 around 1.5 million barrels of oil per day were produced. The pumping capacity is of the order of 3 million barrels per day.

Electricity production has also grown, and doubled in the six year period 1980 to 1986 (LSS, 1990).

Oil Resources

The Emirate of Abu Dhabi has vast resources of oil. Oil is explored and produced on the mainland and offshore. Associated gas from crude production is also produced on the mainland and offshore. Its present production is estimated to be at full capacity and yielding 0.4 million barrels a day. In terms of oil reserves, Abu Dhabi Emirate holds by far the largest reserves. (Atkins. 1990)

The main offshore oil fields are located at Bab, Bu Hasa, Asab, Sahil and Shah and are operated by ADCO (Abu Dhabi Company for Offshore Oil Opertions). Gasco (Abu Dhabi Gas Industries Limited) handles the associated gas from ADCO's onshore crude production and processes it through three LNG extraction plants at Bu Hasa, Bab and Asab. The main settlements associated with inland hydrocarbon extraction are located at Habshan, Bu Hasa and Asab.

Hydrocarbon processing includes two refineries located at Umm Al Nar (rated capacity 60000 b/d) and Ruwais (120000 b/d) sufficient to meet the UAE requirements for refined petroleum products, and a hydrocracker distillation plant at Ruwais (capacity 27000 b/d). South of the Ruwais industrial area, ADNOC has built a new town for its employees.

A network of pipelines is used to transport crude oil and gas from onshore extraction areas to the refineries. The network for oil pipelines focuses on Jebel Dhana which is the main terminal for the export of crude oil on Abu Dhabi

mainland. A gas pipeline network transports LNG from the plants in Bab, Bu Hasa and Asab to Ruwais where they are stored until export. Residue gas is used for fuel requirements and routed to end users through a pipeline which terminates in Umm Al Nar.

Offshore oil production areas are mainly concentrated at Umm Al Dalkh, Zakum and Umm Shaif Islands and to lesser extent at Bunduq fields. Crude oil from Umm Al Dalkh and Upper Zakum flows to Zirku Island oil loading terminal, while the crude from Lower Zakum, Umm Al Shaif and Bunduq flows to Das oil loading terminal. The main settlements associated with offshore hydrocarbon extraction are situated on Das Island, Mubarras, Zirku and Arzanah (Atkins, 1990).

Offshore gas production is mainly operated by Abu Dhabi Gas Liquefying Company, ADGAS, which receives associated gas from the offshore oil fields of Umm Al Saif and Lower Zakum supplemented by gas from the Uweinat gas gap. The LNG is transported by gas pipelines to Das Island processing plant and from there to the LNG export terminal.

1.2 Al Ain City

Al Ain which is the town of the United Arab Emirates University, is situated in the east of Abu Dhabi Emirate near the border with the Sultanate of Oman (Fig. 4). It is the administrative centre of the Eastern Province of the Emirate and one of the largest and most ancient oases of the Arabian

Peninsula due to a plentiful supply of fresh underground water derived from the Oman mountains to the east.

Rapid development has taken place in Al Ain over the past 15 years. Much of the flat ground is now either fenced for irrigation or used for housing. This development has contributed to the setting up of a cement factory south-east of the City (Fig. 4). This factory which commenced production in 1976 produced in 1992, 850,000 tons of cement including portland, sulphate-resistant and special types. Also, progress has been achieved in Al Ain in the agricultural industries which are managing not only to increase production to meet local demand, but also to begin exports, both of fresh and processed goods.

Al Ain is said to be the fastest growing city in the Gulf area. Its many facilities include besides the national university, a new international airport to the north-west of the City (Fig. 4), two big hotels, three hospitals and many schools. There are also many stadiums and offices of the Government ministries in the City.

Al Ain occupies some 9960 km^2 which represent 12.8% of the total area of the state. According to 1991 population estimates (Statistical Section, Department of Planning, Abu Dhabi Emirates, 1993) the total population of the city is 246,487 representing 31% of the total population of the Abu Dhabi Emirate.

Ancient populations of Al Ain, and in other parts of the world, affected the environmental conditions only through processes of providing food and shelter for themselves. The hazards have changed in the city over the past 15 years through the growth of settlements and industrial and agricultural development.

2. AMBIENT AIR MONITORING

The present investigation was carried out by the Environment S.A. Ambient Air Monitor which has various instruments installed into an enclosed truck-type vehicle to provide a Mobile Laboratory (Fig. 5).

This Mobile Laboratory has the advantage of being able to move from one place to another, covering all industrial, residential, agricultural, and commercial areas, eliminating the need for multiple permanent installation. This Mobile Unit is housed in insulated air conditioned truck body for use during all normal weather conditions.

The Mobile Laboratory is equipped with the most advanced monitoring devices. It can provide extremely accurate measurement of pollution gases emitted through car exhausts or industrial production. The device can measure the amount of nine pollutants in the atmosphere : sulphur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides ($NO-NO_2-NO_x$), hydrocarbons; methane and non-methane (MHC_s-NMHC_s), ozone (O_3) and suspended particulate (SP)≤10 μm.

On the other hand, the Mobile Laboratory is equipped with small meteorological unit which can carefully measure the levels of humidity, temperature, wind speed and direction besides solar radiation intensity. The range of automatic and continuous (24 hours/day) analyzers is complemented by a range of calibration, control, acquisition and data processing devices. Measurement of the various devices are recorded every ¼ hour, hourly, and stored in a computer ram which is linked directly to the devices.

2.1 Monitoring Devices

2.1.1 OZONE (O_3) ANALYZER

Ozone is measured with the μv Photometric Ozone Analyzer O_3 41M. Measurement range programmable from 0.1 to 1 ppm with a minimum detectable of 1 ppb during 30" response time; Figure (6) shows the principles of operation, and Figure (7) shows the analyzer. The analyzer has the following characteristics :

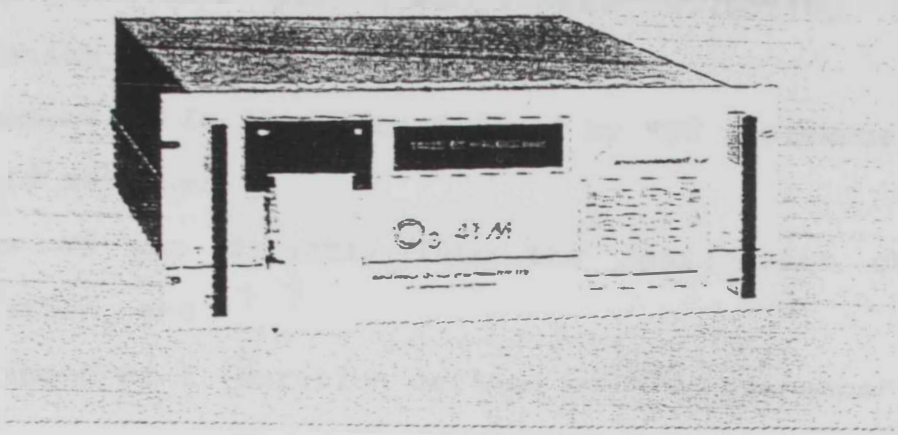


Figure (6) Ultraviolat Photometric O_3 Analyzer

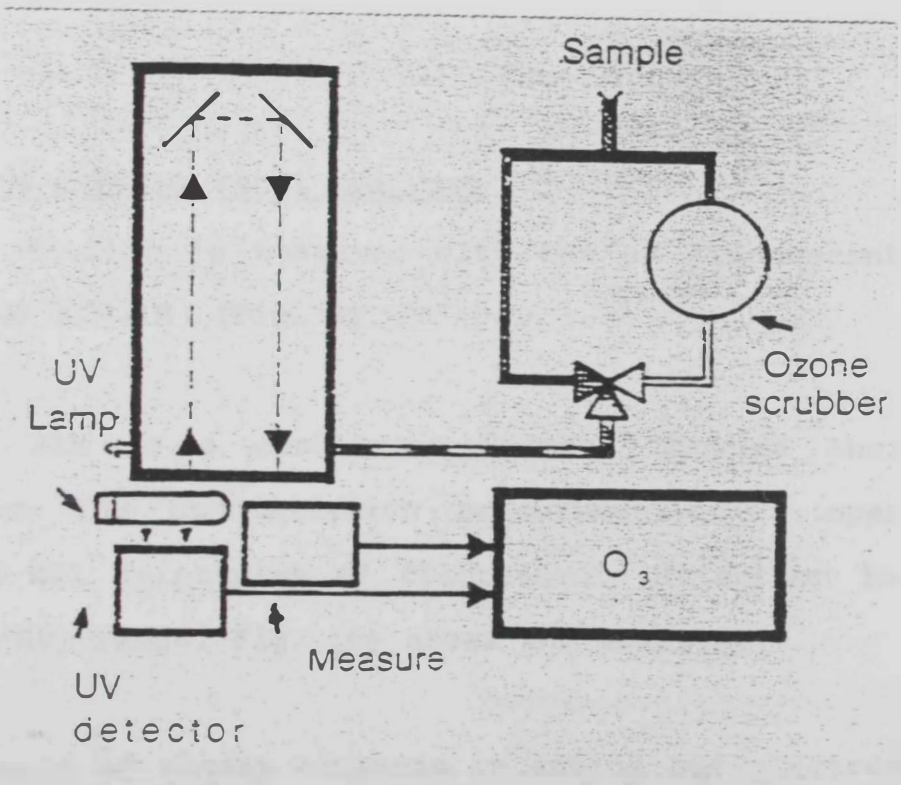


Figure (7) Operational Principles of O_3 Analyzer

One measurement corresponds to the following cycle :

- Passage of the gas through the selective filter ventilation of the measurement chamber,
- Measurement of Io (duration defined by "UV reference"),
- Solenoid switched,
- Passage of gas directly into the measurement chamber ventilation, and
- Measurement of I (duration defined by "UV reference").

The entire cycle lasts about 10".

A barometric sensor measuring pressure P inside the measurement chamber is used for pressure compensation.

A gas temperature sensor T, is used for temperature compensation.

2.1.2 SULPHUR DIOXIDE (SO_2) ANALYZER

Sulphur dioxide is measured with the μv fluorescent SO_2 analyzer model AF 21M (Fig. 8).

The AF 21M is a continuous Sulphur Dioxide Analyzer (specific for low concentration measurement). It operates according to all principles of fluorescence detection in the ultraviolet (UV) range. Fig. (9) shows the analyzer.

As a result of recent advances in optics and electronics, the equipment offers numerous advantages, such as :

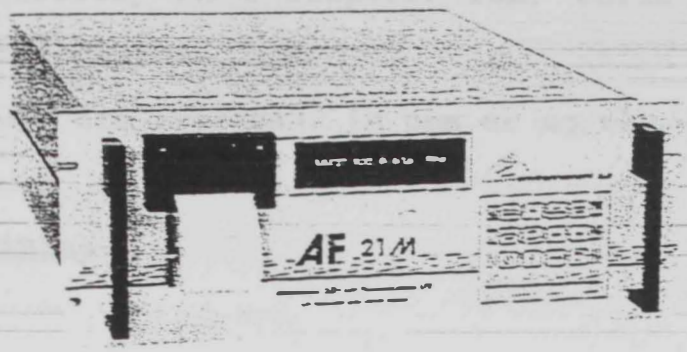


Figure (8) Ultrviolat Fluorescent SO_2 Analyzer

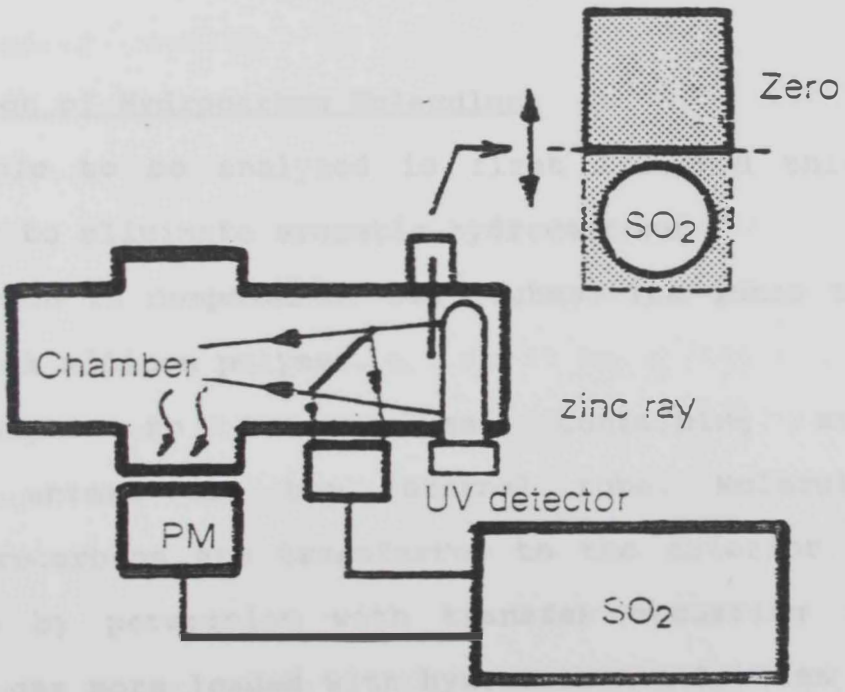


Figure (9) Operational principles of SO_2 Analyzer

a) Measurement range programmable from 0.01 to 10.0 ppm with a lower detection limit of 1.0 ppb.

b) Storage of values measured (mean of every ¼ hour, hourly and stored directly in a computer ram, which is linked directly to the device), and

c) Measured values are expressed in ppm or $\mu g/m^3$.

Operational Principles

a) Sampling

The sampling is taken via a Teflon (PTFE) tube connected to the rear of the analyzer by a pump at the end of the circuit. A Teflon tube connected to the rear of the analyzer by a pump at the end of the circuit. A Teflon inlet filter protects the system against dust.

b) Filtration of Hydrocarbon Molecules

The sample to be analyzed is first filtered through a carbon kicker to eliminate aromatic hydrocarbons.

This device is composed of two tubes. The inner tube is made of special silicon polymer.

The sample to be analyzed containing aromatic hydrocarbons enters via the internal tube. Molecules of aromatic hydrocarbons are transferred to the exterior of the silicon tube by permeation with transfer occurring in the direction of gas more loaded with hydrocarbon molecules to gas less loaded with hydrocarbon molecules.

The pump creates a negative pressure in the outer tube. The partial pressure of the aromatic compounds and the molecules are evacuated to the exterior.

c) Analysis

The hydrocarbon-free sample to be analyzed is now sent to a reaction chamber where it is irradiated with ultraviolet radiation centered around 214 nm. This wavelength is specific for absorption of SO_2 molecules.

These molecules restore a specific fluorescence in the UV, which is optically filtered at outlet.

Before each "reference zero" and every 40 minutes, a shutter closes for 40 sec. between the UV lamp and the reaction chamber inlet.

The photo-multiplier (PM) tube is placed laterally at the reaction chamber outlet. It thus, sees the fluorescence reaction for 40 minutes and the electrical zero for 40 sec. while the shutter is closed.

Electrical zero is the dark current of PM tube, the offset current of the preamplifier which is included in single processing suppresses any possible drift which temperature and time the signal from the PM tube is amplified and converted to digital values for subsequent processing by a microprocessor which calculates the mean measurement values and manages safety alarms and instrument function diagnostics. These different values are seen on an alphanumeric display on the front panel.

2.1.3 CARBON MONOXIDE (CO) ANALYZER

Carbon monoxide is measured with the gas filter CO analyzer Model CO 11M (Fig. 10).

The CO 11M is a continuous analyzer for carbon monoxide, specific for low concentrations in ambient air and in atmospheric conditions. Fig. (11) shows the principles of operation.

It operates according to the principle of detection by infrared absorption.

As a result of recent optical and electronic technologies, the instrument offers numerous advantages, such as :

a) Measurement ranges programmable from 10.0 to 100.0 ppm with a minimum detection limit of 0.1 ppm,
b) Automatic calibration sequence, programmable or remote controlled,
c) Auto-calibration,
d) Memorization of measurement values and display of hourly means for 15 days,
e) Expression of measurement values in ppm or $\mu g/m^3$,
f) Automatic tests of the measurement, and
g) Permanent tests for correct operation (IR energy, flow rate, temperature, pressure, ...etc.).

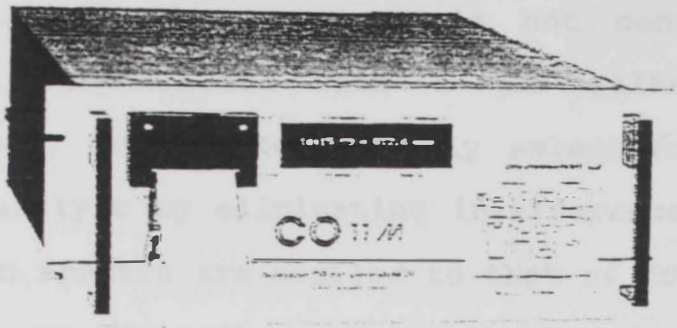


Figure (10) Gas Filter CO Analyzer

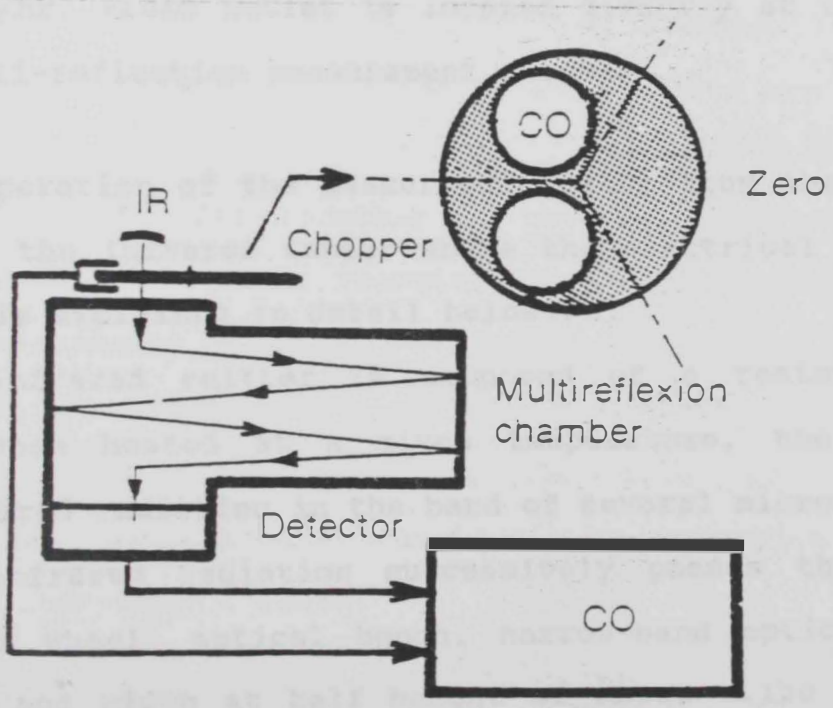


Figure (11) Operational Principles of CO Analyzer

Operational Principles

The absorption spectrum of carbon monoxide contains a maximum at the wavelength of 4.67 μm, which corresponds to the spectrum selected by the optical filter.

Since the absorption spectrum is not continuous, the optical filter is combined with a gas filter called a correlation wheel, leading to a highly selective measurement of the gas to analyze by eliminating interferences from gases whose absorption spectra are similar to that of CO.

Samples drawn through a standardized air inlet system (sampling tube, funnel, Teflon tubing). The Teflon is connected to the rear of the monitor. Dust protection is achieved by inlet dust filter made of Teflon, easily accessible at the rear of the instrument.

A restrictor (calibrated orifice) limits flow rate to about 80 l/hr. Fluid outlet is located directly at the outlet of the multi-reflection measurement chamber.

The operation of the measurement cell, from the infrared emitter to the infrared sensor where the electrical signal is generated is explained in detail below :-

The infrared emitter is composed of a resistive wire winding, when heated at a given temperature, the filament emits infrared radiation in the band of several microns.

The infrared radiation successively passes through the correlation wheel, optical bench, narrow-band optical filter at 4.7 μm and width at half height of about 0.120 μm before reaching the infrared detector.

The correlation wheel is driven by a DC motor. During one half-rotation, the emitted radiation successively passes through 3 sectors of wheel ,

- a first opaque sector
- a second empty sector
- a third sector including a cell filled with CO.

Before entering the multi-reflection measurement cell (5.60 meter path length, equivalent to 28 reflections of the incident beam) the infrared radiation passes through each of the 3 sectors of the correlation wheel at frequency of several times per second. The wheel is rotated by a DC motor at the speed of 1300 rpm. This results in the temporal splitting of the infrared beam into 3 radiations which will be converted into 3 electronic signals by the infrared detector located at the outlet of the multi-reflection chamber. These are :

- A zero signal,corresponding to the total suppression of the infrared radiation incident on the opaque sector.
- A measurement signal corresponding to passage through the empty part of the wheel and through the optical bench. The IR detector thus receives the radiation corresponding to the concentration present inside the optical bench.
- A reference signal corresponding to passage the incident IR radiation through the cell filled with a high concentration of CO at a pressure of atmosphere

(absorption by the gas filter composing the CO cell is total for the lines characteristic of CO).

Changes in the absorption of the IR radiation are measured with a rapid PbSe photo conducting cell chilled to -30°C by a Peltier element in order to reduce noise before signal forming by the measurement preamplifier.

The preamplifier output signal is applied to analog/digital converter which is the interface between detector and processing system.

In order to synchronize the presence of the signal with its acquisition by the microprocessor, the correlation wheel is equipped with needles whose position is detected by an optical splitter at the beginning of each step.

2.1.4 NITROGEN OXIDES (NO, NO_2, NO_X) ANALYZER

Nitrogen oxides are measured with chemiluminescent dual channel NO-NO_2-NO_X analyzer model AC 30M (Fig. 12).

Model AC 30M is a continuous monitor for low concentrations of nitrogen oxides.

Model AC 30M is mounted in a 9 inch, 5 units, 625 mm overall depth.

Monitoring method is the chemiluminescence technique of analysis, AC 30M model has two fundamental features. Figure (13) shows the operational principles.

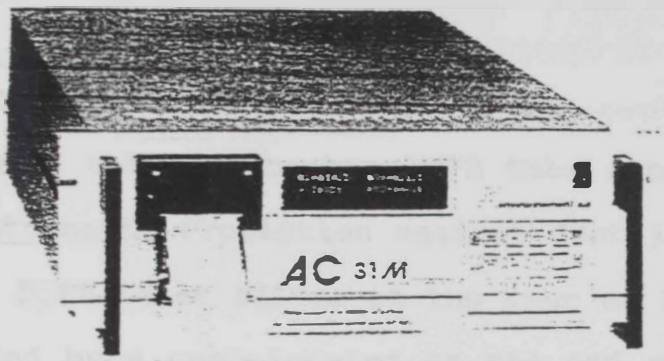


Figure (12) Chemiluminescent Dual Channel $NO-NO_2-NO_x$ Analyzer

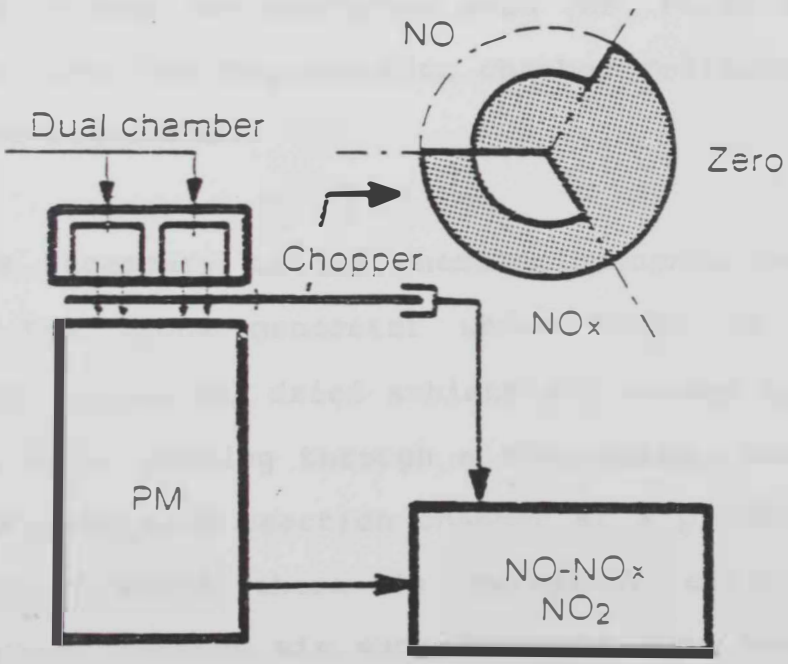


Figure (13) Operational Principles of $NO-NO_2-NO_x$ Analyzer

- Dual NO-NO_x channels, that is two measuring chambers and one photo-multiplier tube for continuous NO and NO_x measurement on the same sample, and
- Permanent microprocessor run alarm checks and operation diagnosis.

Operational Principles

The sample is taken through a PTFE tube connected to the rear of the instrument. Protection against dust is given by an easily accessed PTFE inlet filter at the rear of the monitor. Sample air sucked by a pump located at the end of the circuit goes to the converter oven (NO_x channel) on the one hand, and to the NO reaction chamber directly (NO channel) after passing through a laser perforated synthetic sonic ruby flow regulator,on the other hand. The NO channel is very strictly regulated to a value close to 35 l/h. Sample (NOx channel) after passing through the converter oven (NO_2 to NO reduction) is introduced into the NO_x reaction chamber following passage through a flow regulator.

Ozone as necessary to the chemiluminescence reaction is produced by the ozone generator where there is permanent circulation of silica gel dried ambient air sucked by the same vacuum pump. After passing through a flow-meter, ozonated air is introduced into each reaction chamber at a produced by the ozone generator where there is permanent circulation of silica-gel-dried, ambient air sucked by the same vacuum pump. After passing through a flow-meter, ozonated air is introduced

into each reaction chamber at a constant rate of approximately 15 l/h regulated by sonic ruby.

A negative pressure is created into both reaction chambers by the vacuum pump. One vacuum-meter placed at the common outlet of the chambers indicates the pressure value.

The chemiluminescence reaction taking place in both reaction chambers occurs when ozone and NO molecules come into contact. It is therefore necessary to have a chamber configuration and volume allowing a good homogeneity of the blend, and a transit time compatible with reaction velocities allover the measurement range.

Both reaction chambers are read by one single photo-multiplier tube of high sensitivity to avoid the disadvantage of using the two different PM tubes. A three sections (NO-NO_X-zero) chopper rotates at high speed before the PM tube which is therefore allowed to read in succession and several times per second, reaction chamber NO, then reaction chamber NO_X, then the mask. Thus, at each complete revolution of the chopper, an electrical zero is achieved corresponding to the dark current of the PM tube. This is taken into account in signal processing and eliminates any possibility of signal drift. A high pass filter located between the chopper and the photo-multiplier tubes eliminates emissions due to interference under 610 nm. The PM tube signal is pre-amplified, then processed by a microprocessor which performs in particular the digital calculation of mean measurement values,NO_X and NO signal different to derive NO_2, as well as alarm checks and operation diagnosis of the instrument. The

various values and indications are displayed alphanumerically on the front panel of the monitor.

In order to maintain the dark current of the photo-multiplier tube within values compatible with the minimum measurement range, the PM tube is mounted into a temperature controlled at 12°C plus or minus 0.1°C. Likewise, the high voltage supply of the PM tube is regulated at 1/1000 for gain stabilization.

2.1.5 HYDROCARBON (MHCs, NMHCs) ANALYZER

Hydrocarbon (NMHCs) is measured with DANI TNMH 450-B in order to determine the total non-methane organic contents in ambient air or inert gases by means of flame ionization detection principle (FID), after catalytic subtraction (Fig. 14a,b).

Operational Principles

DANI TNMH 450-B determines the total methane organic contents in ambient air or inert gases by means of the flame ionization detection principle (FID), after catalytic subtraction.

A pump aspirates from the sample line the gas to be analyzed and a small part of it is conveyed at constant flow rate to the analyzer, whereas the rest is vented through a precision back pressure regulator. The gas portion to be analyzed is sent to FID either directly or through a special scrubber which removes all the hydrocarbons except methane.

The built-in programme provides cyclically the scrubber actuation: the obtained response, related to methane contents only, is continuously subtracted from the total response according to the so called "Methane Reference Mode". The Methane Reference Mode actuation lasts 60 seconds and can be repeated at variable intervals from 1 to 99 min.

Single storage and differentiation are then displayed by a powerful microprocessor, thus granting dynamics and stability, the scrubber consists of a special catalytic reactor kept at a rigorously constant temperature. The average life of the catalyzer strictly depends on the quantity and nature of the treated hydrocarbons : under normal operating conditions the life time is of 10,000 operations about (10,000 hours).

2.1.6 Suspended Dust <10 µm Monitor

The ambient air dust monitor MPSI 100 principle is based on the measurement of beta ray absorption by dust sampled in the environment and retained by a fiberglass paper filter provided with a microprocessor controlled sequential feed (Fig. 15).

The microprocessor handles the sequences, makes corrections and computes the dust concentrations which are directly printed in $\mu g/m^3$. By virtue of its operating mode, it can periodically scan, during a cycle, the dust deposit with a view to measure without range switching, the dust concentration comprised between 1 $\mu g/m^3$ and 4 mg/m^3, on 24 hours.

The main advantage of the beta ray gauge system is related to the exceptional repeatability of the measurement, resulting from the remarkable zero setting part of the measurement cycle. Figure (16) shows the operational diagram.

Operational Principles

Among all methods used in measurement of the concentration of dust suspended in atmosphere or a gas, the beta gauge offers real advantage whenever the concentration is to be expressed in terms of mass per unit of volume and whenever the process must be automatic.

In fact, a precision scale can not easily be automated to record micrograms, whereas optical mehtods measuring light absorption or diffusion by particles do not give indication of the mass.

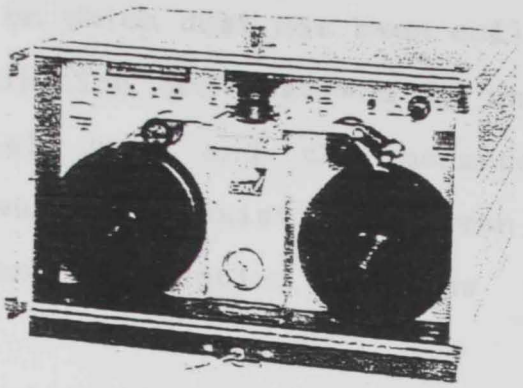


Figure (15) Ambient Suspended Particulate Beta Gauge Monitor

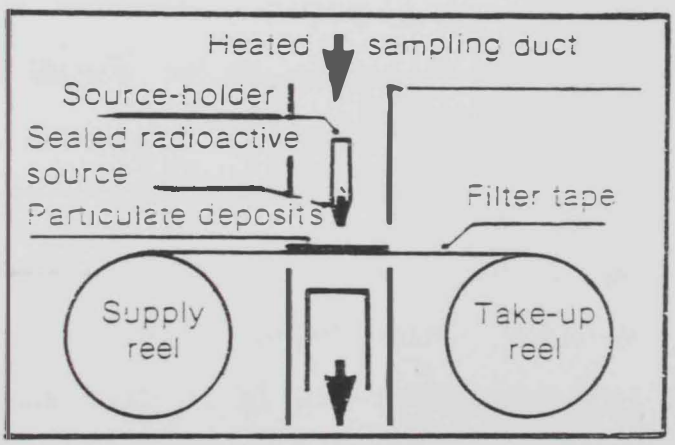


Figure (16) Operational Principles of Suspended Particulate Monitor

A beta gauge is composed of a soft beta rays transmitter, such as 147 pm, and a radiation receiver, respectively placed at each side of the sample to be processed. The sample is usually a filter on which dust has been collected.

The beta radiation are observed by the matter according to an exponential law, and the measurement consists in calculating the variation existing between absorption by the virgin filter and absorption by the filter with dust collected.

The method is sensitive to the point of measuring dust deposits of 20 $\mu g/cm^2$ in a matter of two minutes.

Therefore, with measurement cycles between 1 and 24 hours, it is possible to monitor concentrations of 1000 to 5 $\mu g/m^3$.

CHAPTER III

MONITORING OF SUSPENDED PARTICULATE MATTER LESS THAN 10 MICRON (SPM_{10}) IN AL AIN CITY

1. THE PROBLEM

The Al Ain region lies within the hot arid desert zone and is characterized by meagre and variable rainfall, shade temperatures frequently above 45 °C, and winds blowing from north-west, south-east and south-west (Cox, 1985). Stormy breezes and winds create substantial problems from dust and wind-blown sand. At the regional level, the effect of wind-blown sand differs between various towns and villages depending on the wind direction in relation to dune formation. Al Ain City, sited on stable gravel plains, is at risk only where it abut the dunes or where dunes are advancing across the plains towards it (Cox, 1985).

The atmosphere, in general, is usually polluted with various kinds of natural contaminants. However, the very noticeable one in the City of Al Ain is the natural dust.

Natural dust is brought into the air of Al Ain City by various factors, the most important of which are dust-and/or sand-storms. Dusts locally generated from bare lands and

unpaved roads, by the effect of wind and moving traffic, also contribute their considerable share.

Dusty storms passing over Abu Dhabi Emirate, in general, and Al Ain city in particular are mainly of two kinds :

- Those accompanying the passage of cold or a warm front. Such storms usually remain over Abu Dhabi for very few hours and are often followed by rain sometimes accompanied by thunder storms. The atmosphere is cleared after rain or the passage of cold front. A dusty atmosphere may continue after a warm front, if it is not accompanied by rainfall, until the warm air mass is changed.

- Those formed as a result of pressure or heat disturbances. A few of these are local ones and only affect parts of the Emirate. Others are large scale ones which pass over Abu Dhabi and other Emirates and also affect other countries in the region. The latter are more common and remain over Abu Dhabi Emirate for several days. Some of these come from the north after passing over the Arabian Gulf and are loaded with fine dust and have a yellowish colour. The others, coming from Saudi Arabian desert to the south of the Emirate, have coarser particles (mainly sand), sometimes reddish in colour. Such large scale storms affect Abu Dhabi Emirate either directly by passing through the surface layers of the atmosphere, or indirectly by passing through the atmosphere aloft and are only seen in the sky as dust

clouds precipitating some of their laden-dust over the Emirates.

A preliminary study of dustfall rate and composition was carried out in the City of Al Ain during October and November, 1993 (Hindy and Baghdady, 1994a,b,c). The study was concerned with dustfall as a simple and good tool for showing the degree of pollution in any area. Dustfall jars were set up in five districts in different University premises distributed in the City. The study reveals that : (a) Dustfall in Al Ain is on the average twice the adopted Threshold Limit Value (TLV) for dustfall rate in residential areas in Germany, USA and Eastern Countries including the former USSR (15 tons/mile^2/month), and (b) Wind-blown dust and/or sand from the south-west is the major contributor to dustfall over the city.

This study lends credence that any air pollution study in the City of Al Ain should be directed towards monitoring the various forms of atmospheric particulate matter particularly in the areas, which are located in the pass of the winds hitting the City from the south-western direction. The most important one of these areas is Al Maqam where the female students campus of the United Arab Emirates University is located (Fig. 17).

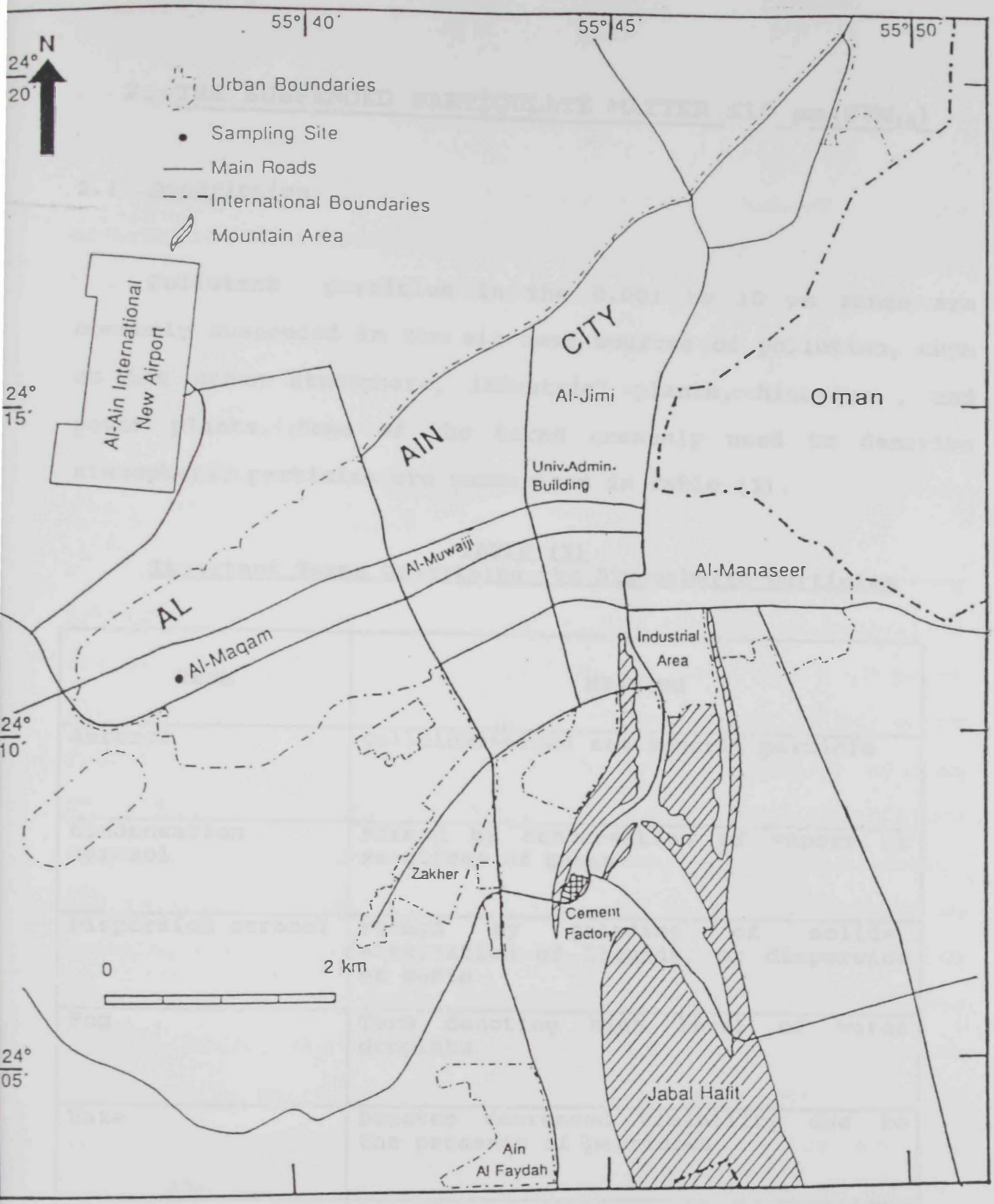


Figure (17) Location Map of the Study Area in Al Ain

2. THE SUSPENDED PARTICULATE MATTER ≤10 μm (SPM_{10})

2.1 Description

Pollutant particles in the 0.002 to 10 μm range are commonly suspended in the air near sources of pollution, such as the urban atmosphere, industrial plants, highways , and power plants. Some of the terms commonly used to describe atmospheric particles are summarized in Table (3).

TABLE (3)
Important Terms Describing the Atmospheric Particles

TERM	MEANING
Aerosol	Colloidal-sized atmospheric particle
Condensation aerosol	Formed by condensation of vapors or reactions of gases
Dispersion aerosol	Formed by grinding of solids, atomization of liquids, or dispersion of dusts
Fog	Term denoting high level of water droplets
Haze	Denotes decreased visibility due to the presence of particles
Mists	Liquid particles
Smoke	Particles formed by incomplete combustion of fuel

(After Manahan, 1991)

2.2 Health Effects

Recent epidemiological studies have focused on the adverse health effects of ambient air pollution, specifically the adverse effects of fine particles, which penetrate more deeply into the respiratory tree than larger particles. The current regulatory standard for particulate matter less than 10 μm in aerodynamic diameter (SPM_{10}) was promulgated by the Environmental Protection Agency in 1987 (Schenker, 1993).

Daily SPM_{10} levels have been correlated with respiratory symptoms, peak expiatory flow rates, and the use of medication for asthma in children with symptoms of the disease (Pope et al., 1993), and with small degrees of impairment in pulmonary function in adults (Pope and Kanner, 1993). Previous studies of patients' visits to emergency rooms for respiratory symptoms found in association between such visits and ambient air pollution (Samet et al., 1981), and in a recent study in Seattle, USA, increases in the SPM_{10} level were associated with more emergency room visits for asthma (Schwartz, 1991). In the Seattle study, the mean SPM_{10} level that was associated with increases in emergency room visits was 30 $\mu g/m^3$, or one fifth of the current US standard for the average value over 24 hours; the daily mean level never exceeded 70 percent of the standard. Hospital admissions for respiratory disorders have also been associated with particulate air pollution (Pope, 1991) and with levels of sulphate aerosols, a component of SPM_{10} during the summer months (Bates and Sizto, 1987). In the National Health Interview Survey, increased concentrations of

fine particles in the ambient air were associated with respiratory conditions severe enough to result in absence from work (Ostro and Rothschild, 1989).

Recent mortality studies have raised further questions about the safety of the current SPM_{10} standard. Analyses in several cities-Philadelphia; Santaclara; California; Detroit; Steubenville; Ohio; St. Louis ; Birmingham and Alabama- have shown a statistically significant direct association between mortality and daily concentrations of particulate matter in the air (Schwartz, 1991).

3. THE PRESENT INVESTIGATION

Monitoring of suspended particulate matter less than 10 μm (SPM_{10}) was carried out in the Female Students Campus of the United Arab Emirates University located at Al Maqam area (Fig. 17)

The sampling instrument and procedure of measurement of SPM_{10} concentration are described in Chapter II (pp. 51 - 53). Monitoring was undertaken daily over a period of three months (December 1993, January 1994, and February 1994). These represent the winter season of 1993-1994 year.

The information gathered by the present investigation is correlated with the corresponding weather data. Hourly observations of meteorological elements that may likely affect the degree of pollution at the study area were obtained from Al Ain Military Station. These data were then processed to meet the requirements of the present investigation.

3.1. Results

The daily results of SPM_{10} during the study period are assembled in Table (4).

The results obtained were monthly averaged and are given in Table (5) which shows the minimum, maximum and mean concentration of SPM_{10} during each of the three study months. The same table indicates the Threshold Limit Value (TLV) according to the U.S. National Ambient Air-Quality Standards (NAAQS) (EPA,1976). Besides, the monthly means were seasonally averaged for the winter, 1993-1994 and are listed at the bottom of the table.

TABLE (4)

Daily Concentration of SPM_{10} ($\mu g/m^3$) in Al Ain During the Period of Study (Dec., 1993 - Feb., 1994)

MONTH/DAY	DECEMBER, 1993	JANUARY, 1994	FEBRUARY, 1994
1	53.6	50.4	102.6
2	62.9	64.5	80.0
3	55.1	94.2	65.5
4	58.1	93.7	67.5
5	70.6	80.5	44.4
6	90.9	67.1	51.3
7	80.1	46.6	54.8
8	100.2	53.3	62.1
9	92.3	46.6	72.3
10	66.8	57.8	66.3
11	65.5	185.3	91.3
12	75.2	86.8	61.9
13	79.2	78.6	70.4
14	86.8	57.8	46.8
15	77.7	87.5	53.4
16	68.8	-----*	81.7
17	47.3	69.9	136.9
18	61.5	47.6	55.4
19	73.4	65.9	52.7
20	60.2	84.0	65.9
21	60.1	61.9	82.8
22	70.3	-----*	102.1
23	65.5	73.8	77.4
24	70.3	106.0	60.2
25	68.0	78.0	51.6
26	47.7	71.8	-----*
27	-----*	63.7	-----*
28	57.7	59.3	-----*
29	54.9	64.4	-----*
30	59.6	83.4	-----*
31	51.0	73.1	-----*

* ----- Not recorded

TABLE (5)

Monthly and Seasonal Range and Mean of SPM10 Concentration in Al Ain Compared with the TLV During the Period of Study (Dec., 1993 - Feb., 1994)

MONTH	NO. OF READINGS	RANGE*			TLV*
		MINIMUM	MAXIMUM	MEAN	
Dec., 1993	30	47.3	100.2	67.7	75**
Jan., 1994	29	46.6	185.3	74.3	
Feb., 1994	27	44.4	136.9	68.8	
Winter 1993-1994	86	46.1	140.8	70.26	

* $\mu g/m^3$
TLV = Threshold Limit Value
** Annual Geometric Mean

3.2. Discussion

The most striking features characterizing the presented data can be summarized in the following sections:

3.2.1 The SPM_{10} Level and Source

The monthly means being 67.7 $\mu g/m^3$, 74.3 $\mu g/m^3$ and 68.8 $\mu g/m^3$ during December, January and February respectively and the winter 1993-1994 mean being 70.26 $\mu g/m^3$ are still below the TLV.

This finding clearly indicates that the concentration of the suspended particulate matter less than 10 micron (SPM_{10}) in Al Ain atmosphere is, on the average, below the Threshold

Limit Value (TLV) according to the U.S. National Ambient Air-Quality Standards (NAAQS (EPA, 1976).

This unexpected result is quite disconcordant with that obtained throughout the preliminary study carried out on dustfall rate in Al Ain during October and November 1993 (Hindy and Baghdady, 1994a), which indicates that dustfall in Al Ain is,on the average, twice the adopted TLV for dustfall in residential areas in Germany, U.S.A. and Eastern Countries including the former U.S.S.R. (15 tons/mile^2/month).

It can be deduced that the problem of particulate pollution in the City of Al Ain is concerned with the dustfall rather than with the suspended particulate matter.

The major contributor to dustfall over the City of Al Ain is suggested by Hindy and Baghdady (1994a) as the wind-blown dust and/or sand from the south-west. This suggestion is based on a distribution map of dustfall allover the City.

On the other hand, the principal sources of SPM_{10} in the atmosphere of Al Ain can not be suggested before studying the relationship between such type of air contaminants and the meteorological parameters, prevailing in the city, particularly the wind speed and direction, which will be considered in the discussion of the effects of atmospheric conditions on SPM_{10} concentration.

However, some common sources of SPM_{10} can be taken into account according to the properties of these particulates. This will be considered in the following brief outline (Godish, 1991).

"One of the major characteristics of particulate matter in the ambient atmosphere is particle size. Particles

range in size from approximately 0.005 to 500 μm. The smallest are molecular clusters; the largest are visible to the unaided eye. Small particles (<1 μm in diameter) behave as gases; that is, they are subject to Brownian motion (the random motion of molecules), follow fluid stream lines around obstacles, and are capable of coagulation. Larger particles are more characteristic of solid matter, as they are strongly affected by gravity and rarely coalesce. Typical size ranges for a variety of natural and anthropogenically derived particles are illustrated in Fig. (18)."

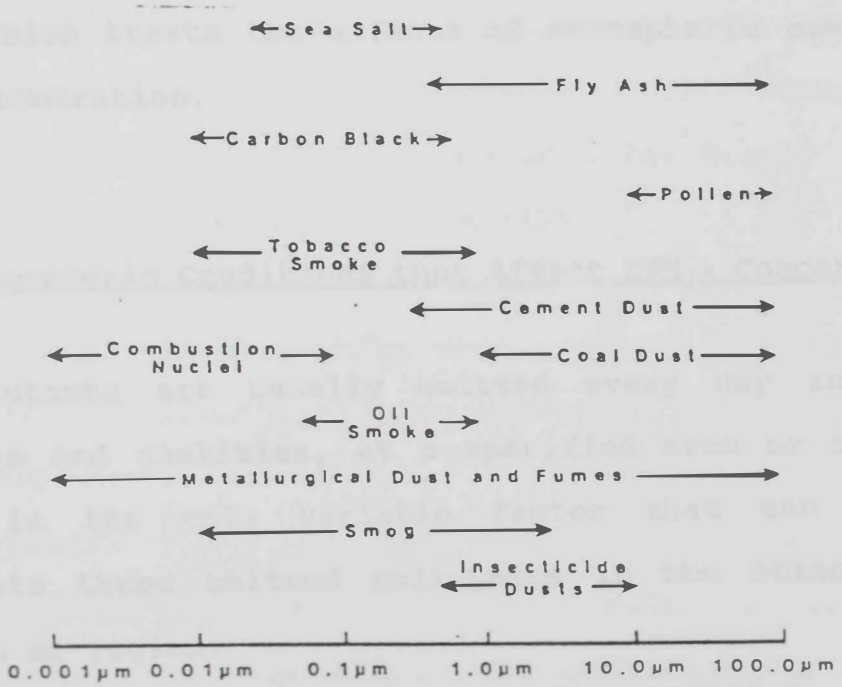


Figure (18) Size ranges and Sources of Common Atmospheric Particles

The maximum range of SPM_{10} concentration in the atmosphere of Al Ain was observed during January. This has been expressed in the minimum, maximum and mean concentrations which are, respectively, 46.6 $\mu g/m^3$, 185.3 $\mu g/m^3$ and 74.3 $\mu g/m^3$. On the other hand, the corresponding minimum range oscillates between the other two months, i.e. December 1993 and February 1994. For example, the minimum and maximum concentrations are, respectively, 47.3 $\mu g/m^3$ and 100.2 $\mu g/m^3$ during December 1993 and 44.4 $\mu g/m^3$ and 136.9 $\mu g/m^3$ during February 1994. However, the lowest monthly mean, i.e. 67.7 $\mu g/m^3$ was observed during December 1993 compared with 68.8 $\mu g/m^3$ observed during February 1994.

Such variation can be explained through the following section which treats the effects of atmospheric conditions on SPM_{10} concentration.

3.2.2 Atmospheric Conditions that Affect SPM_{10} Concentration

Pollutants are usually emitted every day in the same quantities and qualities, at a specified area or region. The weather is the only variable factor that can dilute or concentrate these emitted pollutants in the atmosphere over that area or region.

The most important weather elements that affect the dispersion process of SPM_{10} are speed and direction of the winds, air temperature and atmospheric stability.

(A) Winds :

Dust particles discharged into the atmosphere are transported away from their sources of emission. The distances traveled by particles depend upon their sizes and the prevailing meteorological conditions. The basic importance of transport is signified by the attention that must be paid to the wind direction in treating discrete sources of air pollution.

Pollution emitted from a certain source will be more or less diluted along the direction of transport. Wind speed is also an important factor in dilution even with no changes in wind direction.

The principal features characterizing the prevailing winds in Al Ain are given in Tables (6), (7), and (8) for December 1993, January 1994 and February 1994, respectively. These include the percentage frequencies for hourly wind speed direction during the three study months.

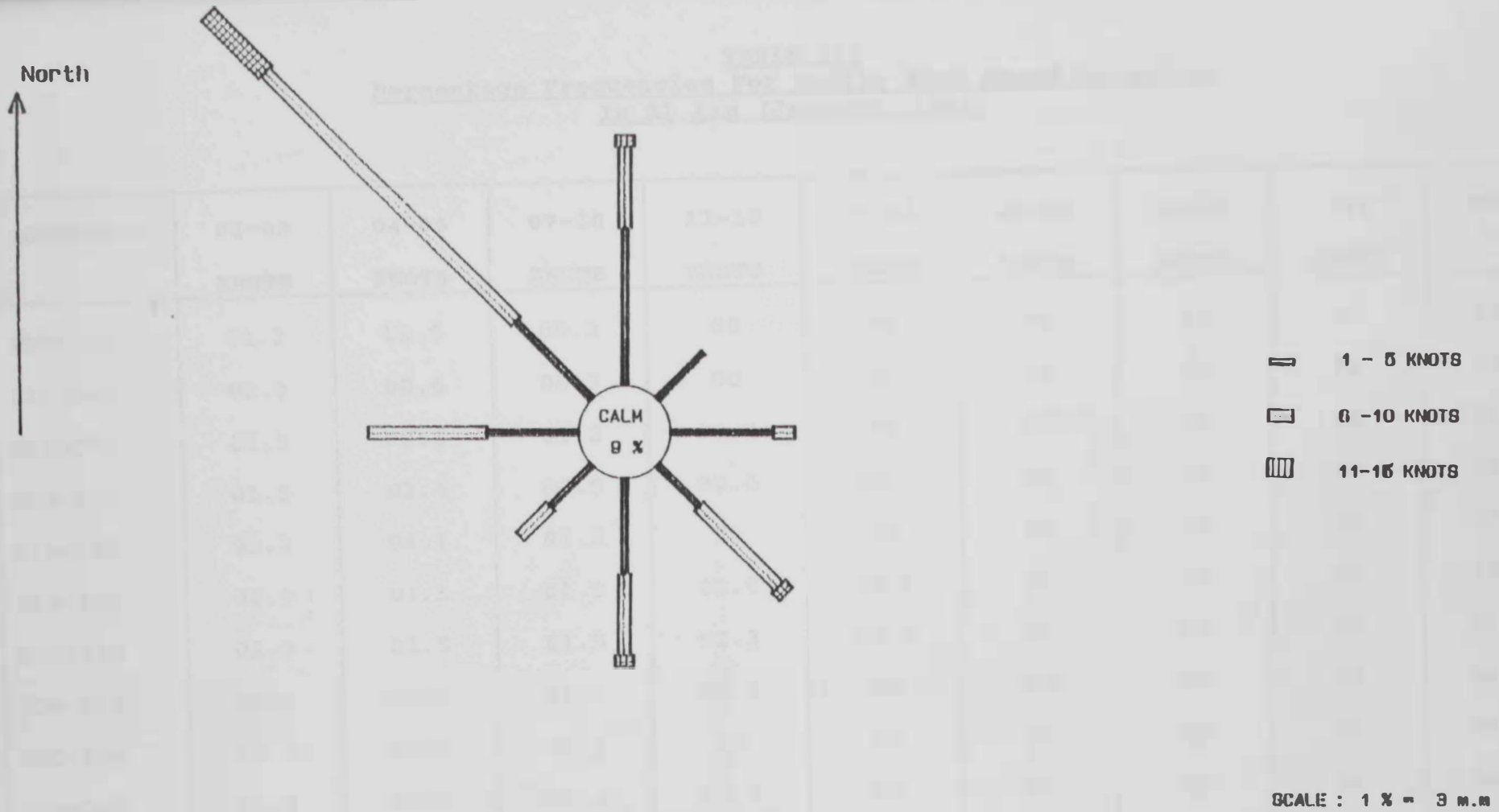
The monthly means of the hourly speeds and frequencies are graphically represented by wind roses in Figs. (19), (20) and (21) for December 1993, January 1994, and February 1994, respectively.

The monthly and seasonal range of temperature and relative humidity, the total amounts of rainfall and the total number of days with dust and/or sand storms at Al Ain during the three study months were also calculated and are given in Table (9).

The correlation between the SPM_{10} levels and the wind speed and direction frequencies reveals that the monthly average concentrations of the SPM_{10} levels and the wind speed

TABLE (6)
Percentage Frequencies For Hourly Wind Speed Direction
In Al Ain (December, 1993)

DIRECTION	01-03 KNOTS	04-06 KNOTS	07-10 KNOTS	11-16 KNOTS	17-21 KNOTS	22-27 KNOTS	28-33 KNOTS	>33 KNOTS	TOTAL
350-101		03.8	00.9	00.3	00	00	00	00	07.6
020-040	03.2	00.3	00	00	00	00	00	00	03.5
050-070	01.5	00.6	00	00	00	00	00	00	02.1
080-100	02.3	01.8	00	00	00	00	00	00	04.1
110-130	01.5	02.3	02.3	00	00	00	00	00	06.2
140-160	02.1	01.8	03.8	01.2	00	00	00	00	08.8
170-190	00.6	02.9	01.8	00	00	00	00	00	05.3
200-220	00.3	02.6	00.9	00	00	00	00	00	03.8
230-250	00.9	02.3	01.2	00	00	00	00	00	04.4
260-280	00.6	04.1	02.6	00.3	00	00	00	00	07.6
290-310	00.3	07.0	10.3	02.1	00	00	00	00	19.6
320-340	02.1	04.1	08.8	02.6	00	00	00	00	17.6
TOTAL	17.9	33.7	32.6	06.5	00	00	00	00	90.6
CALMS									09.4

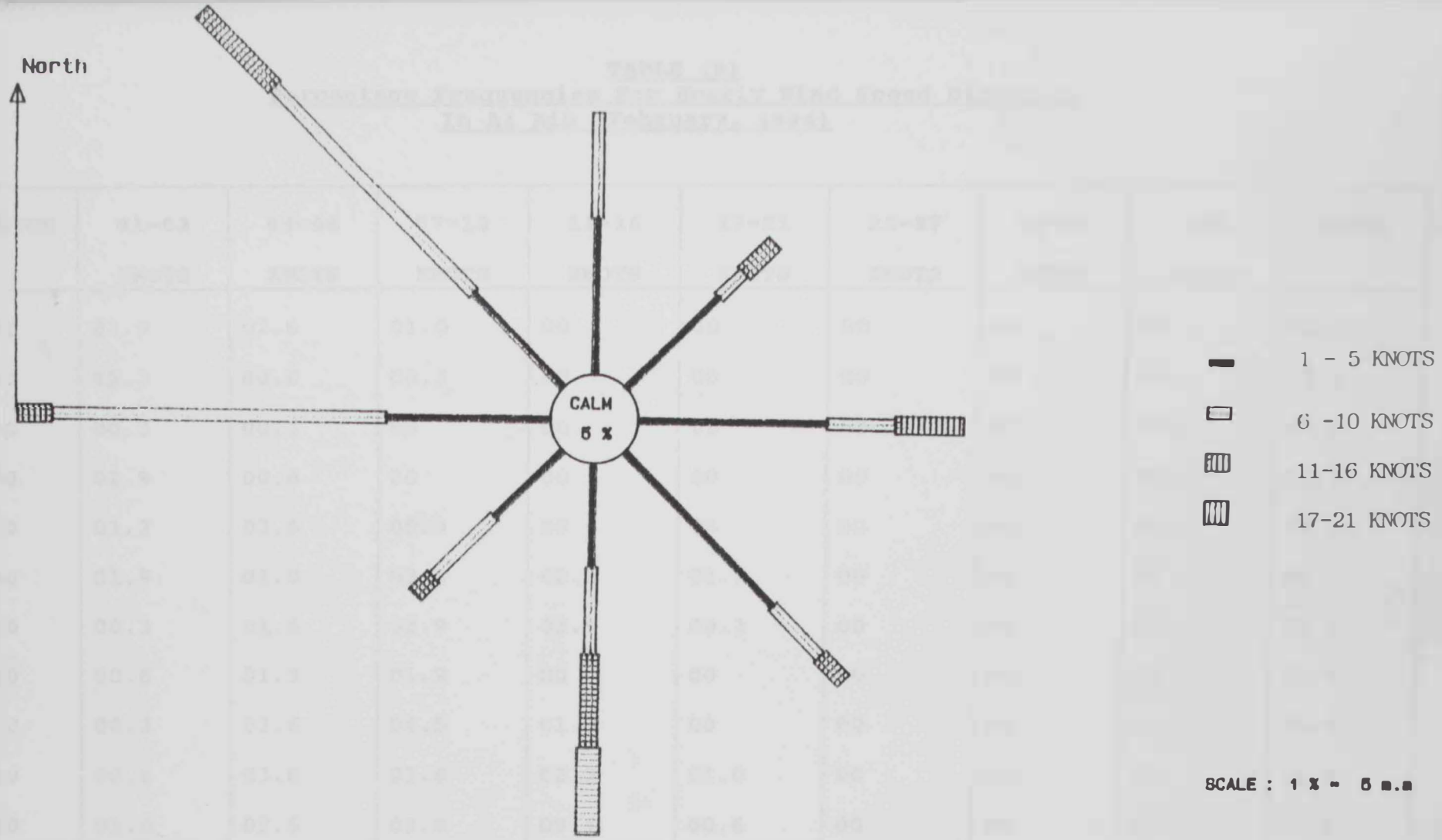


WIND ROSE (HOURLY DATA)

Figure (19) The Monthly Average Variation Of Hourly Speed And Frequencies Of Winds Blowing From 8 Directions In Al Ain (December, 1993)

TABLE (7)
Percentage Frequencies For Hourly Wind Speed Direction
In Al Ain (January, 1994)

DIRECTION	01-03 KNOTS	04-06 KNOTS	07-10 KNOTS	11-16 KNOTS	17-21 KNOTS	22-27 KNOTS	28-33 KNOTS	>33 KNOTS	TOTAL
350-101	01.2	02.9	00.3	00	00	00	00	00	04.4
020-040	02.9	00.6	00.3	00	00	00	00	00	03.8
050-070	01.5	02.1	01.2	03.2	00	00	00	00	07.9
080-100	01.5	02.6	00.9	00.6	00.3	00	00	00	05.9
110-130	02.3	04.1	01.2	00	00	00	00	00	07.6
140-160	02.9	01.5	01.5	02.6	01.5	00	00	00	10.0
170-190	02.9	01.5	01.5	02.3	00.9	00	00	00	07.0
200-220	02.3	02.1	01.2	01.2	00	00	00	00	06.7
230-250	00.3	02.9	02.3	00	00	00	00	00	05.6
260-280	02.3	04.7	02.6	00.9	00	00	00	00	08.5
290-310	02.1	04.4	05.6	01.8	00.6	00	00	00	14.4
320-340	00.9	04.4	05.3	02.3	00	00	00	00	12.9
TOTAL	19.1	33.7	23.8	15.0	03.2	00	00	00	94.7
CALMS									05.3

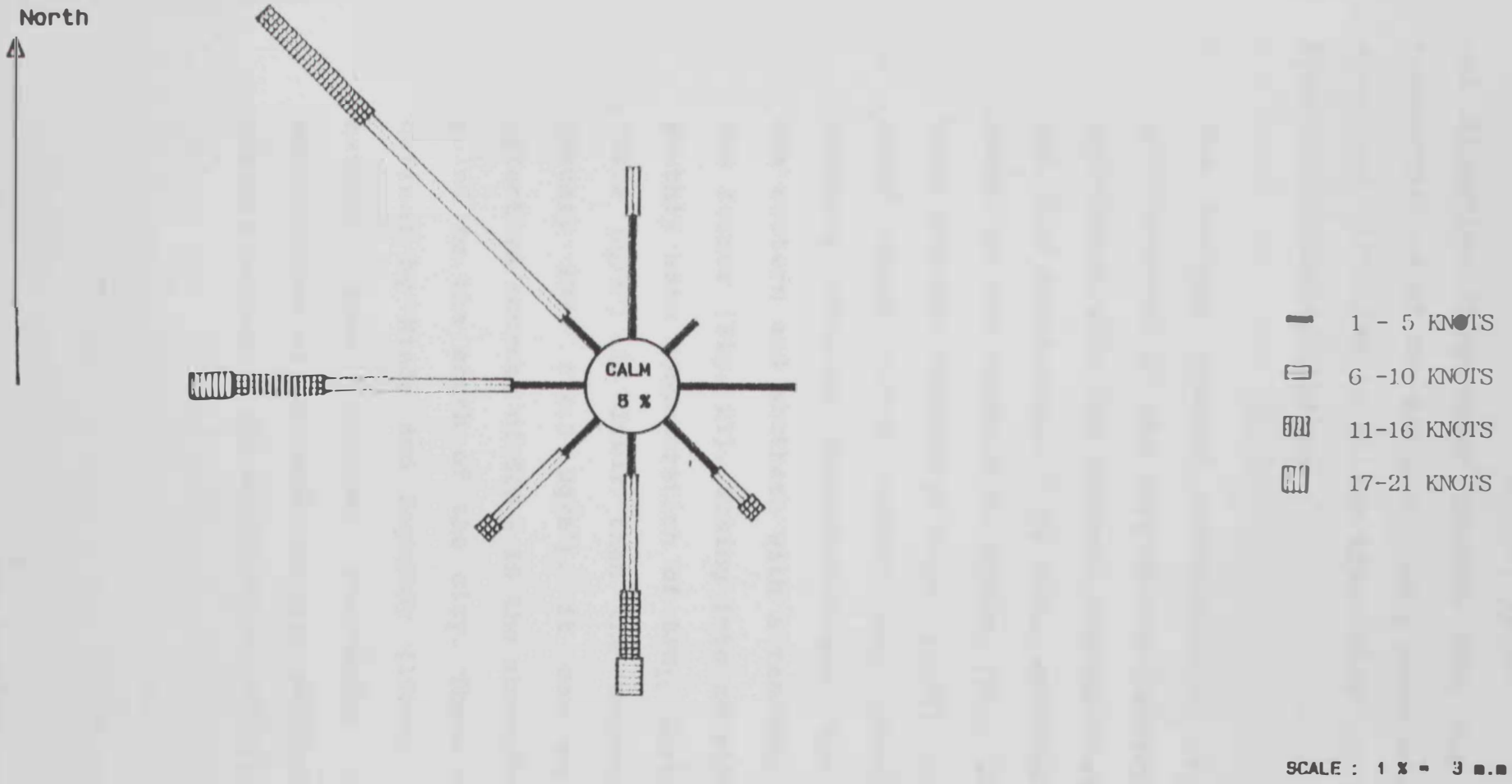


WIND ROSE (HOURLY DATA)

Figure (20) The Monthly Average Variation Of Hourly Speed And Frequencies Of Winds Blowing From 8 Directions In Al Ain (January, 1994)

TABLE (8)
Percentage Frequencies For Hourly Wind Speed Direction
In Al Ain (February, 1994)

DIRECTION	01-03 KNOTS	04-06 KNOTS	07-10 KNOTS	11-16 KNOTS	17-21 KNOTS	22-27 KNOTS	28-33 KNOTS	>33 KNOTS	TOTAL
350-101	01.9	02.6	01.0	00	00	00	00	00	05.5
020-040	02.3	00.6	00.3	00	00	00	00	00	03.2
050-070	00.3	00.3	00	00	00	00	00	00	00.6
080-100	02.9	00.6	00	00	00	00	00	00	03.6
110-130	01.3	02.6	00.3	00	00	00	00	00	04.2
140-160	01.9	01.0	03.2	02.3	01.3	00	00	00	09.7
170-190	00.3	01.6	02.9	02.9	00.3	00	00	00	08.1
200-220	00.6	01.3	01.9	00	00	00	00	00	03.9
230-250	00.3	03.6	04.5	01.3	00	00	00	00	08.8
260-280	00.6	03.6	03.6	02.3	01.0	00	00	00	11.0
290-310	01.0	02.6	08.8	09.4	00.6	00	00	00	22.4
320-340	00.6	04.9	06.5	01.6	00	00	00	00	13.6
TOTAL	14.3	24.4	33.1	19.8	03.2	00	00	00	94.8
CALMS									05.2



WIND ROSE (HOURLY DATA)

Figure (21) The Monthly Average Variation Of Hourly Speed And Frequencies Of Winds Blowing From 8 Directions In Al Ain (February, 1994)

and direction frequencies reveals that the monthly average concentrations of the SPM_{10} is highly correlated with both wind speed and direction in Al Ain City. This can be clearly shown from the following findings :

- The maximum average concentration of SPM_{10} (74.3 $\mu g/m^3$) observed in the City during January 1994 is highly correlated with the maximum average frequency (3.2%) of the wind speed range 17-21 knots recorded during the same month in the southern direction (Fig. 20). However, the same average frequency value (3.2%) in the same wind speed range (17-21 knots) was recorded also during February 1994,but distributed over two directions,i.e. the western and southern with a tendency to be higher in the former (Fig. 21). Taking into consideration that the monthly mean concentration of SPM_{10} during February 1994 (68.8 $\mu g/m^3$) is lower than the corresponding mean of January 1994 (74.3 $\mu g/m^3$), it can be said that the effective sources of SPM_{10} in the atmosphere of Al Ain are found to the south of the city. These sources could be defined by Hindy and Baghdady (1994c) as being mostly natural ones (crustal materials) with a minor contribution of man-made sources, particularly automobile traffic emissions and agricultural activities.

- The mean frequency of the wind speed in the ranges 11-16 knots and 17-21 knots were totally 6.5% , 18.2% and 23.0% during December, January and February respectively. According to Embabi (1991), only winds whose velocity exceeding 11-12 knots can move dunes sands. This means that the study period is characterized by a considerable frequencies of winds having the ability to move dune sands and hence increasing the atmospheric pollution with the fine particulate matter in the City. Accordingly, it is expected that the month of February which is characterized by the higher mean frequency (23.0%) of the wind speed range 11-21 knots should have the higher mean concentration of SPM_{10} during the same month. However, the month of February has shown a mean concentration of SPM_{10} (68.8 $\mu g/m^3$) lower than that of January (74.3 $\mu g/m^3$) which has a lower frequency (18.2%) of wind speed range 11-21 knots. This in turn reflects the effective role of the wind direction besides the wind speed. For instance, the mean wind speed frequency during January in the range of 11-16 knots (15.0%) is distributed between the NE, E-, SE-,S-,SW-,W- and NW- directions with a tendency to be higher in the NW- and S- directions, whereas the corresponding frequency in the range of 17-21 knots (3.2%) is completely consistent to the southern direction (Fig. 20). On the other hand, the mean wind speed frequency during February in the range of 11-16 (19.8%) is distributed between the SE-,S-,SW-,W- and SW- directions with a tendency to be higher in the NW-, W- and S- directions, whereas the corresponding frequency in

the range of 17-21 knots (3.2%) is distributed between the S- and W- directions with a tendency to be higher in the W- direction.

The conclusion which should be drawn from the foregoing figures is that the movement of dune sands and hence the increase in the atmospheric contamination with SPM_{10} is highly affected by the winds blowing from the southern direction.

- The minimum mean concentration of SPM_{10} (67.7 $\mu g/m^3$) observed during the month of December 1993 is associated with the following two phenomena characterizing this month :

  (a) The mean frequency of the wind speed in the lower ranges, i.e. 1-3, 4-6 and 7-10 knots being totally 84.2% is higher in comparison with the corresponding mean frequency of January (76.6%) and February (71.8%). The wind speed in the range of 1-10 knots seems to be of lower effect as an air contaminants carrier in comparison with the higher wind speed range (11-21 knots).

  (b) The mean frequency of both wind speed and direction tends to be much higher in the north-western direction in comparison with the other directions (Fig. 19). The wind-blown dust from this direction seems to be lower than those from the southern and western directions.

- An interesting aspect of the data is the consistent increase of atmospheric pollution with SPM_{10} in the City of Al Ain with increasing the frequency of higher wind

speed range. This inverse relationship (see p. 12) indicates that most of atmospheric particulates in the City originates from outside sources.

- Maximum SPM_{10} concentration is found in the month, which is characterized by the higher percentage of calm periods, i.e. January 1994. Usually these periods help in concentrating the atmospheric pollutants.

TABLE (9)
Monthly And Seasonal Mean Of Some Meteorological Parameters At Al-Ain During The Study Period (Dec., 1993 - Feb., 1994)

PARAMETER		DEC. 1993	JAN. 1994	FEB. 1994	WINTER 1993-1994
Temperature (°C)	Max. Min. Mean	31.0 9.4 22.9	30.03 6.7 21.2	33.0 6.0 21.6	 21.9
Relative humidity R.H. (%)	Max. Min. Mean	100 24 57	94 20 51	97 19 49	 52.3
Total rainfall (mm)		13.7	2.4	Nil	16.1
Total No. of days with sand storms	Nil	Nil	Nil	Nil	Nil

(B) Air Temperature and Pressure and Atmospheric Stability:

The change in air temperature with pressure and hence with altitude (adiabatic lapse rate) is an important consideration in the incidence of air pollution. The two most important conditions from an air pollution stand point are the

super adiabatic lapse rate and negative adiabatic lapse rate (inversion). On clear summer days, rapid heating of the earth by the sun warms the earth near the surface to the point where the lapse rate is super adiabatic. The decrease in air temperature with height is greater than the normal adiabatic lapse rate. Under this condition, the atmosphere is said to be in unstable equilibrium and marked vertical mixing of the air results. This is a condition where pollutants are dispersed rapidly (Faith, 1959).

The opposite condition is a negative lapse rate or temperature increases with height. It may be caused by cooling the air near the ground because of the earth's losing heat by long-wave radiation at night. Under condition of an atmospheric temperature inversion, the atmosphere is said to be stable and very little mixing or turbulence takes place, because the denser air is near the ground. Under these conditions, pollutants in the air do not disperse (Faith, 1959).

In the present study, the warmer month, i.e. December, 1993 (22.9°C mean temperature) is characterised by relatively lower concentration of SPM_{10} (67.7 $\mu g/m^3$ mean concentration). This means that the unstable conditions of air which usually prevail with the increase in temperature is largely responsible for reducing the concentration of SPM_{10} during December, 1993.

3.2.3 The SPM_{10} Fluctuation

Meteorological parameters are probably most important in defining the concentration and fluctuation of SPM_{10}

concentration in the urban atmosphere. Therefore, an attempt has been made to interpret the daily variation of SPM_{10} level during the three study months in accordance with the local climatological information which was collected by Al Ain Meteorological Station, United Arab Emirates Air Force during the same SPM_{10} monitoring period and at the same study City.

Figures (22), (23), and (24) present the diagrams showing the daily variation in the concentration of SPM_{10} during December 1993, January 1994, and February 1994, respectively. On the other hand, Figs. (25), (26), and (27) present composite diagrams showing selected meteorological parameters (Temperature, Wind Speed and Humidity).

From the correlation between the first three figures and the second three ones, one should note the following features:

(a) The daily variation in air temperature is slight, particularly during December 1993 and January 1994. Therefore, the correlation between the fluctuation in the SPM_{10} concentration and the daily changes in air temperature is difficult. However, it can be generally said that the increase in temperature is usually associated with a decrease in the suspended particulate matter concentration due to the dispersion of air pollutants by the effect of the turbulence currents.

(b) The daily SPM_{10} level seems to be inversely proportional with the daily mean wind speed. This is not unexpected, but it must be noticed that this correlation depends also on the wind direction. Winds usually act as a strong

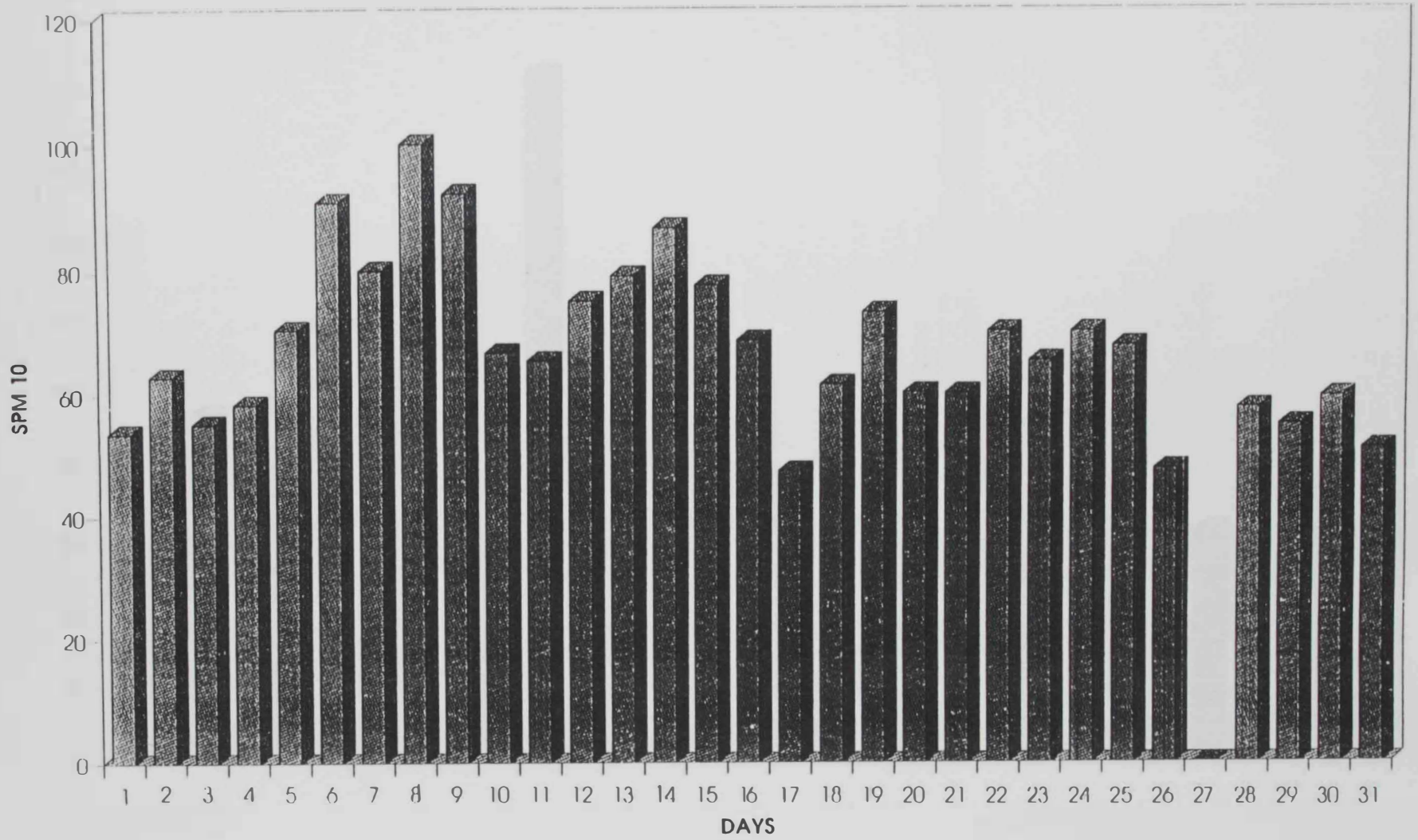


Figure (22) The Daily Variation in the Concentration of SPM10 (ug/m3) in Al Ain (December 1993)

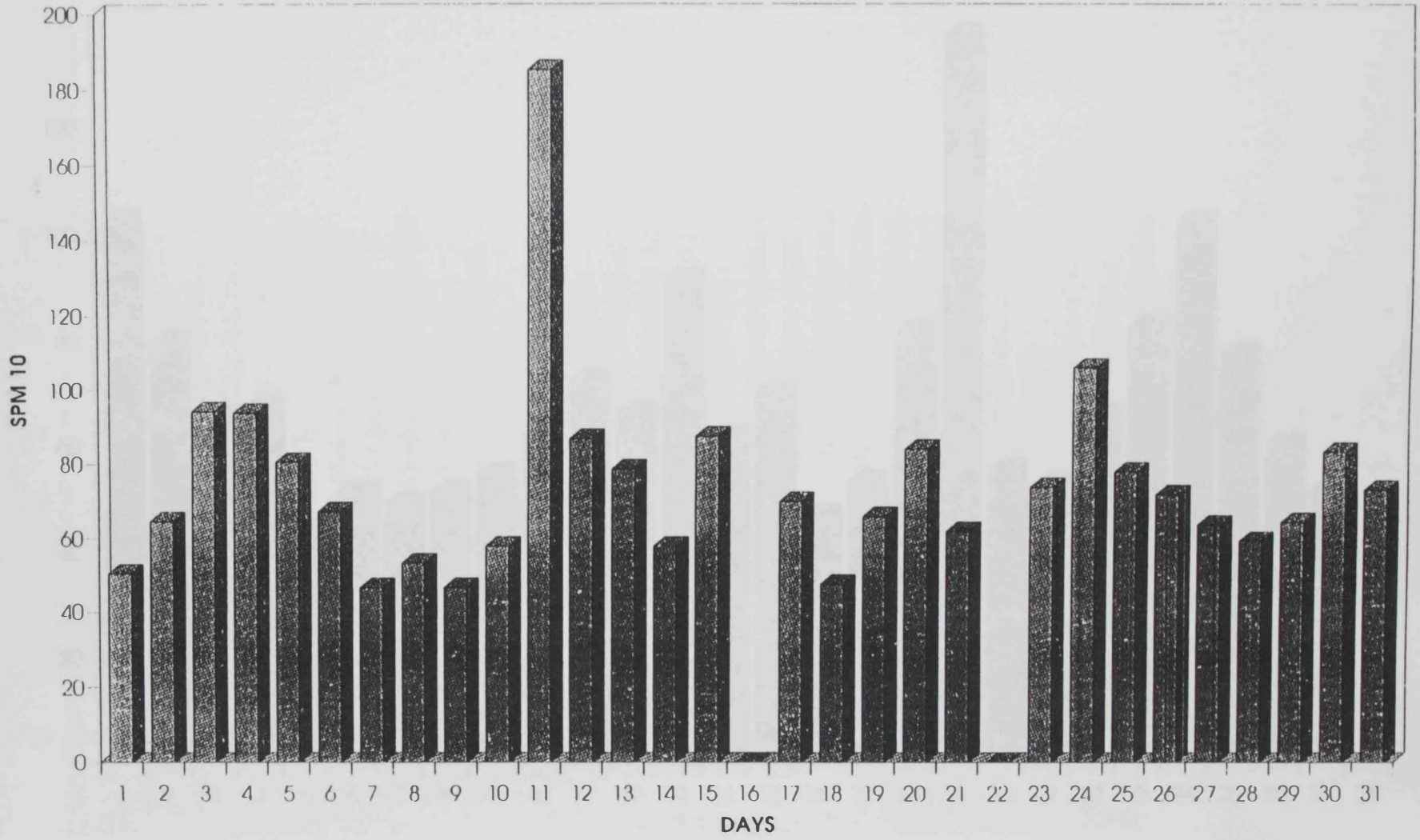


Figure (23) The Daily Variation in the Concentration of SPM10 (ug/m3) in Al Ain (January 1994)

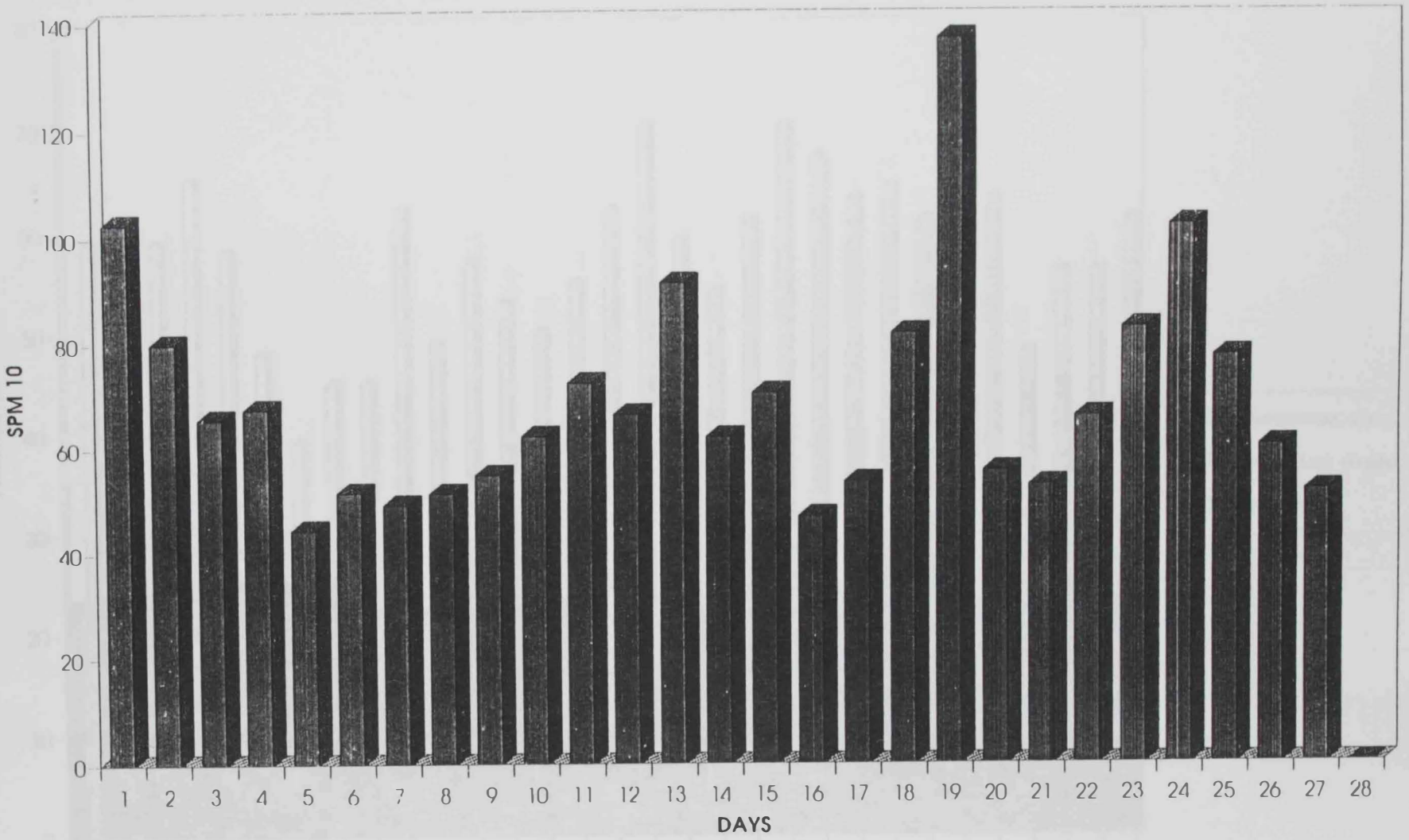


Figure (24) The Daily Variation in the Concentration of SPM10 (ug/m3) in Al Ain (February 1994)

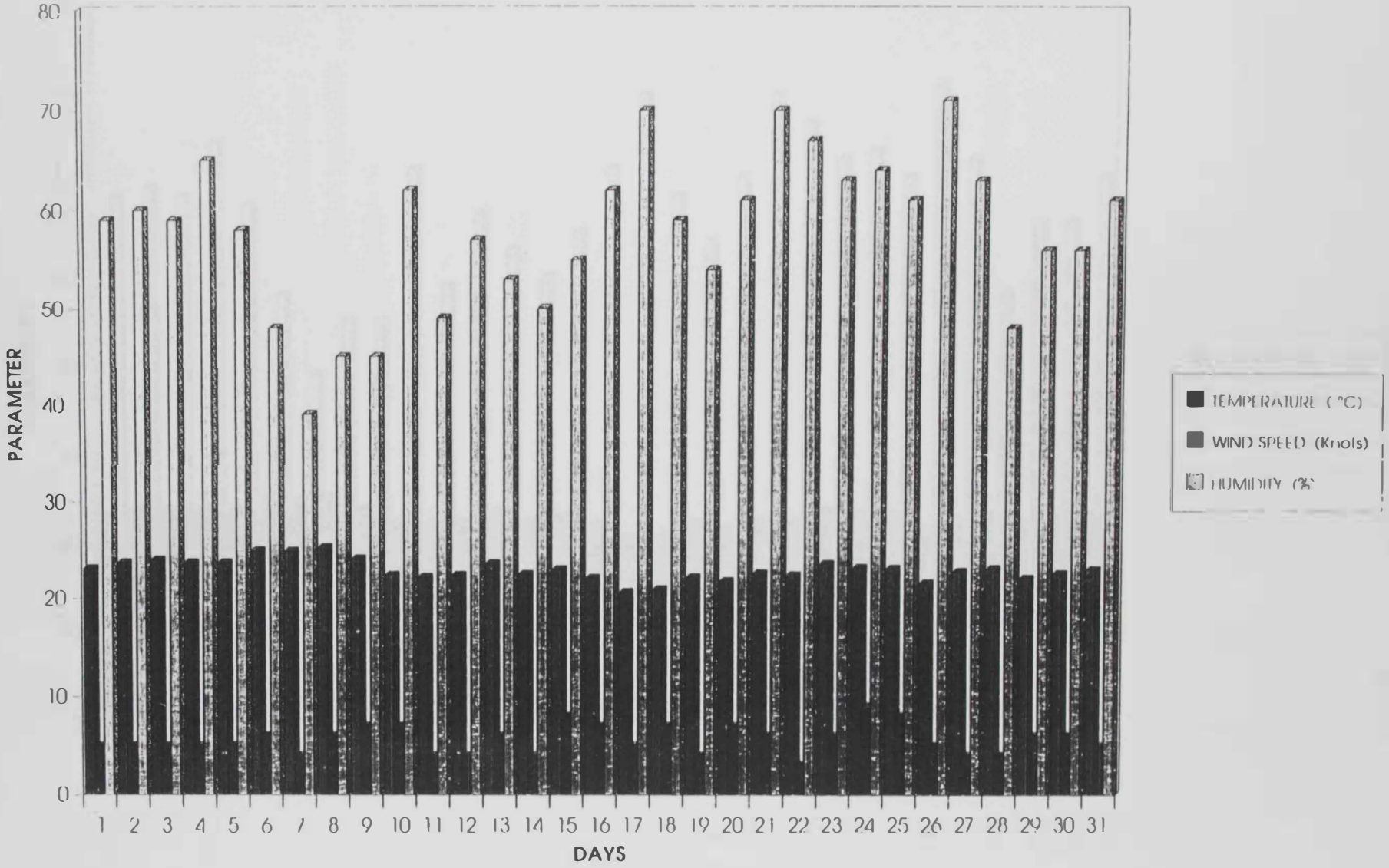


Figure (25) Composite Diagram Showing Daily Variation of Selected Meteorological Parameters in Al Ain (December 1993)

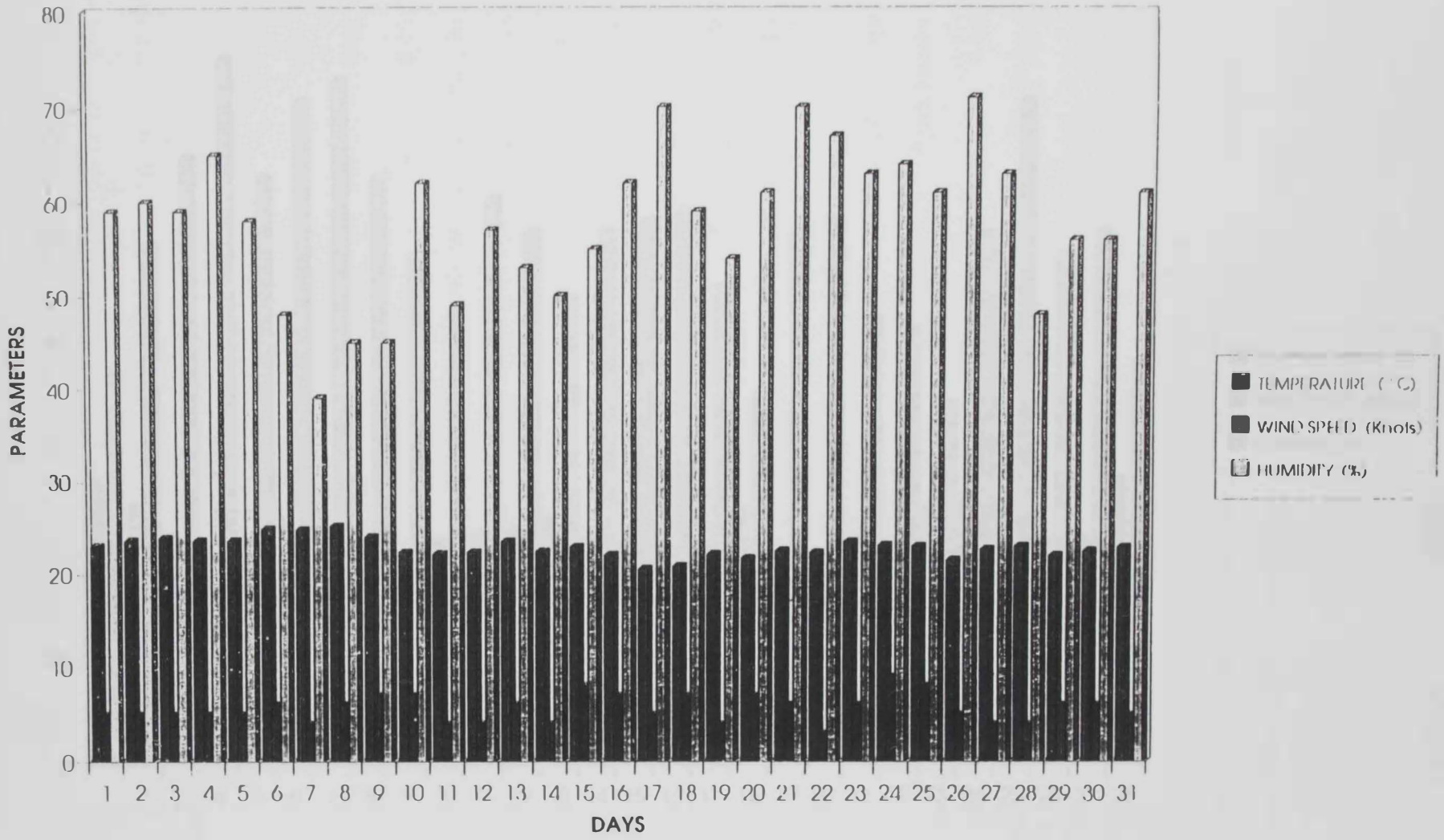


Figure (26) Composite Diagram Showing Daily Variation of Selected Meteorological Parameters in Al Ain (January 1994)

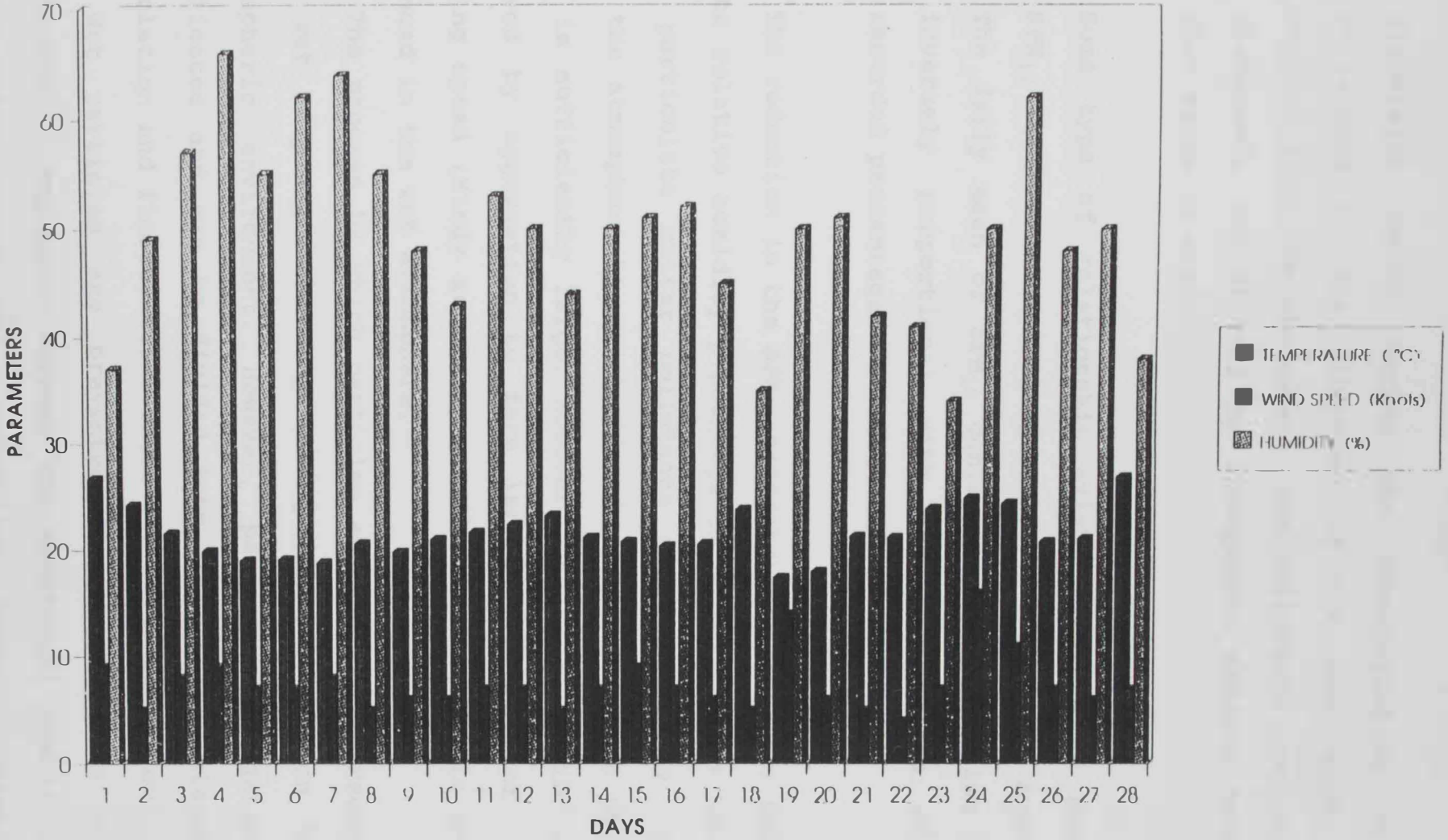


Figure (27) Composite Diagram Showing Daily Variation of Selected Meteorological Parameters in Al Ain (February 1994)

dispersion factor during the transportation of air pollutants in the direction of the mean wind. Once emitted into the atmosphere, the pollutants are carried, dispersed, and diluted by atmospheric motions having a wide range of scales.

(c) Some type of relationship exists between the measured SPM_{10} concentration and the recorded relative humidity. The daily mean of SPM_{10} concentration seems also to be inversely proportional with the daily mean of the recorded percentages of the relative humidity.

The reduction in the SPM_{10} concentration with the increase in the relative humidity percentage is mainly due to the fact that particulate matter pollutants are effectively removed from the atmosphere by gravitational settling if the particle size is sufficiently large. However, the small particles are removed by aggregation to form larger particles of higher falling speed (Hindy and Farag, 1983). Aggregation is greatly enhanced in the wet atmosphere.

The process by which particles aggregate and precipitate from wet suspension is a quite important phenomenon in the atmospheric environment. However, particle aggregation is complicated and may be divided into two general classes of coagulation and flocculation. These are discussed below.

Wet particles are prevented from aggregating by the electrostatic repulsion between the electrical double layers (adsorbed-ion layer and counter-ion layer). Coagulation involves the reduction of this electrostatic repulsion, such

that wet particles of identical materials may aggregate. Flocculation depends upon the presence of bridging compounds, which form chemically bonded links between wet particles and enmesh the particles in relatively large masses called floc networks (Manahan, 1991).

Aggregation was found to be highly responsible for the growth of lead and zinc particles and hence the increase in their falling speed in the atmosphere of Cairo (Hindy and Farag, 1983).

CHAPTER IV

DUST STORMS IN AL AIN
(A CASE STUDY)

1. DUST STORM'S DEFINITION

Desert dust has been present in many parts of the world since the creation of the continents and probably is of the same antiquity on other planets. The dust storm is a common phenomenon that occurs with great frequency and magnitude in aride and semiaride areas (Pewe, 1981).

Goudie (1978) defined a dust storm in terms of a visibility less than 1,000 m. Other visibility limits have been used. For example, dust storms in Arizona have been defined in terms of visibility of less than 800 m. (Pewe et al, 1981).

2. DUST STORM'S SOURCE

Regions where dust originates coincide with major deserts of the world (Fig.28); these arid and surrounding semiarid lands cover 43,300,000 km^2 or 36% of the Earth's land surface (Meigs, 1953). Large dust storms that carry particles thousands of kilometers originate in such areas as the Sahara, the southern coast of the Mediterranean, the northeast Sudan, the Arabian Peninsula, and the lower Volge and North Caucasus

in the U.S.S.R. (Idso, 1976; Shikula, 1981; Prospero, 1981). Other major areas are north and western China with its great deserts (Rahn et al., 1981); central Australia; southwest United States; and the Kalahari of southwest Africa; Chile; Peru; and the drier parts of Argentina and Afghanistan-Baluchistan. Large, frequent dust storms are known from normally semiarid areas that periodically become arid, undergo abnormally strong windy periods, or have their vegetation removed by man or nature. Such areas are the Great Plains of the United States ; central India; and the Russain steppes.

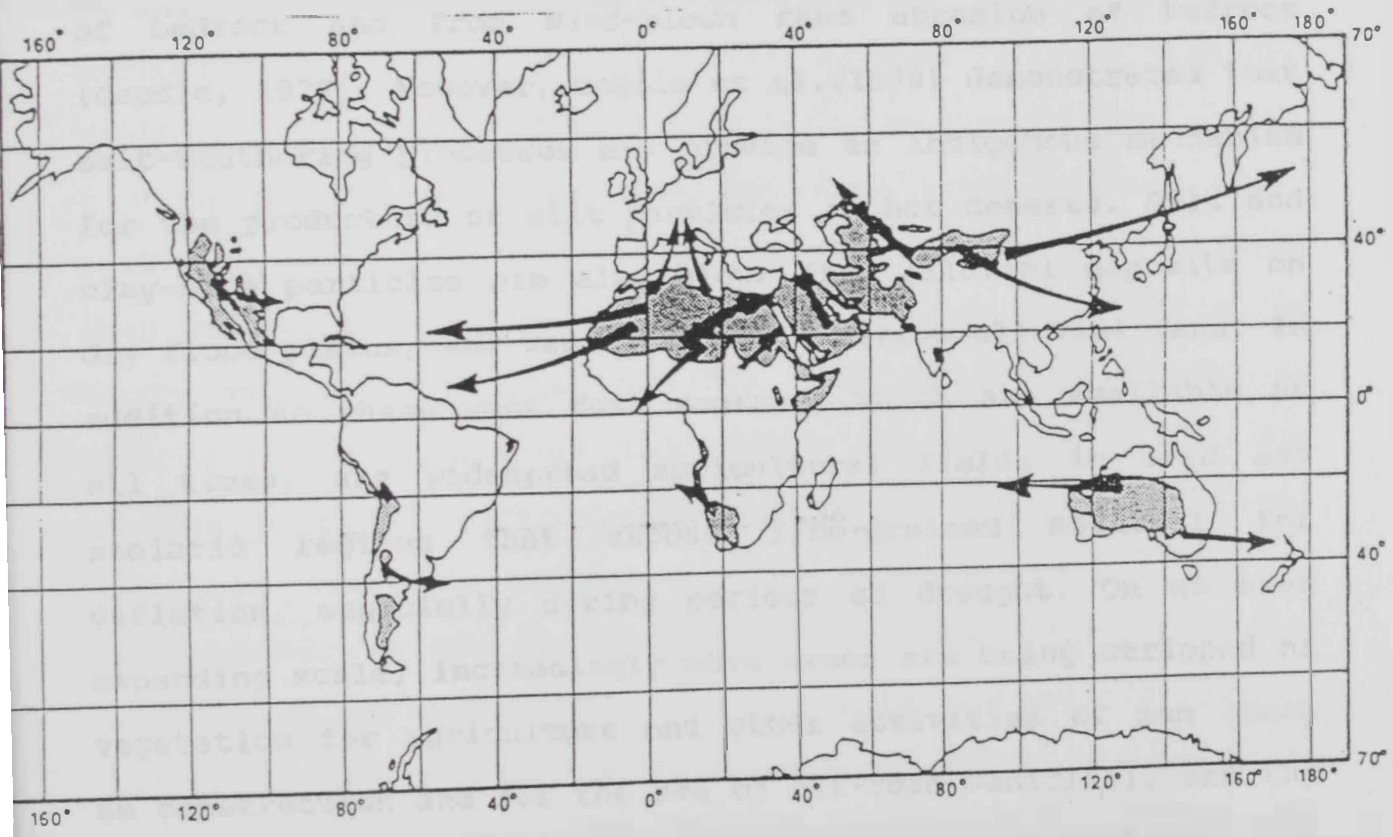


Figure (28) Deserts of the Earth and Major Directions of Dust Transport (After Meigs, 1953)

Both aerodynamic and soil factors must be considered in studying the generation of wind-blown dust (Gillette, 1979; 1981), and the threshold velocity of wind required to raise dust is one of the most important parameters relative to this problem. The threshold velocity for dust-raising winds in the eastern Sahara seems to be about 6 m/s (Morales, 1979b). Particles >100 μm in diameter require the lowest velocity for initiation of movement by wind. In addition to wind stress, dust production is influenced by vegetation, soil structure, moisture content, texture, mineralogy, and surface roughness.

In most desert areas, dust comes from in situ weathering of bedrock and from wind-blown sand abrasion of bedrock (Goudie, 1978). However, Goudie et al.(1979) demonstrated that salt-weathering processes may provide an indigenous mechanism for the production of silt particles in hot deserts. Silt and clay-size particles are also blown from alluvial deposits on dry flood plains, and wadis, as well as from alluvial fans. In addition to these vast dust sources, which are available at all times, are widespread agricultural fields in arid and semiarid regions that expose fine-grained material for deflation, especially during periods of drought. On an ever expanding scale, increasingly more areas are being stripped of vegetation for agriculture and other activities of man (such as construction and for the use of off-road vehicles), and the fine-grained material is removed by wind at a disastrous rate (Nakata et al., 1981, Wilshire et al., 1981, McCauley et al., 1981). Areas most prone to dust storms are, as might be expected, regions with less than 250 mm of annual precipitation.

3. WINDS AND DUST STORMS IN THE EMIRATES

The directions of wind blowing on the United Arab Emirates from various nearby regions are formed as a result of the variation in air pressure experienced in the Emirates from one season to the other during the year, which is caused by the differences in hot air temperature near it's earth surface.

In winter, when the sun strikes perpendicularly on the Tropic of Capricorn, temperature decreases over the Emirates' land and other surrounding Asian lands, forming a huge region of high pressure consisting of Asia, Europe and South Africa excluding the Mediterranean which becomes a low pressure region, in addition to the Azore's high pressure region.

On the UAE map, the equal pressure lines between 1016-1019 millibars are shown close to each other, and increase when we move toward the Asian land to the west, north or south to be respectively 1021-1022-1024 millibars, in contrast to the northern regions in the Indian Ocean, where the sun strikes perpendicularly decreasing the air pressure to 995 millibars. Thus, the Emirates is located on the way of the dry cold southern winds blowing from south Asian high pressure regions and the moist south-western winds blowing from south-western Europe across the Mediterranean, Syria and Lebanon, after readjusting its route because of the local environment aspects (Ghunaim, 1991).

These wind start blowing from the end of October till the end of March, causing the decrease of temperatures to its minimum levels (8.5 °C) on the western coasts and (9 °C) on the

eastern coasts. It also increases the relative humidity and the number of depressions, that is why they are considered a main cause for rainfall in winter.

It is worth mentioning, that the southern winds or south-western winds, which lose a lot of their characteristics by the time they arrive to the Emirates, are pressured while crossing the high mountains towards the eastern areas, thus almost increasing their temperatures than the western coastal areas as noticed from the data of the Climate Stations in Masafi and Dabba (Table 10).

In addition to the southern winds, the Emirates is also influenced by the northerly winds blowing from the Indian Ocean at the beginning of the depressions flowing from the Mediterranean. These winds are characterized as being moist-warm winds, which increase the relative humidity in the region's atmosphere that it passes through, such as the eastern coast. These winds usually tilt to be south-western winds resulting in heavy rainfall accompanied by thunder and lightning storms and heavy winds for several hours, causing the formation of stormy streams (brooks) that sweep away all what it passes by, such as trees, soil and stones. These winds also cause sand storms specially in autumn, because the soil it passes by is soft and lacks plantation covers .

In the summer, between May and September, when the sun gradually strikes perpendicularly on the Tropic of Cancer, the temperature on the Emirates' earth surface is increased, and all the surrounding Asian lands, forming together a large area of low pressure (997-1004 millibars) that spreads to the north of Europe and south of Africa until the coasts of the

Pacific Ocean, except for the Mediterranean which becomes a high pressure area. Therefore, the Emirates is exposed to northern and southern winds from the Indian Ocean locally called (Kaus winds) which increase relative humidity in the air (Ghunaim, 1991).

The Emirates is also influenced by the dry southern winds after its characteristics are readjusted by passing through wide regions in the south, which decreases temperatures and scatters humidity especially at the beginning of the summer, when then it is called (Forty day 5 haune) and is known to the Bedouins as (Bareh Al Jouza). The influence of these winds is gradually eliminated from the beginning of July when the north and north-eastern winds take over.

The previous winds that blow on the Emirates land is named by local names derived from its effect and timing of blowing, such as:

- Winter season winds : Al Na'ashi, Al Shamal, Al Yemani (after Yemen, and it is rainy winds).
- Spring season winds : Al Morba'ania (dry southern winds)
- Summer season winds : Al Bari, Al Kaus, Al Hili (rainy north-westerly wind), Al Matla'ai (Ghunaim, 1991).

3.1 Wind direction and speed

We have found from the previous discussion that the UAE experience different high and low air pressure systems that cause recognizable tilting in wind direction between the summer and the winter. This means that the winds blowing on

the Emirates are unstable and inconstant during these two seasons, for many reasons, some of which are :

1. The characteristics of the general cycle of winds.
2. The nature of the landscapes
3. The distribution of air pressure regions on the nearby land and water.

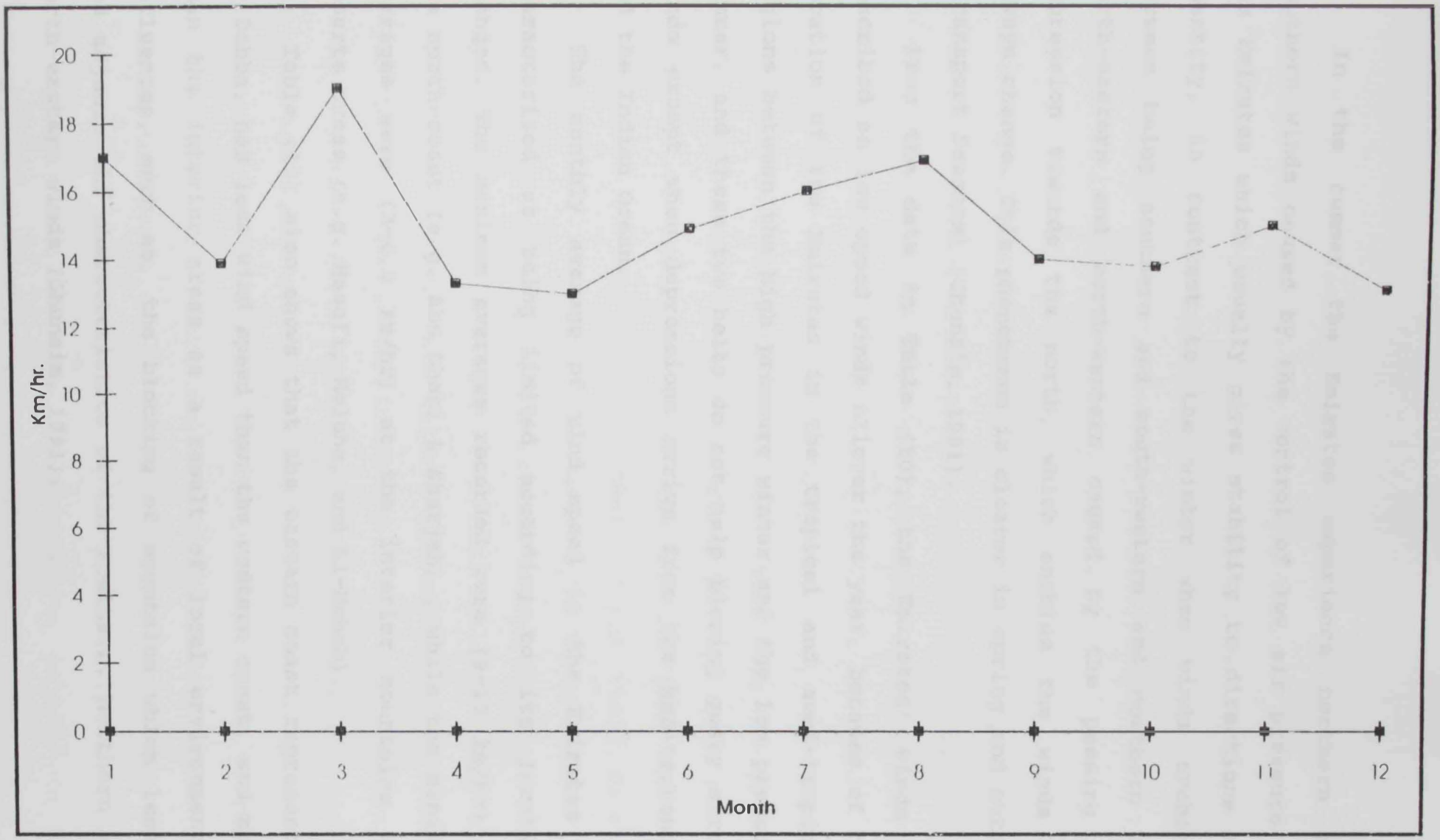
We notice from the data in Table (10) that the average readings of the summer months between May and September are some what similar in the 1987 Climate Stations, if we compare it with the seasonal readings of winter months between December and March in these climate stations for the constant blowing of the cold southern winds, and the arrival of depressions from the Mediterranean, taking into consideration, the variations in readings between different stations for local environmental aspects as in figure (29).

TABLE (10)

Surface Wind Speed Average in the UAE during 1987 from a height of 1 meter, km/hr.

Climate Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Abu Dhabi Airport	9.3	13	14.8	13	13	13	13	14.8	13	13	9.3	11.1
Dabba	9.2	7.6	8.7	11	8.7	9.8	9	9	6.9	4.9	6.5	7.9
Masafi	5.9	6.6	6.7	6.3	7.5	7.3	8.5	9.1	8.6	7	5.5	6.4
Meleha	2.9	3.2	4.4	4.4	5.1	5.2	5	9.4	5.3	3.4	2.3	2.4
Sharjah Airport	9.1	10.4	11.1	11.1	11.9	11.5	11.5	13	10.6	10	7.4	9.3
Al-Hebab	-	-	4.7	5.2	0.4	5.6	5	5.3	4.3	2.1	2	2
Al Ain	2.6	3.3	2.9	2.6	2.9	2.9	3.2	2.8	2.7	2.5	1.7	2.1

(After Ghunaim, 1991)



Figure(29) Total Monthly Speed of Winds blowing in the UAE during the Four Seasons
(After Gunaim, 1991)

In the summer the Emirates experience northern and southern winds caused by the control of low air pressure on the Emirates which usually gives stability to directions and quantity, in contrast to the winter when winds exchange between being southern and south-western and northern and north-eastern and north-western caused by the passing of depression towards the north, which enables the winds to always change. This phenomenon is clearer in spring and autumn (Transport Seasons) (Ghunaim, 1991).

From the data in Table (10), the Emirates' winds is described as low speed winds allover the year, because of the location of the Emirates in the tropical and semi-tropical regions between the high pressure winter and the low pressure summer, and these two belts do not help blowing gusty strong winds except when depressions arrive from the Mediterranean and the Indian Ocean.

The monthly average of wind speed in the Emirates is characterized as being limited according to its location changes. The maximum averages recorded were (9-13 km/hr) at the north-coast (e.g. Abu Dhabi & Sharjah) , while the minimum averages were (3-6.5 km/hr) at the interior mountains and deserts areas (e.g. Masafi, Meleha, and Al-Hebab).

Table (10) also shows that the eastern coast represented by Dabba, has less wind speed than the western coast, and more than the interior areas as a result of local environmental influences, such as, the blocking of mountains which lessen and adjusts the characteristics of the southern, northern and north-eastern winds (Ghunaim, 1991).

Some of the local winds (Prevailing winds) that the Emirates are influenced by are (Ghunaim, 1991) :

1. Surface winds ascending the mountains during the day,specially in the mountain spread mass regions. These are weak winds in the form of pleasant breezes that lose speed while flowing gradually upwards.

2. Surface descending winds during the night caused by the surface cooling of the slopes of the mountains. These have higher speeds than the ascending ones because of earth 's gravity.

3. Land and sea breezes : these winds influence the coastal areas and nearby lands, stretching to more than 50 km. because of the flatness of the surface and the non-existance of any obstacles that block their flowing towards the interior. They are light winds caused by variations in air pressure between nearby land and water in the night and day, and have the form of a daily wind cycle. One of the main climate influences of sea breeze in the Emirates, is the formation of mist (fog) specially in the early hours of the morning. These mists reduce visibility and cause planes arriving at coastal airports, specially the west coast, to change their routes to other airports where landing and takeoff is easier, until the mist disappears and everything returns to normal. The mist might stretch to long distances towards the inside, ranging from 50-80 km., increasing its density in the lower basin areas between sand dunes.

4. Valley winds : are formed as a result of the mountains that are exposed in the route of the general winds, where they change it into the valley streams. These are light winds which lower the temperature, especially during the summer.

5. Al Semoum winds: blow on the Emirates from dry desert areas in the north-western strong sand storms (squalls) especially in the spring and summer, as a result of the very hot earth surface. They are dry hot winds, carrying soft and hard dust and sands, that block visibility for short distances, and throw carried sand in areas where they are blowing. These particles are usually seen on the paved interior roads, which needs to be cleared away continuously to eliminate any traffic jam or road accidents.

These winds reach their maximum blowing percentages between June and July, after which they are gradually decreased and the southern and south-western winds take over.

3.2 Daily changes in prevailing wind direction

One of the noticeable things in the directions of wind in the Emirates is the repetition of changes in its prevailing seasonal directions, for instance, in the western coast from Ras Al Khaimah to Abu Dhabi, the prevailing direction of wind in winter is the southern wind, although it is noticed that this wind changes its direction in the afternoon to be south-west when the sun is striking at the zenith point.

While later, another change appears as a result of the local air pressure between land and sea, the winds starts blowing from the south and south-east. This diversion is quite clear in winter as the weather conditions are unsteady and unstable, as a result of the troughs passing by between the Mediterranean and the Indian Ocean.

It is also noticeable that in the summer, the maximum daily recorded change is at the interior areas, as a result of the air currents which increase the possibility of sandstorms and rainfall hurricanes.

3.3 Winter's Stormy Winds

The stormy winds which lead to dust haze are expected during the winter as a result of the troughs crossing the Arabian Gulf. At the beginning of these troughs, north-eastern (Kaus) winds blow for a day or two. These winds range between active and strong causing a reduction in visibility to less than 5 km, as a result of the rising dust or sandstorms.

In the meantime, the cool fronts are sometimes active and as they pass by they cause a sudden change in the direction and speed of the wind, usually from northerly or north-easterly light wind to south-westerly strong wind accompanied by sandstorms.

In addition, the sandstorms might occur within the cool continent pole air mass which blows at the end of the troughs, when the strong south-westerly winds are blowing.

4. DUST STORMS IN Al AIN

Dust and sand storms, locally known as "Shamal" are common features of the climate in the City of Al Ain and cause serious menace to the inhabitants.

The Shamal is hot, dry wind, often laden with dust and sand that is at its strongest in winter and can reach gale force. The strongest winds are felt along the coast of the Gulf of Oman, followed by the mountain region, the Arabian Gulf coast, the desert dryland and the lightest winds are in the interiors (Al Shamsei, 1993).

Unfortunately, the literature of the Emirates is nearly devoid of any studies concerning the Shamal storms.

5. THE CASE STUDY

Stagnant air with a dust haze usually covers the City of Al Ain for a period varying from a few hours to a few days. In the majority of cases, an active dust and/or sand storm follows, though sometimes a clearance occurs without a storm and sometimes a short and sharp storm passes associated with a cold front.

In the present study, a dust haze followed by a sand storm was monitored in Al Ain during a five-days period (8 - 12 March, 1994). Dust haze is indicated by an atmospheric obscurity due to solid particles. In this case, visibility range is 1000-8000 m. On the other hand, sand storm is

predicted by reduction in visibility to less than 1000 m at eye level due to dust or sand raised locally by winds.

The study includes measurement of the concentration of the suspended particulate matter less than 10 μm aerodynamic (termed SPM_{10}) by the same monitoring device used for the study presented in Chapter III. The study was carried out in the Female Students Campus of the United Arab Emirates University located at Al Maqam area (Fig. 17).

The data of the wind speed and direction prevailing during the study days were collected by Al Ain Meteorological Station, United Arab Emirates Air Force. The reduction in visibility and hence the classification of the study hours into hazy or stormy hours was carried out on a theoretical basis through the present investigation.

5.1 Results

The hourly concentrations of SPM_{10} during the case study period are listed in Table (11). These are graphically represented in Figs. (30), (31), (32), (33), and (34) for the five days: 8 March, 9 March, 10 March, 11 March, and 12 March, respectively.

TABLE (11)

Hourly Concentrations of SPM_{10} ($\mu g/m^3$) in Al Ain During the Period of the Case Study (8-12 March, 1994)

HOURS	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5
01:00	120	110.2	122.6	93.8	125.5
02:00	73.7	84.6	114.6	74.8	387.5
03:00	80.7	96.1	132.5	84.6	482.8
04:00	167.2	200	236.8	275.2	657.2
05:00	165.2	198	235.7	273.1	656.8
06:00	103.6	116	169.6	56.8	513.6
07:00	102.7	114.6	169	56.5	513.9
08:00	74.8	58	134.8	42	751.9
09:00	72.6	56.7	132.6	41.6	751.2
10:00	37.6	27.7	68.6	28.9	617.6
11:00	40.6	28.2	73.7	27.8	750
12:00	132	171.2	140.8	153.1	968.9
13:00	130.4	170.3	140.9	153	969.3
14:00	76.8	144.8	154	138.4	778.6
15:00	75.3	143.7	153.4	139.4	775.6
16:00	22	91.6	110	294	293.5
17:00	21.4	89.7	108.5	292.3	285.2
18:00	7.6	99.3	39.5	180	463.1
19:00	9.9	118.1	42.6	217.2	568.4
20:00	246.8	290	278.3	386.4	267
21:00	243.8	287.2	271.4	385.3	261
22:00	130.8	138.4	120.8	166	----
23:00	130.3	138.1	120.5	165.8	----
24:00	112.9	124.8	94.8	124	----
Daily					
Minimum	7.6	24.7	39.5	27.8	123.5
Maximum	246.8	290.0	278.3	386.4	969.3
Average	99.1	129.0	140.2	160.4	493.2

* ---- Not recorded

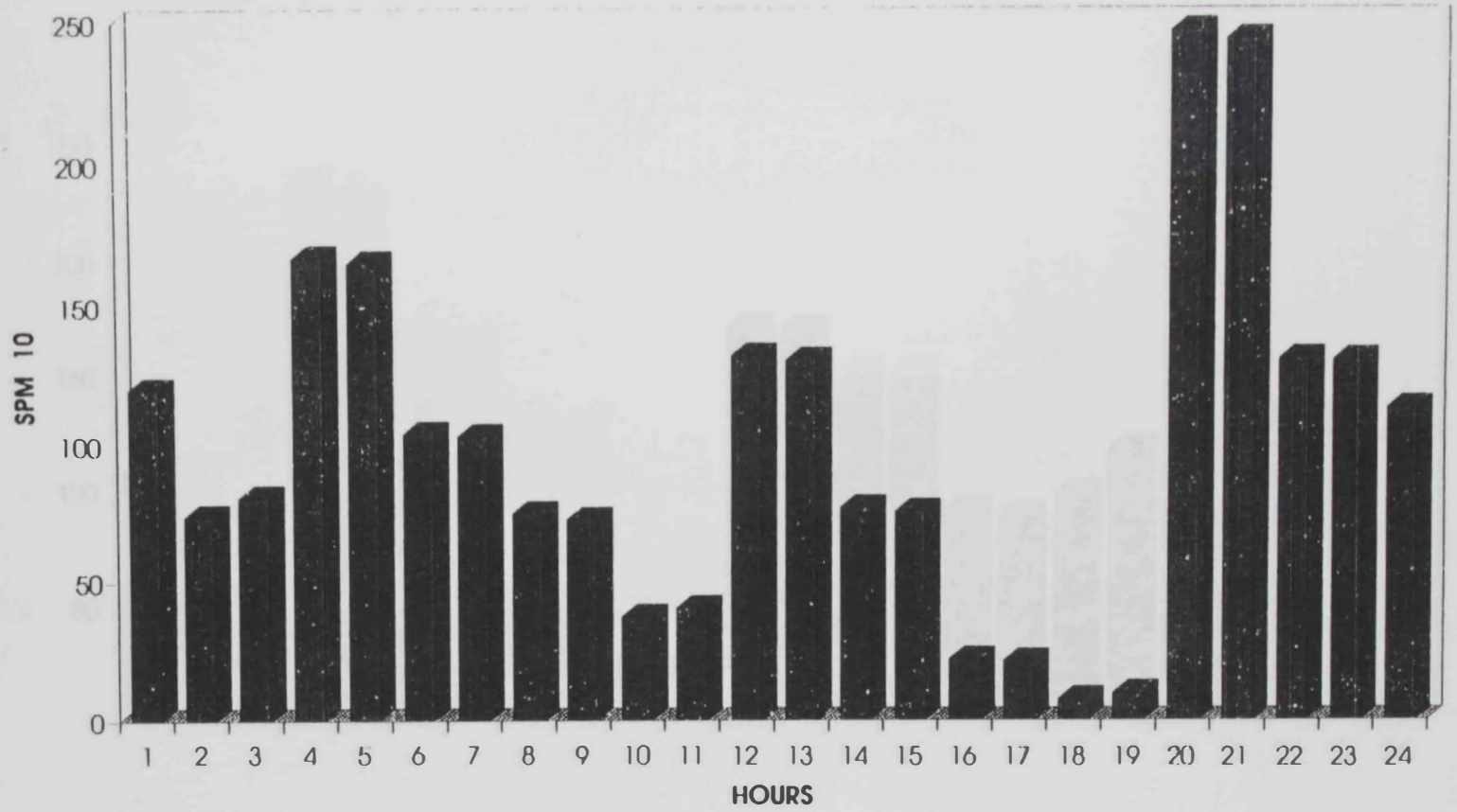


Figure (30) Hourly Concentrations of SPM10 (ug/m3) in Al Ain During 8 March 1994

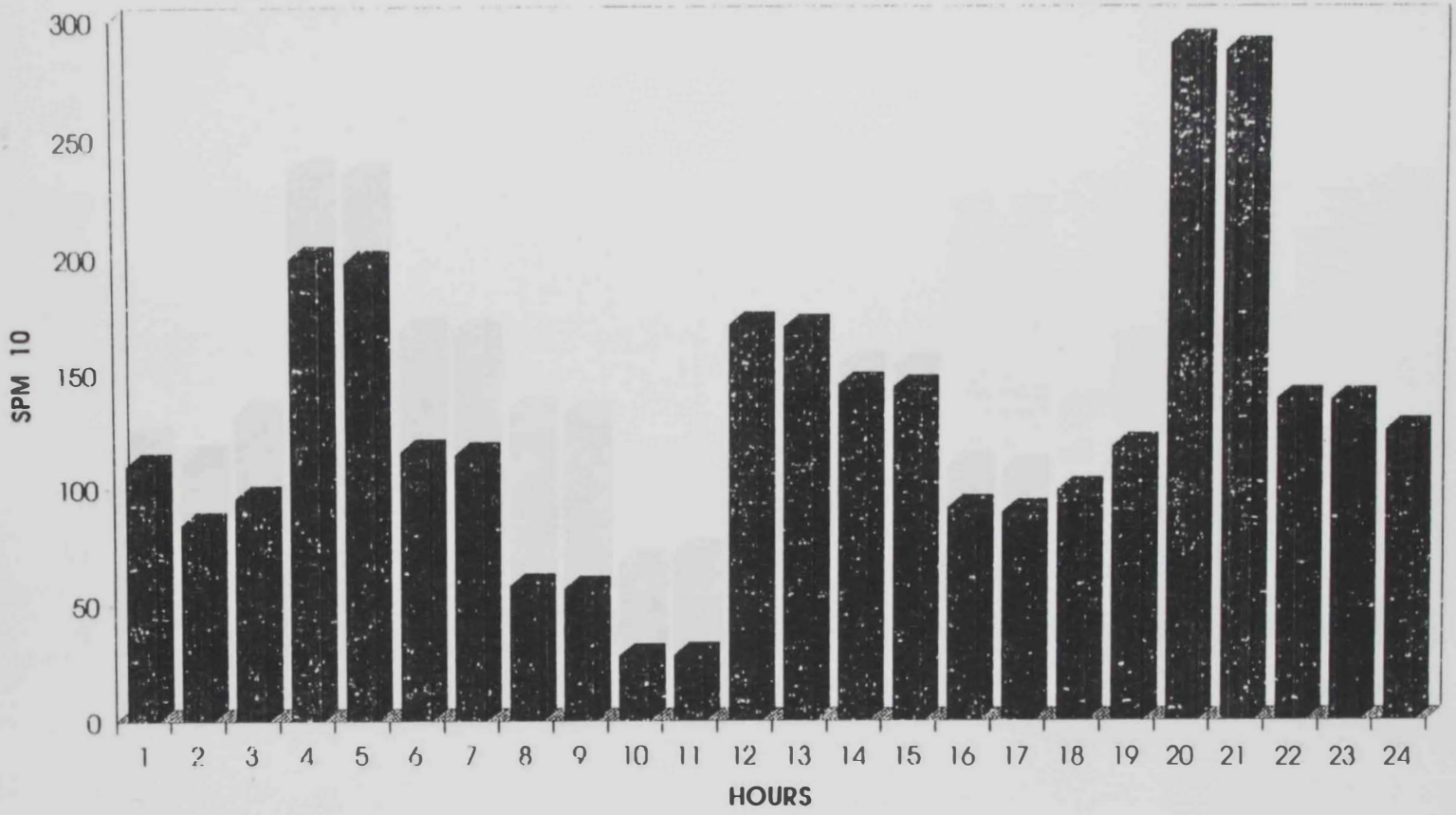


Figure (31) Hourly Concentrations of SPM10 (ug/m3) in Al Ain During 9 March 1994

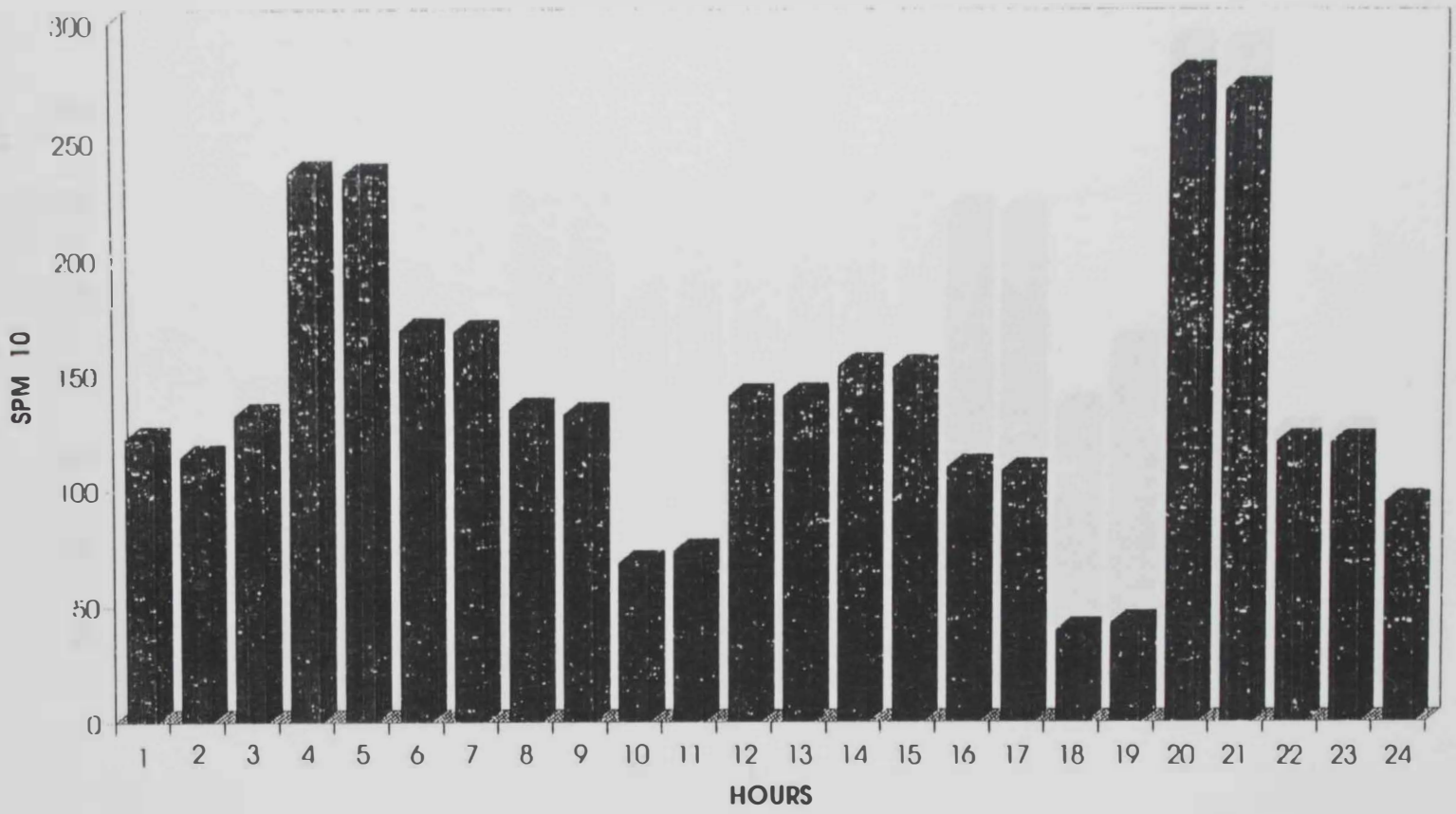


Figure (32) Hourly Concentrations of SPM10 (ug/m3) in Al Ain During 10 March 1994

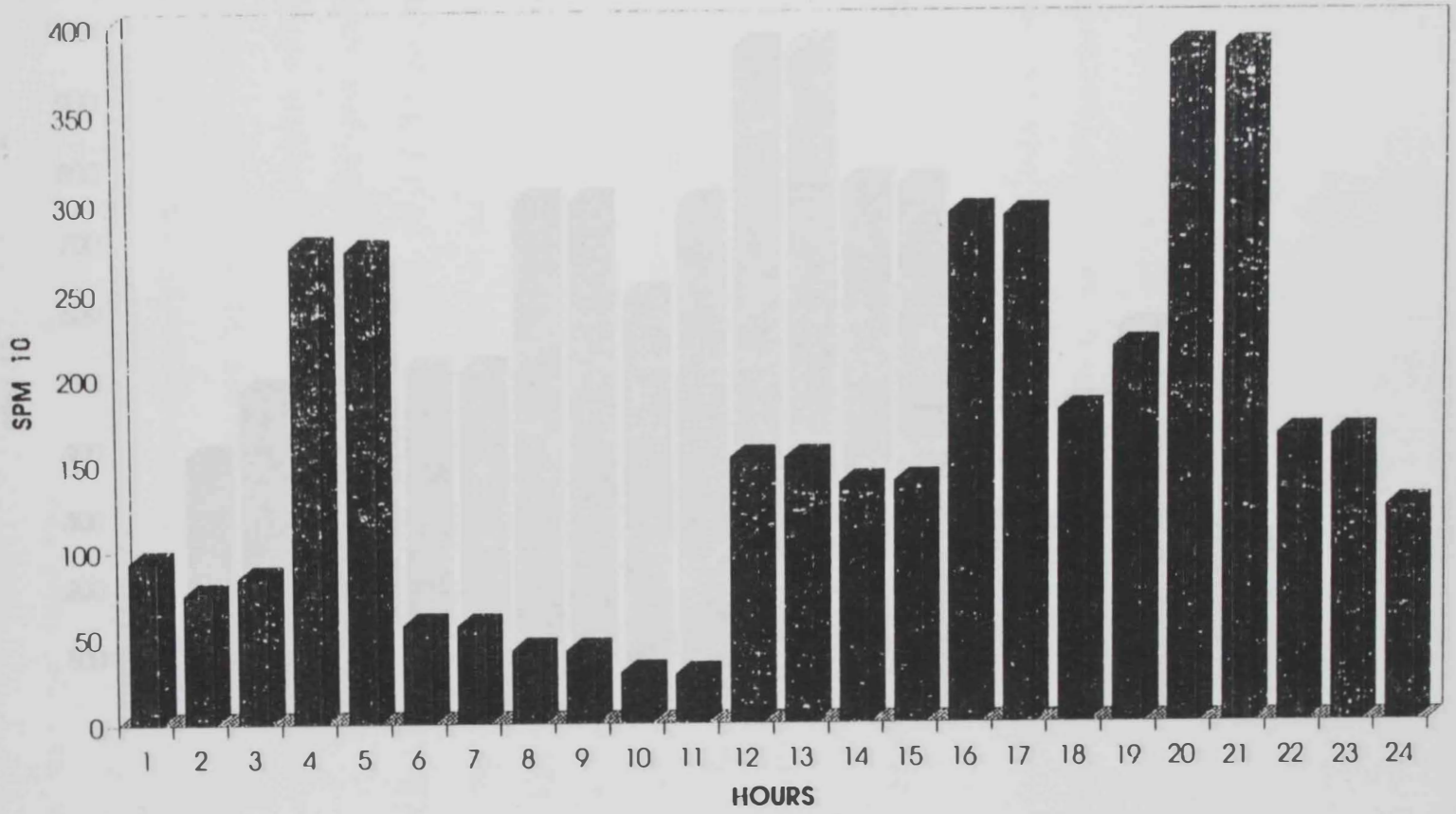


Figure (33) Hourly Concentrations of SPM10 (ug/m3) in Al Ain During 11 March 1994

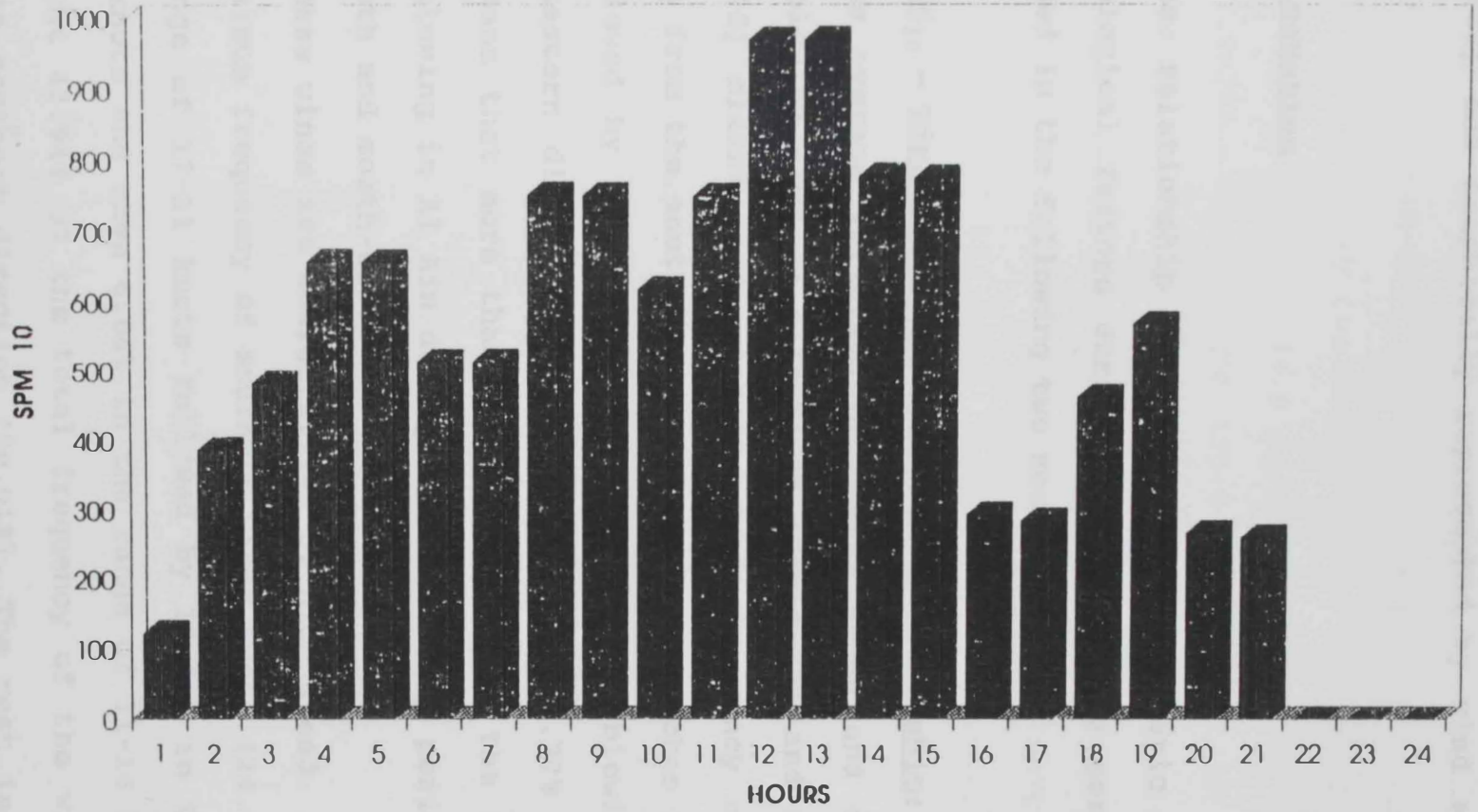


Figure (34) Hourly Concentrations of SPM10 (ug/m3) in Al Ain During 12 March 1994

The principal features characterizing the prevailing winds in Al Ain during the case study period are given in Table (12) and graphically represented by wind rose in Fig. (35).

5.2 Discussion

The relationship between the atmospheric burden and climatological factors during the case study period will be discussed in the following two sections :

(a) SPM_{10} - Wind Speed and Direction Relationship:

The average variation of hourly speed and direction of winds blowing from 12 directions (Table 12) and 8 directions (Fig. 35) clearly indicates the high frequency of the winds blowing from the southern direction which reaches 50.01%. This is followed by the frequency of the winds blowing from the south-eastern direction which amounts to 25.77% (Table 12). This means that more than three quarters of the frequency of winds blowing in Al Ain during the case study period were from the south and south-east.

These winds are characterized by high speed. For example, the maximum frequency of southern winds speed (24.24%) lies in the range of 17-21 knots followed by 13.64% in the range of 22-27 knots and then 6.06% in the range of 11-16 knots. These represent 43.94% of the total frequency of the winds blowing from the southern direction (50.01%). The rest is distributed between 1-3, 4-6, 7-10 and 28-33 knots wind speed ranges. The

latter range which is represented by 1.51% frequency is associated only with the southern direction.

It can be said, therefore, that the winds blowing from the south and south-east are highly responsible for the higher levels of SPM_{10} during the period of the case study. The ranges of these levels are 7.6-246.8 $\mu g/m^3$,24.7-290.0 $\mu g/m^3$,39.5-278.3 $\mu g/m^3$,27.8-386.4 $\mu g/m^3$, and 123.5-969.3 $\mu g/m^3$ on 8 March, 9 March, 10 March, 11 March, and 12 March, respectively with a daily mean of ,99.1 $\mu g/m^3$,129.0 $\mu g/m^3$,140.2 $\mu g/m^3$,160.4 $\mu g/m^3$,and 493.2 $\mu g/m^3$ for the five days, respectively. These means are 0.38, 0.50, 0.54, 0.62, and 1.90 times the 24-hour Threshold Limit Value (TLV) (260 $\mu g/m^3$) according to the U.S. National Ambient Air-Quality Standards (NAAQS) (EPA, 1976). This means that during 8 March, 9 March, 10 March and 11 March the concentration of SPM_{10} was below the TLV, whereas the level of SPM_{10} monitored during 12 March far exceeds the TLV.

TABLE (12)

Percentage Frequencies For Hourly Wind Speed Direction In Al Ain (8-12 March, 1994)

DIRECTION	01-03 KNOTS	04-06 KNOTS	07-10 KNOTS	11-16 KNOTS	17-21 KNOTS	22-27 KNOTS	28-33 KNOTS	>33 KNOTS	TOTAL
350-101	00	03.0	00	00	00	00	00	00	03.0
020-040	00	00	00	00	00	00	00	00	00
050-070	00	00	00	00	00	00	00	00	00
080-100	00	01.5	00	00	00	00	00	00	01.5
110-130	00	01.5	00	03.0	00	00	00	00	04.5
140-160	00	01.5	01.5	09.1	06.1	07.6	00	00	25.8
170-190	01.5	01.5	01.5	07.6	22.7	13.6	01.5	00	50.0
200-220	00	01.5	00	00	00	00	00	00	01.5
230-250	00	00	00	00	00	00	00	00	00
260-280	01.5	00	00	00	00	00	00	00	01.5
290-310	01.5	00	03.0	01.5	00	00	00	00	06.1
320-340	00	01.5	03.0	01.5	00	00	00	00	06.1
TOTAL	04.5	12.1	09.1	22.7	28.8	21.2	01.5	00	100
CALMS	00	00	00	00	00	00	00	00	

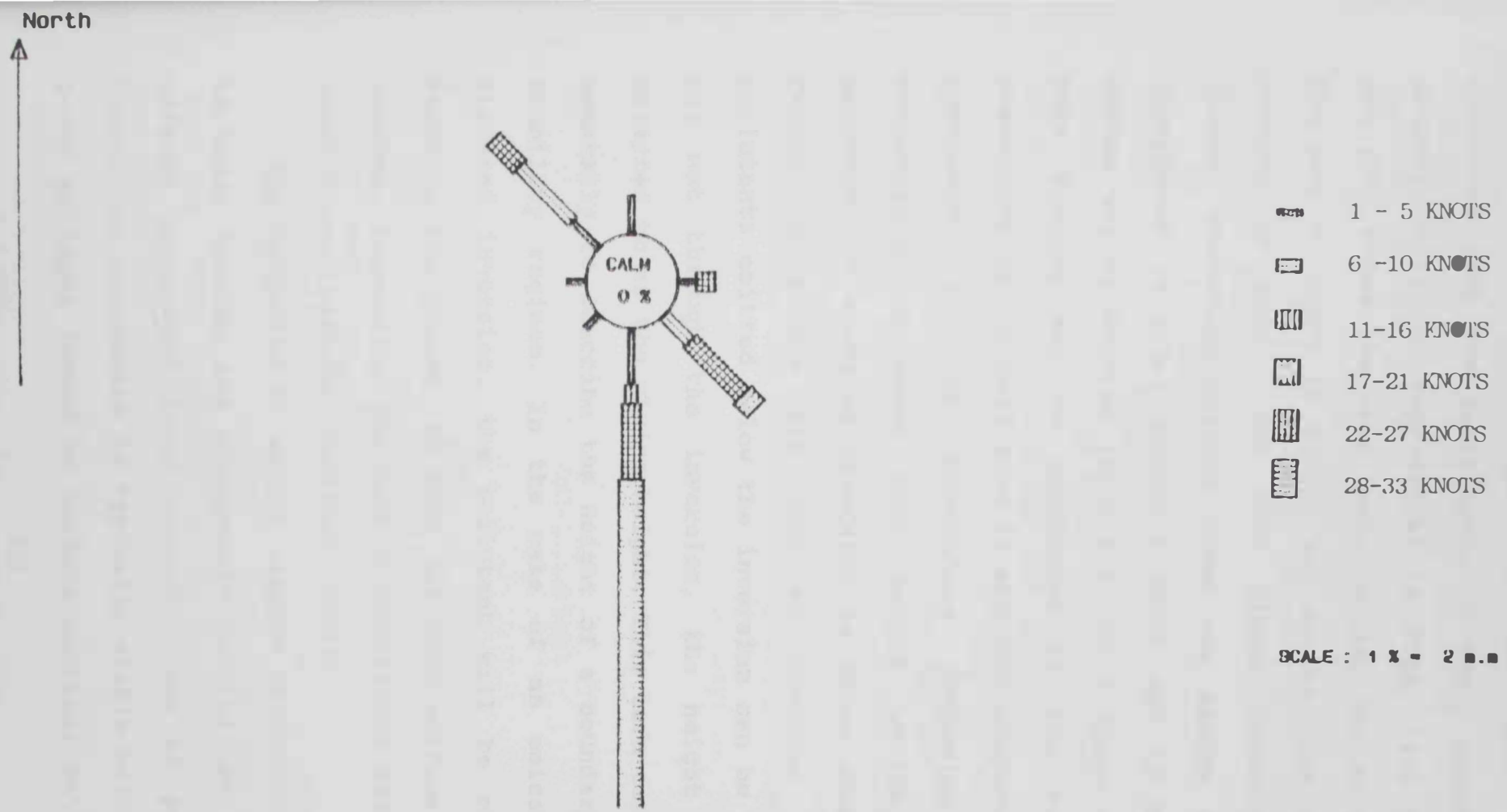


Figure (35) The Average Variation of Hourly Speed and Frequencies of Winds Blowing from 8 Directions in Al Ain
(8-12 March, 1994)

An interesting aspect of the data presented is concerned with the daily cycle of SPM_{10} concentration. The diurnal variation represented in Figs. (30),(31),(32),(33) and (34) shows the same basic rhythm, having one maxima at the end of night (4 a.m.), and another one maxima in the evening (8 p.m.), but with higher concentrations. The diurnal variation further shows one minima when sunlight disappears (6 p.m.) during 8 March and 10 March and one minima during daytime (10 a.m.) on 9 March and 11 March. This finding may be attributed to the fact that the atmosphere in the Gulf area is strongly characterized by the phenomenon of the temperature inversion, i.e. the temperature increases with height unlike the normal decrease. An elevated inversion is often observed where a region of stable air caps an unstable layer below. Pollutants emitted below the inversion can be mixed up too, but not through the inversion, the height of which is referred to as the mixing height. This term can be used more generally to describe the height of a boundary between two stability regimes. In the case of an emission above an elevated inversion, the pollutant will be prevented from reaching the ground, so that for both surface and elevated sources, inversions can have a significant effect on ground level concentrations (Harrison, 1992).

The variation of mixing heights throughout the day due to solar heating and atmospheric cooling can have profound effects on ground level concentrations of pollutants. At night, the atmosphere is typically stable with a shallow (~ 1-300 m) layer formed by surface cooling. As the sun rises

the surface heating generates consecutive eddies and the turbulent boundary layer increases in depth, reaching a maximum in the afternoon, at a depth of ~ 1000m. As the solar input decreases and stops, the surface cools and a shallow stable layer begins to form again in the evening (Harrison, 1992).

In this idealized day, concentrations from surface sources will thus be at a maximum in the periods when the stable layers (with low wind speeds and mixing heights) are present and minimized during the afternoon.

The only exception observed from the available data is the appearance of one minima during daytime (10 a.m.) in two days (9 March and 11 March). This exceptional case seems to be due to development of strong consecutive turbulent motion during daytime and hence leads to highly pronounced minimum SPM_{10} concentrations found at the daytime (Abdel Salam et al., 1981).

(b) SPM_{10} - Visibility Relationship:

One of the main facts of particulate air pollution is the diminution in visibility caused by light scattering due to the particles. Scattering efficiency per unit mass of aerosol is critically dependent upon the size distribution of the aerosol, but aerosol <10 μm (SPM_{10}) mass loading is a good predictor of visibility impairment (Harrison, 1992), as indicated by Fig. (36).

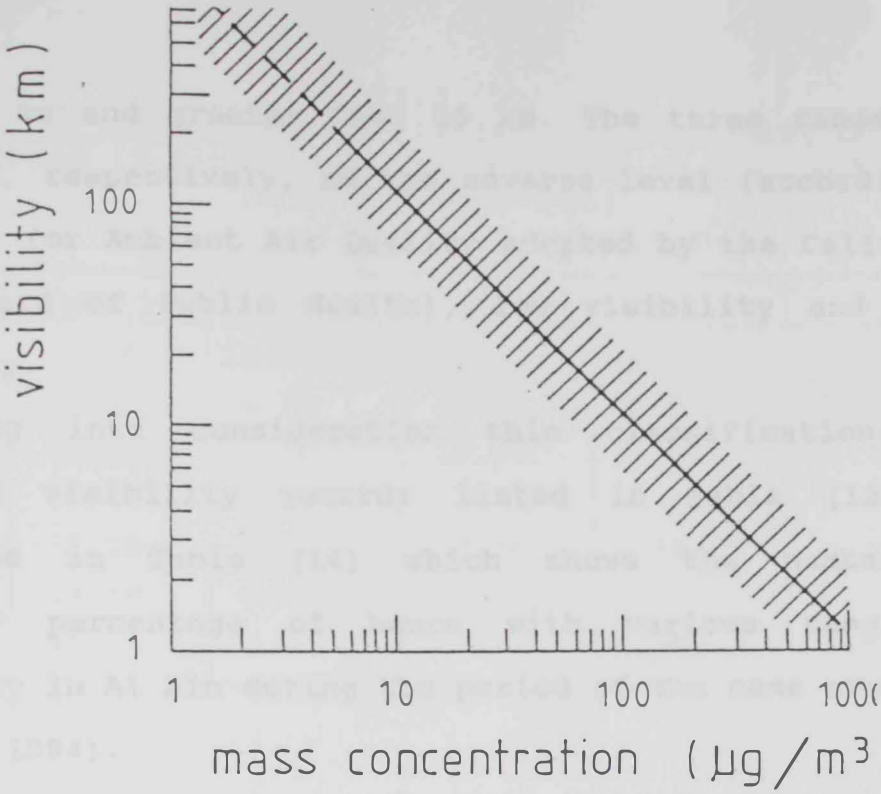


Figure (36) Atmospheric Visibility as a Function of Suspended Particle Concentration (After Charlson, 1968)

Note: The relationship is approximate only, but most data fit within the shaded area.

From this figure and by using the SPM_{10} observations, the 24-hr visibility values in kilometers for the five days of the case study period (8-12 March 1994) could be predicted. These values are assembled in Table (13) and graphically represented by figs. (37),(38),(39),(40) and (41) for the five days, respectively.

By correlation between the SPM_{10} levels listed in Table (12) and represented by figs. (30),(31),(32),(33) and (34) and the predicted visibility records and graphs, it can be seen that visibility is much reduced by the particulate mass concentration.

According to Abdel Salam (1968), the visibility records can be classified into three ranges. These are less than 5

km, 5-15 km and greater than 15 km. The three ranges are described, respectively, as the adverse level (according to standards for Ambient Air Quality adopted by the California State Board of Public Health), low visibility and clear visibility.

Taking into consideration this classification, the predicted visibility records listed in Table (13) are summarized in Table (14) which shows the number and frequency percentage of hours with various ranges of visibility in Al Ain during the period of the case study (8-12 March 1994).

From the extracted table, it can be noticed that the number of stormy hours with visibility less than five kilometers is 20 hours representing 95.24% of total hours of records (21) during 12 March, 4 hours representing 16.67% of total hours of records (24) during 11 March, 5 hours representing 20.83% of total hours of records (24) during 10 March and then 2 hours representing 8.33% of total hours of records during each of 8 and 9 March. This means that the dust storm had frequently blown in Al Ain at some hours during 8, 9, 10 and 11 March and then blown allover the day during 12 March. However, the deterioration of visibility during the first four days can be partly attributed to the effect of the temperature inversion discussed in the preceding section. This conclusion is based on the available data of visibility (Table 13) which indicate that the hours of less than 5 km visibility are 8 p.m. and 9 p.m. during 8 and 9 March, 4 a.m., 5 a.m., 7 p.m., 8 p.m. and 9 p.m. during 10 March and 4 a.m., 5 a.m., 8 p.m., and 9 p.m.

TABLE (13)

Predicted Atmospheric Visibility (Km) According to SPM_{10} concentration in Al Ain During the Period of the Case Study (8-12 March, 1994)

HOURS	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5
01:00	10.50	14.00	12.04	13.00	10.00
02:00	15.80	18.00	12.07	16.00	2.90
03:00	16.00	15.00	12.00	15.00	2.50
04:00	8.00	5.20	3.50	4.50	1.50
05:00	8.10	5.10	3.50	4.70	1.60
06:00	11.10	9.50	6.10	19.80	2.00
07:00	12.00	10.50	6.20	20.00	1.95
08:00	15.50	18.00	11.75	26.00	1.38
09:00	16.10	19.00	11.90	28.00	1.40
10:00	31.00	42.00	27.00	40.00	1.30
11:00	27.00	40.00	25.00	42.00	1.45
12:00	8.80	6.00	11.60	8.78	1.25
13:00	9.00	6.10	11.50	8.80	1.25
14:00	15.00	7.00	7.00	8.90	1.28
15:00	15.10	7.10	7.20	8.85	1.30
16:00	50.00	13.00	12.90	9.20	3.85
17:00	48.00	17.00	13.00	9.30	3.90
18:00	155.00	12.00	30.00	8.50	2.6
19:00	120.00	9.10	2.80	5.30	1.9
20:00	4.10	4.00	2.90	3.00	4.00
21:00	4.00	3.80	3.10	3.10	4.20
22:00	8.90	7.50	12.18	8.68	----
23:00	9.10	7.65	12.20	8.60	----
24:00	11.00	8.20	14.90	9.00	----

* ---- Not recorded

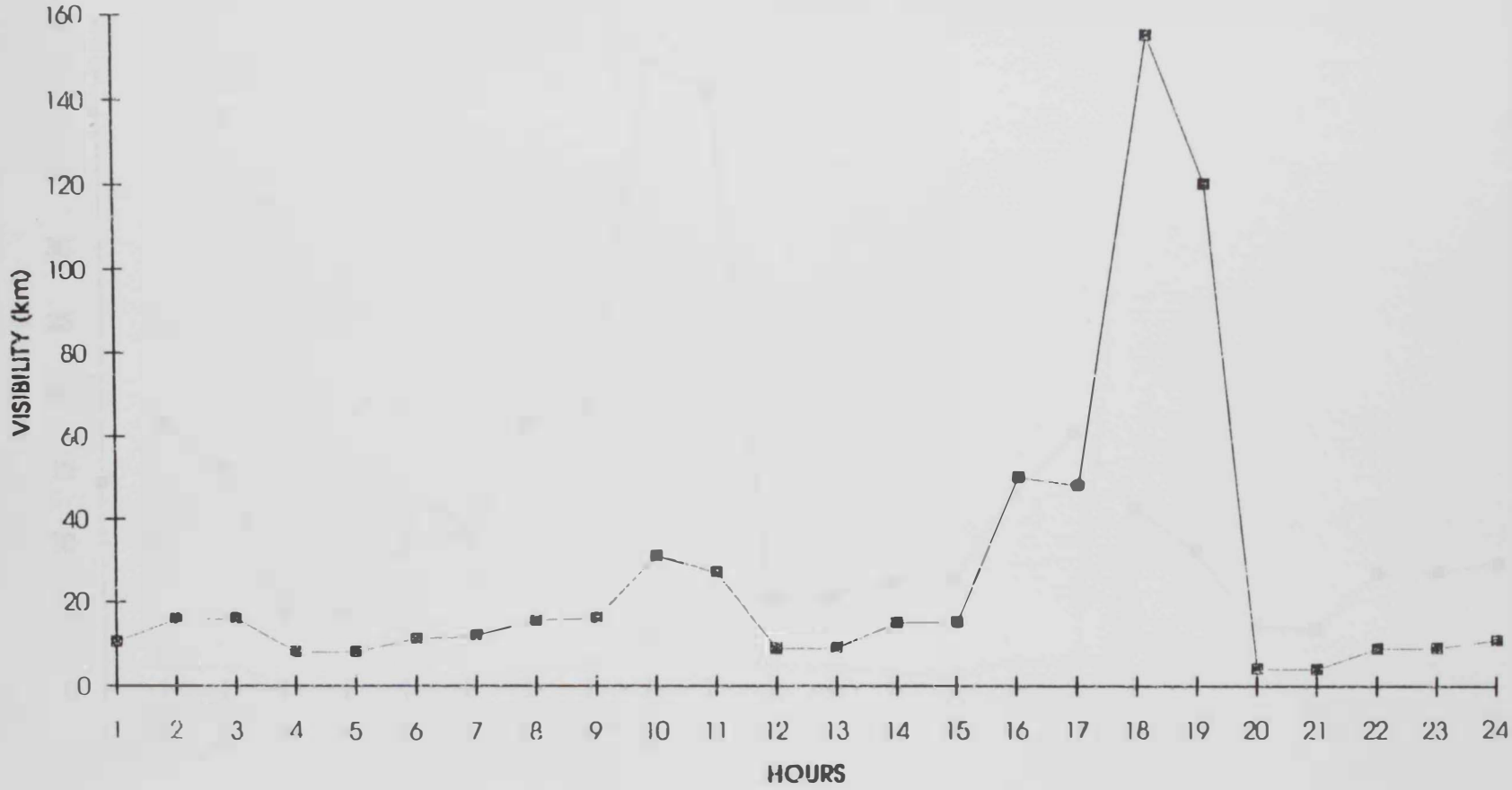


Figure (37) Predicted Hourly Visibility in Al Ain on 8 March,1994

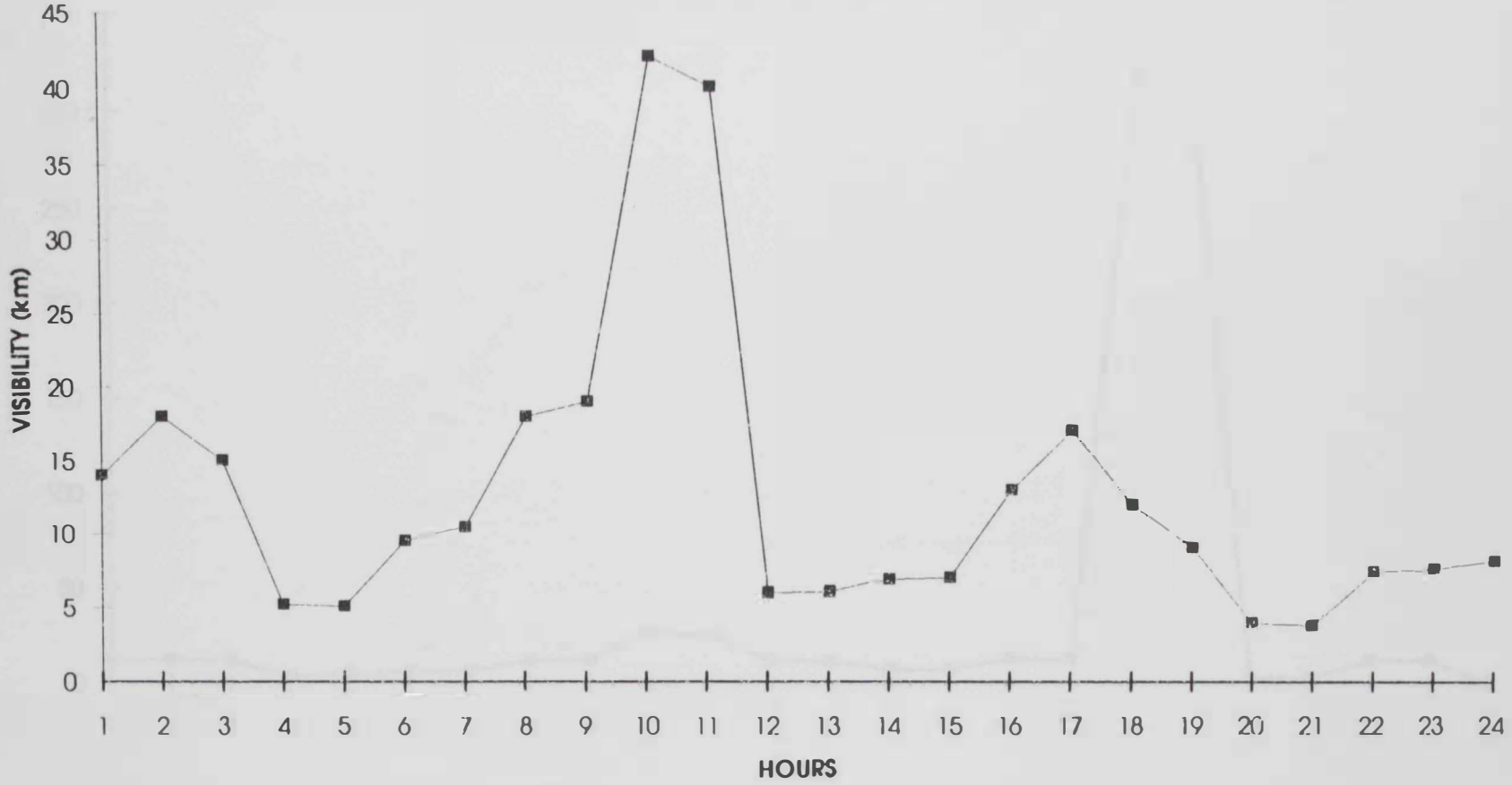
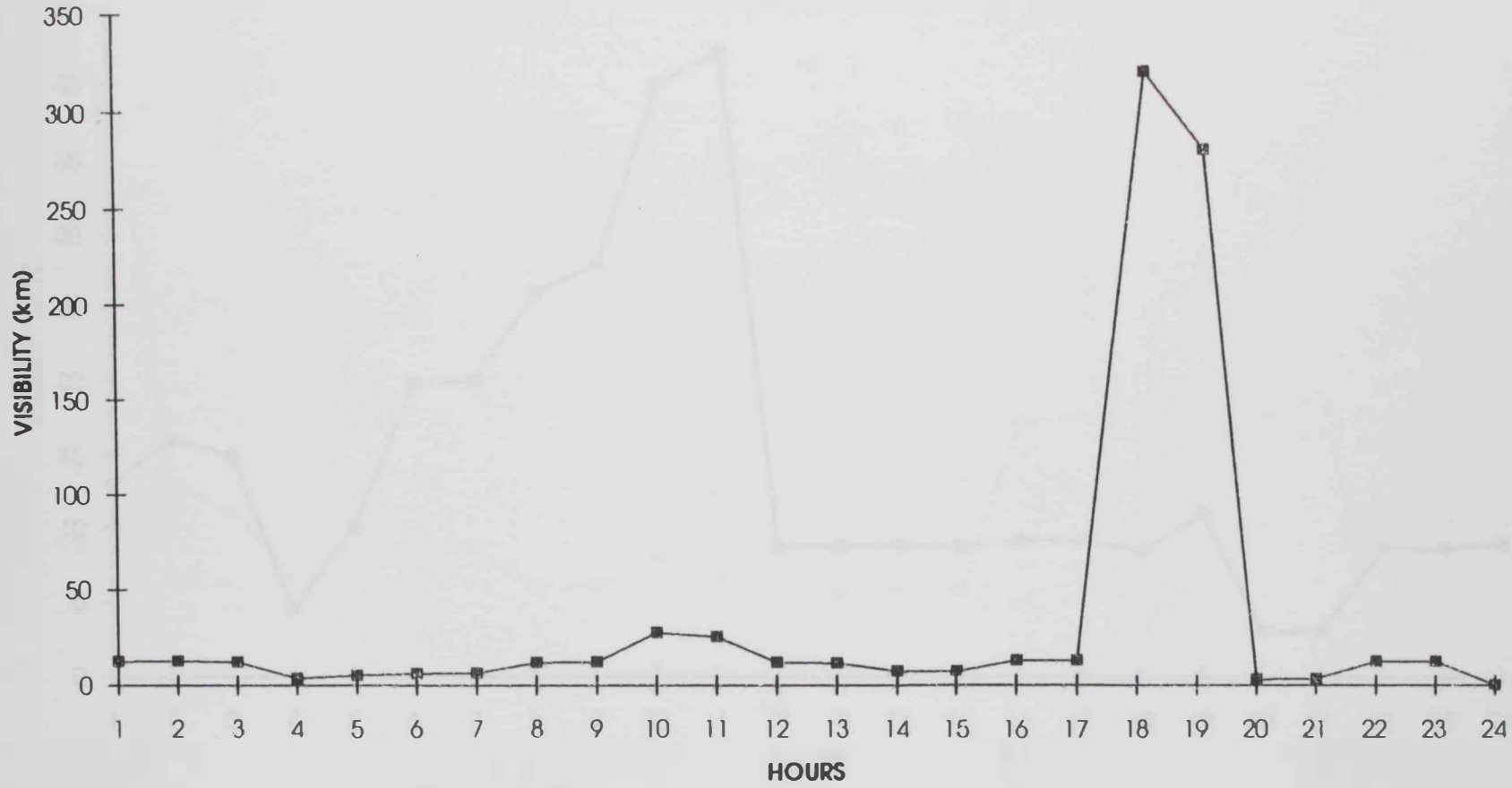


Figure (38) Predicted Hourly Visibility in Al Ain on 9 March ,1994



Figur (39) Predicted Hourly Visibility in Al Ain On 10 march,1994

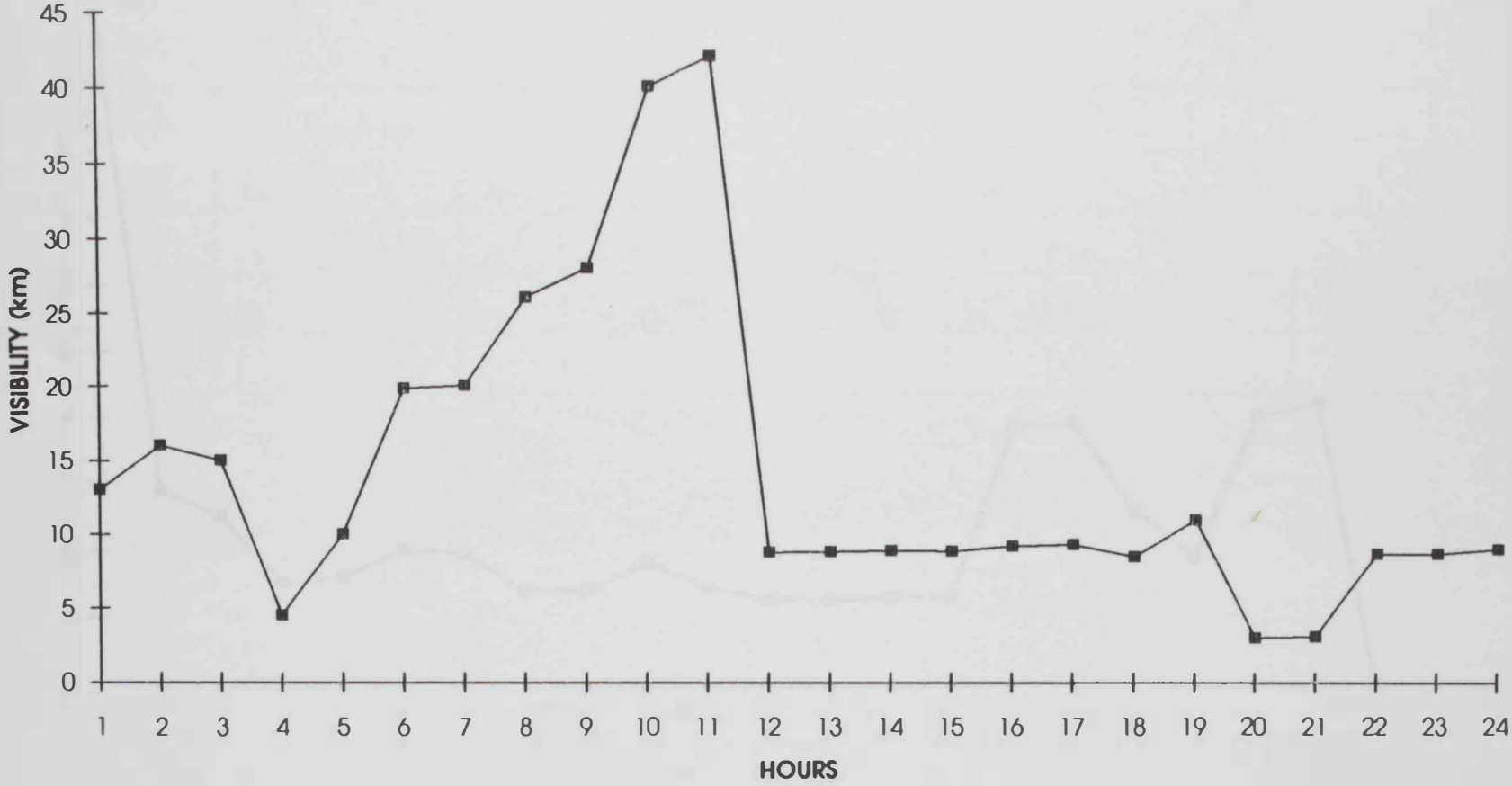


Figure (40) Predicted Hourly Visibility in Al Ain on 11 March,1994

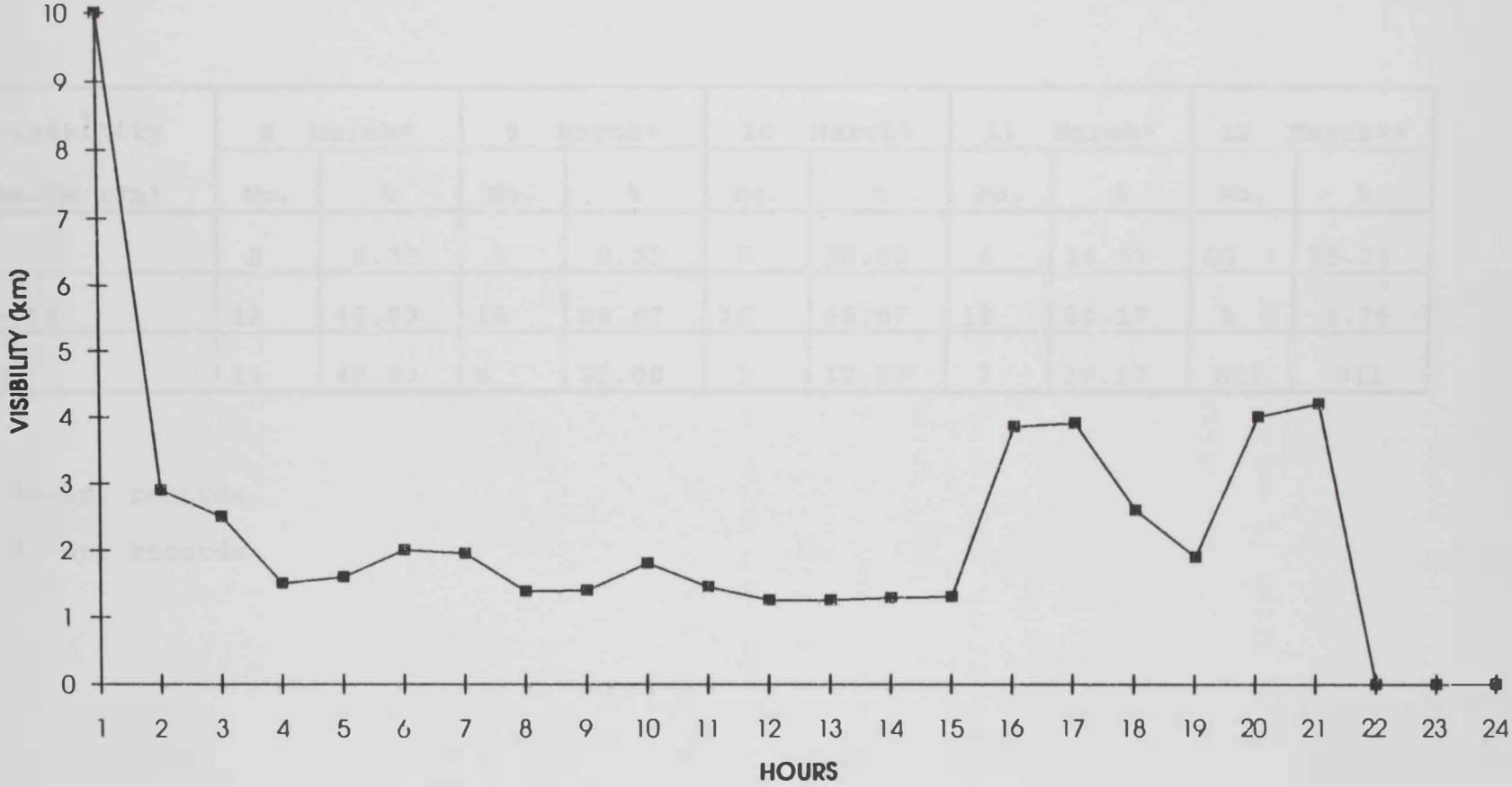


Figure (41) Predicted Hourly Visibility in Al Ain on 12 March ,1994

TABLE (14)
Number and Frequency Percentage of Hours with
Various Ranges of Predicted Visibility in Al Ain
(8 - 12 March 1994)

Visibility Range (Km)	8 March*		9 March*		10 March*		11 March*		12 March**	
	No.	%	No.	%	No.	%	No.	%	No.	%
<5	2	8.33	2	8.33	5	20.83	4	16.67	20	95.24
5 - 15	11	45.83	16	66.67	16	66.67	13	54.17	1	4.76
>15	11	45.83	6	25.00	3	12.50	7	29.17	Nil	Nil

* 24-hr. records

** 21-hr. records

during 11 March. These hours are characterised by the occurrence of the temperature inversion in Al Ain, as previously explained on pp. 112-114.

The extracted table further shows that 45.83%, 66.67%, 66.67% and 54.17% of the hourly visibility during 8, 9, 10 and 11 March are within 5-15 km, i.e. the low visibility range. The corresponding frequency on 12 March is 4.76% (one hour) of the total hours of observations (21).

On the other hand, the table indicates that in 45.83%, 25.00%, 12.50% and 29.17% of the 24 hours during 8, 9, 10 and 11 March, respectively, the visibility was clear, whereas no hours with clear visibility could be observed during the dust stormy day (12 March 1994).

From the foregoing findings, it seems reasonable to define the dust storms in Al Ain City in terms of a visibility less than 5 km. This value has been previously applied in a study carried out in Kuwait (Abdel Salam, 1968).

CHAPTER V

ACID GASES IN THE ATMOSPHERE OF ABU DHABI CITY

1. ACID RAIN

Acid rain is a serious global pollution problem caused by wet deposition. Acidity of water is commonly measured as a molar concentration of H^+ion and expressed as pH=log $(1/[H^+])$. In relatively unpolluted atmosphere, acidity of rain water is caused mainly by dissolved CO_2 (carbonate acidity). The pH of rain water in equilibrium with CO_2 is in the range of 5.6 to 5.7 (Novotny and Chester, 1981). However, investigations in the early 1950s noticed a surprisingly low pH of precipitation in southern Scandinavia, and a similar phenomenon was reported in the late 1960s in the north-eastern United States and southern portions of Ontario and Quebec. The pH values were reported near 4 or less (Cogbill and Likens, 1974; Likens and Borman, 1974).

The origin of acid rain is attributed primarily to the presence of sulphates and sulphites (SO_4^{-2} and SO_3^{-2}) and nitrates (NO_3^{-2}) in the atmosphere. Sulphur is one of the elements always found in the atmosphere and occurs as SO_4^{-2} and SO_3^{-2} in aerosols and SO_2 and H_2S gases. Hydrogen sulphide in air is normally oxidized to SO_2, which is then oxidized to SO_3.

The oxidation reaction proceeds quickly if such metallic catalysts as iron and manganese oxides are present (Stern, 1976). These metallic compounds are commonly emitted by burning processes in fly ash.

The SO_4^{-2} and NO_3^- anions in the air are balanced by cations, primarily NH_4^+, Ca^{+2}, Mg^{+2} and Na^+. The major sources of these compounds are sea spray, soil dust and ammonia volatalization from soils. Since the Na^+ from sea spray is already balanced by Cl^- in the absence of other buffering agents in the air, there may not be other cations available to balance additional SO_4^{-2} and NO_3^- ions and they can only react with H^+ to produce acid rain (Cogbill and Likens, 1974).

2. ACID GASES

The rate of acidic deposition is usually estimated by the product of the ground level concentration of the precursor gases SO_2 and NO_x. Although the elevated acidity of precipitation is commonly attributed to energy production, several other sources contribute to the acid gases (SO_2 and NO_x) contents of the atmosphere. Global estimates indicate that about 70% of atmospheric sulphur originates from marshland or sea and about 30% is from cultural anthropogenic sources (Junge, 1960). However, Swedish investigators have calculated that more than 70% of the sulphur in the atmosphere over southern Sweden is from human activities, and 77% of it is believed to originate from sources outside Sweden, mainly from burning of low-quality "brown" coal in Central Europe and

from coal burning operations in Great Britain. There are no appreciable coal deposits in Scandinavia, and most of energy is generated from hydropower or from imported oil and high-quality coal (Novotny and Chester, 1981). Similarly, in the United States the origin of acid rain is attributed to coal burning operations (primarily from power plants) in the north eastern and mid-western United States (Gatz and Changnon, 1976).

The origin of nitrates is not well known but nitrates are attributed largely to agricultural and traffic sources. Data from New York State and parts of England revealed that approximately 50 to 70% of the acidity is ascribed to sulphuric acid, and 30 to 40% is due to nitric acid (Glass et al, 1979). The proportion may be reversed in areas of heavy traffic (e.g. southern California) where high amounts of nitric oxides are emitted from automobiles.

3. EXTENT OF ACIDITY PROBLEM

Acidity is a local as well as (and primarily) a regional problem. The lowest pH values of precipitation are measured usually in the vicinity of large coal-fired power plants, near smelting operations and in heavy traffic corridors. The pH values are often measured locally near or below 3. It is interesting to note that in England, in the early part of this century, the pH of rain in the vicinity of Leeds (a heavy coal-use region) was measured on occasions to be below 3.0 (Glass et al, 1979). The lowest pH value reported for an

individual strom in Europe up to now is 2.4 on April 10, 1974 at Pitlochry, Scotland. In the same month, values of 2.7 and 3.5 were reported on the west coast of Norway and at a remote station in Iceland, respectively (Liken et al., 1979).

In the United States there is a noticeable trend of increased acidity of precipitation in the period from 1950 to the late 1980s. Recent studies of acid fog downwind from the Los Angeles basin show a fog water with pH levels as low as 1.69 (Chiras, 1991). As stated by Likens et al. (1979), an irony in this matter is that the trend to relieve local air pollution problems by building taller and taller stacks has turned the local problems into regional ones. Thus, the coal-burning operations in the Appalachian region may be causing acidification of lakes in New York State, New England, and Ontario for more than a thousand kilometers away. Besides the eastern United States and north-eastern Europe, acid rain has been measured in other parts of the world.

4. ALARMING FACTS

Some alarming facts are associated with the acid rain problem (Galloway and Cowling, 1978) :

(a) The pH of precipitation has been decreasing over most of the north-eastern United States and north western Europe for the past few decades as energy demand has increased.

(b) Acid precipitation affects almost all parts of the ecosystem, including forests and surface waters. Some aquatic systems of low alkalinity have already manifested such decreases in pH that fish populations are no longer self-sustaining.

(c) Low pH values (less than 5.6) are experienced over large portions of North America and Europe.

(d) The atmospheric content of sulphur - the primary source of acidity - is likely to increase unless drastic and expensive measures are undertaken globally to reduce sulphur emissions from power plants and urban and industrial operations, with diminishing resources of low-sulphure oil, the prospects for reducing SO_2 emission are not good.

5. MONITORING IN ABU DHABI

The present investigation includes long-term measurements of SO_2 and NO, NO_2, and NO_x in Abu Dhabi City. These measurements were carried out during winter and spring of the two years 1991 - 1992 and 1992 - 1993. Winter study was undertaken during December, January and February, whereas spring study was undertaken during March, April, and May.

The sulphur dioxide and nitrogen oxides were measured by the Abu Dhabi Men's Higher Colleges of Technology using the Environment S.A. Mobile Laboratory. The instruments of

measurements are AF 21M SO_2 Analyzer and AC 30M $NO/NO_2/NO_x$ Analyzer. The measuring principles and operation of the two instruments are described in detail in Chapter II.

The sampling site is the campus of the Abu Dhabi Men's Higher Colleges of Technology which is located at light administrative and residential area in the middle sector of the City (Fig. 42).

5.1 Results

The daily records of SO_2 and NO, NO_2 and NO_x are presented in the following manner : Table (15) for winter 1991-1992 months, Table (16) for spring 1992 months, Table (17) for winter 1992-1993 months, and Table (18) for spring 1993 months.

The minimum, maximum and average levels for each month are shown at the bottom of each table.

On the other hand, the seasonal averages for the minimum, maximum and average levels were calculated and assembled in Table (19).

5.2 Discussion

The available results of sulphur dioxide and nitrogen oxides concentrations in the atmosphere of the town of Abu Dhabi will be treated from the point of view of the three aspects : (a) level of concentration compared with the ambient air quality standards, (b) seasonal variation, and (c) relationship with the relative humidity levels prevailing in the town during the periods of study. The latter aspect will

help in focusing on the ability of the two gases to react in the humid conditions in the town to produce sulphuric acid and sulphates and nitric acid and nitrates.

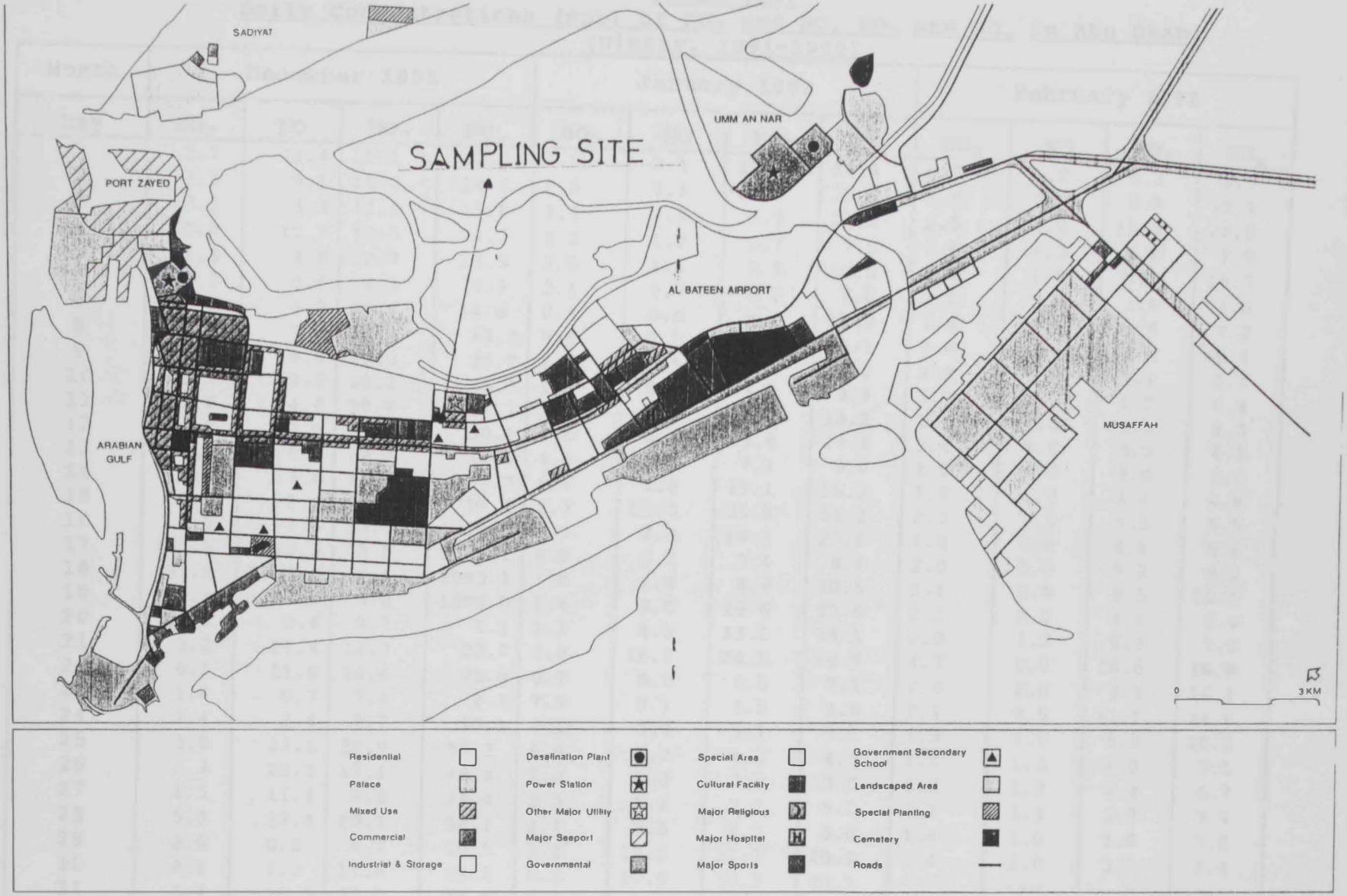


Figure (42) Location Map of the Study Areas in Abu Dhabi

Table (15)
Daily Concentrations (ppb) of SO_2 and NO, NO_2 and NO_x in Abu Dhabi (Winter, 1991-1992)

Month	December 1991				January 1992				February 1992			
Day	SO_2	NO	NO_2	NO_x	SO_2	NO	NO_2	NO_x	SO_2	NO	NO_2	NO_x
1	2.7	11.4	22.1	33.5	1.9	3.1	13.3	16.4	0.5	1.2	5.3	6.5
2	1.5	9.1	15.5	24.6	2.9	9.1	24.3	33.4	3.8	2.3	8.8	11.1
3	0.5	3.3	12.5	15.8	1.4	2.9	8.3	11.2	2.5	4.8	15.8	20.6
4	2.0	10.7	13.5	24.2	2.2	1.2	6.7	7.9	0.6	1.3	6.2	7.5
5	1.3	3.6	10.7	14.3	2.5	1.1	9.4	10.5	1.3	2.8	7.5	10.3
6	0.3	0.4	4.5	4.9	3.1	0.7	6.3	7.0	1.2	1.0	3.6	4.6
7	1.9	4.2	10.4	14.6	8.4	0.6	9.4	10.0	1.3	1.4	5.8	7.2
8	1.6	3.3	10.0	13.3	8.1	7.0	22.1	29.1	7.6	18.4	31.0	49.4
9	2.9	15.8	16.0	31.8	2.1	0.5	7.7	8.2	2.2	1.3	5.1	8.4
10	2.9	19.7	16.2	35.9	1.1	0.1	3.7	3.8	1.7	1.2	5.2	8.4
11	2.6	14.6	18.1	32.7	2.0	2.4	10.8	13.2	1.1	1.0	3.3	4.3
12	3.2	12.9	17.2	30.1	4.6	8.7	18.4	27.1	2.4	1.0	3.5	4.5
13	1.7	4.4	12.8	17.2	4.4	0.9	7.1	8.0	1.6	1.0	3.6	4.6
14	2.3	7.6	17.6	25.2	6.4	7.8	19.1	26.9	1.8	1.0	3.8	4.8
15	1.2	2.0	13.1	15.1	2.3	21.3	35.0	56.3	2.3	1.0	4.5	5.5
16	1.7	7.5	10.5	18.0	2.3	7.0	18.1	25.1	1.3	1.0	4.1	5.1
17	107.6	1090.3	3.8	1094.1	0.8	0.7	7.4	8.1	2.0	1.0	5.2	6.2
18	297.9	2979.0	4.1	2983.1	1.6	1.6	8.9	10.5	2.4	1.5	9.5	11.0
19	135.1	1288.0	8.0	1296.0	1.4	9.0	18.6	27.6	2.2	2.2	4.4	6.6
20	1.9	0.4	5.7	6.1	1.1	4.9	13.2	18.1	2.0	1.3	6.3	7.6
21	3.2	11.4	12.3	23.7	2.0	16.3	24.6	40.9	4.7	2.2	16.6	18.8
22	6.1	11.6	16.4	28.0	0.7	0.9	6.6	7.5	2.4	6.8	9.3	16.1
23	1.8	0.7	7.4	8.1	7.5	0.1	4.5	4.6	2.1	3.5	11.1	14.6
24	1.4	2.4	7.7	10.1	4.1	0.0	3.1	3.1	1.3	4.5	5.8	10.3
25	3.8	33.4	22.9	56.3	6.8	0.2	4.3	4.3	1.1	1.3	6.2	7.5
26	2.3	29.3	17.1	46.4	2.0	0.0	3.0	3.0	1.2	1.3	4.4	5.7
27	1.5	11.1	7.3	18.4	3.3	2.1	7.1	9.2	2.1	1.1	2.3	3.4
28	5.0	37.4	20.7	58.1	2.4	0.5	4.5	5.0	1.8	1.0	1.8	7.8
29	2.0	0.8	9.7	10.5	5.2	17.2	31.7	48.9	1.4	1.0	3.5	4.4
30	2.8	1.2	11.0	12.2	5.1	15.0	30.3	45.3	----	----	----	----
31	3.4	10.5	25.0	35.5	0.3	1.0	5.9	6.9	----	----	----	----
Monthly												
Minimum	0.3	0.4	3.8	4.9	0.3	0.0	3.1	3.1	0.5	1.0	1.8	2.8
Maximum	297.9	2979.0	25.0	2983.1	8.4	21.3	35.0	56.3	7.6	18.4	31.0	49.4
Average	19.5	181.8	12.9	194.7	3.2	4.6	12.7	17.3	2.1	2.4	7.0	9.4

Table (16)
Daily Concentrations (ppb) of SO_2 and NO, NO_2 and NO_x in Abu Dhabi (Spring, 1992)

Month	March 1992				April 1992				May 1992			
Day	SO_2	NO	NO_2	NO_x	SO_2	NO	NO_2	NO_x	SO_2	NO	NO_2	NO_x
1	1.6	1.1	4.1	5.2	1.2	1.7	8.5	10.2	4.2	7.5	14.8	22.3
2	0.4	1.5	7.3	8.8	0.1	7.2	9.9	17.1	1.6	11.3	14.7	26.0
3	1.0	2.7	8.1	10.8	0.2	2.3	7.6	9.9	2.1	14.0	20.2	34.2
4	1.5	1.0	6.6	7.6	----	----	----	----	1.4	15.7	21.8	37.5
5	8.0	1.8	11.2	13.0	----	----	----	----	1.7	6.3	18.6	24.9
6	9.3	2.2	18.4	20.6	3.6	8.3	26.0	34.3	3.3	9.3	18.1	27.4
7	5.4	16.2	48.1	64.3	1.0	5.2	23.3	28.5	0.8	6.9	17.5	24.4
8	3.7	6.0	28.5	34.5	1.4	3.6	21.6	25.2	0.2	2.6	7.6	10.2
9	2.3	5.7	23.6	29.3	1.1	9.3	24.9	34.2	1.2	7.4	13.4	20.8
10	1.9	1.3	7.8	9.1	----	----	----	----	0.2	5.5	12.1	17.6
11	0.7	1.0	4.0	5.0	12.7	54.6	29.1	83.7	1.3	7.7	12.5	20.2
12	1.3	1.0	4.9	5.9	3.6	14.5	8.7	23.2	0.3	3.1	6.8	9.9
13	1.1	1.0	4.0	5.0	3.0	3.8	12.8	16.6	0.6	4.0	8.4	12.4
14	1.8	1.1	10.5	11.6	6.3	49.4	32.0	81.4	0.9	3.7	11.6	15.3
15	1.7	2.4	15.1	17.5	9.0	44.0	22.3	66.3	0.3	1.3	9.6	10.9
16	1.1	1.4	7.6	9.0	1.9	6.9	10.6	17.5	0.7	4.7	17.1	21.8
17	2.2	1.3	8.4	9.7	----	----	----	----	1.9	12.9	21.9	34.8
18	4.1	1.8	16.4	18.2	----	----	----	----	7.7	11.6	17.6	29.2
19	1.3	1.0	7.5	8.5	1.6	1.0	7.0	8.0	1.1	8.7	14.3	23.0
20	0.3	0.9	3.8	4.7	3.8	1.9	8.5	10.4	0.7	10.3	12.9	23.2
21	0.6	0.9	4.2	5.1	0.6	3.1	12.8	15.9	0.1	1.9	9.1	11.0
22	1.3	2.3	14.5	16.8	3.9	23.2	22.6	45.8	----	----	----	----
23	0.4	0.9	4.0	4.9	8.3	16.5	25.0	41.5	----	----	----	----
24	1.3	0.8	5.4	6.2	0.4	3.4	12.7	16.1	----	----	----	----
25	1.5	1.0	5.3	6.3	2.7	15.3	15.7	31.0	----	----	----	----
26	2.1	1.8	9.9	11.7	1.1	8.5	11.4	19.9	----	----	----	----
27	2.3	2.3	13.6	15.9	1.4	12.3	12.4	24.7	----	----	----	----
28	2.1	1.3	12.1	13.4	6.9	2.8	9.3	12.1	0.3	2.3	10.8	13.1
29	----	----	----	----	0.8	3.2	12.6	15.8	0.0	1.0	6.7	7.7
30	11.0	15.2	26.8	42.0	0.6	8.6	17.6	26.2	0.3	4.5	15.0	19.5
31	3.5	7.2	24.7	31.9	----	----	----	----	1.3	13.4	14.2	27.6
Monthly												
Minimum	0.3	0.8	3.8	4.7	0.1	1.0	7.0	8.0	0.0	1.0	6.7	7.7
Maximum	11.0	16.2	48.1	64.3	12.7	54.6	32.0	83.7	7.7	15.7	21.9	37.5
Average	2.6	2.7	11.8	14.6	2.8	10.3	13.0	23.8	1.4	5.7	11.2	16.9

Table (17)

Daily Concentrations (ppb) of SO_2 and NO, NO_2 and NO_x in Abu Dhabi (Winter, 1992-1993)

Month	December 1992				January 1993				February 1993			
Day	SO_2	NO	NO_2	NO_x	SO_2	NO	NO_2	NO_x	SO_2	NO	NO_2	NO_x
1	0.5	18.3	9.6	27.9	0.8	1.7	8.2	9.9	1.2	4.2	14.9	
2	1.3	24.1	11.6	25.7	0.5	1.6	13.0	14.6	0.9	8.4	8.4	19.1
3	1.1	22.8	13.4	36.2	1.1	21.6	24.1	45.7	1.0	2.3	2.3	21.8
4	0.6	2.8	8.6	11.4	0.5	7.9	17.8	25.7	0.9	1.5	1.5	14.6
5	1.9	1.1	11.8	12.9	0.5	5.1	11.7	16.8	1.4	2.4	2.4	12.2
6	1.1	0.4	11.8	12.2	0.7	8.8	14.5	23.3	0.8	1.1	1.1	13.8
7	1.7	15.3	14.2	29.5	0.5	5.8	15.1	20.9	1.3	4.1	4.1	15.1
8	1.9	31.5	27.6	59.1	0.8	11.9	19.0	30.9	1.3	1.1	1.1	13.8
9	1.1	5.9	16.1	22.0	1.1	16.2	18.4	34.5	1.3	4.3	4.3	24.6
10	0.7	0.8	9.2	10.0	0.9	16.7	16.6	33.4	----	10.7	10.7	27.7
11	1.0	4.1	15.1	19.2	0.7	10.0	13.3	23.3	1.0	20.4	20.4	40.0
12	1.9	4.6	17.3	21.9	0.6	10.4	11.6	22.0	1.4	16.5	16.5	32.6
13	1.2	19.8	28.4	48.2	1.2	25.1	12.8	37.9	0.8	23.8	23.0	46.8
14	1.0	18.7	21.8	40.5	0.5	0.4	7.7	8.1	2.5	36.4	27.8	64.2
15	1.1	13.4	17.6	31.0	1.4	0.1	7.2	7.3	2.7	32.5	24.7	57.2
16	0.5	7.5	13.3	20.8	1.3	30.5	21.4	51.9	3.5	68.7	42.5	111.2
17	1.1	55.1	23.3	78.4	1.1	11.4	22.2	33.6	12.7	131.7	67.6	199.3
18	0.1	4.7	14.5	19.2	1.3	0.9	12.1	13.0	6.4	67.8	43.3	111.1
19	0.1	0.1	9.8	9.9	1.3	0.3	10.3	10.6	----	----	----	----
20	0.9	17.2	16.9	34.1	1.1	----	----	----	----	----	----	----
21	0.6	12.1	15.0	27.1	0.6	----	----	----	0.8	9.6	14.5	24.1
22	0.7	1.3	9.9	11.2	0.7	----	----	----	0.9	3.2	12.2	15.4
23	----	----	----	----	0.4	----	----	----	1.1	16.3	12.4	28.7
24	----	----	----	----	1.1	----	----	----	1.1	0.6	6.3	6.9
25	0.2	26.0	17.1	43.1	1.1	----	----	----	1.0	0.3	5.3	5.6
26	0.7	7.2	15.5	22.7	1.4	7.0	28.4	35.4	1.0	0.1	6.4	6.5
27	0.3	2.1	13.7	15.8	1.4	6.2	18.9	25.1	1.6	3.6	10.3	13.9
28	0.1	0.8	10.4	11.2	1.3	5.1	16.7	21.8	1.9	15.7	24.8	40.5
29	0.8	8.6	14.7	23.2	2.1	36.2	30.9	67.1	----	----	----	----
30	0.7	4.0	12.8	16.8	4.4	69.9	40.6	110.5	----	----	----	----
31	0.6	1.1	6.6	7.7	2.2	20.2	28.4	48.6	----	----	----	5.6
Monthly												
Minimum	0.1	0.1	6.6	7.7	0.4	0.1	7.2	7.3	0.8	0.1	5.3	5.3
Maximum	1.9	55.1	28.4	88.3	4.4	69.9	40.6	100.5	12.7	131.7	67.6	199.3
Average	0.8	10.8	14.7	24.5	1.1	10.7	17.6	24.6	2.0	17.4	17.6	35.0

Table (18)

Daily Concentrations (ppb) of SO_2 and NO, NO_2 and NO_x in Abu Dhabi (Spring, 1993)

Month	March 1993				April 1993				May 1993			
Day	SO_2	NO	NO_2	NO_x	SO_2	NO	NO_2	NO_x	SO_2	NO	NO_2	NO_x
1	3.4	19.5	25.6	45.1	0.4	2.3	11.4	13.7	0.8	4.3	14.1	18.4
2	9.5	29.7	25.2	55.0	0.5	0.7	8.1	8.8	1.1	12.7	26.1	38.8
3	3.1	15.6	22.6	38.2	1.5	11.2	17.5	28.7	1.3	16.3	22.8	39.1
4	1.1	4.6	13.3	17.9	0.8	9.0	16.9	25.9	1.2	15.8	22.8	38.5
5	0.6	2.4	11.5	13.9	3.3	2.1	13.6	15.7	0.5	8.9	17.2	26.1
6	0.5	2.5	10.8	13.3	0.9	11.6	17.3	28.9	0.9	7.3	14.6	21.8
7	0.8	2.4	9.2	11.6	0.7	17.1	19.8	37.0	0.1	0.4	4.6	5.0
8	0.7	2.2	11.8	14.0	0.3	6.7	14.2	20.9	0.3	0.0	4.5	4.5
9	1.2	9.6	16.0	25.6	0.9	2.4	12.3	14.7	0.6	1.3	7.5	8.8
10	1.0	10.4	13.4	23.8	0.9	18.2	18.5	36.7	0.4	1.3	10.5	11.8
11	1.6	0.1	7.1	7.2	0.8	24.2	17.1	41.3	0.4	1.7	12.3	14.0
12	0.8	1.8	9.9	11.7	0.4	0.5	8.6	9.1	0.3	1.3	9.7	11.0
13	1.0	0.1	6.5	6.6	1.8	0.0	5.1	5.1	0.4	0.9	5.9	6.8
14	4.0	0.8	7.3	8.1	0.9	0.0	7.1	7.1	0.7	1.5	8.7	10.2
15	2.8	9.7	17.6	27.3	0.5	4.1	8.9	13.0	0.5	0.1	6.1	6.2
16	0.3	32.1	28.0	60.1	0.6	0.9	10.0	10.8	0.4	0.4	7.0	7.3
17	1.0	2.5	17.6	20.1	0.3	3.8	13.7	17.5	0.2	0.7	11.4	12.1
18	0.2	0.9	12.4	13.4	1.2	6.7	11.6	18.3	0.3	2.5	12.9	15.4
19	----	3.5	12.1	15.5	1.7	8.3	16.2	24.4	0.5	4.8	15.4	20.2
20	----	16.4	20.2	36.4	0.9	8.9	20.1	29.1	0.6	1.0	10.0	11.0
21	----	2.4	10.0	12.4	0.7	13.4	17.0	30.4	0.6	0.2	9.2	9.4
22	----	0.0	6.2	6.2	0.8	11.2	17.5	28.6	0.3	1.1	11.3	12.4
23	----	0.0	4.5	4.5	0.6	7.5	13.3	20.8	0.4	1.4	8.7	10.1
24	----	0.0	4.2	4.2	0.4	2.0	11.6	13.7	----	----	----	----
25	----	0.0	4.3	4.3	0.4	0.7	7.5	8.2	----	----	----	----
26	----	0.7	9.0	9.7	0.4	0.1	4.4	4.5	----	----	----	----
27	----	0.7	7.5	8.2	0.1	0.1	7.0	7.1	----	----	----	----
28	29.9	1.1	7.8	8.9	0.5	6.5	11.9	18.4	0.7	6.7	9.0	15.7
29	34.0	1.6	8.3	9.9	0.7	1.3	11.0	12.3	----	----	----	----
30	29.4	3.0	13.4	16.4	0.4	0.1	5.0	5.1	----	----	----	----
31	27.0	3.8	14.2	18.0					----	----	----	----
Monthly												
Minimum	0.0	0.0	4.2	4.2	0.1	0.0	4.4	4.5	0.1	0.0	4.5	4.5
Maximum	9.5	32.1	28.0	60.1	3.3	24.2	20.1	41.2	1.3	16.3	26.1	39.1
Average	1.7	5.8	12.5	18.3	0.9	6.0	12.5	18.5	0.6	3.8	11.8	15.6

Table (19)
Seasonal Range Concentrations (ppb) of SO_2 and NO, NO_2 and NO_x in Abu Dhabi
(Dec. 1991 - May 1992, Dec. 1992 - May 1993)

Season	Winter 91-92			Spring 1992			Winter 92-93			Spring 1993		
Pollutant	Min	Max	Av	Min	Max	Av	Min	Max	Av	Min	Max	Av
SO_2	0.40	104.60	8.30	0.10	10.40	2.20	0.40	6.30	1.30	0.00	4.70	1.06
NO	0.50	1006.20	62.90	0.90	28.80	6.20	0.10	85.60	12.90	0.00	13.90	5.20
NO_2	2.80	30.30	10.80	5.80	34.00	12.00	4.36	45.50	15.20	4.40	24.70	12.30
NO_x	3.60	1029.60	73.80	6.80	61.80	18.40	6.80	129.30	28.00	4.40	46.80	17.50

5.2.1 Sulphur Dioxide

Sulphur dioxide is a colourless gas with a pungent irritating odour. It is extremely irritant to the mucous membranes of the eyes and respiratory tract. Most people can detect it by taste at 0.3 to 1 ppm (Stern, 1976).

Sulphur dioxide is emitted into the atmosphere through combustion of solid and liquid fuels. The total emission of the gas varies considerably with the nature or origin of fossil fuels, so the concentration of SO_2 increases as the consumption of fuel increases. Therefore, there is a direct correlation between the population density of an area and the SO_2 air level (Meyer, 1982), which is then taken as an index of air pollution. Natural SO_2 emissions arise in roughly equal proportions from terrestrial and marine sources (Mason, 1992).

Sulphur dioxide in the ambient atmosphere has been the most extensively studied gaseous pollutant over the past 30 years. This pollutant together with particulate matter, has been the basis for some of the most far reaching and controversial air quality standards (Hindy et al, 1988).

SO_2 in Abu Dhabi Atmosphere (1991 - 1993 level):

Sulphur dioxide concentrations in the atmosphere of Abu Dhabi City during the two study periods : Dec. 1991-May 1992 and Dec. 1992-May 1993 were found to be below the air quality standard (30 ppb-annual average) set by the U.S. National Ambient Air Quality Standards (NAAQS) (EPA, 1976). This finding is based on both monthly and seasonal means of the SO_2 concentrations which did not reach even 20 ppb.

SO_2 Levels in Two Different Seasons:

Dealing with the monthly variation of sulphur dioxide concentrations, it is clear from Tables (15-18) that the maximum monthly average concentration of the SO_2 was detected in Dec. 1991 with a level ranging from 0.3 ppb to 297.9 ppb and monthly mean of 19.5 ppb. However, the maximum level observed during that month can be easily attributed to a local emission source of SO_2 near the study site. This local source had caused a sharp increase in SO_2 concentrations on 17 Dec., 18 Dec., and 19 Dec., 1991 with the levels of 107.6 ppb, 297.9 ppb and 135.1 ppb, respectively.

This abnormality is due to some unknown local emission.

The sulphur dioxide emitted from this source had increased the seasonal average of SO_2 during winter 1991-1992 to be 8.26 ppb. This value is 3.65 times the corresponding average of spring 1992 (2.26 ppb). However, there was another increase in the seasonal average of SO_2 concentration during winter 1992-1993 (1.30 ppb) compared with the corresponding average of spring 1993 (1.06 ppb).

There are two reasons for the moderate winter-spring variation of SO_2 concentration found in Abu Dhabi atmosphere. The first reason which represents a minor effect, is the slightly higher emission of such pollutant during the relatively colder months of each year, as a result of more burning of liquid and gaseous fuels. The second reason which represents a paramount effect, is the restricted ventilation of the city air during the winter months, because of long periods of stability in the atmosphere as a result of longer

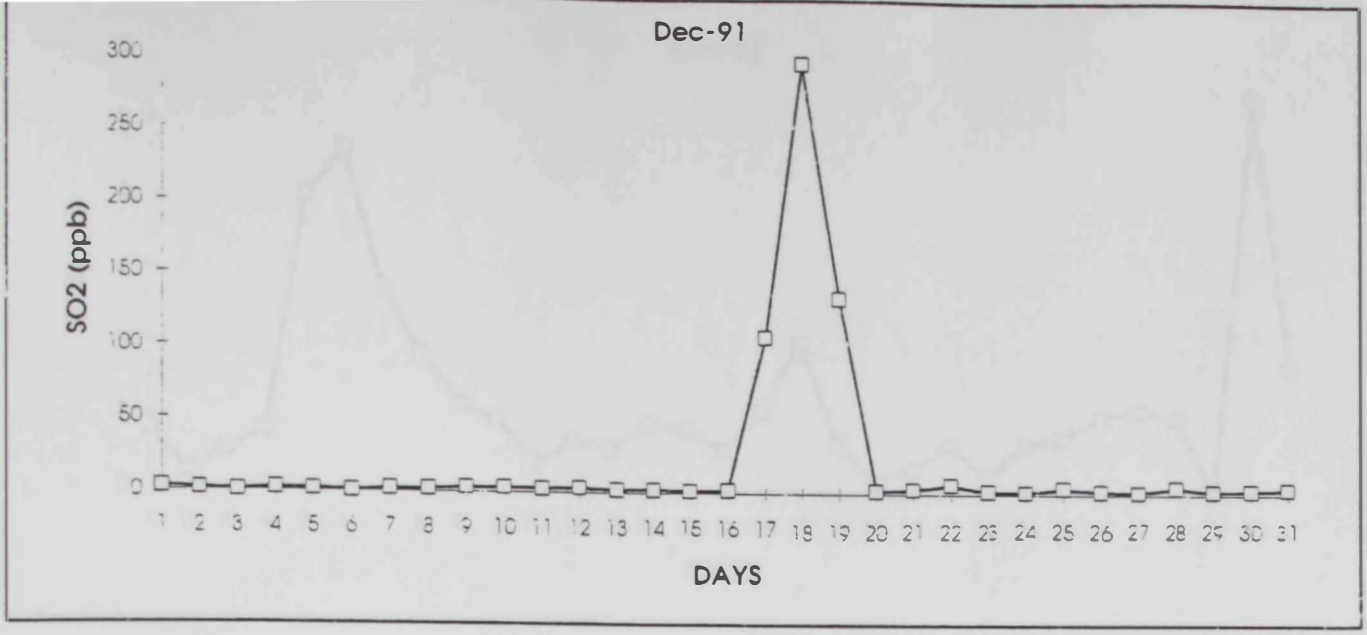
nights frequently associated with temperature inversions. The same two reasons were found to be responsible also for a moderate seasonal variations in SO_2 concentrations in Cairo atmosphere (Hindy et al, 1988).

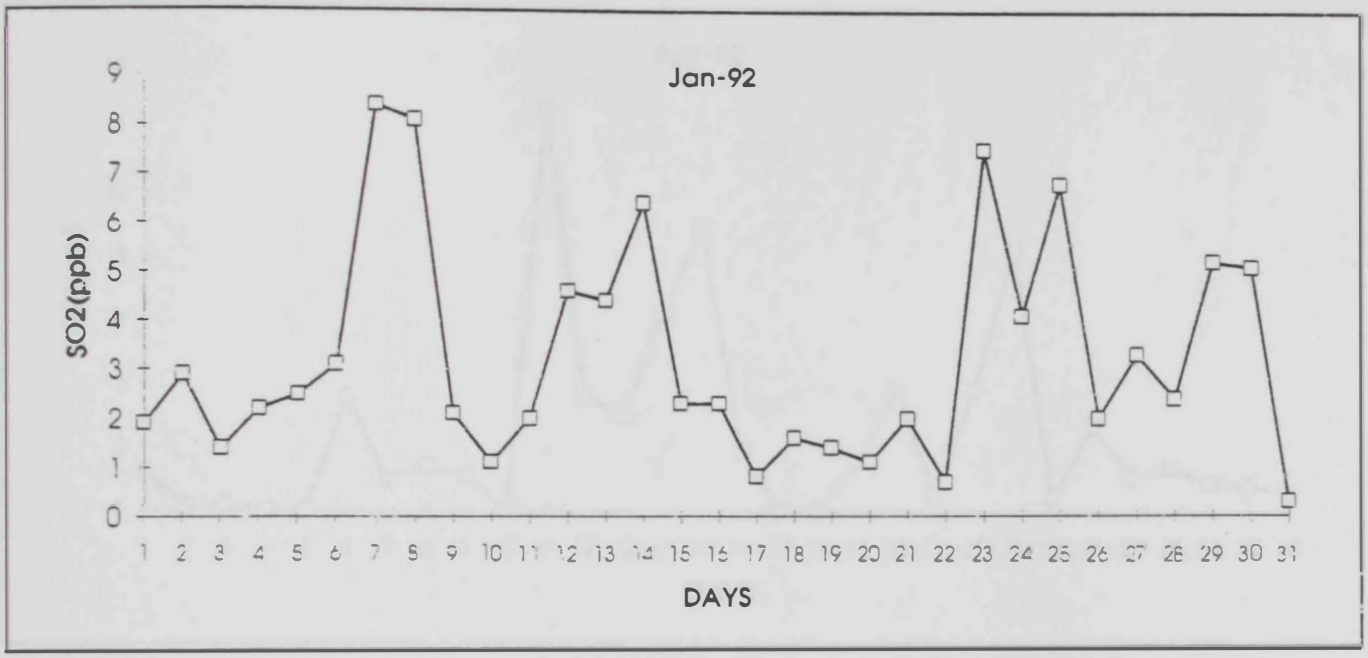
SO_2-Relative Humidity Relationship:

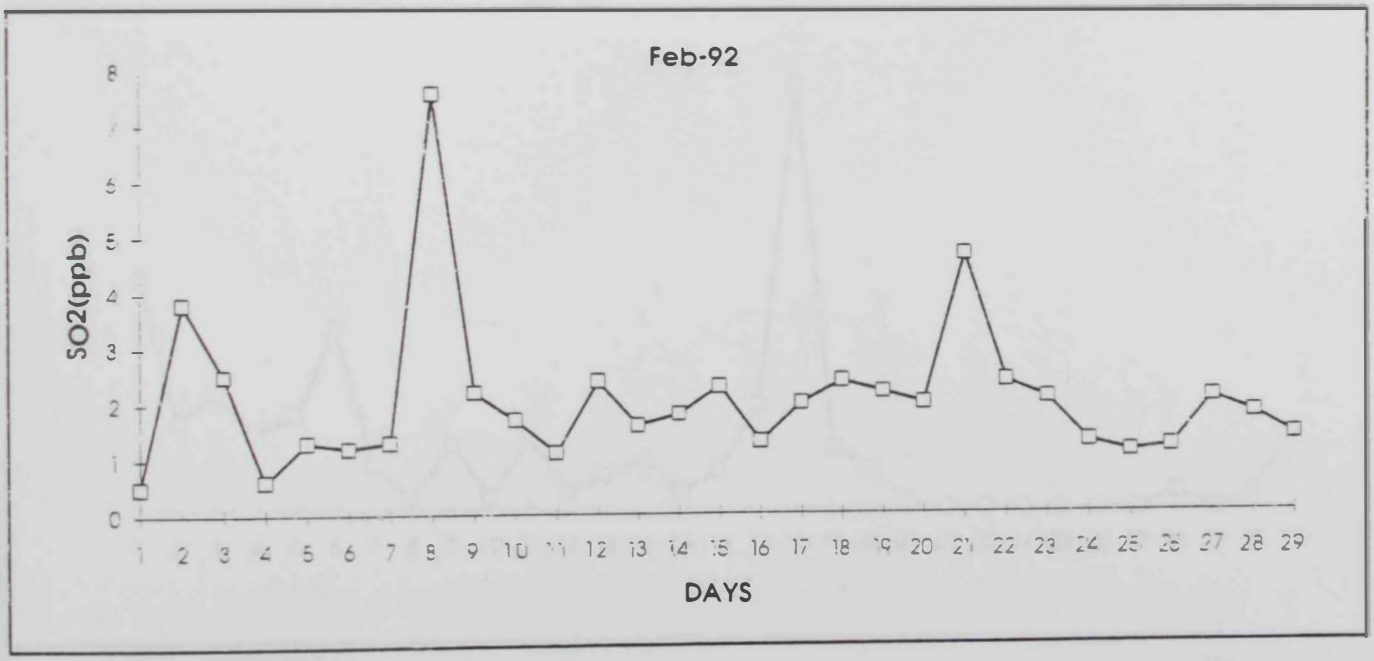
In order to investigate the ability of the sulphur dioxide to form sulphuric acid and sulphates in the atmosphere of Abu Dhabi, the daily observations of SO_2 levels for the winter and spring months of the two periods : Dec. 1991 - May 1992 and Dec. 1992 - May 1993 assembled in Tables (15),(16),(17) and (18) were graphically plotted and presented in figs. (43),(44),(45), and (46), respectively. In the same manner, the daily records of relative humidity in Abu Dhabi town during the same two periods were graphically represented in figs. (47),(48),(49), and (50). These records were obtained from the Abu Dhabi International Airport Station, Department of Civil Aviation, Abu Dhabi.

The correlation between the SO_2 graphs and relative humidity graphs reveals a strong inverse relationship between the measured SO_2 concentration and the recorded relative humidity. The daily mean concentration of sulphur dioxide seems to follow mostly the daily variation in relative humidity.

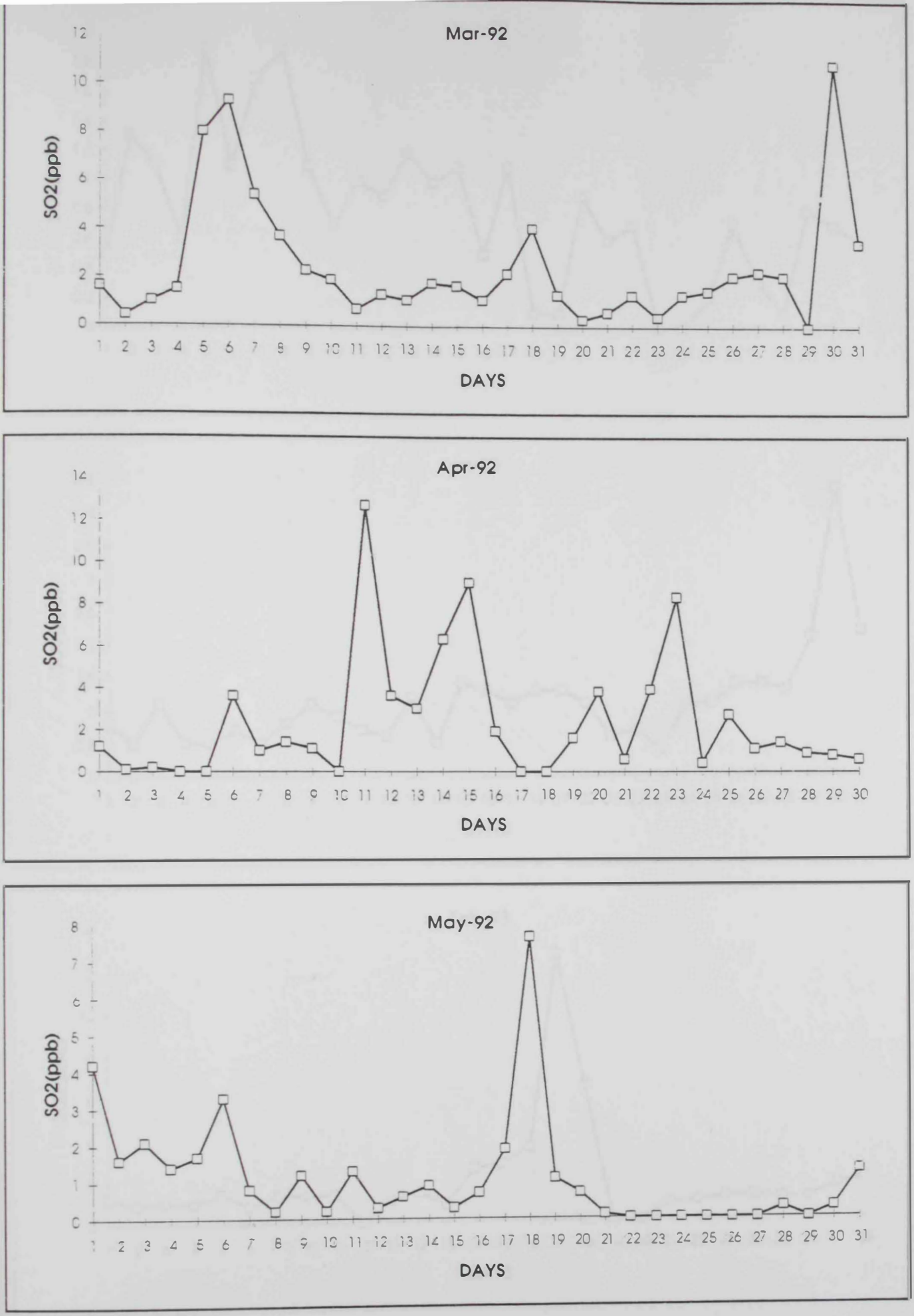
In combustion of sulphur containing materials, most of the sulphur is converted to sulphur dioxide, and a part of it,



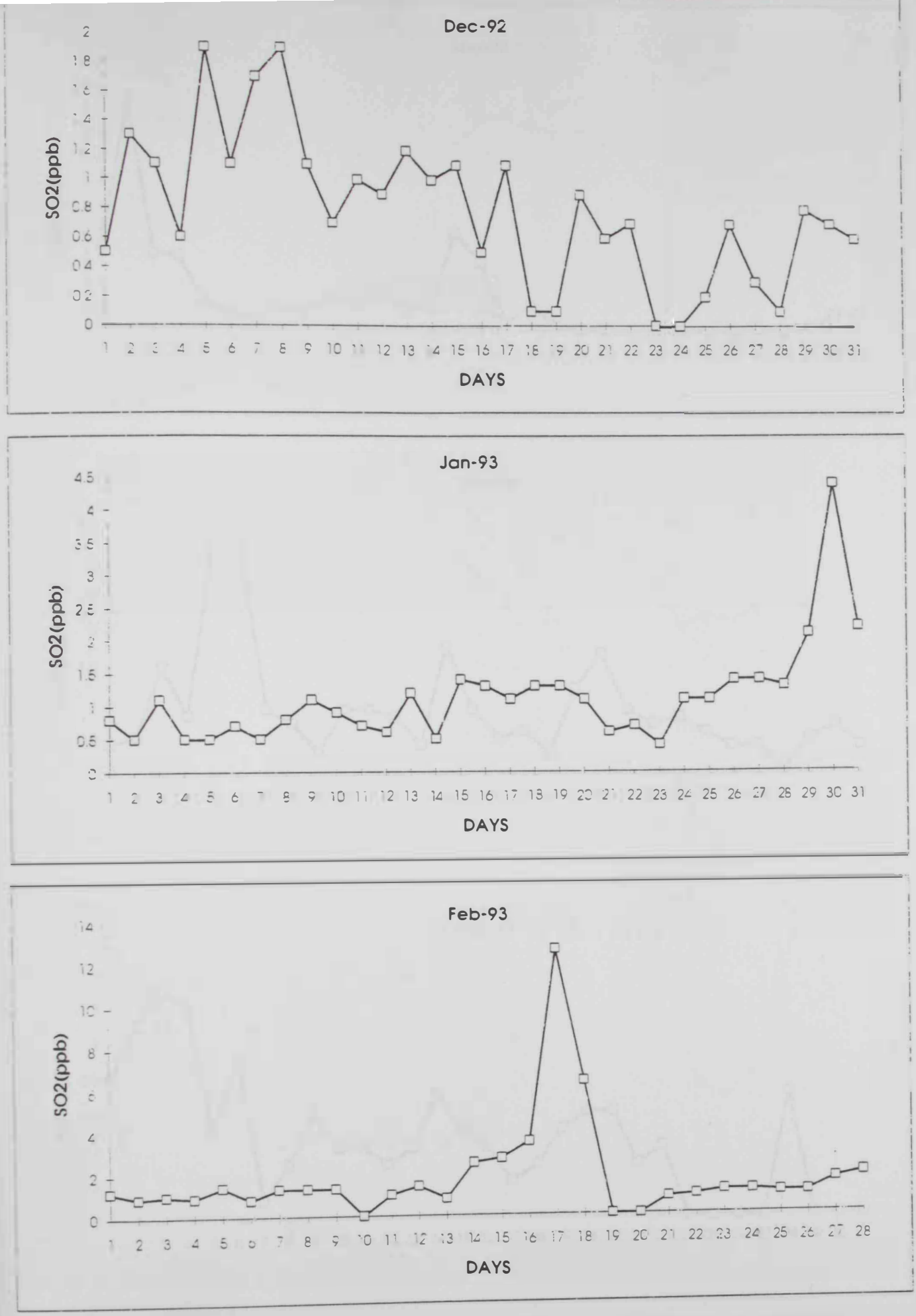




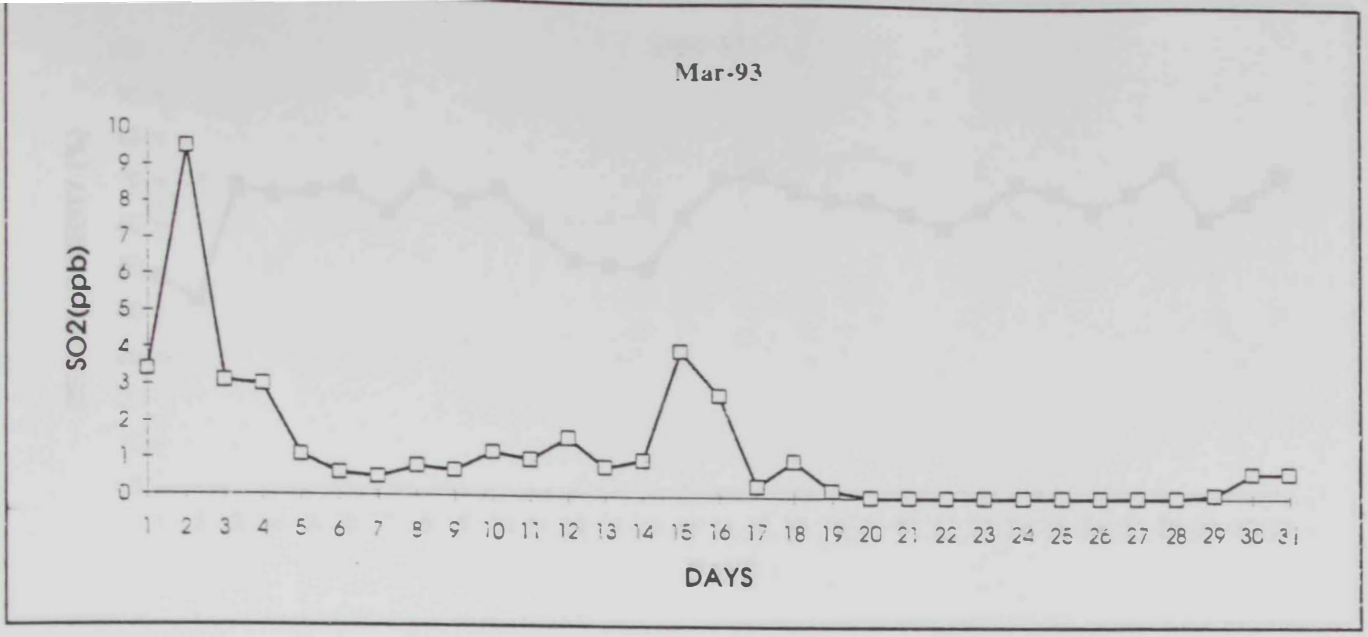
Figure(43) Daily Average of Sulphur Dioxide Concentration in Abu Dhabi (Winter 1991/92)

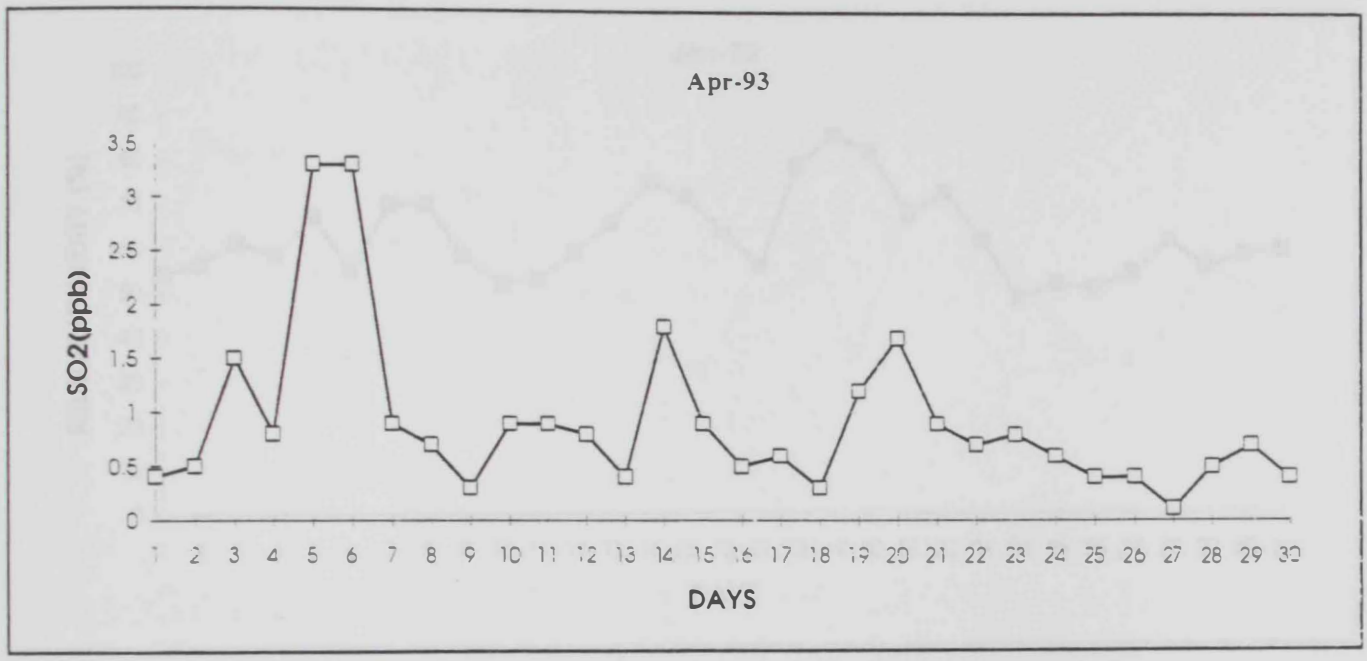


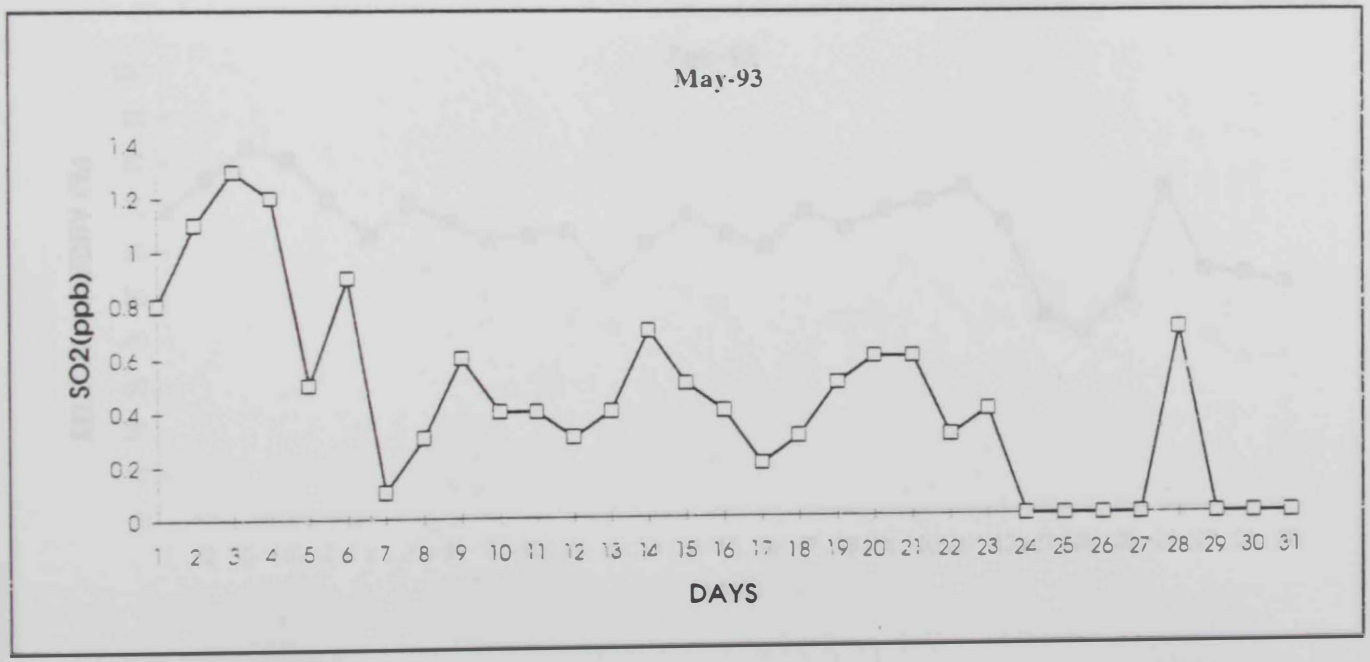
Figure(44) Daily Average of Sulphur Dioxide Concentration in Abu Dhabi (Spring 1991/'92)



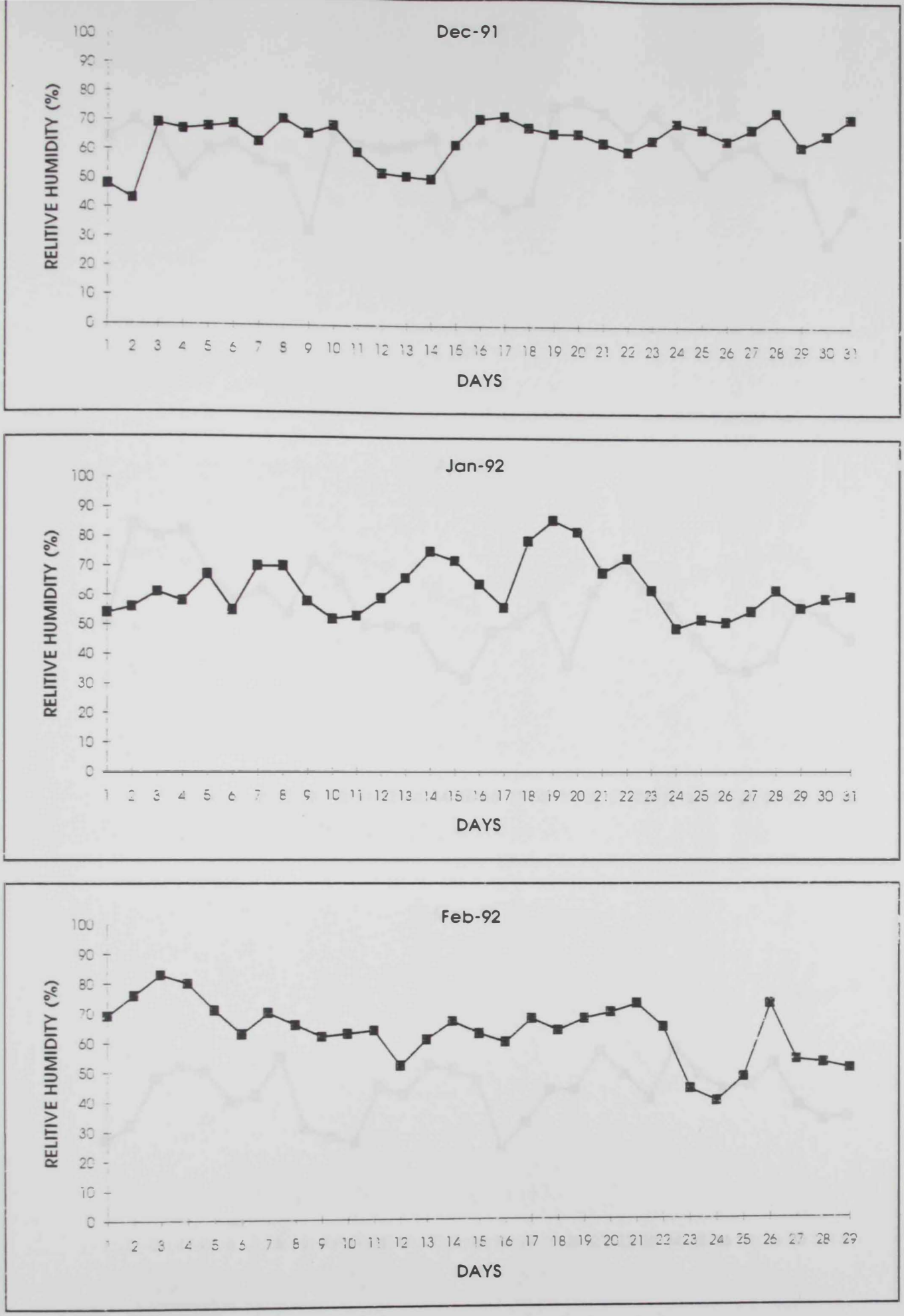
Figure(45) Daily Average of Sulphur Dioxide Concentration in Abu Dhabi (Winter 1992/93)



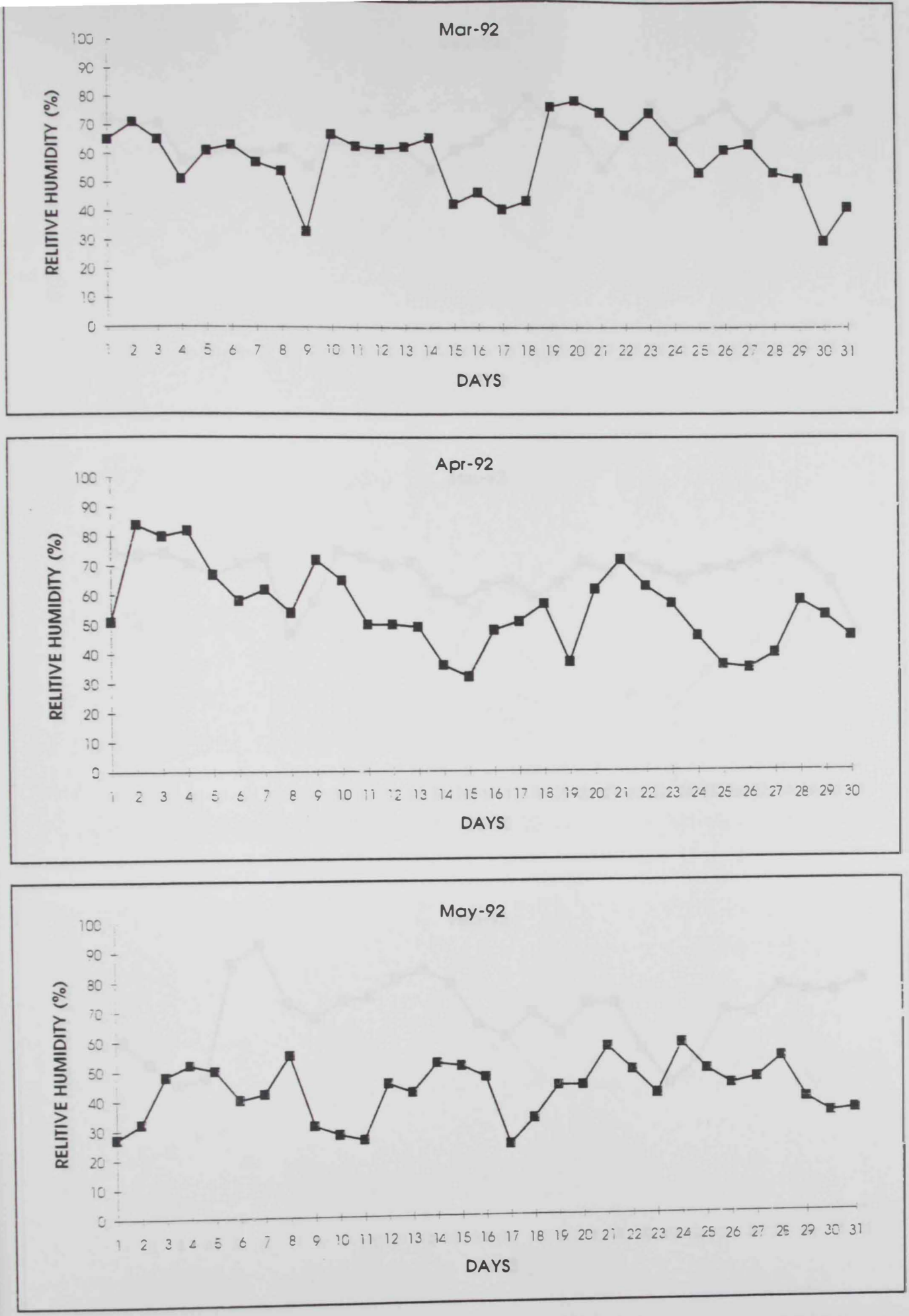




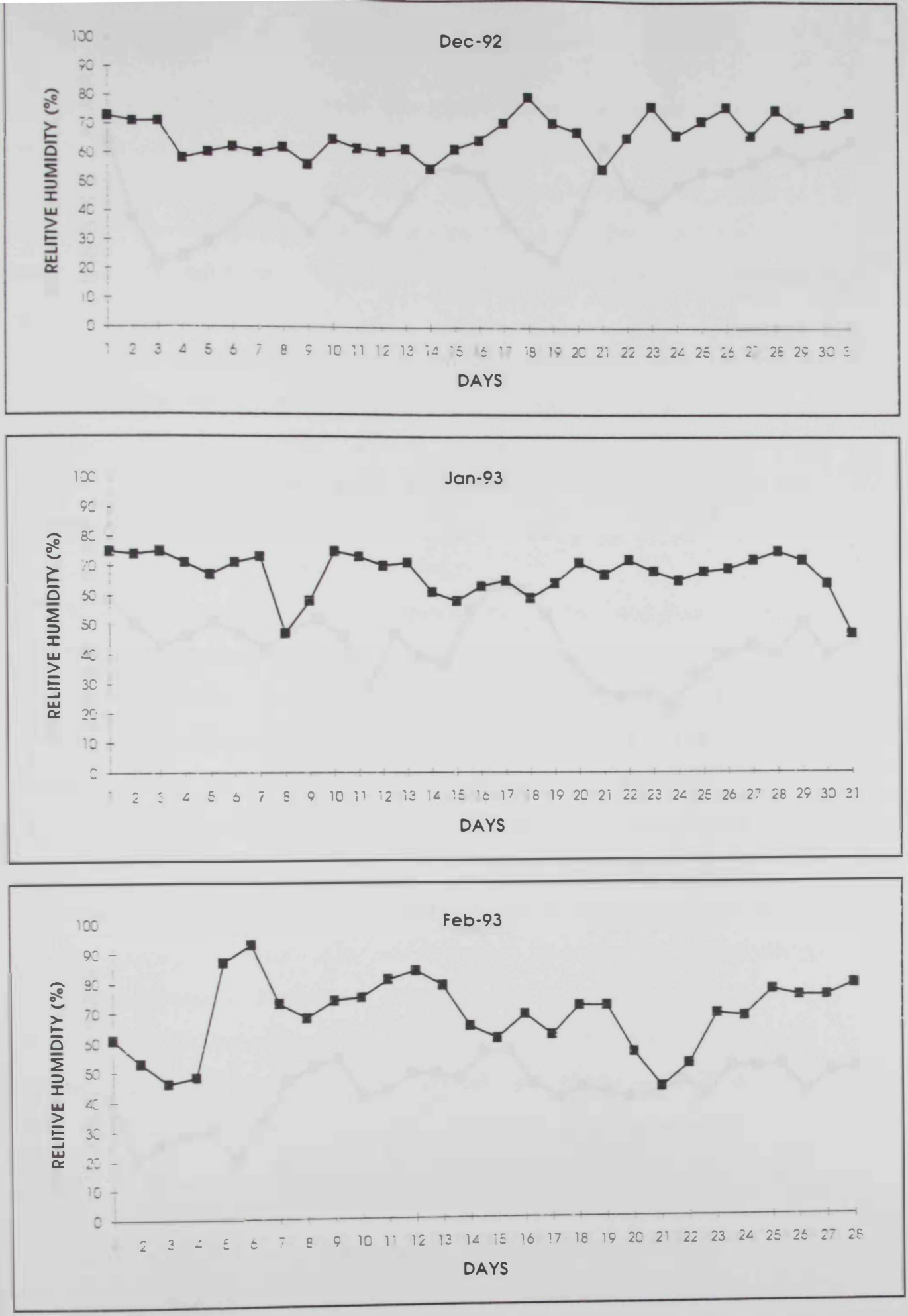
Figure(46) Daily Average of Sulphur Dioxide Concentration in Abu Dhabi (Spring 1992/93)



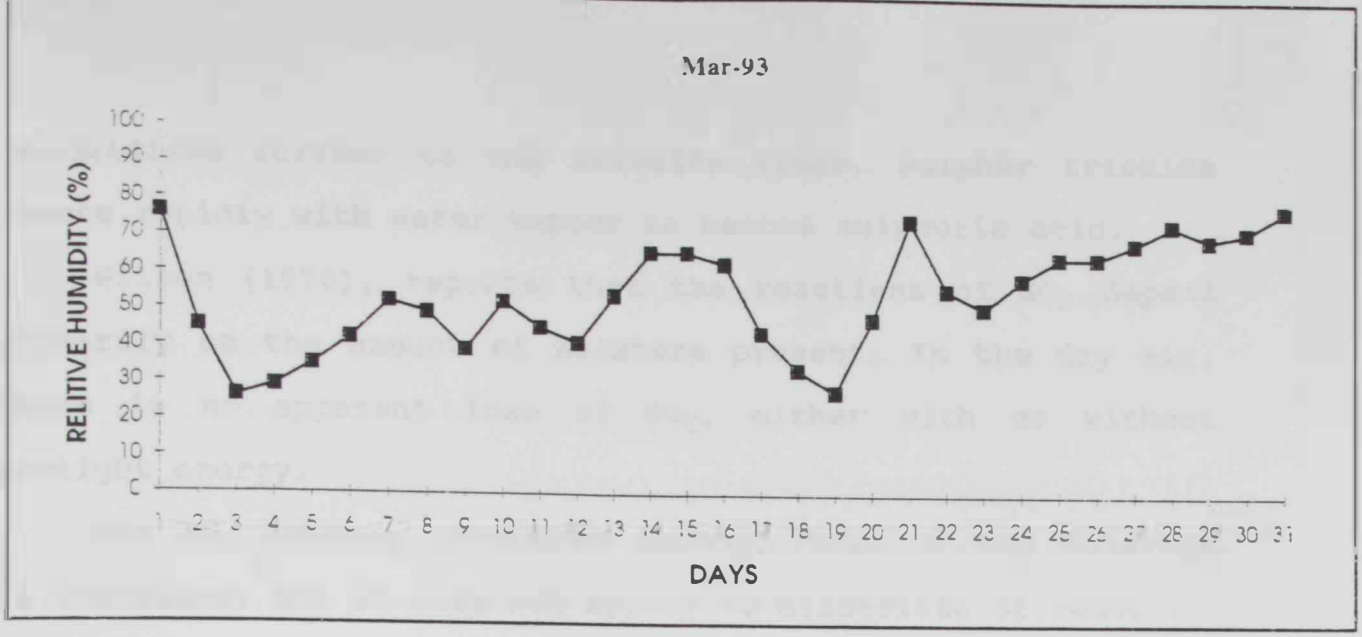
Figure(47) Daily Average of Relative Humidity Percentage in Abu Dhabi (Winter 1991/92)

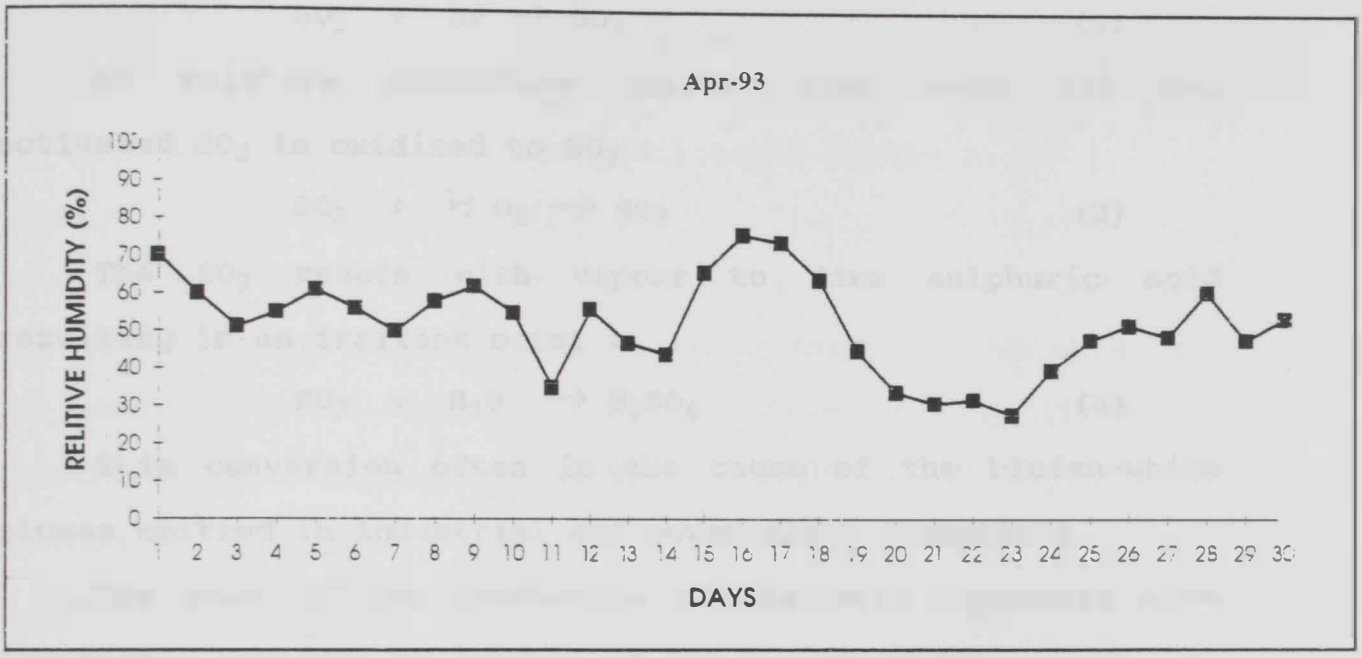


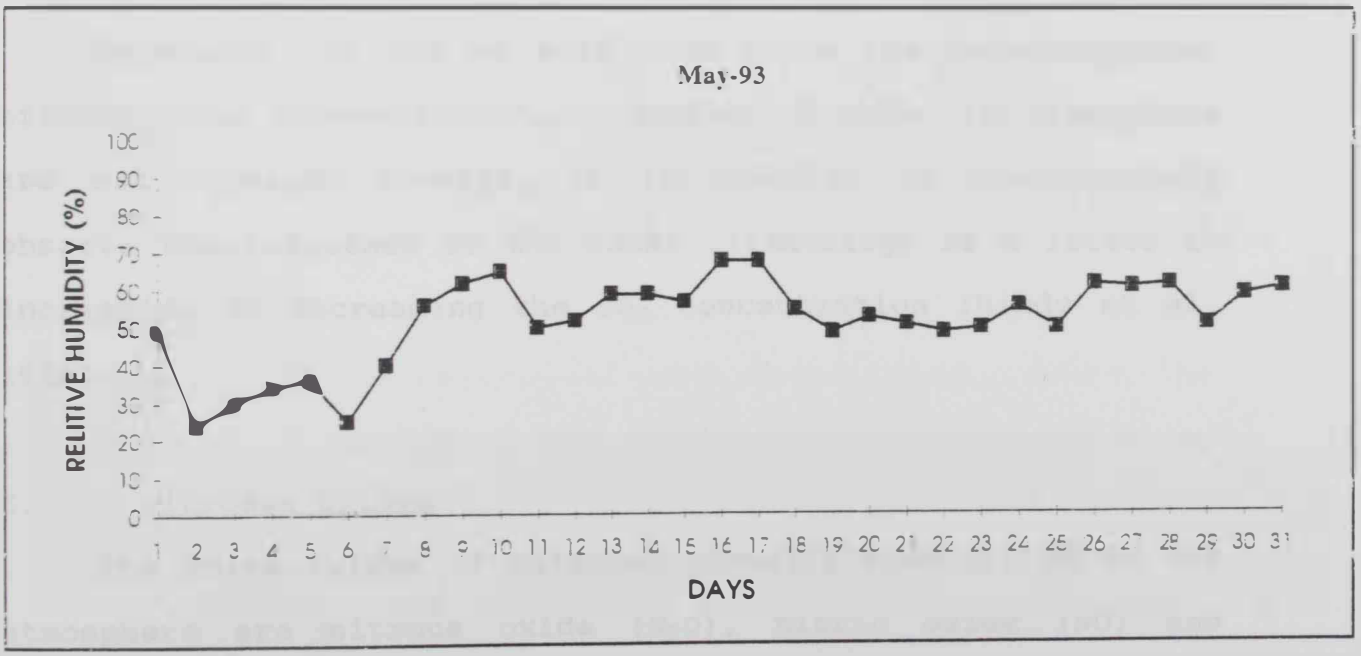
Figure(48) Daily Average of Relative Humidity Percentage in Abu Dhabi (Spring 92)



Figure(49) Daily Average of Relative Humidity Percentage in Abu Dhabi (Winter 1992/93)







Figure(50) Daily Average of Relative Humidity Percentage in Abu Dhabi (Spring 93)

is oxidized further to the trioxide stage. Sulphur trioxide reacts rapidly with water vapour to become sulphuric acid.

Wilson (1970), reports that the reactions of SO_2 depend primarily on the amount of moisture present. In the dry air, there is no apparent loss of SO_2, either with or without sunlight energy.

The SO_2 becomes activated (energy level of the molecule is increased) but it does not appear to dissociate or react :

$$SO_2 + h\nu \rightarrow SO_2 \qquad (1)$$

At relative humidities greater than about 30% the activated SO_2 is oxidized to SO_3 :

$$SO_2 + \tfrac{1}{2} O_2 \rightarrow SO_3 \qquad (2)$$

The SO_3 reacts with vapour to form sulphuric acid resulting in an irritant moist :

$$SO_3 + H_2O \rightarrow H_2SO_4 \qquad (3)$$

This conversion often is the cause of the bluish-white plumes emitted in industrial and power-plant operations.

The rate of the production of the acid increases with increasing humidity percentage or SO_2 concentration.

Generally, it can be said that while the meteorological effects upon concentration of sulphur dioxide in atmosphere are not straight forward, it is possible to qualitatively observe the influence of the local climatology as a factor in increasing or decreasing the SO_2 concentration (Hindy et al, 1988).

5.2.2 Nitrogen Oxides

The three oxides of nitrogen normally encountered in the atmosphere are nitrous oxide (N_2O), nitric oxide (NO) and

nitrogen dioxide (NO_2). Nitrous oxide, a commonly used anesthetic known as "laughing gas", is produced by microbiological processes and is a component of the unpolluted atmosphere at a level of approximately 300 ppb (Manahan, 1991). This gas is relatively unreactive and probably does not significantly influence important chemical reactions in the lower atmosphere. Its concentration decreases rapidly with altitude in the stratosphere due to the photochemical reaction:

$$N_2O + h\nu \longrightarrow N_2 + O \qquad (4)$$

and some reaction with singlet atomic oxygen :

$$N_2O + O \longrightarrow N_2 + O_2 \qquad (5)$$

$$N_2O + O \longrightarrow NO + NO \qquad (6)$$

These reactions are significant in terms of depletion of the ozone layer. Increased global fixation of nitrogen, accompanied by increased microbial production of NO_2, could contribute to ozone layer depletion (Manahan, 1991).

Colourless, odorless nitric oxide (NO) and pungent red-brown nitrogen dioxide (NO_2) are very important in polluted air. Collectively designated NO_x, these gases enter the atmosphere from natural sources, such as lightning and biological processes, and from pollutant sources. The latter are much more significant because of regionally high NO_2 concentrations, which can cause severe air quality deterioration. Practically, all anthropogenic NO_x enter the atmosphere as a result of the combustion of fossil fuels in both stationary and mobile sources. Globally, somewhat less than 100 million metric tons of nitrogen oxides are emitted to the atmosphere from these sources each year. United States

production of nitrogen oxides is of the order of 20 million metric tons per year. The contribution of automobiles to nitric oxide production in the U.S. has become somewhat lower in the last decade as newer automobiles with nitrogen oxide pollution controls have become more common (Manahan, 1991).

NO_x in Abu Dhabi Atmosphere (1991-1993 level):

Nitrogen oxides (NO_x) concentrations observed in the atmosphere of Abu Dhabi city during the two periods: Dec. 1991-May 1992 and Dec. 1992-May 1993 are mostly much less than the air quality standard (50 ppb-annual average) set by the U.S. National Ambient Air Quality Standards (NAAQS) (EPA, 1976). For example, the monthly average concentration of NO_x during 11 of the 12 months of observation ranges between 9.4 ppb during February 1992 and 23.9 ppb during December 1992 (Tables 15 and 17 respectively).

The only exception of this trend is the high monthly average concentration of NO_x observed during December 1991 which reaches 194.7 ppb. This level is 3.9 times the air quality standard (50 ppb). As previously mentioned on dealing with the results of SO_2, this high monthly average concentration is due to the extremely high concentrations of NO and hence NO_x recorded on 17 Dec., 18 Dec., and 19 Dec. 1991. The levels of NO during the three days were, respectively, 1090.3 ppb, 2979.0 ppb, and 1288.0 ppb. The corresponding levels of NO_x were 1094.1 ppb, 2983.1 ppb and 1296.0 ppb.

The reason of these unexpected concentrations is due to the same local emission source previously mentioned on dealing with the SO_2 levels (p. 138).

The effect of such local source may be confirmed by the available results which show that the emitted nitrogen oxides during the three days of that abnormal case were in the form of nitric oxide (NO), the primary form in which NO_x is released to the atmosphere.

Nitric oxide is biochemically less than active and less toxic than nitrogen dioxide (NO_2). However, NO has the ability to attach to hamoglobin and reduces oxygen transport efficiency (Manahan 1991).

NO_x Levels in Two Different Seasons:

Monthly results of NO, NO_2 and NO_x assembled in Tables (15),(16),(17) and (18) clearly indicate that the maximum range of NO concentration was during Dec. 1991 (0.3 ppb-2979.0 ppb with an average of 181.8 ppb), followed by Feb. 1993 (5.3 ppb-199.3 ppb with an average of 17.4 ppb). The data further show that the maximum range of NO_2 concentrations was during Feb. 1993 (5.3 ppb-67.6 ppb with an average of 17.6 ppb), followed by Jan. 1993 (7.2 ppb-40.6 ppb with an average of 17.6 ppb). These maximum ranges of NO_x and NO_2 had been reflected in the maximum ranges of NO_x during Dec. 1991 (4.9 ppb-2983.1 ppb with an average of 194.7 ppb) to be followed by Feb. 1993 (5.6 ppb-199.3 ppb with an average of 35.0 ppb).

Taking into account the effect of the previously mentioned local emission source in increasing sharply the concentration of NO and hence NO_x, it can be said that the

maximum levels of both NO and NO_2 and the sum of the two gases (NO_x) were observed during the same month,i.e. Feb. 1993.

A similar finding can be reached through examining the minimum levels of NO, NO_2 and NO_x which were observed in one month, i.e. Feb. 1992. During that month the ranges of NO, NO_2 and NO_x were, respectively, 1.0 ppb-18.4 ppb with an average of 2.4 ppb, 1.8 ppb-31.0 ppb with an average of 7.0 ppb and 2.8 ppb-49.4 ppb with an average of 9.4 ppb.

This means that there is a direct relationship between NO and NO_2 in the atmosphere of the City of Abu Dhabi. This relationship will be discussed in the following section.

NO - NO_2 Relationship:

Most NO_2 entering the atmosphere from pollution sources does so as NO generated from internal combustion engines. At very high temperatures, the following reaction occurs:

$$N_2 + O_2 \rightarrow 2\ NO \qquad (7)$$

The speed with which this reaction takes place increases steeply with temperature. In a mixture of 3% O_2 and 75% N_2, at room temperature (27 °C), the equilibrium concentration of NO is only 1.1×10^{-10} ppm, whereas at higher temperatures it is much higher. Therefore, high temperatures favor both a high equilibrium concentration and a rapid rate of formation of NO. Rapid cooling of the exhaust gas from combustion "freezes" NO at a relatively high concentration because equilibrium is not maintained. Thus, by its very nature, the combustion process both in the internal combustion engine and in furnaces produces high levels of NO in the combustion products (Manahan, 1991).

Accordingly, the major proportion of emitted NO_x (as the sum of NO and NO_2 concentrations) is in the form of NO, although most of the atmospheric burden is usually in the form of NO_2. The major conversion mechanism is the very rapid reaction of NO with ambient ozone, the alternative reaction with molecular oxygen being relatively very slow at ambient air concentrations (Harrison, 1990).

Data assembled in Tables (15),(16),(17) and (18) reveal that the NO_2 levels in the atmosphere of Abu Dhabi are mostly higher than the NO levels. This can be shown from the calculated NO/NO_2 concentration ratios listed in Table (20). From these ratios, it can be seen that with the exception of Dec. 1991's ratio, all other months' ratios are below 1.0 and mostly below 0.5 . The only exception of Dec. 1991 is attributed to severe unknown local emission of NO during 17 Dec.,18 Dec., and 19 Dec. 1991.

TABLE (20)

NO/NO_2 Concentration Ratio in the Atmosphere of Abu Dhabi During the Study Two Periods

Month	NO-Average (ppb)	NO_2-Average (ppb)	NO/NO_2 Ratio
Dec. 1991	181.9	12.9	14.10
Jan. 1992	4.6	12.7	0.36
Feb. 1992	2.4	7.0	0.34
Mar. 1992	2.9	12.2	0.24
Apr. 1992	12.4	16.2	0.76
May. 1992	7.1	13.9	0.76
Dec. 1992	10.8	14.7	0.73
Jan. 1993	13.2	17.6	0.75
Feb. 1993	18.7	19.0	0.98
Mar. 1993	5.8	12.5	0.46
Apr. 1993	6.0	12.5	0.48
May 1993	3.8	11.8	0.32

These results indicate undoubtedly that nitrogen oxides (NO_x) in the atmosphere of Abu Dhabi City tend to be in the form of nitrogen dioxide (NO_2) and to a lesser degree in the form of nitric oxide (NO).

As regards to the winter-spring differences, it can be easily seen from the seasonal averages of NO, NO_2 and NO_x ranges listed in Table (19) that the winter average concentrations of NO, NO_2 and NO_x being, respectively, 62.90 ppb, 10.80 ppb and 73.80 ppb during winter 1991-1992 and 12.90 ppb, 15.20 ppb and 28.00 ppb during winter 1992-1993 were higher than the corresponding spring average concentrations

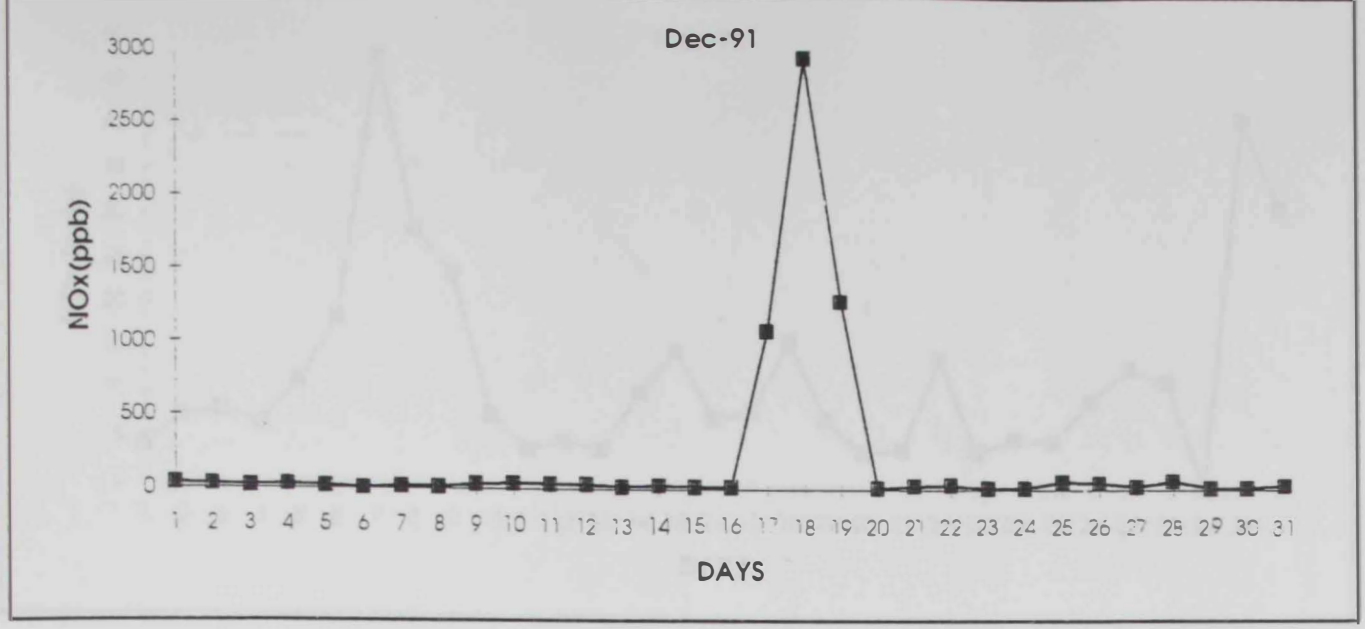
which were 6.20 ppb, 12.00 ppb and 18.40 ppb during spring 1992 and 5.20 ppb, 12.30 ppb and 17.50 ppb during spring 1993.

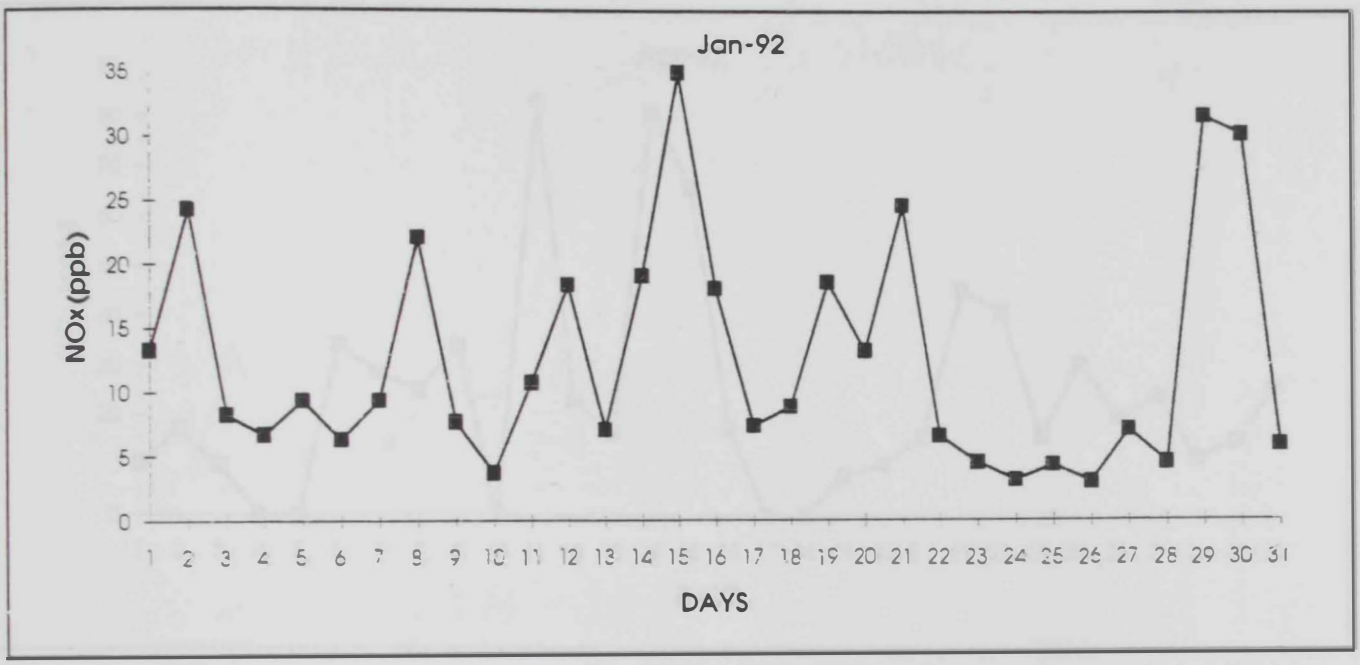
The two reasons considered to be responsible for the same phenomenon observed in the case of SO_2 levels can be considered also responsible for the winter-spring variation of NO, NO_2 and NO_x concentrations. These two reasons which were discussed on pp. 138-139 are : the more burning of liquid and gaseous fuels during the relatively colder months and the restricted ventilation of the city air during the winter months.

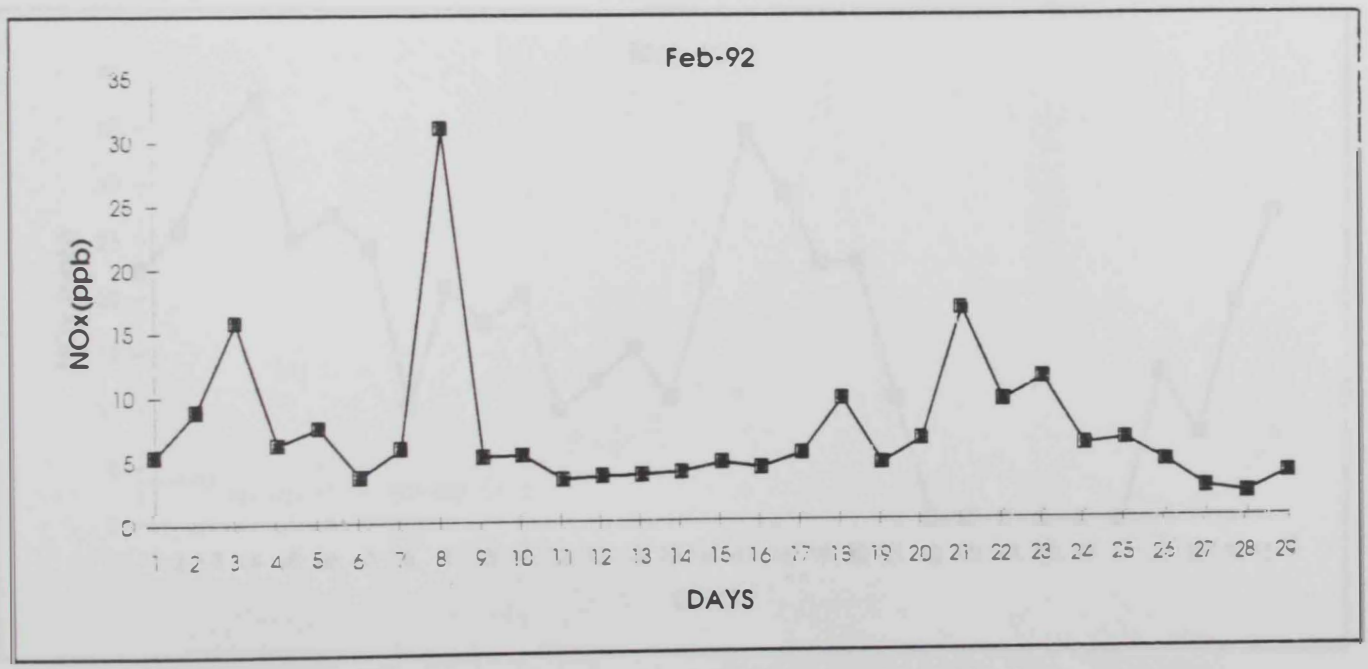
NO_x - Relative Humidity Relationship:

In the same manner followed in the case of SO_2 and in order to clarify the ability of nitrogen oxides to form nitric acid and nitrates in the atmosphere of the City of Abu Dhabi, daily observations of NO_x ,the measured sum of NO and NO_2, levels for the winter and spring months of the two periods: Dec. 1991-May 1992 and Dec. 1992-May 1993 ,listed in Tables (15),(16),(17) and (18) were graphically represented in Figs. (51),(52),(53) and (54) respectively. These will be correlated with the relative humidity graphs (Figs. 47, 48, 49, and 50) representing the relative humidity records during the same two periods of the pollutants study.

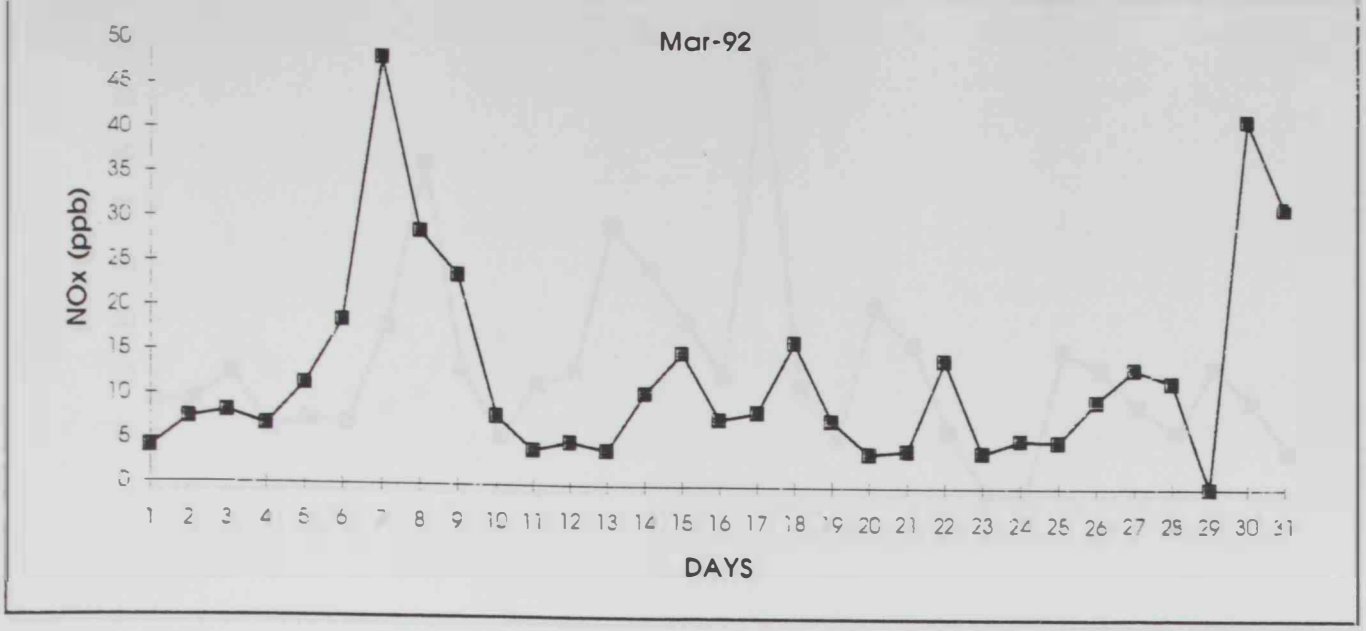
Through such correlation, it can be noticed that, in general, there is a relatively strong inverse relationship between NO_x and relative humidity levels. The daily mean

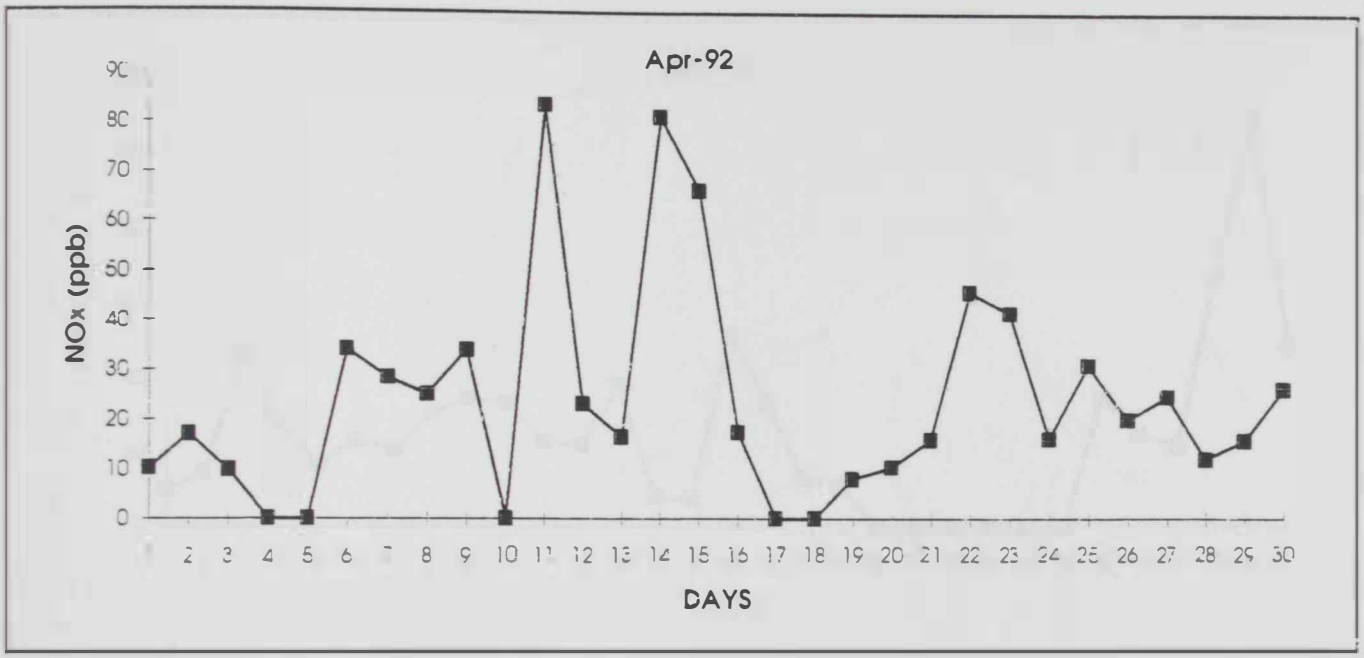


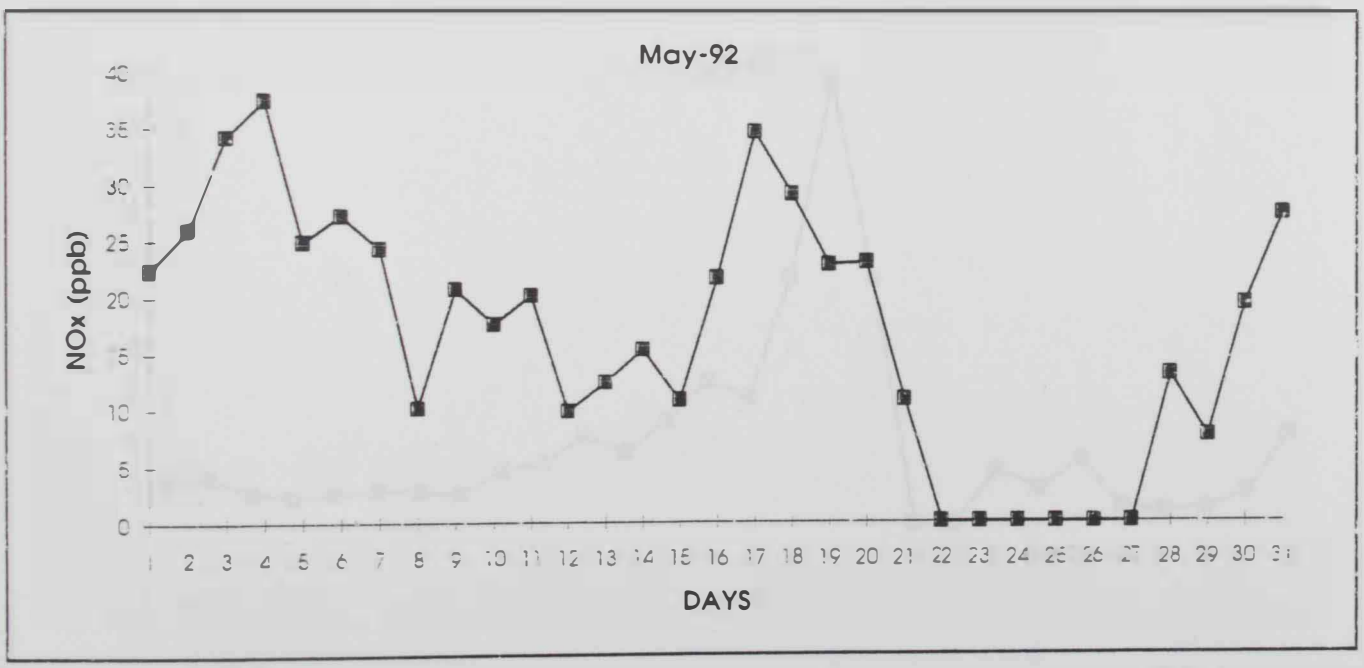




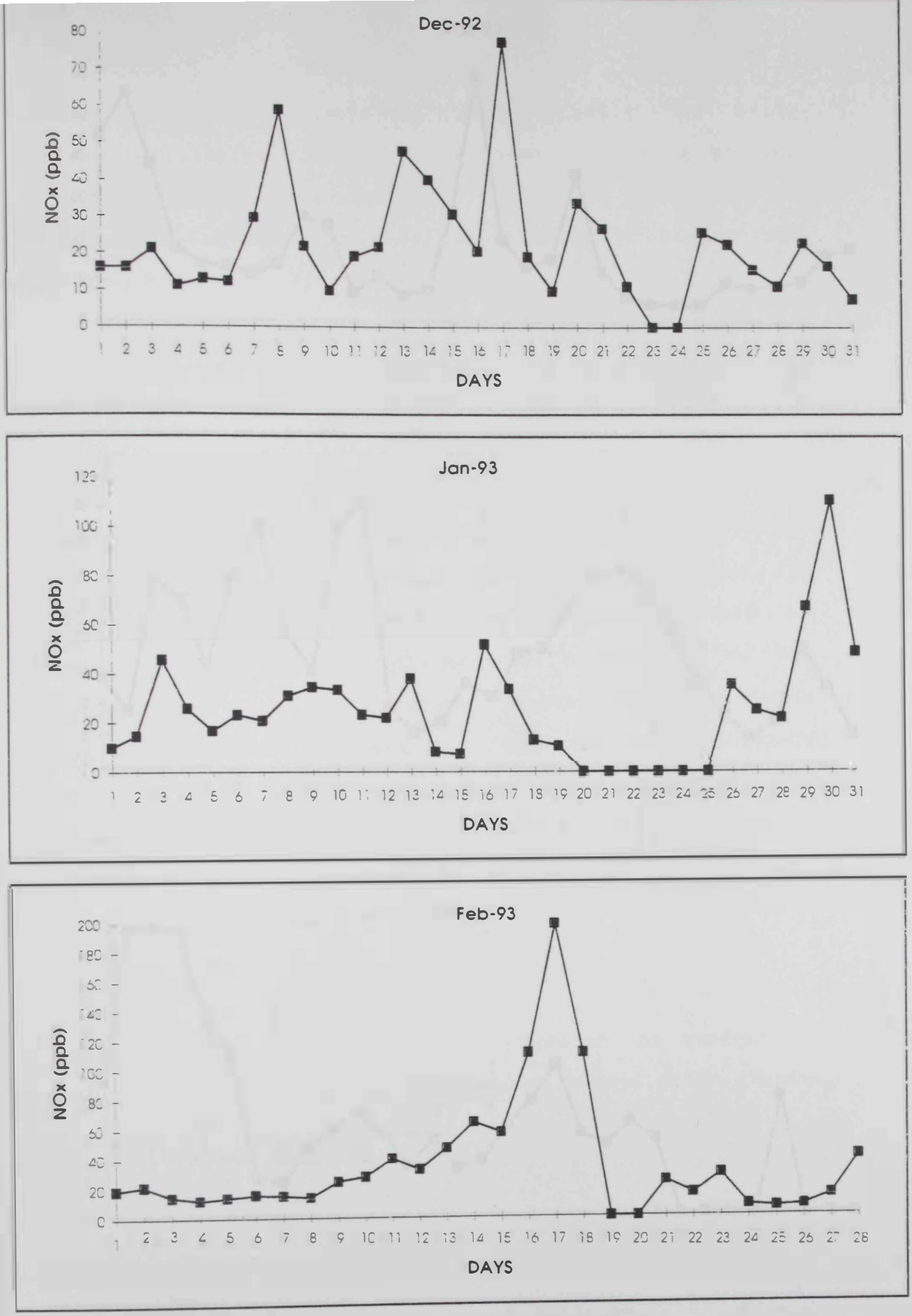
Figure(51) Daily Average of Nitrogen Oxide Concentration in Abu Dhabi (Winter 1991/92)



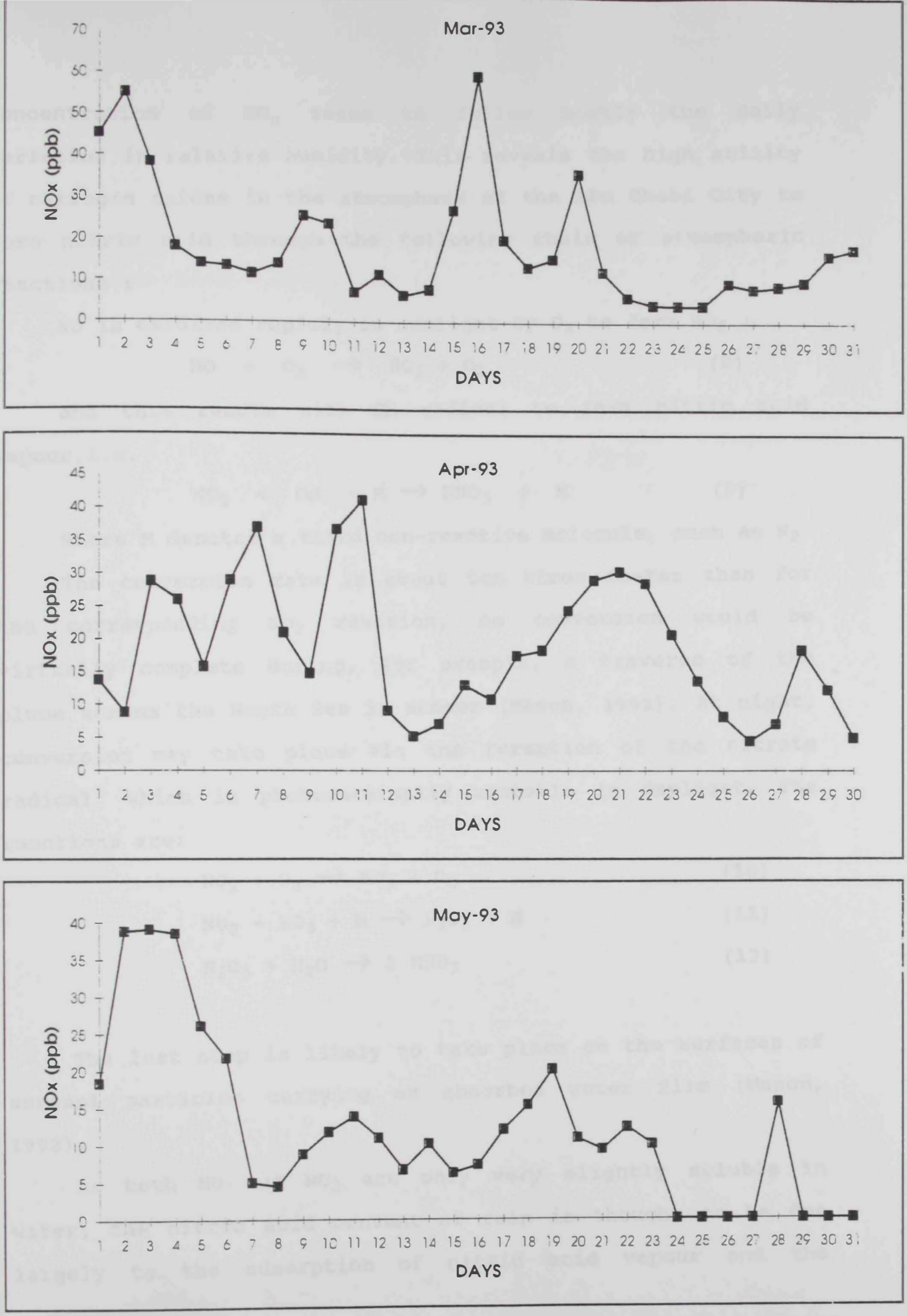




Figure(52) Daily Average of Nitrogen Oxide Concentration in Abu Dhabi (Spring 92)



Figure(53) Daily Average of Nitrogen Oxide Concentration in Abu Dhabi (Winter 1992/93)



Figure(54) Daily Average of Nitrogen Oxide Concentration in Abu Dhabi (Spring 93)

concentration of NO_x seems to follow mostly the daily variation in relative humidity. This reveals the high ability of nitrogen oxides in the atmosphere of the Abu Dhabi City to form nitric acid through the following chain of atmospheric reactions :

NO is oxidized rapidly in sunlight by O_3 to form NO_2 :

$$NO + O_3 \rightarrow NO_2 + O_2 \qquad (8)$$

and this reacts with OH radical to form nitric acid vapour,i.e.

$$NO_2 + OH + M \rightarrow HNO_3 + M \qquad (9)$$

Where M denotes a third non-reactive molecule, such as N_2

The conversion rate is about ten times faster than for the corresponding SO_2 reaction, so conversion would be virtually complete during, for example, a traverse of the plume across the North Sea in summer (Mason, 1992). At night, conversion may take place via the formation of the nitrate radical, which is photochemically unstable in daylight. The reactions are:

$$NO_2 + O_3 \rightarrow NO_3 + O_2 \qquad (10)$$

$$NO_2 + NO_3 + M \rightarrow N_2O_5 + M \qquad (11)$$

$$N_2O_5 + H_2O \rightarrow 2\ HNO_3 \qquad (12)$$

The last step is likely to take place on the surfaces of aerosol particles carrying an absorbed water film (Mason, 1992).

As both NO and NO_2 are only very slightly soluble in water, the nitric acid content of rain is thought to be due largely to the adsorption of nitric acid vapour and the

capture of raindrops of aerosols containing N_2O_5. The latter results in the following reaction:

$$N_2O_5 + H_2O(liq) \longrightarrow 2\ HNO_3 \qquad (13)$$

which is believed to be rapid, but conversion rates have not yet been established (Mason, 1992).

CHAPTER VI

ATMOSPHERIC QUALITY IN ABU DHABI CITY

1. MONITORING STATIONS

Short-term survey of air pollutants has been conducted in Abu Dhabi City for background data and also to evaluate pollution level. Two sampling stations were selected for the survey; the first was the building of the Food and Environment Control Center, Abu Dhabi Municipality (Fig.54) and the second was the Housing Complex of Umm Al Nar industrial area (Fig. 54).

The first station, being located at Al Salam St., one of the major economic, administrative and residential streets in Abu Dhabi City can give an indication of the atmospheric contamination due to the human activities taking place in the City. This sampling station lies inside the dense urban mass, which is concentrated in the northern sector of the City (Fig. 54).

The second station, being located at the Housing Complex of the industrial area of Umm Al Nar, which is located 25 km to the east of Abu Dhabi and about 4 km to the north of Al Maqta Bridge (Fig.55) can give an indication of the industrial area pollution in Abu Dhabi City. The Umm Al Nar industrial area includes the Abu Dhabi National Oil Company (ADNOC) refinery, desalination and power generation plants of Water and Electricity Department (WED), National Chlorine Industries

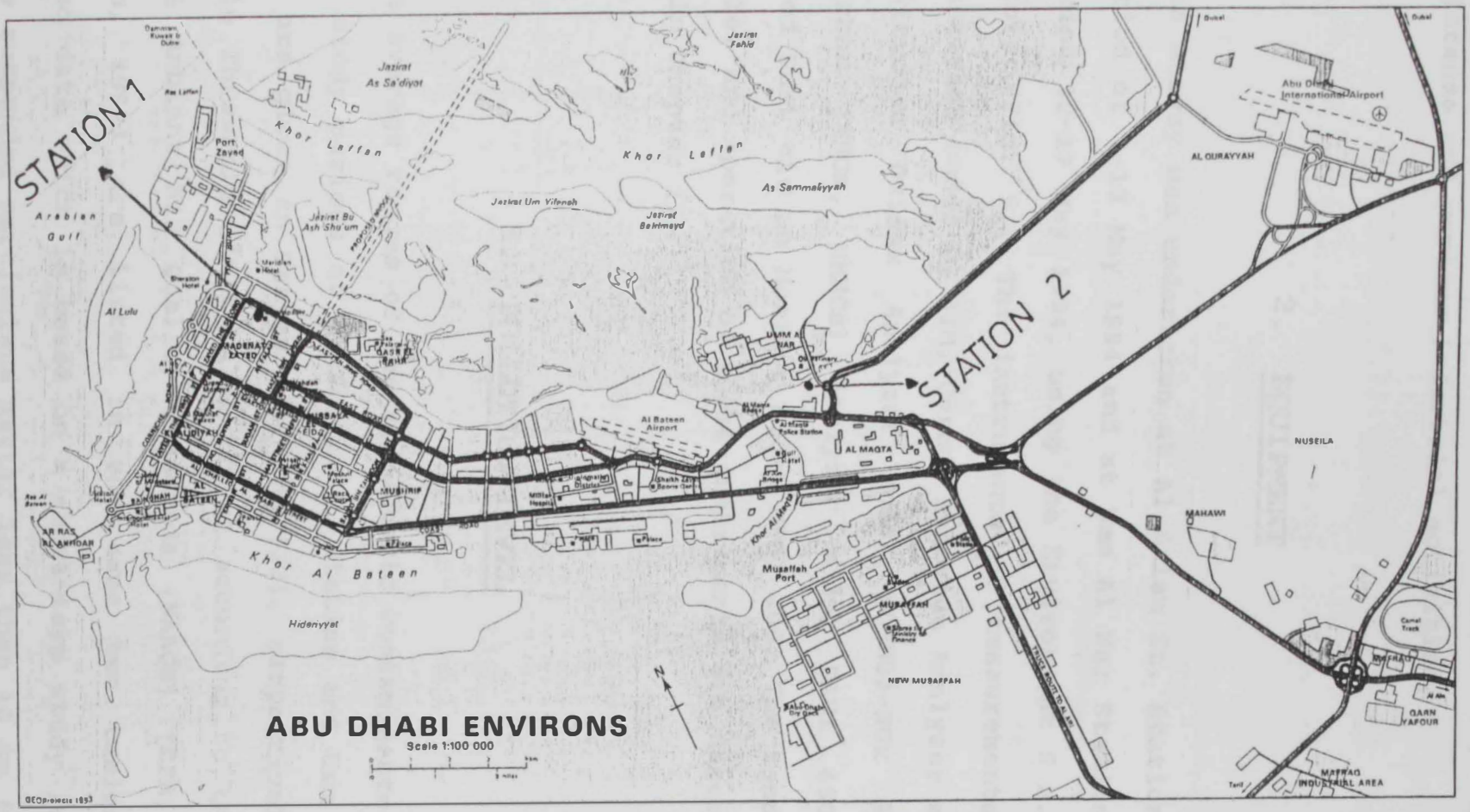


Figure (55) Abu Dhabi City, Sampling Sites

(NCI) and the tank farms of ADNOC Fuel Oil Distribution (FOD).

Potential atmospheric pollution may be expected from these intense and various industrial activities.

2. EQUIPMENT

The survey was undertaken at Al Salam St. Station during the period of 3-10 May 1994 and at Umm Al Nar Station during the period 10-17 May 1994, using the Environment S.A. Mobile Laboratory (Fig. 5). The instruments of measurements are : Ozone Analyzer model O_3 41M, Carbon Monoxide Analyzer model CO 11M, Nitrogen Oxides Analyzer model NO-NO2-NOx AC 30M, Hydrocarbon (MHCs, NMHCs) Analyzer model DANI 450-B and Suspended Dust <10 μm Monitor model MPSI 100. The measurement principles and operation of these instruments are described in detail in Chapter II.

3. POLLUTION LEVEL

The average ranges of the atmospheric contaminants during the two study periods at Al Salam St. Station and Umm Al Nar Station are given in Tables (21) and (22), respectively. The available Threshold Limit Value (TLVs) according to the U.S. National Ambient Air Quality Standards (NAAQS) (EPA, 1976; Harrison, 1992) are listed in the same two tables. The presented data which is based on a short-term study indicate that the suspended particulate matter less than 10 μm (SPM_{10}),

ozone (O_3), carbon monoxide (CO), nitrogen oxides (NO_x) and non-methane hydrocarbons (NMHCs) levels at both residential and industrial areas under investigation are on the average less than the standard levels designed to protect the public health in the U.S.A.

TABLE (21)
Daily Range of Atmospheric Pollutants Compared with the TLVs at Al Salam St. Station, Abu Dhabi (3-10 May 1994)

Pollutant	Range			TLV*
	Minimum	Maximum	Mean	
SPM_{10} ($\mu g/m^3$)	94.0	285.0	161.8	260 (24-hr level)
O_3 (ppb)	0.7	2.3	1.4	80 (1-hr level)
CO (ppm)	0.1	1.3	0.6	9 (8-hr level)
NO (ppb)	0.0	23.5	10.0	
NO_2 (ppb)	3.3	9.8	6.6	
NO_x (ppb)	3.4	31.2	16.6	50 (annual average)
MHCs (ppm)	5.2	6.2	6.0	
NMHCs (ppm)	0.1	0.2	0.1	
NMHCs (ppm)	0.1	0.1	0.1	0.24 (3-hr level, 6-9 a.m.)

* TLV= Threshold Limit Value

TABLE (22)
Daily Range of Atmospheric Pollutants Compared with the TLVs at Umm Al Nar Station, Abu Dhabi (10-17 May 1994)

Pollutant	Range			TLV*
	Minimum	Maximum	Mean	
SPM_{10} ($\mu g/m^3$)	84.5	785.5	193.9	260 (24-hr level)
O_3 (ppb)	0.7	3.6	2.3	80 (1-hr level)
CO (ppm)	0.0	0.2	0.1	9 (8-hr level)
NO (ppb)	0.0	54.8	10.7	
NO_2 (ppb)	3.9	13.2	6.8	
NO_x (ppb)	5.6	61.9	17.7	50 (annual average)
MHCs (ppm)	5.0	5.9	5.6	
NMHCs (ppm)	0.0	0.1	0.1	
NMHCs (ppm)	0.0	0.1	0.1	0.24 (3-hr level, 6-9 a.m.)

* TLV= Threshold Limit Value

4. Role of Meteorological Parameters

It is a well known fact that attention must be paid to the wind direction in treating discrete sources of air pollution. Therefore, the hourly records of wind speed and

direction obtained by the Environment S.A. Mobile Laboratory during the two periods of investigation were utilized in defining the emission sources of the measured atmospheric pollutants. The available records were, therefore, processed to meet the requirements of the study.

The principal features characterizing the prevailing winds at the two monitoring stations in Abu Dhabi City are given in Tables (23) and (24) for Al Salam St. and Umm Al Nar, respectively. These include the percentage frequencies for hourly wind speed direction at the two stations.

The daily means of hourly speeds and frequencies are graphically represented by wind roses in Figs. (56) and (57) for Al Salam St. and Umm Al Nar, respectively.

Besides, the daily average ranges of temperature and relative humidity (recorded by the Environment S.A. Mobil Laboratory), the total amounts of rainfall and the total number of days with dust and/or sand storms (provided by Abu Dhabi International Airport Station, Department of Civil Aviation, Abu Dhabi) were calculated for each of the two monitoring stations and are given in Table (25).

TABLE (23)
Percentage Frequencies For Hourly Wind Speed Direction
At Al Salam St. Station, Abu Dhabi
(3-10 May, 1994)

DIRECTION	01-03 KNOTS	04-06 KNOTS	07-10 KNOTS	11-16 KNOTS	17-21 KNOTS	22-27 KNOTS	28-33 KNOTS	>33 KNOTS	TOTAL
350-101	25.4	13.0	00	00	00	00	00	00	38.4
020-040	02.3	00	00	00	00	00	00	00	02.3
050-070	00	00	00	00	00	00	00	00	00
080-100	02.3	00	00	00	00	00	00	00	02.3
110-130	00.6	00	00	00	00	00	00	00	00.6
140-160	05.6	05.1	00.6	00	00	00	00	00	11.3
170-190	02.8	00	00	00	00	00	00	00	02.8
200-220	00.6	01.1	00	00	00	00	00	00	01.7
230-250	00	00.6	00	00	00	00	00	00	00.6
260-280	02.8	01.7	00	00	00	00	00	00	04.5
290-310	06.8	02.8	00	00	00	00	00	00	09.6
320-340	09.6	16.4	00	00	00	00	00	00	26.0
TOTAL	58.8	40.7	00.6	00	00	00	00	00	100
CALMS	00	00	00	00	00	00	00	00	00

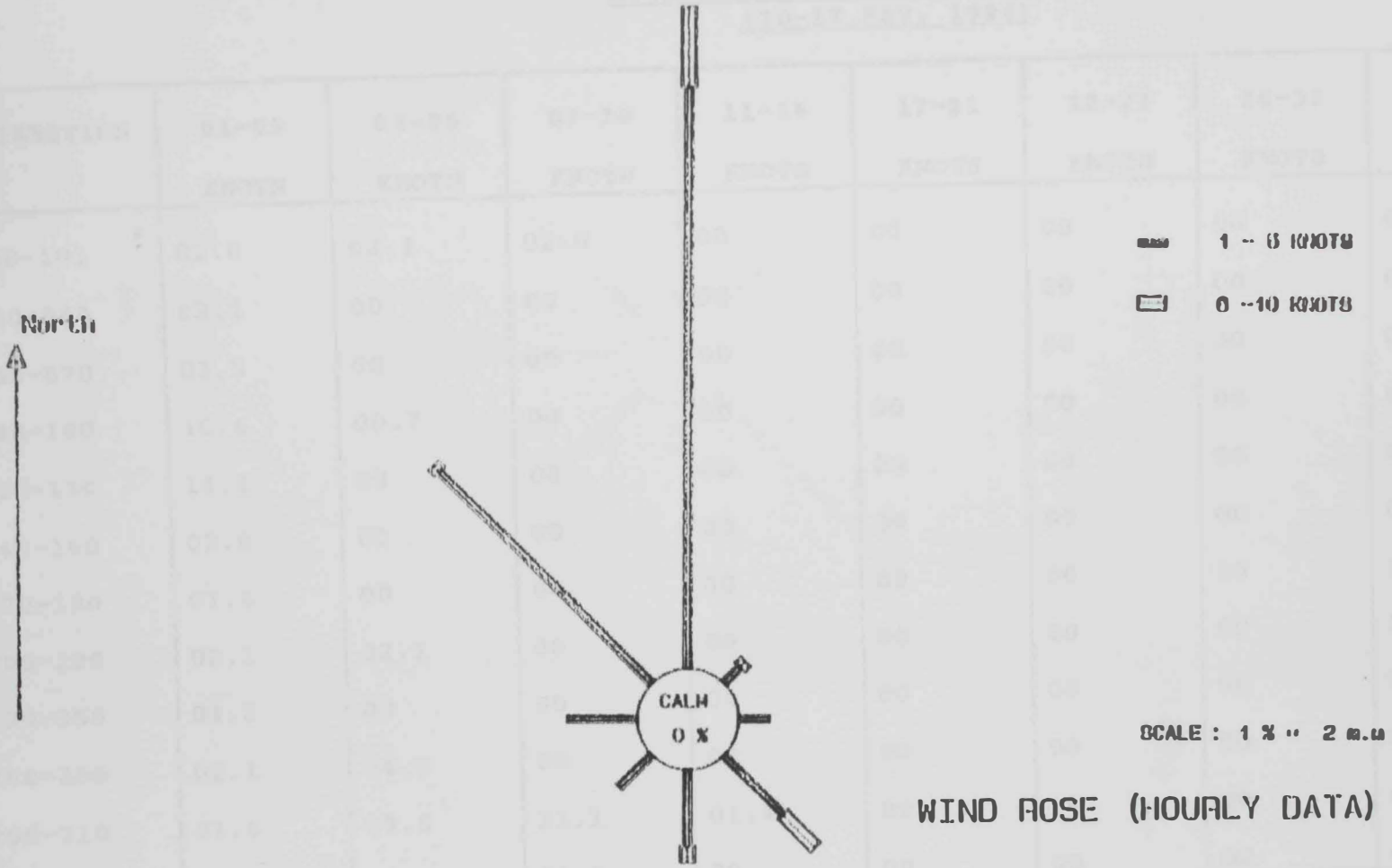
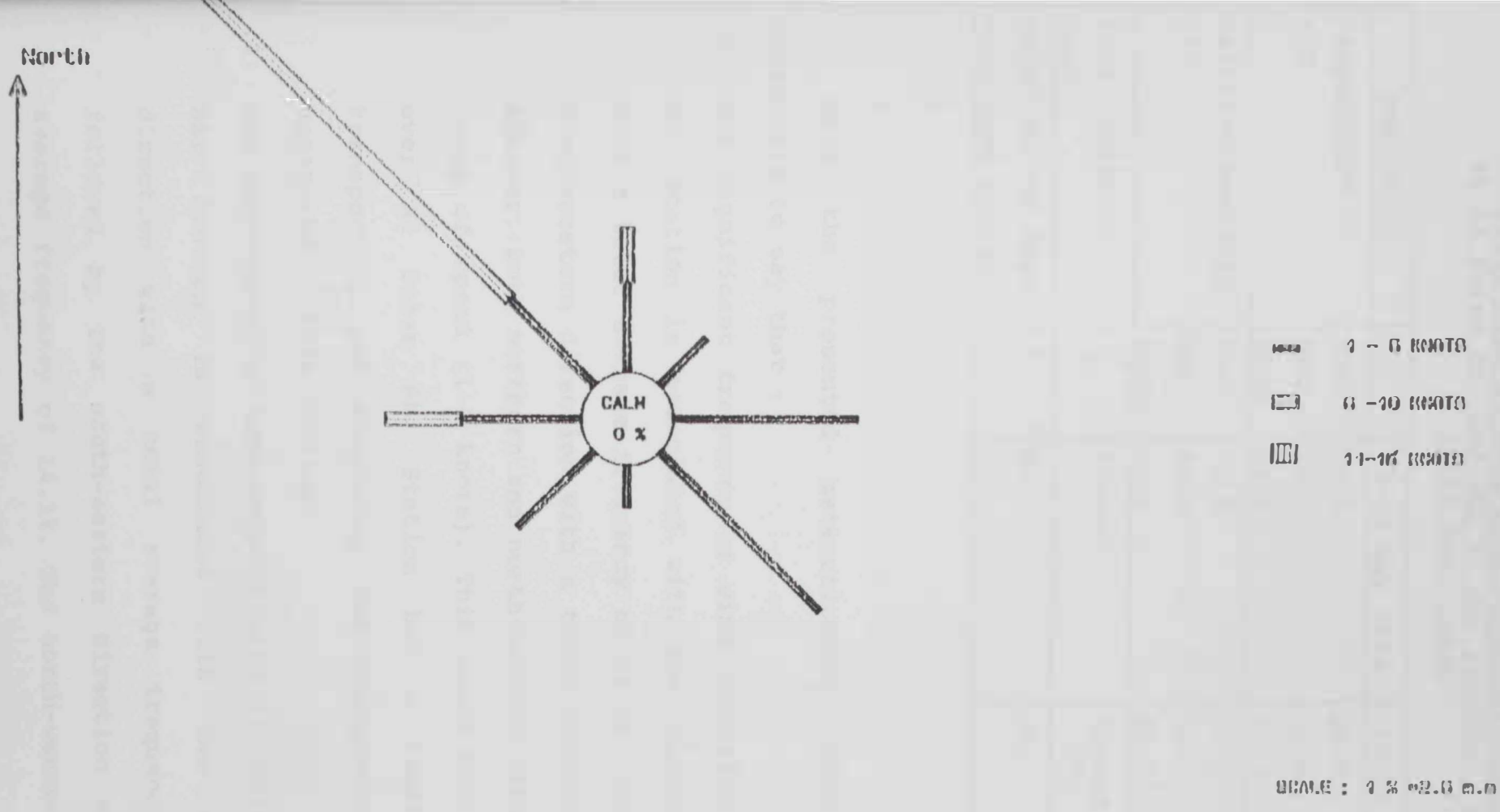


Figure (56) The Average Variation of Hourly Speed and Frequencies of Winds Blowing from 8 Directions at Al Salam St. Station in Abu Dhabi (3 - 10 May,1994)

TABLE (24)
Percentage Frequencies For Hourly Wind Speed Direction
At Umm Al Nar Station, Abu Dhabi
(10-17 May, 1994)

DIRECTION	01-03 KNOTS	04-06 KNOTS	07-10 KNOTS	11-16 KNOTS	17-21 KNOTS	22-27 KNOTS	28-33 KNOTS	>33 KNOTS	TOTAL
350-101	02.8	02.1	02.8	00	00	00	00	00	07.7
020-040	02.1	00	00	00	00	00	00	00	02.1
050-070	03.5	00	00	00	00	00	00	00	03.5
080-100	10.6	00.7	00	00	00	00	00	00	11.3
110-130	14.1	00	00	00	00	00	00	00	14.1
140-160	02.8	00	00	00	00	00	00	00	02.8
170-190	01.4	00	00	00	00	00	00	00	01.4
200-220	02.1	02.1	00	00	00	00	00	00	04.2
230-250	04.2	00	00	00	00	00	00	00	04.2
260-280	02.1	04.9	00	00	00	00	00	00	07.0
290-310	01.4	08.5	21.1	01.4	00	00	00	00	32.4
320-340	00.7	03.5	04.9	00	00	00	00	00	09.2
TOTAL	47.9	21.8	28.9	01.4	00	00	00	00	100
CALMS	00	00	00	00	00	00	00	00	00



WIND ROSE (HOURLY DATA)

Figure (57) The Average Variation of Hourly Speed and Frequencies of Winds Blowing from 8 Directions at Umm Al Nar Station in Abu Dhabi (10 - 17 May,1994)

TABLE (25)
Daily Mean of Some Meteorological Parameters
At Al Salam St. and Umm Al Nar Stations, Abu Dhabi
(3-17 May, 1994)

PARAMETER		3-10 May 1994	10-17 May 1994
Temperature (°C)	Min	29.4	24.3
	Max	38.7	36.8
	Mean	33.3	30.0
Relative humidity (%)	Min	25.5	25.4
	Max	56.6	50.7
	Mean	44.6	50.7
Total RainFall (mm)		Traces	Traces
Total No. of days with sand storms		Nil	Nil

From the presented meteorological data, it seems reasonable to say that :

(1) The significant frequency of wind direction at Al Salam St. Station is associated with the northern direction with a total average frequency of 38.4%, followed by the north-western direction with a total frequency of 26.0%. However, both northern and north-western winds have a low range of speed (1-6 knots). This means that winds blown over Al Salam St. Station had a limited role in transporting and dispersing the atmospheric pollutants monitored at this station.

(2) The corresponding frequency of wind direction at Umm Al Nar Station is associated with the north-western direction with a total average frequency of 32.4%, followed by the south-eastern direction with a total average frequency of 14.1%. The north-western winds have

a higher speed mostly in the 7-10 knots range with an average frequency of 21.1%, whereas the south-eastern wind speed lies totally in the 1-3 knots range. This means that the north-western winds blowing over Umm Al Nar Station had played an effective role in transporting the atmospheric contaminants in this direction.

(3) The average ranges of temperature, being 29.4-38.7 °C with a mean of 33.3 °C at Al Salam St. and 24.3-36.8 °C with a mean of 30.0 °C at Umm Al Nar can be considered an effective reducing factor of SPM_{10} concentration through the unstable conditions which may prevail with the increase in temperature.

(4) The trace amounts of rainfall recorded during the two study periods had also contributed in reducing the detected levels of the atmospheric contaminants which are usually precipitated with the rainfall.

(5) The two study periods were devoid of sand storms. This means that such source of natural pollution was ineffective in contaminating the atmosphere of both monitoring stations with SPM10 during those periods.

5. DIURNAL PATTERN

In order to show the daily cycle of atmospheric pollutants in the Abu Dhabi City, the hourly concentrations of SPM_{10}, O_3, and NO, NO_2 and NO_x were averaged for the seven study days at each of the two monitoring stations. The data available are assembled in Tables (26) and (27) for Al Salam

St. Station and Umm Al Nar Station, respectively. Besides, the hourly averages of SPM_{10}, O_3 and NO_x are graphically represented in Figs. (58) and (59) for SPM_{10}, (60) and (61) for O_3 and (62) and (63) for NO_x for the two stations, respectively. The most striking features characterizing the two tables and six figures can be summarized in the following sections:

5.1 SPM_{10} Diurnal Pattern

The mean concentrations of SPM_{10} at Al Salam St. throughout the day show that the diurnal pattern of the pollutant has a principal maximum (285.0 $\mu g/m^3$) exceeding the TLV (260.0 $\mu g/m^3$) (EPA, 1976) in the late evening (at 10 p.m.). This peak value appears to be independent of the local activities, particularly traffic emission, since the late evening in the City is usually characterized by light traffic density. Therefore, the observed peak seem to result from pollution being trapped near the ground in a shallow, stable or neutral layer with light winds above the cooled ground. This phenomenon is known as the heat inversion and may occur in the early morning and/or in the late evening. A detailed description of the phenomenon is given on pp. 113-114.

With respect to the corresponding daily cycle obtained for the mean concentration of SPM_{10} at Umm Al Nar (Table 27,Fig. 59), it can be noticed that there are two maxima; one at 8 a.m. and the other is at 8 p.m.

TABLE (26)

Average Levels of SPM_{10}, Ozone and Nitrogen Oxides over the 24 Hours at Al Salam St. Station in Abu Dhabi (3-10 May, 1994)

HOURS	SPM_{10} $\mu g/m^3$	O_3 ppb	NO ppb	NO_2 ppb	NO_x ppb
01:00	152.6	1.4	4.5	9.1	13.6
02:00	146.3	2.3	2.3	4.4	6.7
03:00	127.3	2.3	0.0	3.4	3.4
04:00	135.7	2.1	0.1	3.3	3.4
05:00	159.5	2.1	0.2	3.3	3.5
06:00	213.0	2.1	0.0	4.0	4.0
07:00	189.7	1.5	4.1	7.1	11.2
08:00	151.9	1.0	17.0	6.2	23.2
09:00	137.0	1.2	16.0	6.9	22.9
10:00	112.9	1.0	14.2	6.3	20.5
11:00	94.0	1.2	14.8	6.1	20.9
12:00	116.9	1.2	11.2	5.3	16.5
13:00	95.2	1.3	9.4	5.3	14.7
14:00	109.9	1.8	5.4	5.4	10.8
15:00	95.2	2.0	2.5	5.0	7.5
16:00	181.2	1.8	2.7	6.6	9.3
17:00	200.2	1.5	3.2	9.1	12.3
18:00	232.8	1.0	18.3	7.8	26.1
19:00	150.2	0.8	18.1	9.3	27.4
20:00	156.2	0.8	15.0	8.2	23.2
21:00	198.8	0.9	21.0	8.5	29.5
22:00	285.0	0.9	18.0	9.8	27.8
23:00	244.0	1.0	23.5	7.7	31.2
24:00	170.1	0.7	20.6	9.6	30.2
Daily					
Minimum	94.0	0.7	0.0	3.3	3.4
Maximum	285.0	2.3	23.5	9.6	31.2
Average	161.8	1.4	10.0	6.5	16.6

TABLE (27)

Average Levels of SPM_{10}, Ozone and Nitrogen Oxides over the 24 Hours at Umm Al-Nar Station in Abu Dhabi (10-17 May, 1994)

HOURS	SPM_{10} $\mu g/m^3$	O_3 ppb	NO ppb	NO_2 ppb	NO_x ppb
01:00	169.7	1.6	21.0	9.3	30.3
02:00	201.4	2.2	13.2	7.7	20.9
03:00	181.6	1.7	8.6	6.6	15.2
04:00	151.4	2.2	7.1	6.4	13.5
05:00	134.9	1.4	12.3	8.6	20.9
06:00	112.3	1.1	29.8	13.2	43.0
07:00	106.7	0.7	54.8	7.1	61.9
08:00	785.5	1.0	28.2	6.6	34.8
09:00	145.5	1.6	13.0	6.3	19.3
10:00	194.0	2.3	7.6	7.3	14.9
11:00	207.2	2.6	6.5	8.2	14.7
12:00	126.2	3.1	4.8	7.2	12.0
13:00	92.8	3.6	3.3	5.5	8.8
14:00	213.4	3.5	4.0	5.2	9.2
15:00	236.2	2.7	14.6	6.1	20.7
16:00	84.5	3.4	5.9	4.9	10.8
17:00	99.1	3.6	3.9	4.9	8.8
18:00	202.8	3.7	3.2	3.9	7.1
19:00	230.2	3.1	4.3	4.9	9.2
20:00	351.9	2.9	1.5	7.0	8.5
21:00	187.6	3.0	0.0	5.6	5.6
22:00	160.1	2.8	0.4	5.9	6.3
23:00	139.1	1.6	1.8	10.5	12.3
24:00	139.1	1.2	6.4	9.5	15.9
Daily					
Minimum	84.5	0.7	0.0	3.9	5.6
Maximum	785.5	3.6	54.8	13.2	61.9
Average	193.8	2.3	10.6	7.0	17.6

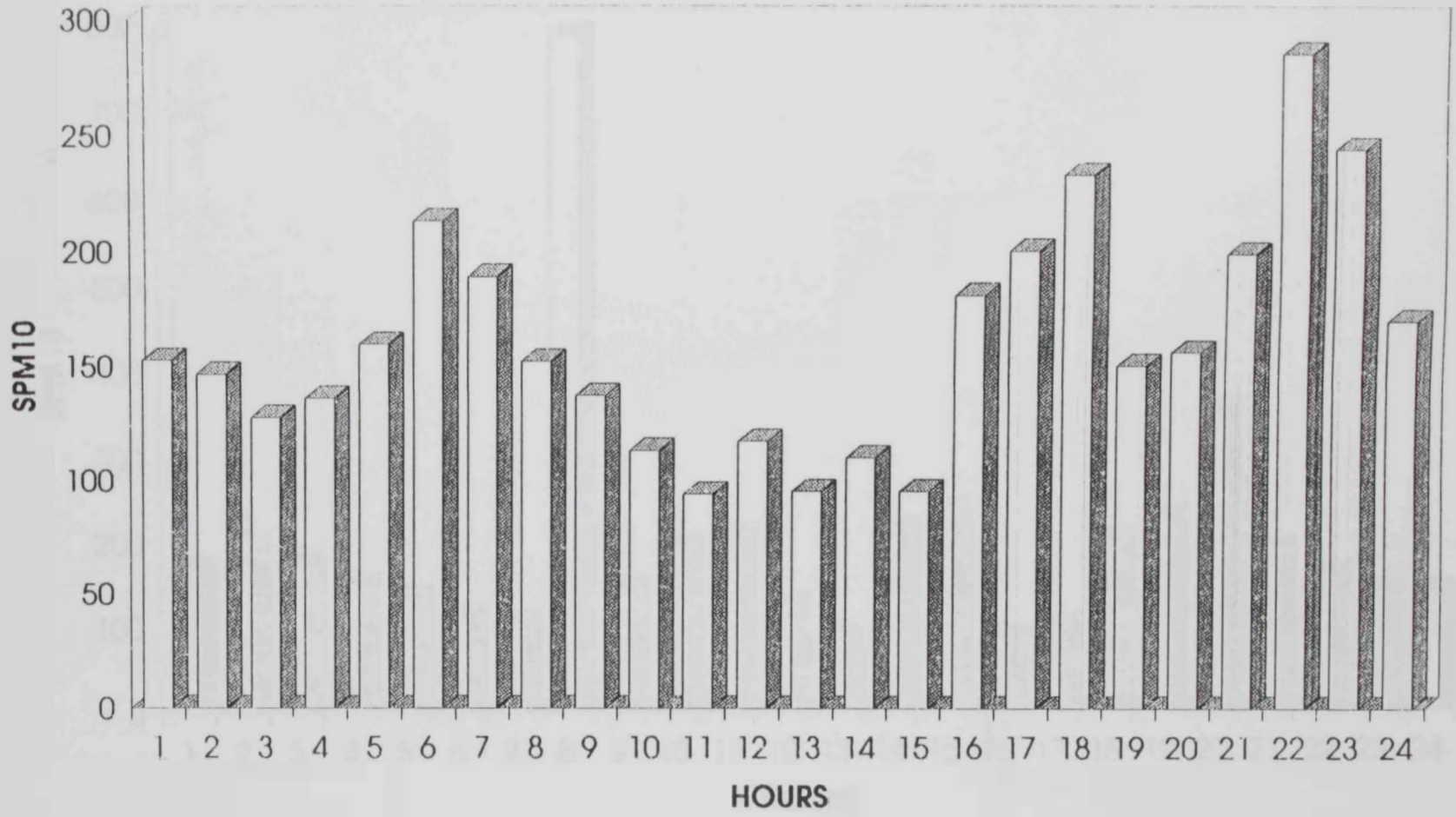


Figure (58) Diurnal Pattern of Average Concentration of SPM10 (ug/m3)
At Al Salam St. Station
(3 - 10 May 1994)

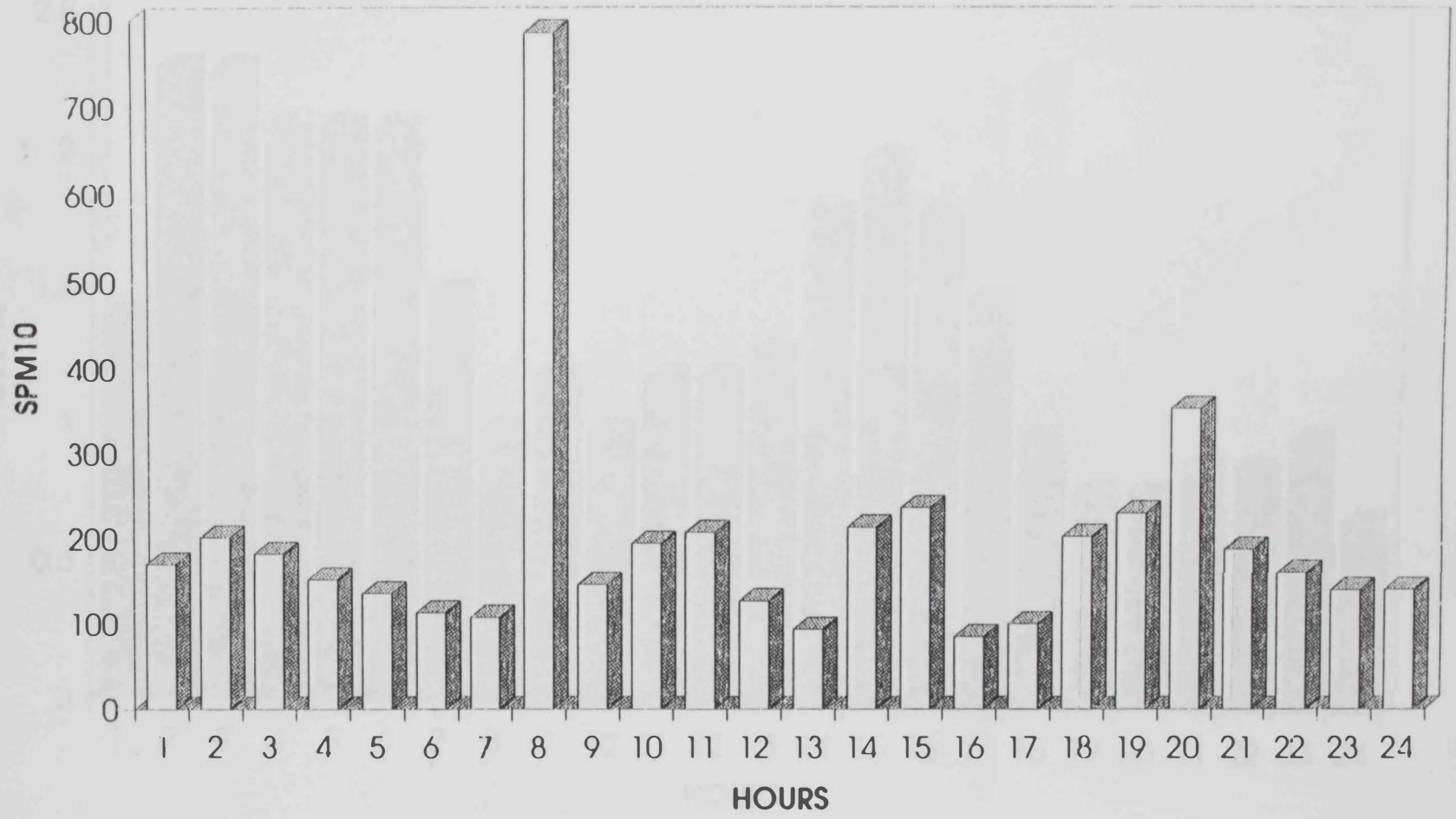


Figure (59) Diurnal Pattern of Average Concentration of SPM10 (ug/m3)
At Umm Al Nar Station
(10 - 17 May 1994)

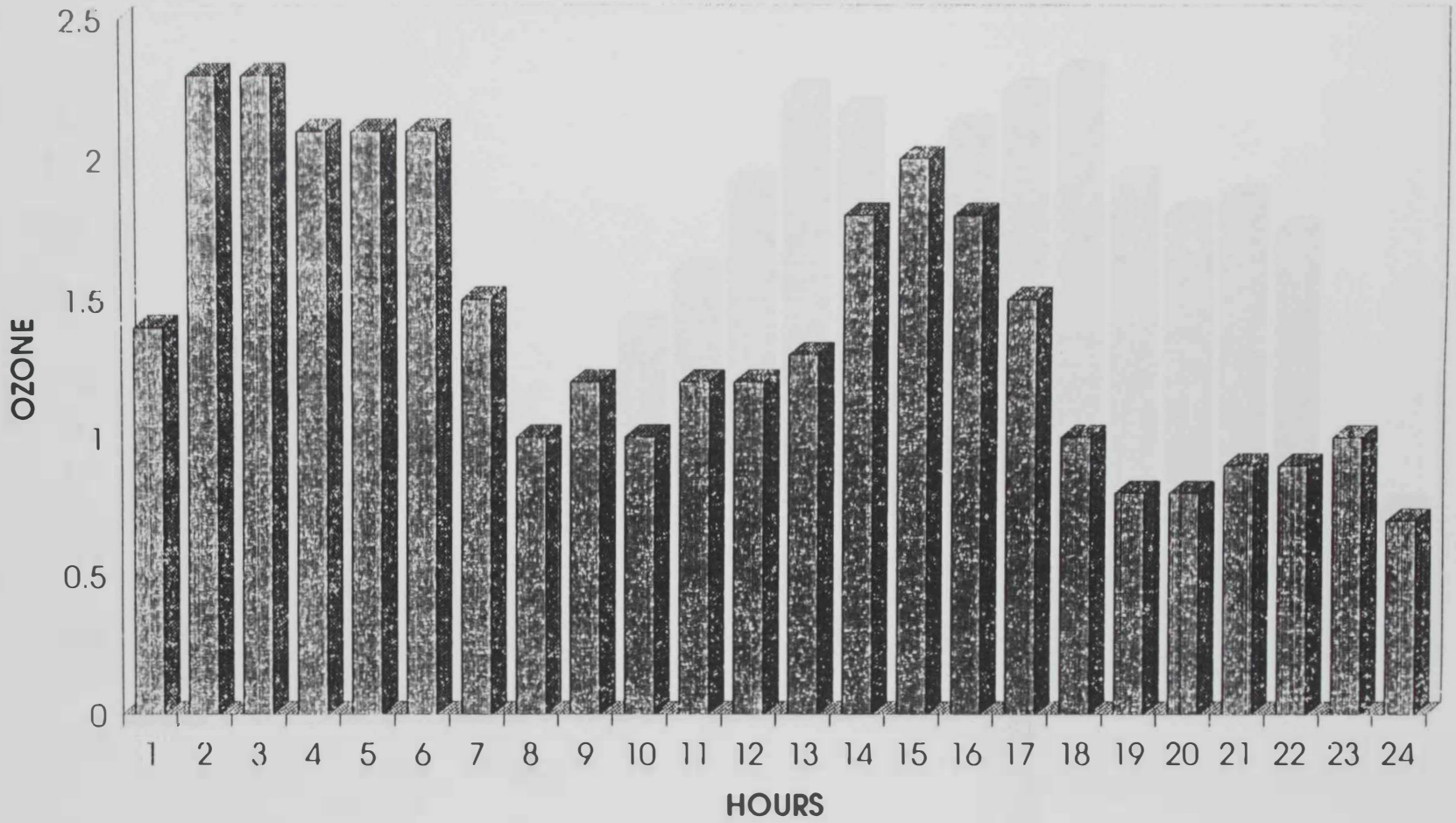


Figure (60) Diurnal Pattern of Average Concentration of Ozone (ppb)
At Al Salam St. Station
(3 - 10 May 1994)

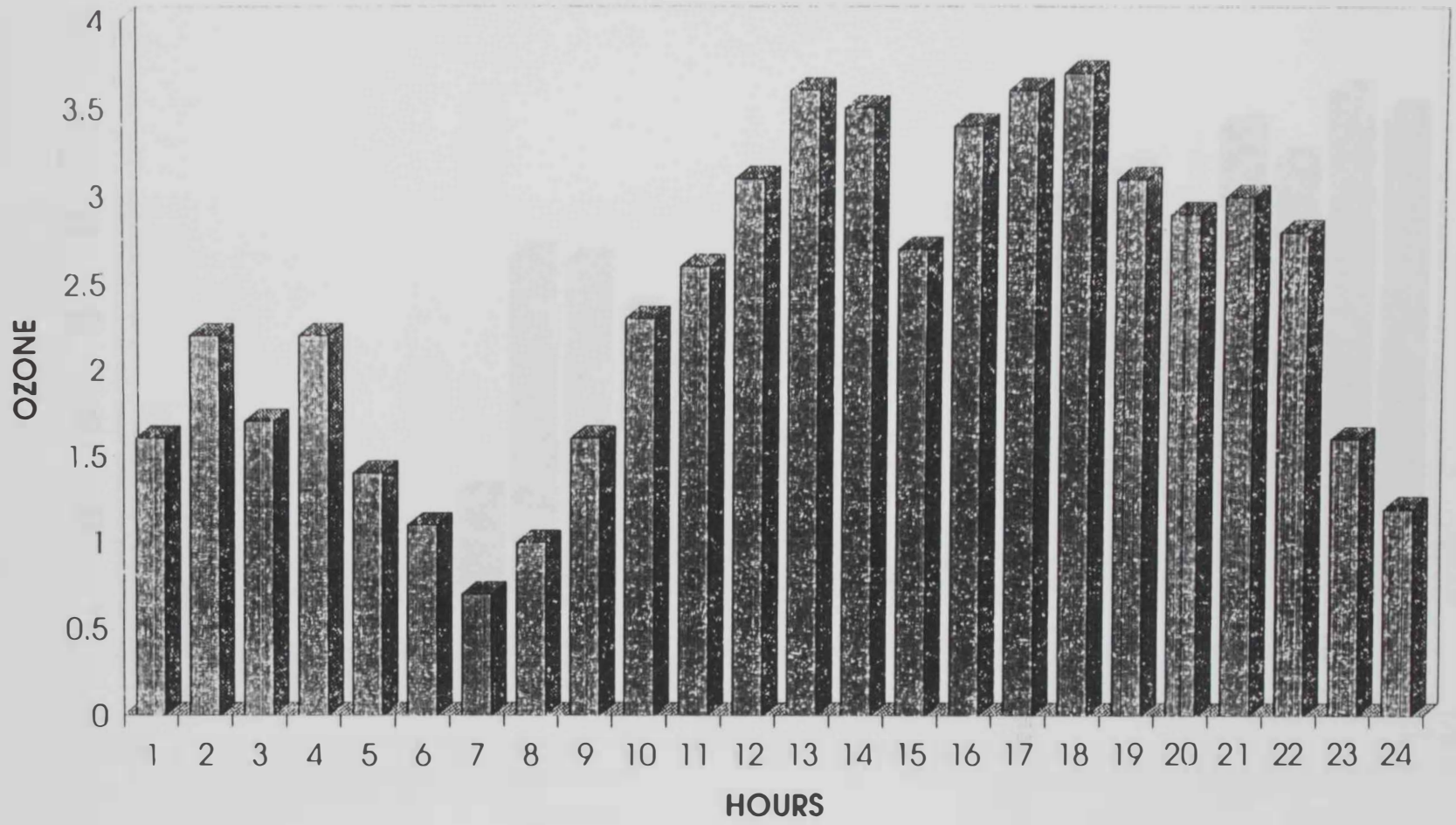


Figure (61) Diurnal Pattern of Average Concentration of Ozone (ppb) At Umm Al Nar Station (10 - 17 May 1994)

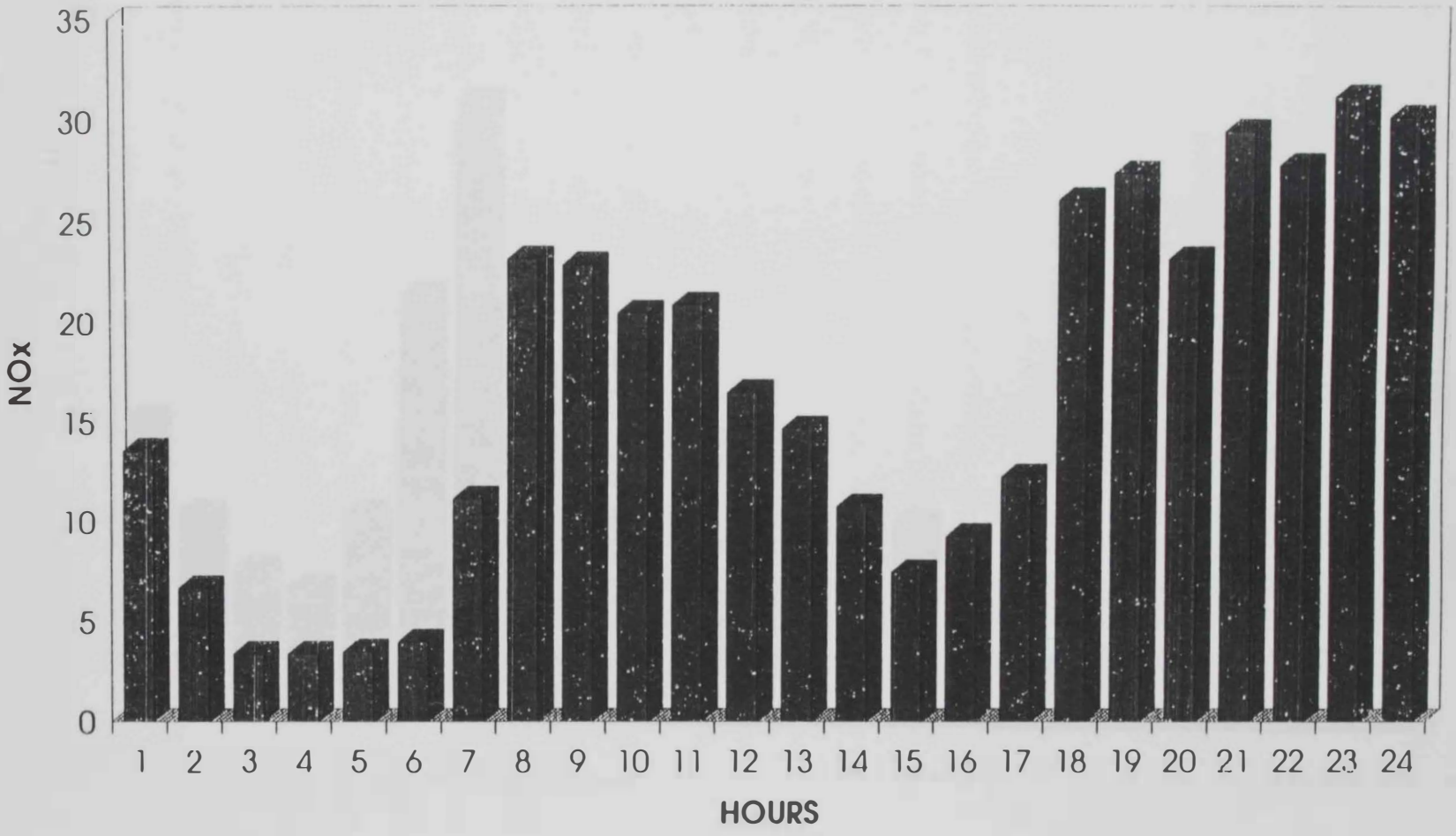


Figure (62) Diurnal Pattern of Average Concentration of Nitorgen Oxides (ppb)
At Al Salam St. Station in Abu Dhabi
(3 - 10 May 1994)

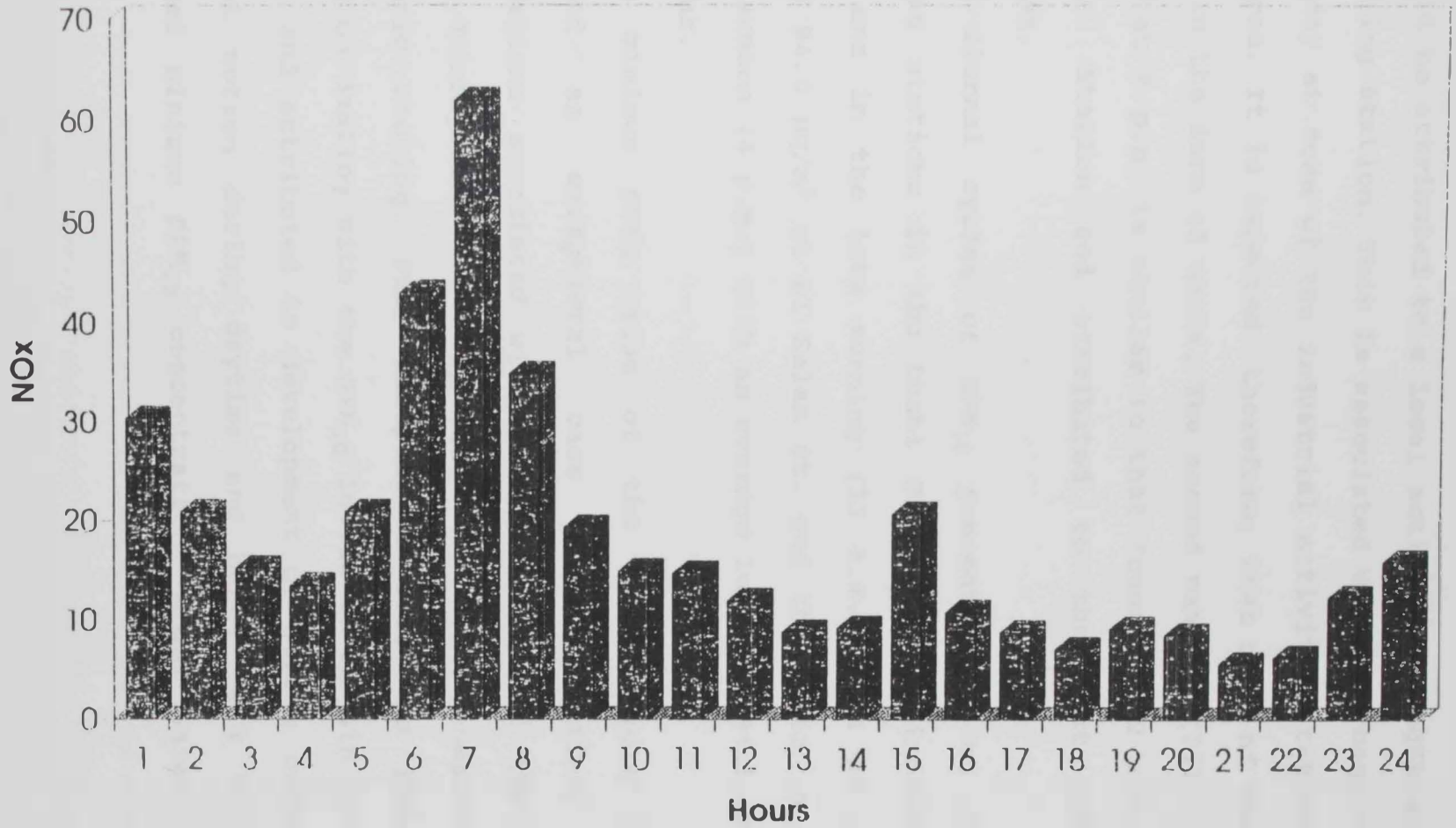


Figure (63) Diurnal Pattern of Average Concentration of Nitrogen Oxides (ppb)
at Umm Al Nar Station in Abu Dhabi
(10-17 May 1994)

The first is very sharp reaching 785.5 $\mu g/m^3$, i.e. more than three times the TLV (260 $\mu g/m^3$) (EPA, 1976). This sharp peak could be attributed to a local activity taking place near the sampling station. This is associated with the beginning of the workday at some of the industrial activities taking place in the area. It is expected, therefore, that most of the SPM_{10} will be in the form of smoke. The second maximum (351.9 $\mu g/m^3$) observed at 8 p.m. is similar to that found at 10 p.m. in Al Salam St. Station and attributed to the heat inversion phenomenon.

The diurnal cycles of SPM_{10} concentration at the two monitoring stations in Abu Dhabi City further indicate two minima; one in the late morning (11 a.m.) with an average level of 94.0 $\mu g/m^3$ at Al Salam St. and the other is in the late afternoon (4 p.m.) with an average level of 84.5 $\mu g/m^3$ at Umm Al Nar.

The minimum peak value of the late morning can be considered an exceptional case of the ideal SPM_{10} concentrations associated with the variation of the mixing heights throughout the day due to solar heating and atmospheric cooling. Such exceptional case was previously observed on dealing with the SPM_{10} levels in Al Ain City (pp. 113-114) and attributed to development of strong consecutive turbulent motion during daytime and hence lead to highly pronounced minimum SPM_{10} concentration (Abdel Salam et al, 1981).

5.2 Ozone Diurnal Pattern

In clean dry atmospheres, ozone concentrations near the sea level were found to be in the range of 20 ppb in winter to 70 ppb in summer (Table 1) (Hesketh, 1972). Until recently, these background levels were assumed to have originated from stratospheric intrusion. Recent studies suggest, however, that the dominant source of background O_3 levels over the United States at remote and rural sites is atmospheric photochemistry involving natural sources of CH_4,CO, NMHCs and NO_x (Godish, 1991).

Although the hourly average concentrations of ozone detected at both monitoring stations are less than the background level, the diurnal patterns of this atmospheric components (Figs 60 and 61) show a general tendency of these average concentrations to be higher during some hours of the day and lower during others. This tendency is clear in the diurnal pattern of ozone concentrations at Umm Al Nar (Fig. 61) which shows an elevated increase in the O_3 level begins at 7 a.m. with a minimum average concentration of 0.7 ppb to reach a maximum average concentration of 3.6 ppb at 1 p.m., then decreased to 3.5 ppb at 2 p.m. and to 2.7 ppb at 3 p.m. Another gradual increase begins after the last hour (3 p.m.) to reach the peak value of the whole day (3.7 ppb) at 6 p.m., then gradual decrease begins till the end of the 24-hr. period at midnight.

In fact, ozone concentrations that occur over urban and nonurban areas reflect an interplay emissions of NO_x and HCs, transport meteorology, and atmospheric chemistry. If we begin with a small mass of relatively clean air and follow its

passage over an urban area and areas downwind, we can see some of the dynamics involved in O_3 formation and its subsequent history (Godish, 1991).

As an air mass moves toward an urban center, it picks up NO_x and HCs. Within a time scale of an hour, OH begins to degrade HCs, producing RO_2 (peroxy radicals). As the air mass moves over the urban center, O_3 precursors peak and then decline with increasing downwind distance. Ozone concentrations increase and are sustained over a period of 1-5 hr as the more reactive olefinic and aromatic HCs are depleted by photochemical reactions.

After 5-10 hr travel time downwind, moderately reactive HCs increasingly play more important role in net O_3 production. Ozone levels in the air mass subsequently decrease as a consequence of dilution, conversion of NO_2 to HNO_3 and surface removal. Under nighttime conditions, O_3 production ceases.

Ground-based heat inversions, which may rise to a height of tens to hundreds of meters, limit mixing of ground-level emissions, which would serve as O_3 scavengers. Protected by the inversion layer, O_3 may persist aloft with a half life of as much as 80 hr.

At sunrise, the inversion breaks up, bringing O_3 and other products isolated aloft during the nighttime hours to the ground, where they mix with pollutants confined below (and those newly produced) to begin the next day's photochemistry.

The persistence of O_3 aloft at night can result in its long range transport. It is apparently the cause of nighttime concentrations exceeding those reported for midday at remote

sites. This contradicts the view, once widely held, that maximum O_3 concentration always occur near solar noon (Godish, 1991).

The above contradiction can be clearly noticed in the diurnal pattern of the average concentration of ozone at Al Salam St. (Fig. 60) which shows a higher concentrations of ozone during the five hours 2-6 a.m. compared with the solar hours.

The fluctuation of the hourly average concentrations of ozone at both monitoring stations (Figs. 60 and 61) in combination with dynamics involved in O_3 formation and its subsequent history indicate with no doubt that although the ozone is present in the atmosphere of Abu Dhabi City in concentrations below the background levels, it originates in the form of a secondary photoxidant through atmospheric photochemical reactions.

5.3 Nitrogen Oxides Diurnal Pattern

Hourly averages of nitrogen oxides ; NO, NO_2 and NO_x (the sum of NO and NO_2) show an interesting diurnal pattern at each of the two monitoring stations.

Diurnal pattern of NO, NO_2 and NO_x at Al Salam St. (Table 26,Fig. 62) indicates that there is a gradual decrease in their concentrations begins at 1 a.m. with an average concentrations of 4.5 ppb, 9.1 ppb and 13.6 ppb for NO, NO_2 and NO_x, respectively and ends at 5 a.m. with an average concentrations of 0.2 ppb, 3.3 ppb and 3.5 ppb for the three components, respectively. This is followed by a gradual increase begins at 6 a.m. with an average concentration of 0.0

ppb, 4.0 ppb and 4.0 ppb for NO, NO_2 and NO_x, respectively to reach a peak value at 11 a.m. with an average concentration of 14.8 ppb, 6.1 ppb and 20.9 ppb for the three components, respectively. This is followed by another gradual decrease begins at noon-hr with an average concentration of 11.2 ppb, 5.3 ppb and 16.5 ppb for NO, NO_2 and NO_x, respectively and ends at 3 p.m. with an average concentration of 2.5 ppb, 5.0 ppb and 7.5 ppb for the three components, respectively. Finally, relatively gradual increase begins at 4 p.m. with an average concentration of 2.7 ppb, 6.6 ppb and 9.3 ppb for NO, NO_2, and NO_x, respectively to reach the maximum level of the daily cycle of NO (23.5 ppb) at 11 p.m., NO_2 (9.8 ppb) at 10 p.m. and NO_x (31.2 ppb) at 11 p.m. The next day's cycle begins at the midnight with a decrease in NO, NO_2 and NO_x concentrations to 20.6 ppb, 9.6 ppb and 30.2 ppb, respectively.

Diurnal pattern of NO, NO_2 and NO_x at Umm Al Nar (Table 27 and Fig. 63) may show a similar trends for the decrease and increase of the concentrations of the three components, but with some exceptions due to the characteristic of the monitoring station being located near a complex industrial area.

Such fluctuation in the hourly levels of nitrogen oxides may be attributed to the available results (Tables 27 and 28) which indicate that the major proportion of NO_x in the atmosphere of Abu Dhabi City during the period of study was in the form of NO with a mean level of 10.0 ppb at Al Salam St. Station and 10.7 ppb at Umm Al Nar Station compared with 6.6 ppb and 6.8 ppb of NO_2 at the two stations, respectively.

Usually, atmospheric levels of NO are related to the fuel combustion processes associated with the various human and industrial activities taking place in the area of concern.

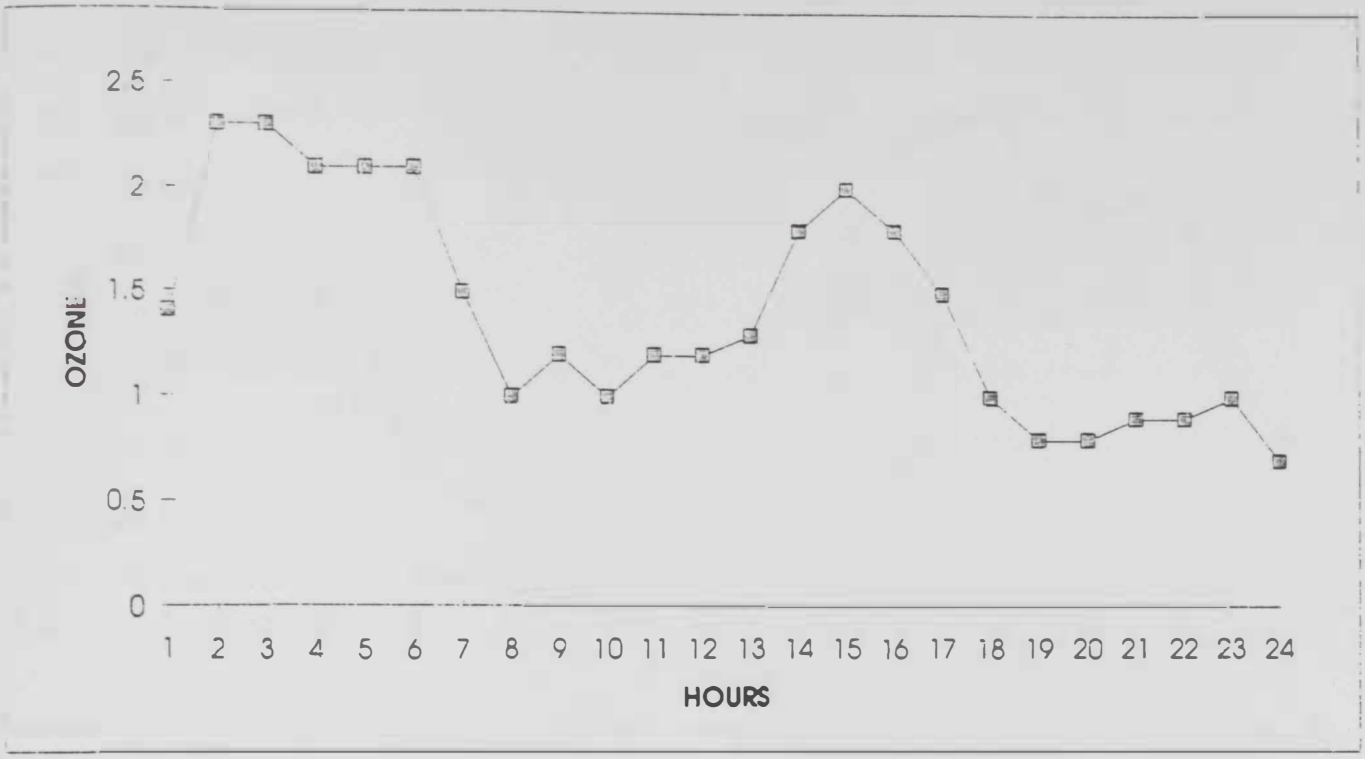
On the other hand, a principal sink process for NO occurs through its conversion by both direct oxidation and photochemical processes to NO_2. These have been explained on dealing with nitrogen oxides as acid gases (pp. 149-162).

It should be noted that the recent finding of May, 1994 associated with the higher levels of NO compared with NO_2 which is in contrast with that drawn from the Dec. 1991-May 1992 and Dec. 1992-May 1993 data may be due to the difference in the characteristics of the monitoring stations and/or to the increase in the NO emission in the City atmosphere.

6. OZONE-NITROGEN OXIDES RELATIONSHIP

Through examining the data of nitrogen oxides levels at the two monitoring stations in Abu Dhabi City, it has been noticed that there is a strong inverse relationship between NO_x and O_3 concentrations.

Therefore, the daily cycles of the NO_x and O_3 concentrations were further graphically presented in a composite diagrams to show clearly such relationship at Al Salam St. (Fig. 63) and Umm Al Nar (Fig. 64) monitoring stations.



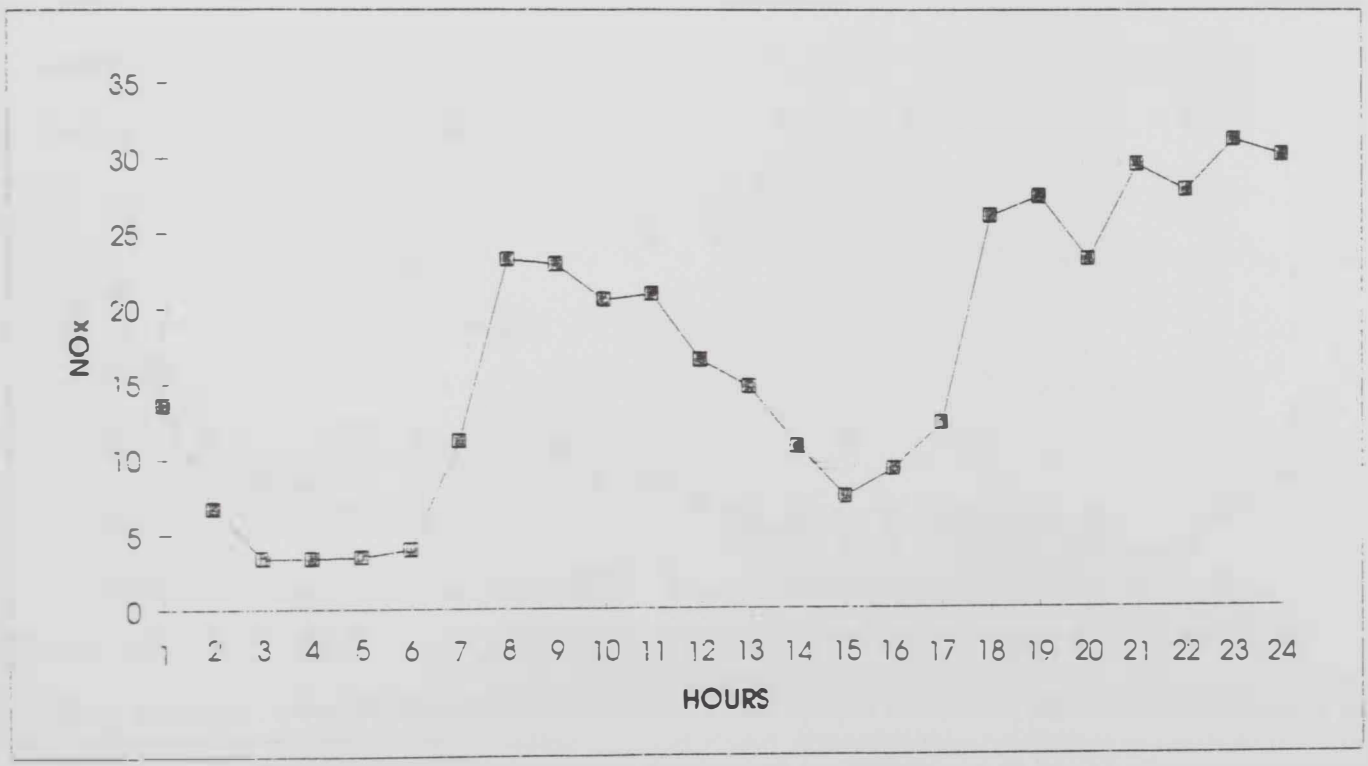
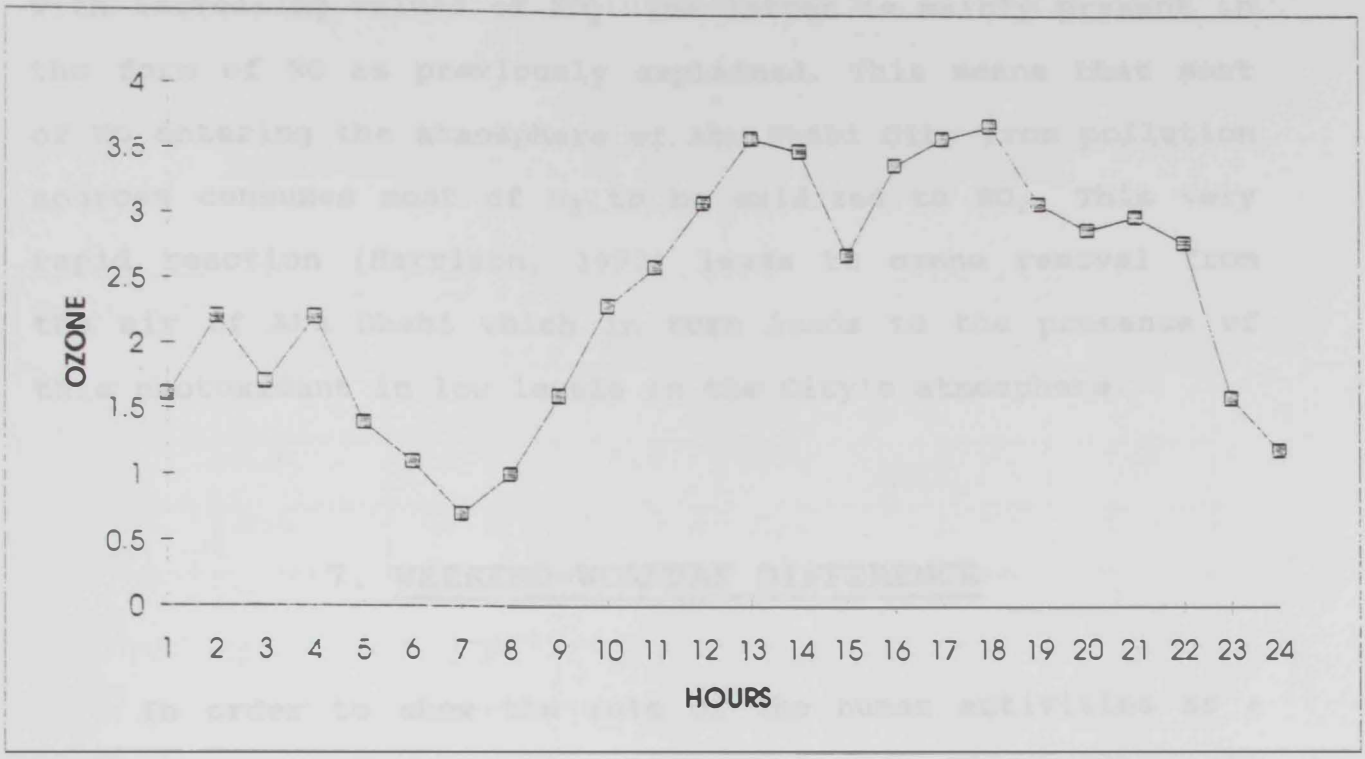


Figure (63) Composite Diagram Showing Daily Average Concentrations (ppb) of O3 and NOx at Al Salam St. Station (3-10 May 1994)



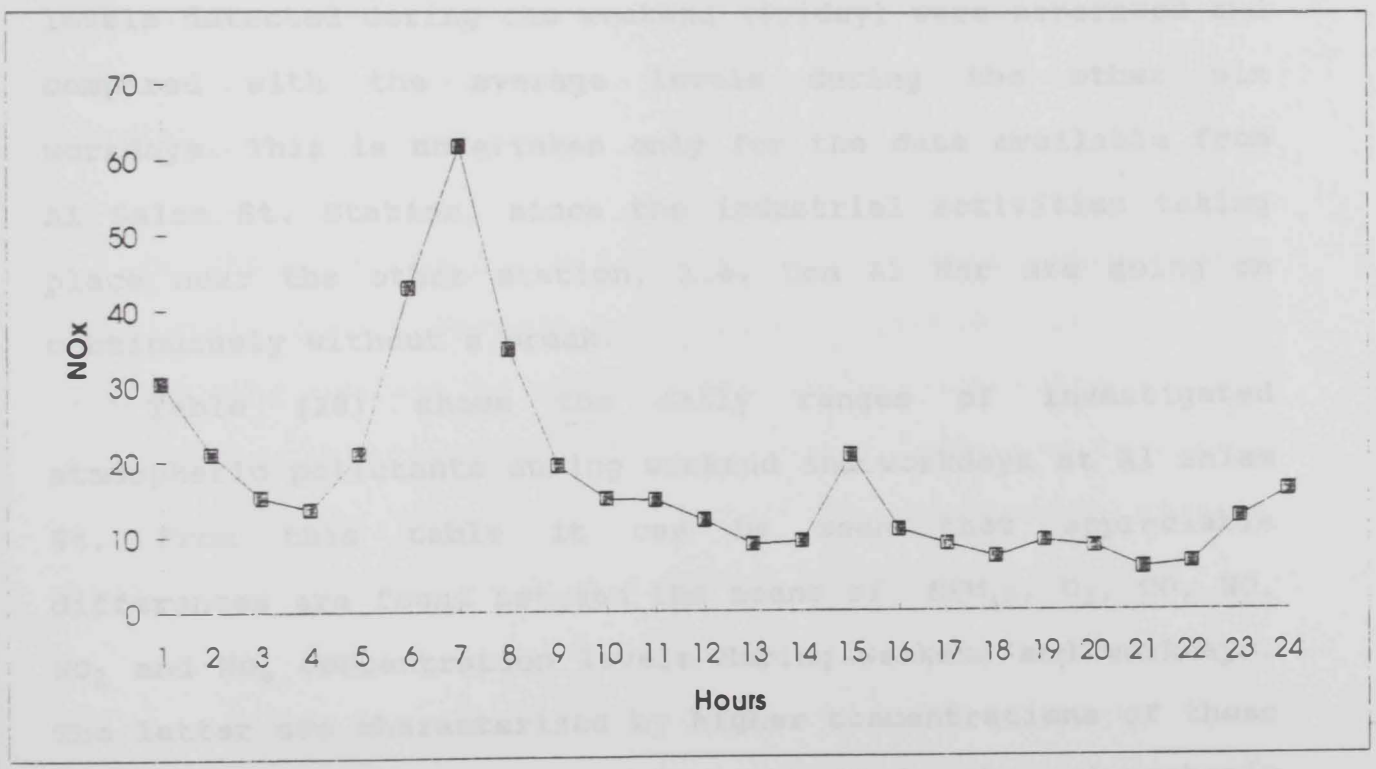


Figure (64) Composite Diagram Showing Daily Average Concentrations (ppb) of O3 and NOx at Umm Al Nar Station (3-10 May 1994)

The two diagrams display a progressive depletion of ozone with increasing values of NO_x. The latter is mainly present in the form of NO as previously explained. This means that most of NO entering the atmosphere of Abu Dhabi City from pollution sources consumes most of O_3 to be oxidized to NO_2. This very rapid reaction (Harrison, 1992) leads to ozone removal from the air of Abu Dhabi which in turn leads to the presence of this photoxidant in low levels in the City's atmosphere.

7. WEEKEND-WORKDAY DIFFERENCE

In order to show the role of the human activities as a source of atmospheric pollution in the Abu Dhabi City, the levels detected during the weekend (Friday) were separated and compared with the average levels during the other six workdays. This is undertaken only for the data available from Al Salam St. Station, since the industrial activities taking place near the other station, i.e. Umm Al Nar are going on continuously without a break.

Table (28) shows the daily ranges of investigated atmospheric pollutants during weekend and workdays at Al Salam St. From this table it can be seen that appreciable differences are found between the means of SPM_{10}, O_3, CO, NO, NO_2 and NO_x concentration levels during weekend and workdays. The latter are characterized by higher concentrations of these pollutants. This clearly indicates that the atmospheric pollution sources associated with the human activities,

chiefly motor vehicles, are considerably less on weekends at the monitoring station.

TABLE (28)
Daily Range of Atmospheric Pollutants During Weekend and Workdays at Al Salam St. Station, Abu Dhabi (3-10 May 1994)

Pollutant	Weekend Range			Workday Range*		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
SPM_{10} (µg/m3)	6.4	359.6	128.4	98.1	272.6	159.0
O_3 (ppb)	0.0	1.1	0.8	0.6	2.4	1.4
CO (ppm)	0.0	0.0	0.0	0.1	1.3	0.6
NO (ppb)	0.0	30.3	7.0	0.0	26.2	9.3
NO_2 (ppb)	3.3	9.8	5.6	2.4	14.8	7.6
NO_x (ppb)	3.3	30.3	12.6	2.4	35.2	17.9
MHC (ppm)	5.7	6.3	6.5	4.5	5.6	5.0
NMHC (ppm)	0.1	0.3	0.1	0.1	0.3	0.1

* Average of six days

On the other hand, no differences are found between NMHC mean levels during weekend and workdays. Furthermore, the MHC level during weekend is higher than the corresponding average level during workdays. This result clearly indicates that most of hydrocarbons found at Al Salam St. monitoring station originate most probably from a nearby large petrol station.

CHAPTER VII

AIR POLLUTION LEGISLATION AND CONTROL IN ABU DHABI EMIRATE

1. GENERAL PRINCIPLES

The source of pollution is controlled individually, either by indirect methods when enhancing the operations quality and economical usage of materials and fuel, or by providing industrial health means and improving social standards. This would be achieved if managers of these factories are concerned and have enough knowledge of air pollution control means.

We can not leave the control of pollution sources , under any circumstances, in any community to the personal individual interest, for many reasons, some of which are (Abdel Salam, 1978):-

(1) The size of the problem might need to supply machinery with pollution control equipment.

(2) It is not fair from an economical and moral point of view, for an industry to carry out its activities without control operations, while similar industry is controlling air pollution sources.

(3) The control levels used might be much less than those which should be used in order to reach the necessary reduction in air pollutants.

(4) Industries that has non-dangerous pollutants or those of secondary effect, might not need control operations.

(5) Individuals might not have necessary potentials to carry out control means according to set requirements.

Therefore, social and technical authorities in the community must supervise control means of air pollution sources in the whole regions, either by national societies or by government authorities or both together.

These organisations should aim to :-

(1) Set specifications and technical measures for control operation.

(2) Examine solutions for pollution problems.

Although the private societies in the industry and trading sectors are active in holding effective seminars for cleaning the air and in demonstrating different methods for developing control means, but they will not be able to control all different problems without the interference of government authorities. The government authorities has the ability to legislative rights and to enforce control requirements which has a great effect on the polluted area. Also it specify accepted maximum pollution levels (degrees) which guarantees good health and welfare for all citizens. Therefore, the control of air pollution is the responsibility of the government as well as the individuals.

The concerned government authorities carries out a program which is suitable for the country's needs and potentials. The characteristics of this program are as follows (Abdel Salam, 1978):-

(1) To specify and estimate the size of the air pollution general and private problems in the community.

(2) To set levels for maximum degrees of accepted pollutants concentration, and to issue decrees to be applied on all pollution sources aiming to control air pollution.

(3) To record pollution sources found in the community in order to estimate the actual effect of pollution and to decide :-

    (a) The need for prevention and solutions

    (b) The expected pollution possibilities

    (c) The relations between pollutants and their concentrations in the atmosphere

    (d) The subjective basics of the legislation articles concerning the protection from pollution.

(4) To permanently enforce control levels on all pollution sources in order to achieve the possible minimum pollution and to find solutions for air pollution problems.

The treatment of different air pollution problems is controlled by various factors and not necessarily the academic method. The treatment of these different sources is controlled by surrounding obstacles, thus it is treated by confronting the problems and not the industries.

The general view of the people whom are directly connected with solving dangerous and general problems could share effectively and wisely in solving the problem.

2. ACCEPTED LEVELS

The amount of possible air pollutants levels, is not yet agreed upon internationally, also many of the nations did not succeed in setting unified levels for air property in their various parts. This is because the air is controlled by various factors which differs from one place to the other and from country to another. The different environmental aspects, social standards, nutrition habits, and other factors play a role in estimating these amounts for each country.

On the other hand, a number of levels were set to protect plants, animals and materials. Also few countries did set levels aiming to protect human beings.

The majority of published levels on average air pollutants concentrations during one day for the protection of human beings, are in the range of 1 to 5 of the accepted maximum concentration degrees, for pollutants in working environments.

Some of those concerned with the science of air pollution, suggested considering a 3.3% of maximum concentration degree as accepted for these pollutants in working environments, and to re-evaluate these degrees whenever results of studies,

researches or experiments are known in this field (Stern, 1976).

This is essential if the decision for American levels of maximum concentration degrees in the working environments, is a warning as not to use these degrees or even re-adjust them to be used in estimating or protecting from external pollution.

3. ABU DHABI EMIRATE'S TLV

It is essential to mention that the American levels of maximum concentration degrees apply basically to the American society. Attempts to enforce the same limits on the society of the Emirate should be discouraged, in view of the large difference in topography, social habits, working conditions...etc. What should be done is to consider the American system as basis of guidelines and to modify, add or eliminate whatever necessary parameters to apply to our own environment.

Currently, there is no legislation for the protection and management of the atmospheric environment in the Abu Dhabi Emirate. However, the Abu Dhabi Municipality has proposed a set of guidelines for a number of air pollutants for which there is a potential for concern in Abu Dhabi Emirate. Available standards are given in Table (29).

TABLE (29)
The Proposed Maximum Emission Limits for Air Discharge in Abu Dhabi Emirate

POLLUTANT	STANDARD APPLICABLE TO	STANDARD
Smoke	All stationary fuel burning sources	Ringlemann no. 2 or equivalent opacity (not to exceed more than 5 minutes in any period of one hour)
Solid particles	Any trade, industry plant fuel burning equipment	0.25 gm/Nm^3 (Corrected to 12% CO_2)
Sulphuric acid mist or sulphur trioxide	Any trade, industry, or process (other than combustion processes and plants for the manufacture of sulphuric acid	0.10 gm/Nm^3 as sulphur trioxide
Acid gases	Any trade, industry, or process in which sulphuric acid is manufactured	3.0 gm/Nm^3 as sulphur trioxide
Fluorine compounds	Any trade, industry, or process in the operation of which fluorine, hydrofluoric acid or any inorganic fluorine compounds are emitted	0.10 gm/Nm^3 as hydrofluoric acid
Hydrogen chloride	Any trade, industry, or process	0.20 gm/Nm^3 as hydrogen chloride
Chlorine	Any trade, industry, or process	0.20 gm/Nm^3 as hydrogen chloride
Hydrogen sulphide	Any trade, industry, or process	5 ppm as hydrogen sulphide gas
Nitric acid or oxides of nitrogen	Any trade, industry, or process in which the manufacture off nitric acid is carried out	3.0 gm/Nm^3 as nitrogen dioxide
Nitric acid or oxides of nitrogen	Any trade, industry, or process other than nitric acid plants	1.0 gm/Nm^3 as nitrogen dioxide
Carbon monoxide	Any trade, industry, or process	25 gm/Nm^3 as carbon monoxide
Copper and its compounds	Any trade, industry, or process	20 mg/Nm^3 as copper
Lead and its compounds	Any trade, industry, or process	10 mg/Nm^3 as lead

TABLE (29)
The Proposed Maximum Emission Limits for Air Discharge - Cont.

POLLUTANT	STANDARD APPLICABLE TO	STANDARD
Arsenic and its compounds	Any trade, industry, or process	10 mg/Nm^3 as arsenic
Antimony and its compounds	Any trade, industry, or process	10 mg/Nm^3 as antimony
Cadmium and its compounds	Any trade, industry, or process	5 mg/Nm^3 as cadmium
Mercury and its compounds	Any trade, industry, or process	5 mg/Nm^3 as mercury

Source : Abu Dhabi Municipality (1992)

4. SULPHUR RECOVERY IN OIL INDUSTRY

Sulphur in crude oil occurs as the particularly malodorous hydrogen sulphide and mercaptans, and as thiophenes, sulphides and polysulphides (Parker, 1978), although the distribution and concentration of these different types differ for each crude oil. The sulphur content varies according to the origin of the crude as exemplified in Table (30).

During the processing of crude oil, further hydrogen sulphide and mercaptans can be produced by the breakdown of larger sulphur-containing molecules but, in general, sulphur compounds remain distributed amongst the products in proportions which increase with increasing product boiling point and in a way which depends on the spectrum of compound types in the original crude (Parker, 1978). This is demonstrated in Table (30) for Abu Dhabi crude oil products.

TABLE (30)
Sulphur Content of Various Crude Oils in Abu Dhabi

CRUDE OIL	CRUDE DENSITY	CRUDE SULPHUR (Wt%)
ABU DHABI		
ASAB (ASB)	0.8200	0.8100
BAB (BAB)	0.8145	0.7100
BU HASA (BUH)	0.8285	0.7700
SHAH (SHA)	0.8740	1.4600
SAHIL (SHL)	0.8265	0.8500
THAMAMA C (THC)	0.7585	0.1100
THAMAMA F (THF)	0.7720	0.1300
UPPER ZAKUM (UZK)	0.8535	1.8300

Source : ADNOC (1994)

Although some of the sulphur contents do not appear high, sulphur can be a small part of a large molecule and hence the content of sulphur-containing compounds can be very large (Parker, 1978).

When sulphur removal is necessary it is normal practice, therefore to use processes which break the molecules down and remove the sulphur in the form of hydrogen sulphide rather removing the sulphur compounds themselves (Parker, 1978).

TABLE (31)
Sulphur Content in Various Refinery Products in Abu Dhabi

PRODUCT	UNIT	TOTAL SULPHUR
Jet fuel A-1 Kerosen	% mass	Max 0.30
Illumiating Kerosen	ppm/Wt	Max 3000
Low Sulphur DPK Kerosen	% mass	0.030
DPK Kerosen	% mass	0.007
Gas oil pour point+6	% Wt	Max 1.0
Gas oil pour point 0	% Wt	Max 0.5
Gas oil pour point-6	% Wt	Max 0.3
Gas oil pour point-9	% Wt	Max 0.3
Gas oil pour point+9,+3	% Wt	Max 1.0
Gas oil pour point+3	% Wt	Max 0.5
Streat Run Residue	% Wt	2.0-3.0
Liquified Petroleum Gas LPG	ppm/Wt	Max 200
Light Naphta (pentane plus)	kg/cm2	Max. 0.90
Low sulphur Naphta	ppm/Wt	Max 100
Naphta	ppm/Wt	Max 100
Low sulphur heavy Naphta	ppm/Wt	Max 100
Motor octane gas 90 Ron*	ppm/Wt	Max 1000
Motor octane gas 97 Ron*	ppm/Wt	Max 1000
Fuel oil-viscosity 180C.S	% Wt	Max 3.0
Fuel oil-viscosity 380C.S	% Wt	Max 4.0

*Ron = Research Octane Number

Source : ADNOC (1994)

4.1 The Sulphur Recovery Unit

A simplified flow diagrams for Umm Al Nar and Ruwais refineries are shown in Figs. (66) and (67), respectively. Each of the two refineries has a sulphur recovery unit operating on the basis of a modified "Claus process". Figure (68) shows a flow diagrams for two stages of the recovery process of sulphur in one of these two units.

It is common practice to recover sulphur in elemental form rather than to burn the hydrogen sulphide and release the resulting sulphur dioxide to the atmosphere through a tall chimney or stack.

In the first stage of recovery the sour fuel gas produced from the various refinery units is sweetened by absorbing the hydrogen sulphide (H_2S) in diethanol amine solution. Sweetened fuel gas is then sent to the refinery fuel gas system.

The sorbent, rich in hydrogen sulphide, is then regenerated by steam heating and stream stripping. The stripped H2S or acid gas is fed to the sulphur recovery unit to recover sulphur.

In the second stage the stripped hydrogen sulphide known as acid gas produced in the amine unit is partially oxidized by proper proportion of air in a muffle furnace into sulphur dioxide (SO_2). The remaining H_2S and SO_2 is made to react in reactors (Claus reaction) to produce elemental sulphur through two steps. The first step is a thermal reaction and the second one is a catalytic conversion :

$$1^{st} \text{ step: } 2\ H_2S + 3\ O_2 \longrightarrow 2\ SO_2 + 2\ H_2O \qquad (14)$$

$$2^{nd} \text{ step: } SO_2 + 2\ H_2S \longrightarrow 3\ S + 2\ H_2O \qquad (15)$$

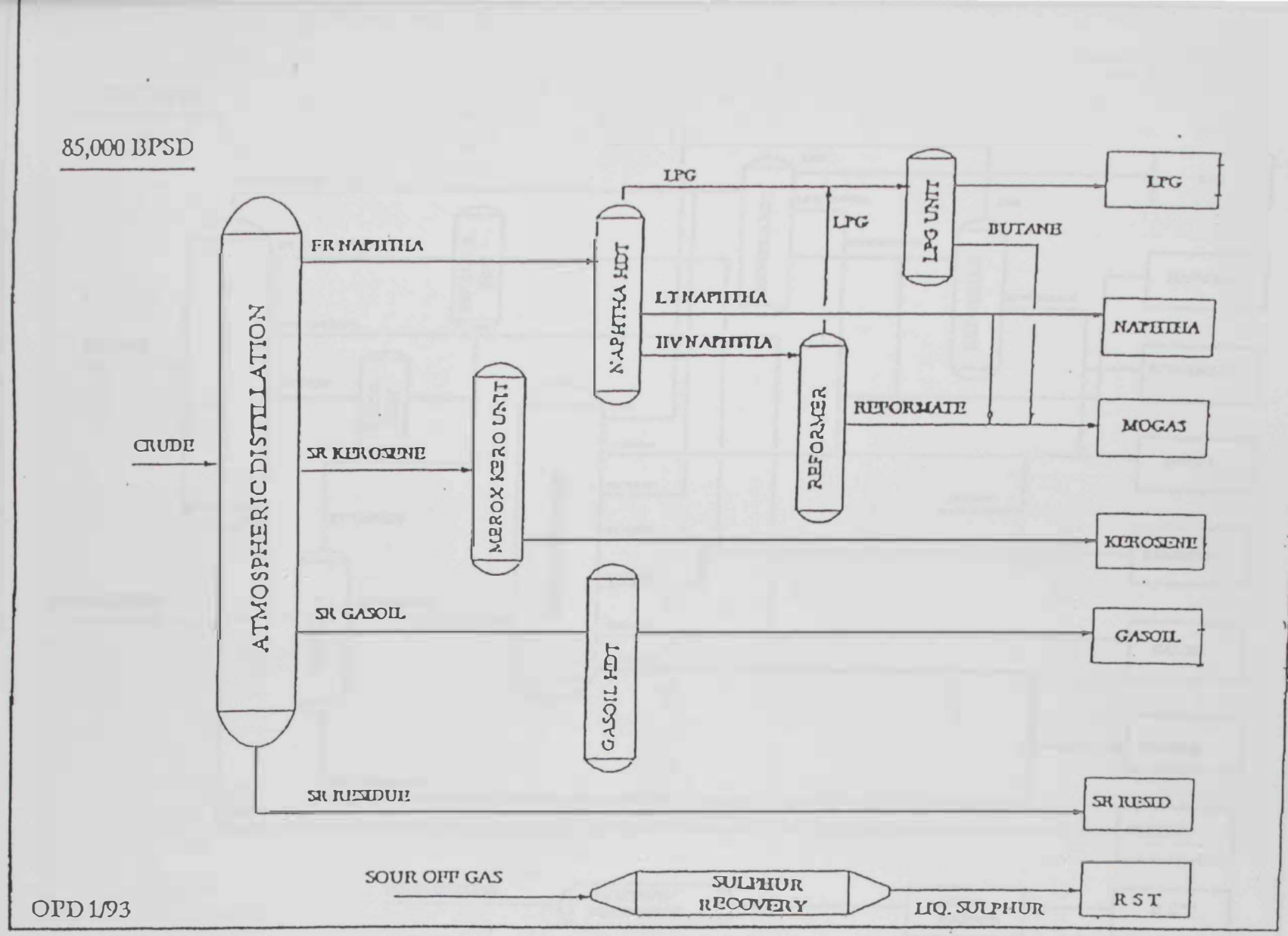


Figure (66) A Simplified Flow Diagram for Umm Al Nar Refinery

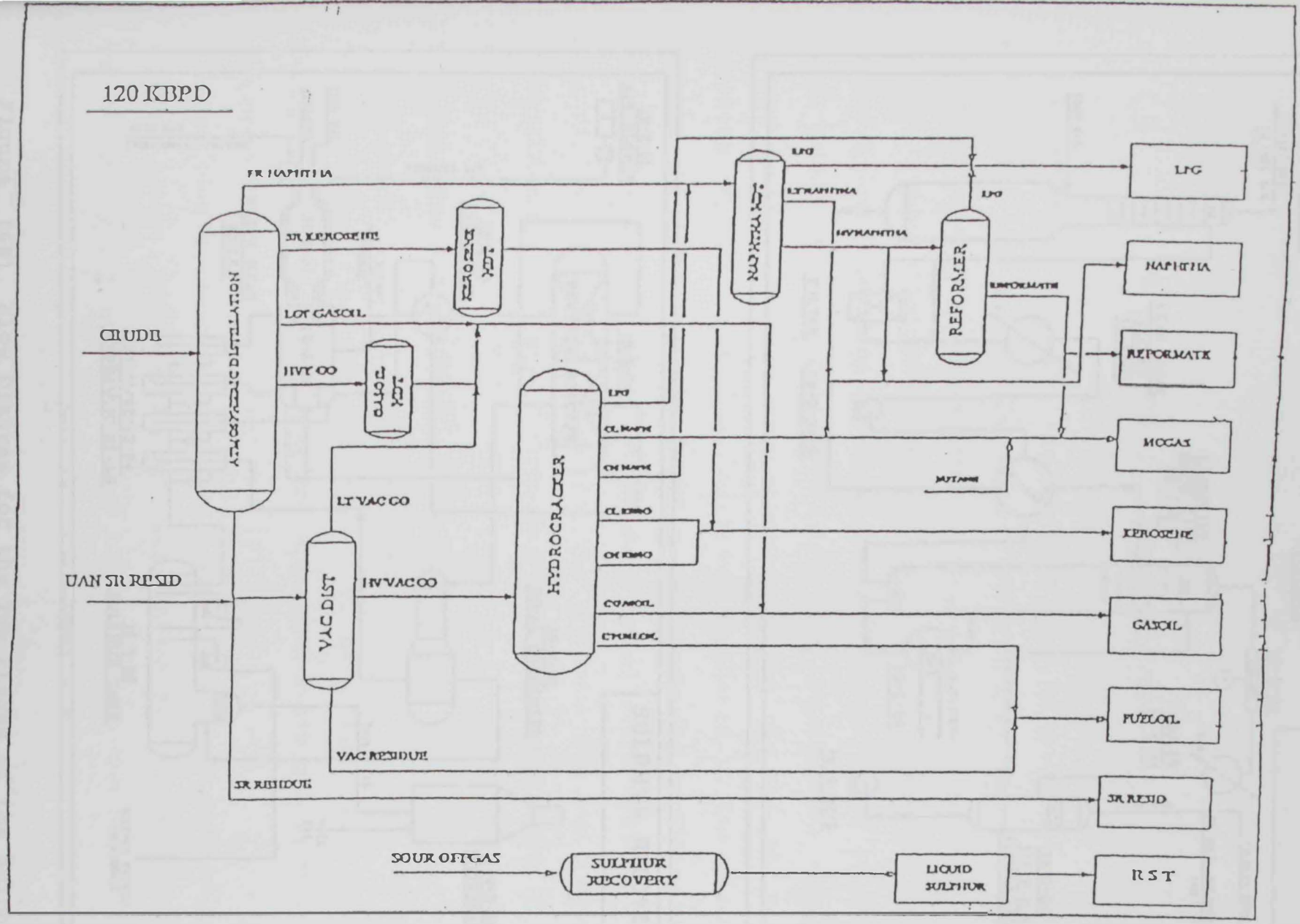


Figure (67) A Simplified Flow Diagram for Ruwais Refinery

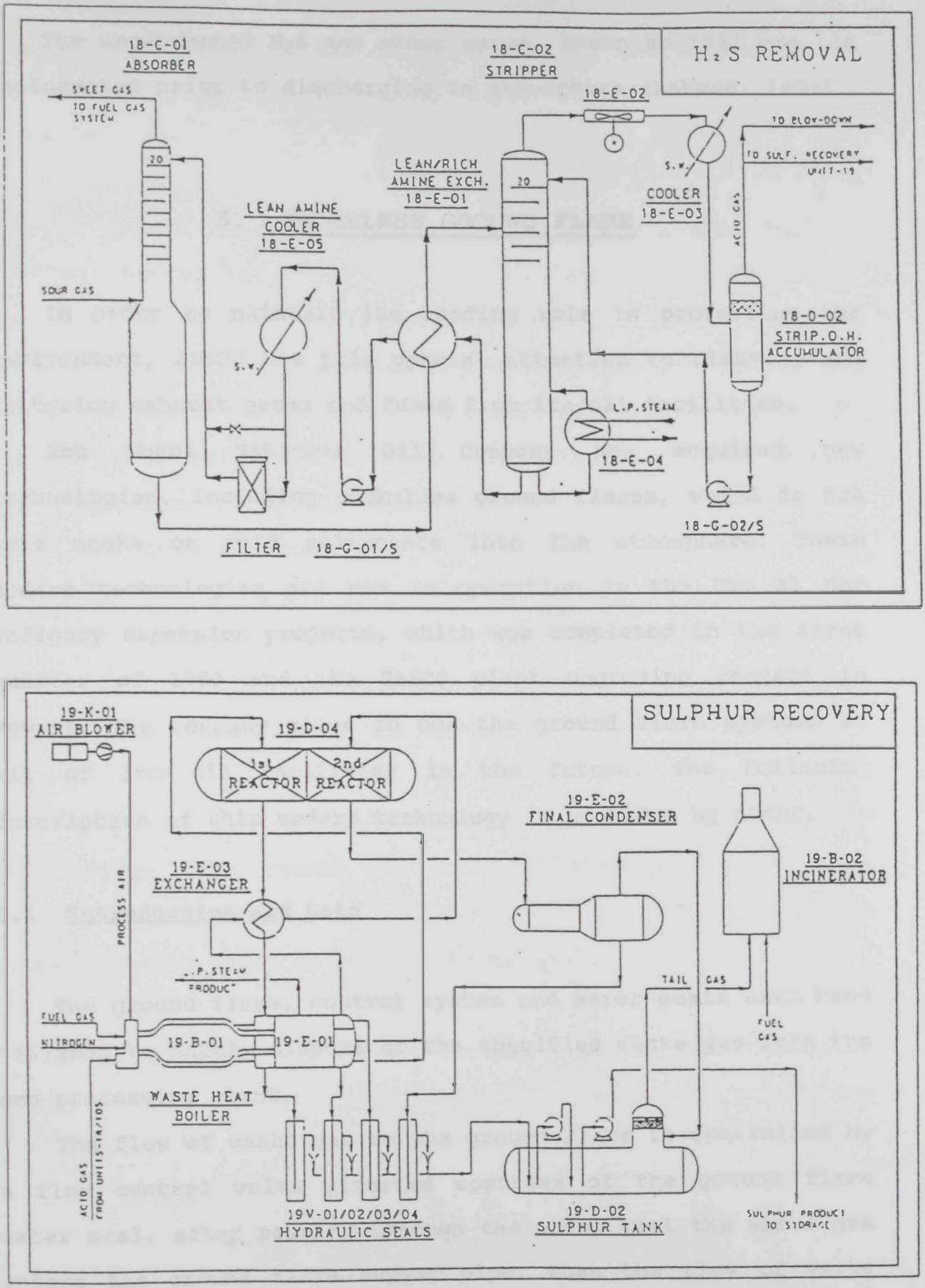


Figure (68) Flow Diagram for the Two Stages of the Sulphur Recovery Process in Abu Dhabi Refineries

The unconverted H_2S and other gases, known as tail gas, is incinerated prior to discharging to atmosphere (Rahman, 1994).

5. SMOKELESS GROUND FLARE

In order to maintain its leading role in protecting the environment, ADNOC has paid special attention to cleaning and filtering exhaust gases and fumes from its oil facilities.

Abu Dhabi National Oil Company has acquired new technologies, including smokeless ground flares, which do not emit smoke or acid pollutants into the atmosphere. These modern technologies are now in operation in the Umm Al Nar refinery expansion projects, which was completed in the first quarter of 1993 and the GASCO plant upgrading project in Ruwais. The company plans to use the ground flare systems at all of its oil facilities in the future. The following description of this modern technology is provided by ADNOC.

5.1 Introduction and Data

The ground flare, control system and water seals have been designed to safely dispose of the specified waste gas from the gas processing plant.

The flow of waste gas to the ground flare is controlled by a flow control valve situated upstream of the ground flare water seal, after passing through the water seal the waste gas enters the ground flare supply pipe. When the flow of waste gas exceeds the ground flare capacity, control valve limits

the waste gas flow to the ground flare and the supplus waste gas is diverted via a second water seal to an existing elevated flare.

The ground flare combusts the waste gas via nine burners in three stages 1st, 2nd, and 3rd, via STAGE CONTROL SYSTEM. The first stage will be in operation at all times, except in case of ground flare shut down. The 2^{nd} and 3^{rd} stages are controlled by individual flow control valves situated in the supply pipes which branch from the main/first stage supply pipe. The circular, stage burner manifolds within the ground flare are arranged with the 1^{st} stage in the single inner ring, the 2^{nd} stage and 3^{rd} stage in the two outer rings.

The ground flare is provided with three continuous pilots to light the waste gas at the burners.

The pilots are ignited from a manual electrical IGNITION SYSTEM. The pilot flames are detected by thermocouples which are located within the pilot nozzles and which transmit signals to the pilot monitoring system.

Steam is required for the smokeless flaring of the waste gases. Steam to the first stage burner is in continuous operation.

5.2 Equipment Description

Ground Flare

The ground flare is of poliedrical construction and is composed of steel wall panel sections for quick assembly at site. The panels are insulated internally with 150 mm thick castable refractory and are supported by refractory encased concrete columns. The open area below the panels acts as an air inlet for the ground flare burners. A wind shield is provided around the air inlet and this is also insulated.

The ground flare consists of three waste gas manifolds with a total of nine stand pipes for the burners. On the top of each pipe is mounted an Airfoil Flare gas ground flare burner, which is designed for pre-mix steam prior to ignition and combustion. The manifolds are arranged in three stages (sets).

Steam manifolds are positioned close to the waste gas manifolds. They are of similar configuration to the waste gas manifolds and arranged in three stages.

The outlet from the steam manifolds are connected via an offset branch to the side inlet steam connection on each stand pipe.

Waste gas manifold is provided with three pilots for the ignition of the waste gas. The pilots are positioned across the diameters of the manifolds and are located as follows:-

Pilot 1 just outside 1st stage waste gas burner

Pilot 2 & 3, just outside 2nd stage waste gas

manifold and inside 3rd stage waste gas.

All manifolds are provided with drain connections which are connected with the common drain line discharge in the drain pit.

All horizontal piping inside the ground flare chamber is covered by single (crushed stoned), to protect from heat radiation.

A central electrical control station is located close to the ground flare to provide the following:

Ignition of pilots

Monitoring of pilots

Stage control (Waste gas)

Automatic ground flare shut down on pilot failure.

Four pressure switches are located on waste gas manifold to regulate the opening of the 2nd and 3rd stages.

Flare Pilots

The ground flare is provided with three pilots, they are of the self inspirating type and utilize the gas pressure in a venturi to entrain combustion air. Sufficient combustion air is entrained to ensure the pilots remain lit even when blanketed by inert gas.

The pilot gas nozzles are provided with a flame retention system comprising of eight retention ports surrounding the main port which are enclosed within a windshield to ensure a stable flame and positive ignition even in conditions of high draught.

The pilots are lit via H.E. ignitor. Each pilot being selected via the ignition push button positioned on panel.

Pilot flame indication is generated by simplex heat resisting chromel/alumel thermocouples fitted internally within the pilot nozzle. To ensure long life they are positioned within the cool part of the flame. The millivolt signals generated by the thermocouples are fed by cable to activate trip amplifiers and give individual visual indication of pilot on/off condition at the ignition station. Volt free contracts are also supplied for remote pilot flame off or power failure indication.

Water Seal

The water seal is located upstream the waste gas train valve.

During operating of the water seal some water will be displaced, collected in the over flow weir and will be drained via an over flow drain loop. The over flow drain loop should not be allowed to run dry as this will otherwise allow the flare gas to escape or allow the air to enter the flare system. During commissioning, the seals should be filled with water and the water flow should be maintained until it is seen to be discharging from the overflow drain loops.

The water seal is provided with the facility to drain the water out of the water seal during periods of maintenance. At all other time the water should not be allowed to drain and the valves V 501 should be kept closed.

The water seal is fitted with level control to indicate the water levels which must be connected to the control room alarm system. This instrument (LIC 201) is connected with

control valve LV 201 to maintain the constant level of water in the water seal.

The water seal is also provided with reflex type level gauge to indicate the position of the water level locally.

Manual electric ignition panel and control system

The manual/automatic electric ignition panel is designed for hazardous area operation. The H.E. transformer is used to ignite the pilots.

The ignition panel is provided with main switch.

Operating mode

When the ignition panel selector switch is switched the panel is ready for ignition.

Select which pilot is to be lit check that the power is on and the gas pressure is suitable for ignition.

Press pilot start push-button on ignition pulse generator to produce a spark in the pilot nozzle. This procedure should be repeated until all the pilots are lit.

The pilots can only be extinguished by shutting the manual isolating valve located on ignition panel.

6. CEMENT DUST COLLECTION

Cement making is inevitably a dusty business, as it is much concerned with hot dry powders, or materials containing a proportion of fine dry particles. Dust can escape through the main chimney, through a number of subsidiary venting points,

from items of plant, and from conveying systems. The extent to which it is contained depends much on the choice of efficient plant to collect dust wherever air or gas is emitted, and it also depends very much on the overall plant layout, where the aim is to reduce to a minimum the number of transfer points on conveyor systems carrying potentially dusty materials, such as dry raw materials, clinker and cement. It is also very much a function of the way in which not only dust arrestment but all plant in the cement works is maintained (Parker, 1978).

Cement dust is not a toxic substance. However, when discharged in large quantities to the atmosphere, it can combine with other air contaminants to aggravate respiratory ailments and cause significant damage to plant life (Hindy and Attia, 1993).

The collection of cement dust from the various emission sources, particularly from rotary cement kilns has long been a difficult problem. The difficulty arises from the large volumes of gas involved, the heavy loading of very fine particles, the high gas temperatures, and in case of wet-process kilns, the presence of a large amount of water vapor. Electrostatic precipitators and fabric filters are the only collection devices capable of achieving the high degree of dust removal required (99±%) from the kiln gases.

6.1 Electrostatic Precipitators

Historically, electrostatic precipitators have been the predominant choice by the cement industry for dust removal from kiln gases. The electrostatic precipitation process has

been applied industrially in cement factories for well over half a century.

The electrostatic precipitator makes use of the fact that electrically charged particles subjected to an electrical field are attracted towards, and deposited on, the electrodes creating the field. The separation of the suspended particulate matter from the gas stream requires three fundamental steps:-

1. Inducing an electrical charge on the suspended particles.
2. Collecting the charged particulate matter on a grounded surface.
3. Removing the collected material from the electrodes to a storage hopper from which it may be withdrawn continually or at intervals.

The charge is applied by passing the suspended particles through a high-voltage, direct current corona. The corona is established between an electrode maintained at high voltage and a grounded collecting surface. The particulate matter is disloaded from the collecting surface by mechanical means, such as vibrating with rappers. The collected particulate material falls to a hopper from where it is removed by mechanical means. Figure (69) illustrates a typical electrostatic precipitator, whereas Fig. (70) shows two views of an electrostatic precipitator unit installed on a kiln at one of the cement factories in United Arab Emirates, and Fig. (71) clarify the difference in the stack emission before and after the electrostatic precipitator operation at the same cement factory.

6.2 Fabric Filters

Filtration is the oldest and generally one of the most reliable of the many methods by which dusts, mists and fumes may be removed from gases. Filters are especially desirable for extracting particulate matter from gases produced by industrial operations since they generally give very satisfactory collection efficiencies with only moderate power consumption (Stern, 1976).

The main constructional elements of the pulse-jet fabric filter, which are the same for all filter types, are shown in Fig. (72). The dust-laden gas enters in the lower part of the filter housing and passes from the outside to the inside of cylindrical bags held open by interior metal cages. The dust-laden gas is separated into clean gas and dust on the filter bags. The dust accumulates within the fabric and on the outer surface of the filter bag, whereas the cleaned gas passes out the top of the bag. Many bags operate in parallel if the gas flowrate is large. Bags are cleaned in groups by a momentary pulse of compressed air introduced at their tops through a venturi. The air pulse snaps the bags open and drives large particles and agglomerates away from the bag surface into the dusty gas stream, from which they fall into the dust hopper,. Usually, the bags are cleaned on-line, that is, while process gas flows through adjacent bags (Hindy, 1989).

Pulse-jet cleaning technique has seen increased application in many types of fabric filters manufactured in the last two decades. Nearly every large manufacturer of fabric filter equipment offers at least one model cleaned by

this cleaning process. Several characteristics of pulse-jet cleaning make this system very attractive for a large number of applications. For example, because the pulse of high pressure air is brief, typically 0.1 second in duration, the primary air flow does not have to shut off during the cleaning. Instead, the pulse temporarily reverses the flow through the fabric due to the transient reversal of pressure gradient. The particle agglomerates dislodged by the pulse and reversed flow are sufficiently large so that much of the dust can settle to the hopper during the brief interruption of filtration. Thus, the equipment operates essentially on a continuous basis and with almost no moving parts except for solenoid valve elements (Hindy, 1989).

Continuously rated fabric cleaned by pulse-jet are now widely applied for many types of dust and fume control in industry, especially since the enaction of laws for the protection of the environment. Fabric filters are now the most effective dust removing devices, especially for sub micrometer particles. For a long time, it has been an accepted fact that fabric filters cannot be applied in some industries, e.g. steel industry, foundry industry, cement industry, and power stations, because most dust present in the waste gases has a diameter smaller than 1 μm. The recent successful introduction of fabric filters in these industries is, therefore, an important contribution to air pollution control (Hindy, 1989).

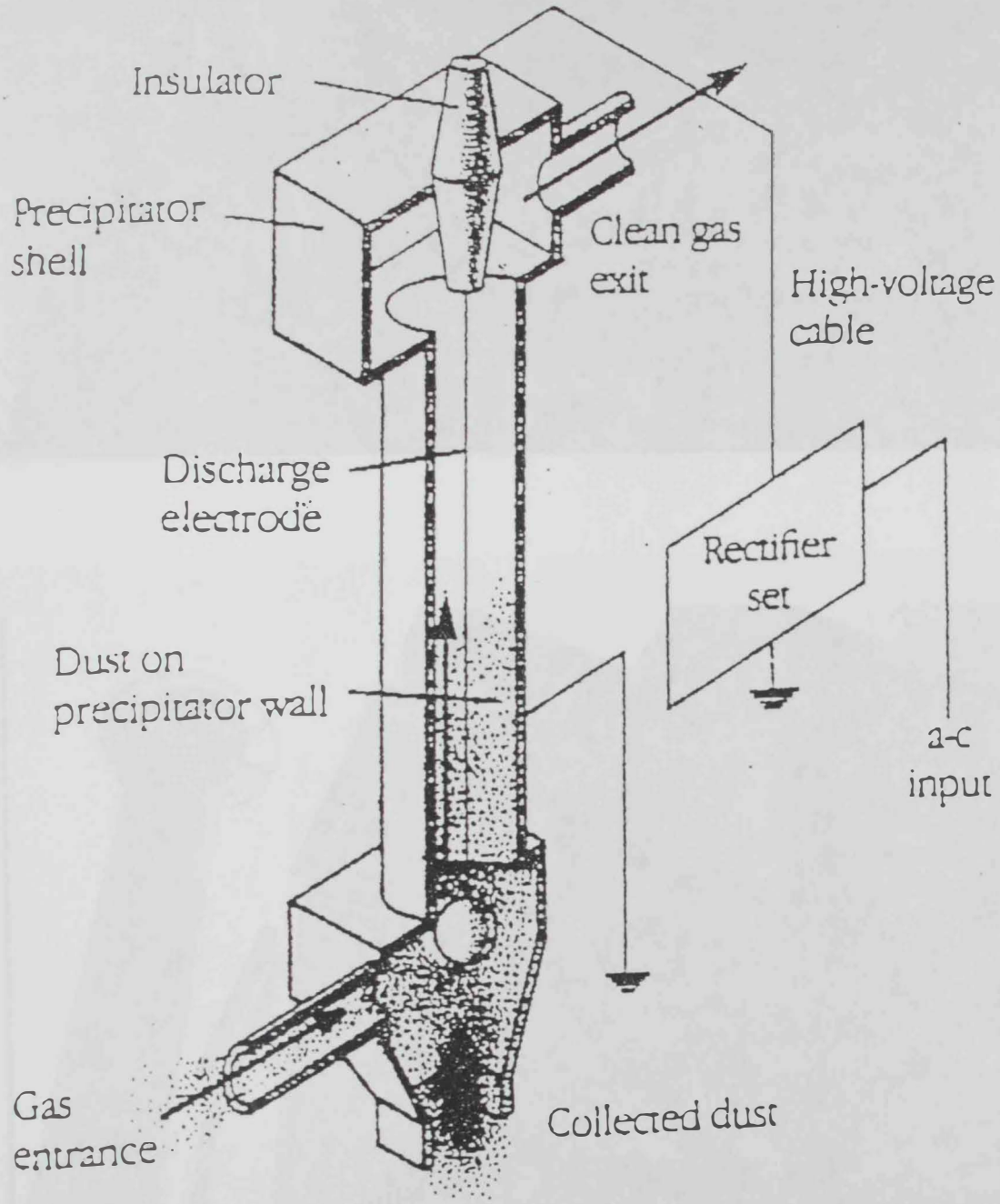


Figure (69) Diagram for A Single Electrode in Electrostatic Precipitator
(After Chiras, 1991)

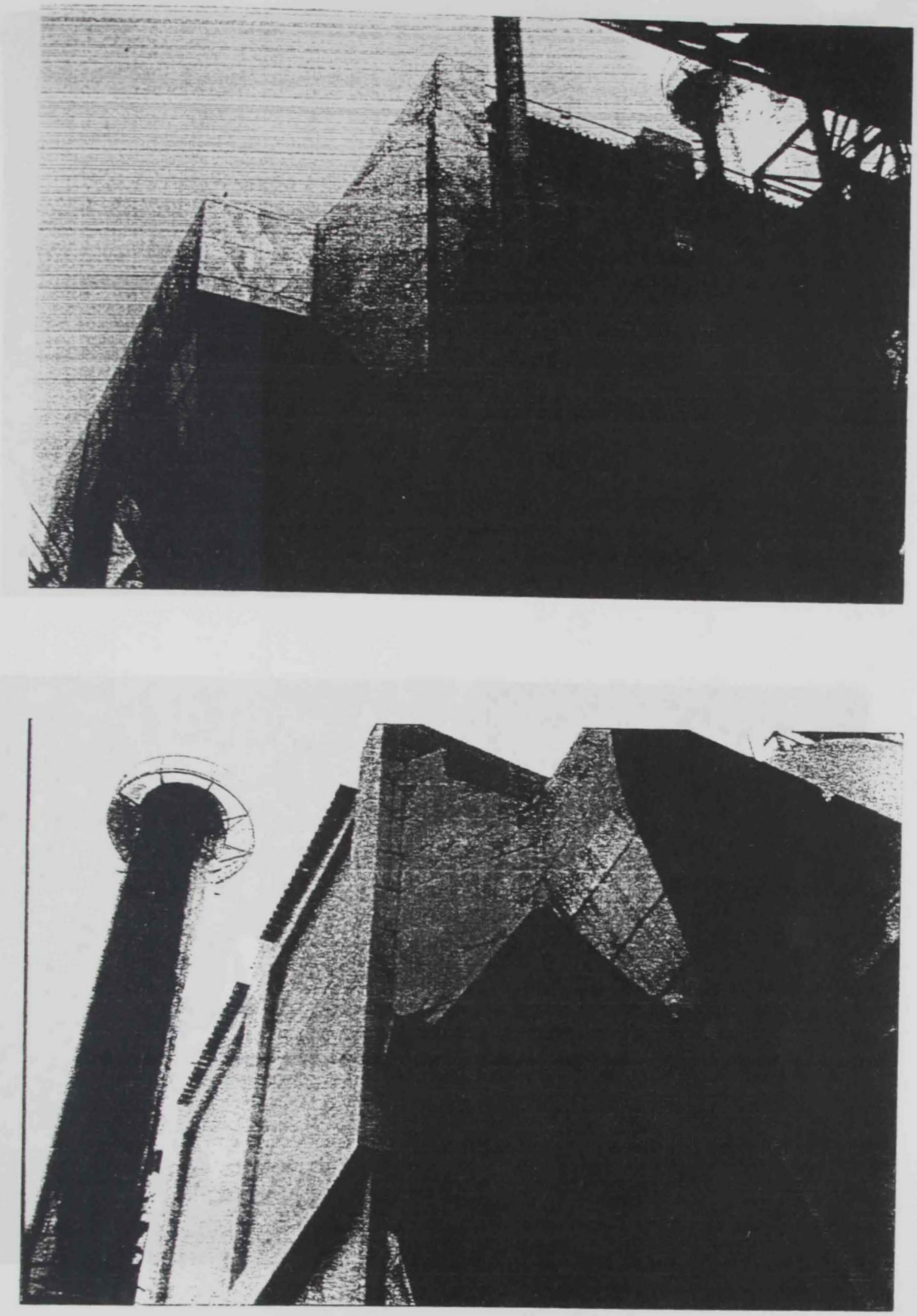


Figure (70) Two Views of Electrostatic Precipitator Installed on A Kiln at a Cement Factory In United Arab Emirates

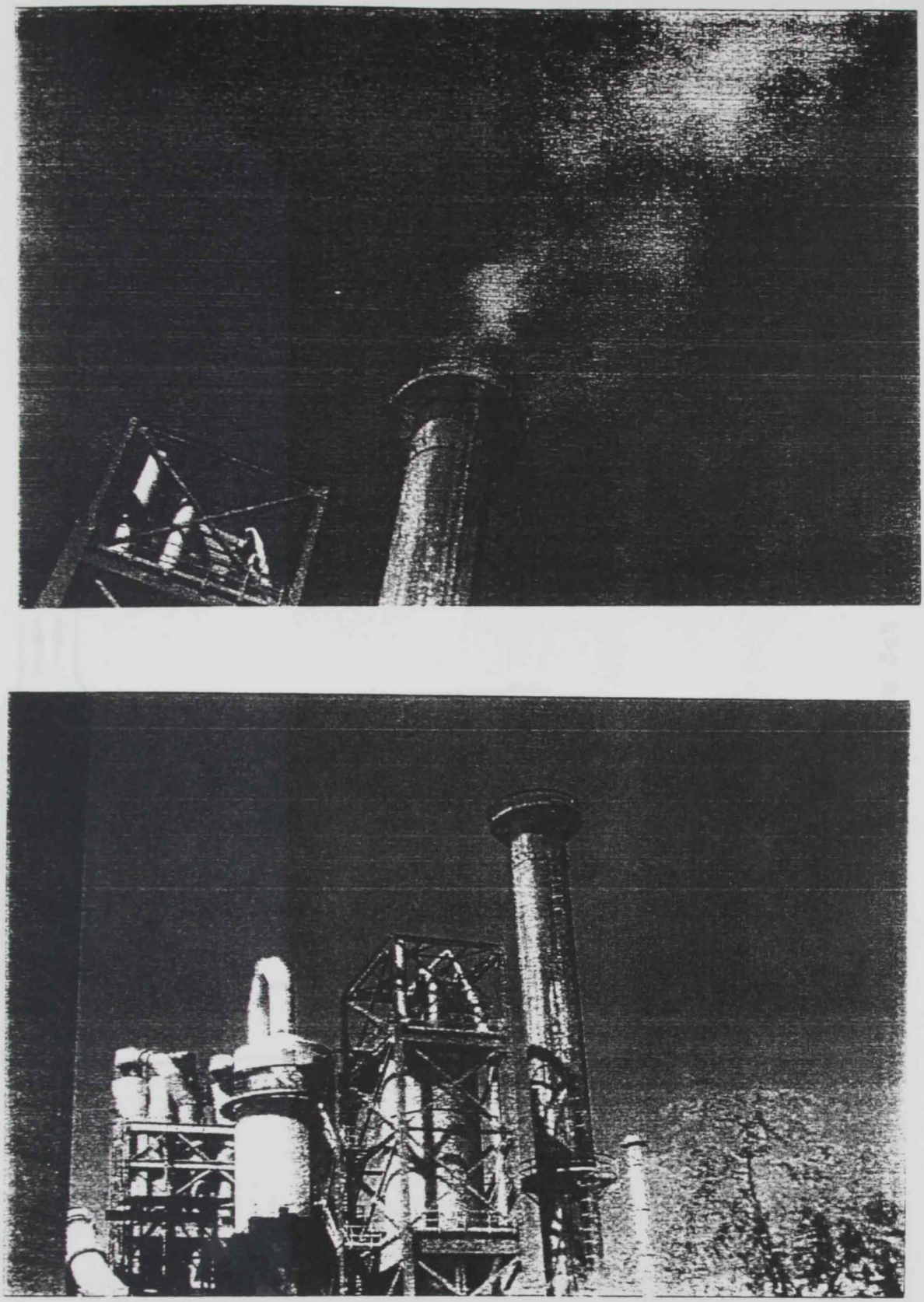


Figure (71) Stack Emission Before (B) and After (A) Electrostatic Precipitator Operation at A Cement Factory in United Arab Emirates

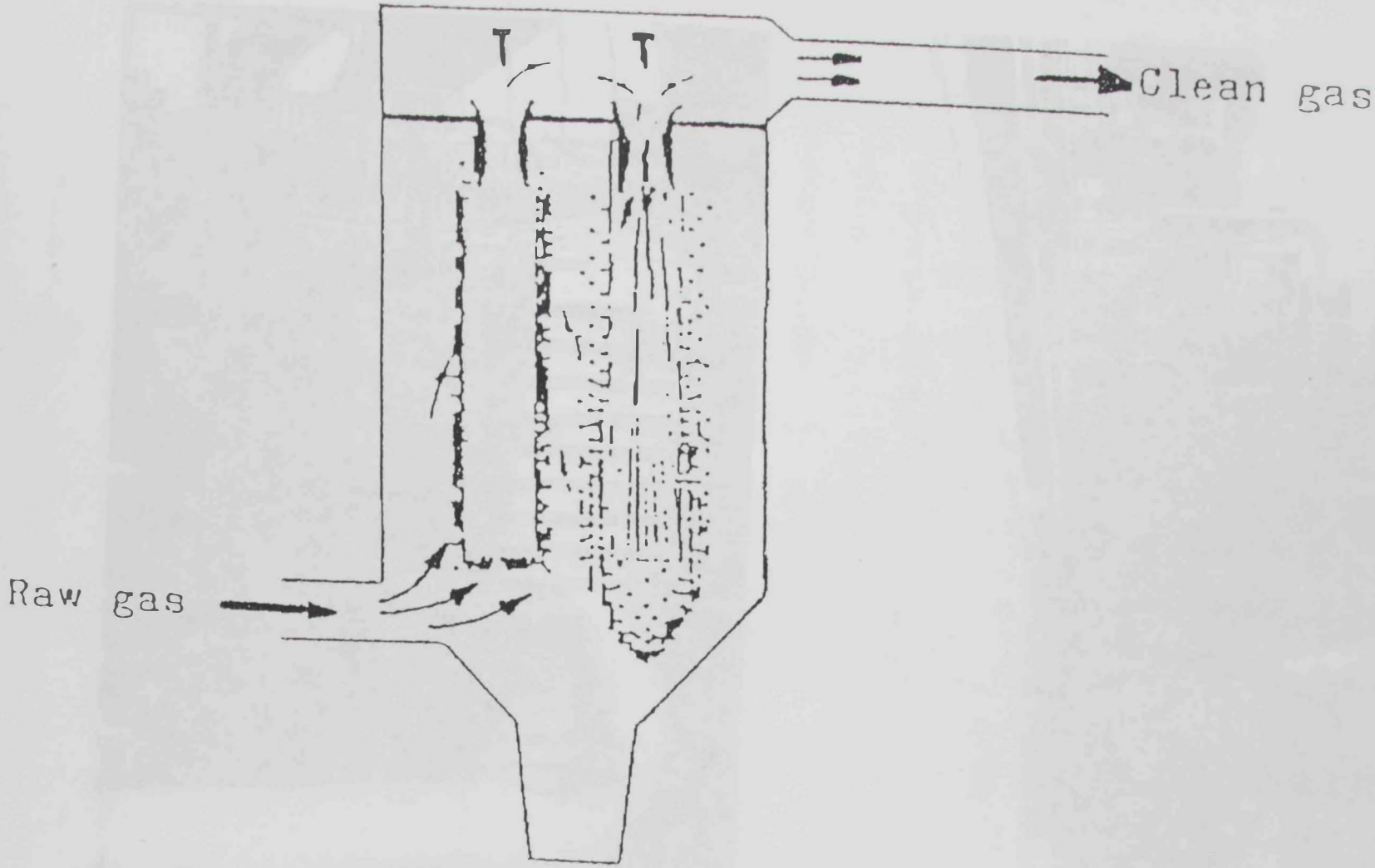
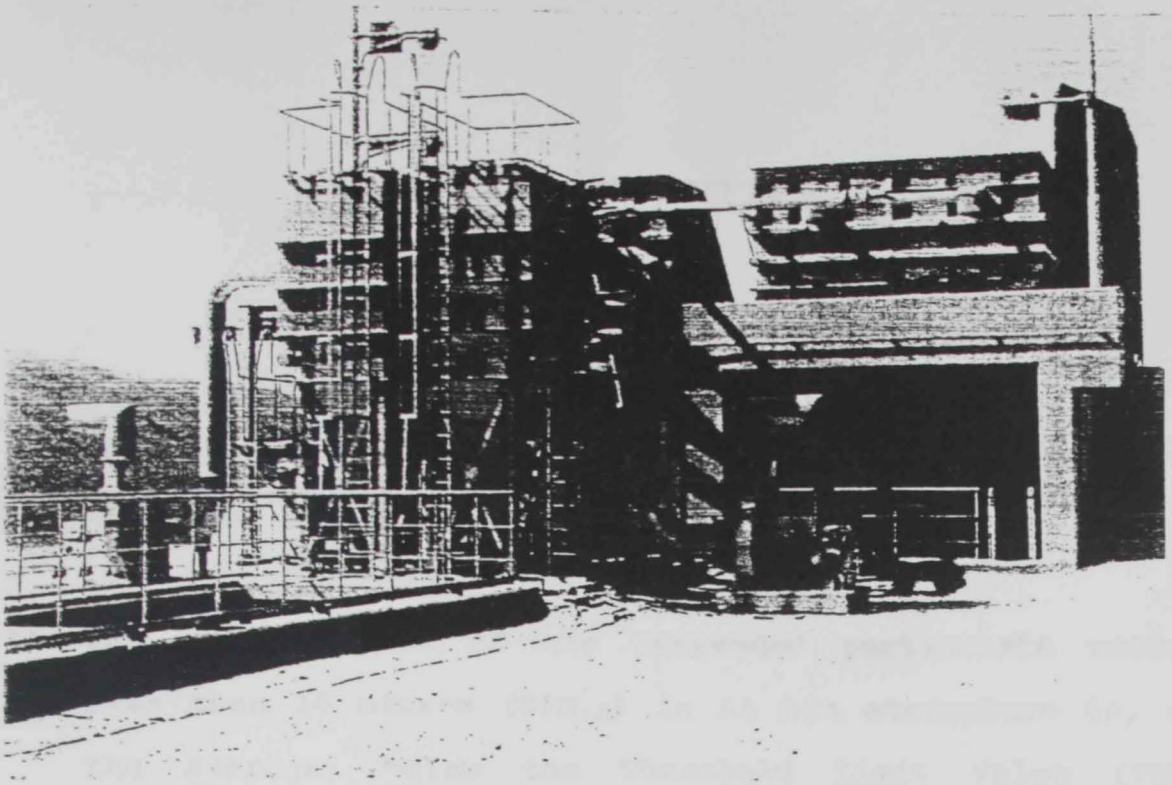


Figure (72) Schematic of Pulse Jet Fabric Filter



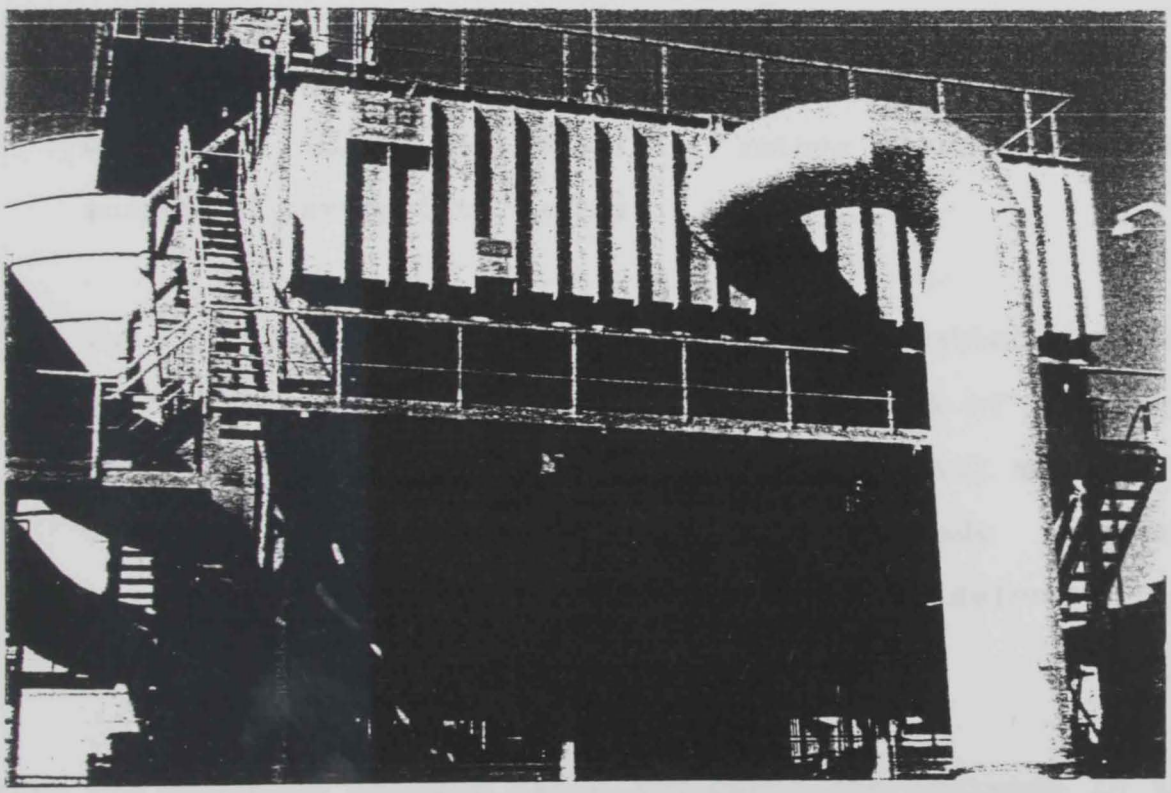


Figure (73) Two Types of Fabric Filters Installed on Cement Mills at Two Cement Factories in United Arab Emirates

CHAPTER VIII

SUMMARY AND CONCLUSIONS

Through presenting and discussing the results of this investigation, it has been well acknowledged that :

(1) The concentration of the suspended particulate matter less than 10 micron (SPM_{10}) in Al Ain atmosphere is, on the average, below the Threshold Limit Value (TLV) according to the U.S. National Ambient Air Quality Standards (NAAQS).

(2) The problem of particulate pollution in Al Ain is concerned with the dustfall rather than with the suspended particulate matter.

(3) The effective sources of particulate matter in the atmosphere of Al Ain are found to the south of the city. These sources are mostly natural ones (crustal materials) with a minor contribution of man-made sources, particularly automobile traffic emissions and agricultural activities.

(4) The movement of dune sands and hence the increase in the atmospheric contamination with SPM_{10} is highly affected by the winds blowing from the southern direction.

(5) Diurnal variation of SPM_{10} in Al Ain atmosphere shows the same basic rhythm, having one maxima at the end of night (4 a.m.) and another one maxima in the evening (8 p.m.), but with higher concentrations due to the effect of the temperature inversion characterizing the Gulf region.

(6) The dust storms in Al Ain are reasonably defined in terms of a visibility less than 5 km.

(7) The acid gases, sulphur dioxide (SO_2) and nitrogen oxides (NO_x) concentrations in the atmosphere of Abu Dhabi City are less than the U.S. National Ambient Air Quality Standards (NAAQS).

(8) There is a relatively strong inverse relationship between SO_2 and NO_x and relative humidity levels in the atmosphere of Abu Dhabi City due to the conversion of SO_2 to sulphuric acid (H_2SO_4) and NO_x to nitric acid (HNO_3).

(9) Nitrogen oxides in the atmosphere of Abu Dhabi City tend to be in the form of nitrogen dioxide (NO_2) and to a lesser degree in the form of nitric oxide (NO).

(10) Suspended particulate matter less than 10 μm (SPM_{10}), ozone (O_3), carbon monoxide (CO), and non-methane hydrocarbons (NMHCs) levels in the atmosphere of Abu Dhabi City are less than the U.S. National Ambient Air Quality Standards (NAAQS).

(11) Although ozone is found in the atmosphere of Abu Dhabi City in concentrations below the background levels, it originates in the form of a secondary photoxidant through atmospheric photochemical reactions.

(12) Most of NO entering the atmosphere of Abu Dhabi City from pollution sources consumes most of O_3 to be oxidized to NO_2.

(13) Weekends at residential areas in Abu Dhabi town are characterized by lower levels of SPM_{10}, O_3, CO and NO_x than workdays due to the high reduction in the pollution sources associated with the human activities, chiefly motor vehicles during Fridays.

(14) Weekends at residential areas in Abu Dhabi town are characterized by higher levels of methane hydrocarbons (MHCs) than workdays.

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