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COMPREHENSIVE INVESTIGATION OF SOLID AEROSOLS IN FAISALABAD (PAKISTAN) ATMOSPHERE

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ABSTRACT

The results obtained from an investigation of solid aerosols in the Industrial city of Faisalabad (Pakistan) are reported and analysed in this paper. X-ray diffraction studies of the various solid aerosols zones (residential, industrial / traffic and commercial zones) showed that non-clay minerals such as quartz, calcite and albite are contained in most of the samples in almost comparable amounts. Chemical analysis of some samples was carried out for complementing the X-ray diffraction data. The amount of quartz in the samples of industrial zones/ traffic zones was found to be IN an order of magnitude more than in the samples of relatively residential zones. As the dust particles of these compounds are poor substrate for promoting nucleation of ice in the atmospheric clouds, they are liable to stay steadily in the atmosphere as pollutant. The results of Solid aerosols collected from various sites show that the sources of quartz, calcite and albite in the Solid aerosols are both local and remote.

Key words: solid aerosol, calcite, quartz, albite, magnitude, pollutant, residential zone, and remote, urban, X-ray diffraction.

INTRODUCTION

Solid aero sols in the atmosphere comes from many sources, namely, the dust blown off the earth's crust, the gases released into the air by burning fuel and the waste created by man. The Solid aerosols therefore cause pollution, which threatens life on the planet including man's own existence. The study of Solid aerosols has become an active field of research in the modern world (Bhaskar, 1994).

Recently a global air monitoring programme for the study of SPM (suspended particulate matter) was conducted by the World Health Organization as a part of the Global Environment Monitoring System (GEMS). Some 50 countries participated in the GEMS air-monitoring project and data were obtained approximately at 175 sites in 75 cities around the world. The results of this study reported by Bennett *et al*. (1985) and de Koning *et al*. (1986) showed that Teheran, Bombay and Calcutta are the most polluted cities in Asia. This study also indicated, though not supported by sufficient data, that Faisalabad in Pakistan is also emerging as a highly polluted city.

Aim of the Study:

Comprehensive analysis of solid aero sols can be assessed only on the basis of adequate data collected at properly selected sampling stations, using well defined sampling procedures along with analytical techniques It is preferable to conduct both physiochemical and biological monitoring and correlate their results to evaluate an integrated approach for air pollution control. Keeping in view these facts it was imperative to study the physiochemical composition of solid aerosols collected from Faisalabad environment so as to ascertain their contributions to over all pollution in Faisalabad. This situation motivated us to start a study on the air pollution in the area. As a first step, a Solid aerosol was collected from various zones in the city and was subjected to phase/compound analysis by x-ray diffraction. Wet chemical analysis of a few samples was also carried out for supporting the x-ray diffraction results. It is hoped that this study will be very useful towards the future environmental study programs related to Industrial areas cum commercial areas like Faisalabad. (Shahida, 2000..and Tossavainen, 1979).

MATERIALS AND METHODS

Faisalabad is the third largest industrial city in Pakistan. With an estimated population of almost 4 million citizens. It is an important center for industrial production and is located in the Punjab province. The district lies between East longitudes 73° and 74^{o} and North latitudes 30° and 31.15°. Gujranwala and Sheikhupura districts bound it in its North. The district is a flat alluvial plain formed by Chenab and Ravi rivers. The Ravi flows along the Southeastern boundary of the district. The land close to the river is relatively much fertile than that away from the river. The area is exceptionally favorable for canal irrigation. There is no interruption in the monotony of the plain and the lands fall to only 55 meters from North-East to the South-West of the district. A general elevation of the land comprising of Faisalabad district is about 150 meters above the sea level. The climate of the district is hot and dry. Its mean maximum and minimum temperatures in summer are about 39°C and 27°C and in winter about 21°C and 6°C respectively. Its summer season starts almost from the end *of* March and stretches up to October. May, June and July are the hottest months. The winter months are November, December and January, December and January are the coldest months. The rainy season is from July to September, July and August receives more rains than any other months of the year. Most of the winter, rain falls in the months of January, February and March. The mean minimum humidity in winter ranges from 46.9% in March to 54.5% in December while the mean maximum humidity in summer ranges from 57% in May to 79.5% in August. The mean maximum humidity in rainy season is 77.7% and the mean minimum humidity in rainy season is 59.9% (Source; Meteorological Cell Department of Crop Physiology U. A. F. 2005)**.** Faisalabad district has made rapid strides in the field of industry after independence. It is now called "the Manchester of Asia" for its extensive development of textile industry. The development has been made possible by the continued efforts of pioneering entrepreneurs as well as workers over a period of four decades. Before independence, there were only five industrial units in Faisalabad (Then Lyallpur). Now, there are dozens of textile mills with others subsidiary units. Total (50) SPM (suspended particulate matter) samples were collected from different sites of Faisalabad city using SYNTAX MAP MATHOD. Roughly, there are more than 512 large industrial units out of witch 328 are textile units, 92 engineering units and 92 of chemicals and food processing units other industries include hosiery, carpet and rugs, nawar, and lace, printing and publishing and pharmaceutical products etc. there are also some 12000 house- hold industries, which include some 60,000 power loom factories.

ZONE CLASSIFICATION

The city was divided into three zones, Zone I (Trafic/Industrial Zone), Zone II (Safe Zone), Zone III (Residential/Commercial Zone). Most of the area under consideration belongs to city center while remaining area was situated at (10-15) Km away from city center.

SAMPLE COLLECTION

Kimoto High Volume air sampler was used for the collection of suspended particulate matter in the atmosphere of randomly selected areas of Faisalabad city. The high volume air sampler used to pump large volumes of air up to 2000m^3 at a rate of 0.8. m^3/min. The filter used in a high volume air sampler was glass fiber filter. Which have a collection efficiency of 99% for particles. Samples were collected for a period of 12 hours (720 minutes) at an average flow rate of (0.8 m^3 min). Particulate matter was trapped on each filter. Triplicate samples were collected from each place-

SAMPLING MECHANISMS

Kimoto high volume air sampler was used for the sampling purpose. A high flow rate (0.8 m^3 min^{-1}) draw the air sample through a covered housing 20 x 25 cm rectangular glass fiber filters. The covered housing necessary to protect the filler from precipitation and falling debris. Glass fiber filter was used because of their gradual head loss build up characteristics and non-hygroscopic properties. Contamination or damage to filter was avoided while inserting or removing them from the sampler. On removing from the sampler it was folded in such a way that surface containing the deposits faced each other. The filter was weighed before and after sampling.

PHASE/COMPOUND ANALYSIS

Phase/compound analysis of the Solid aero sols were carried out by employing an automated powder x-ray diffractometer (Rigaku model D/MAX-II A) which is equipped with a scintillation counter and a pulse—height analyser. The electronic circuit panel of the diffractometer is capable of computing Bragg angles (2θ), d- spacing, and peak height and peak width at half-maximum intensity.

In the powder x-ray diffraction method, a very fine powder having particle/crystallite size of less than 10 μm is placed in a monochromatic x-ray beam. Each crystallite of the powder is a tiny single crystal, oriented randomly with respect to the incident x-ray beam. Just by chance, some of the crystallites will be correctly oriented so that their similar lattice planes can reflect the incident beam. Other crystallites will be correctly oriented for reflections from another set of lattice planes and so *on.* The result is that every set of lattice planes will be capable of reflection. The powder x-ray diffractometer gives reflections from all the possible sets of lattice planes of a crystallographic material. The set of reflections so obtained, called a diffraction pattern a plot between the Bragg angles and the integrated intensities of the corresponding reflections is a characteristic of the material. The phases / compounds present in a sample could therefore be identified from their characteristic x-ray diffraction patterns.

The x—ray diffraction results reported in this study were obtained by running the diffractometer in the step—scan mode with the diffractometer conditions Table 1). The diffraction data (Bragg angles, d-spacing, and integrated intensities) were obtained with the step size of 0.02° (2θ).The quality of the pattern was found to decrease with the step size of larger or less than 0.02". The peak positions *(2θ* angles) and d-spacing obtained with the step size of 0.02^o were found to have the best accuracy.

Table 1. Diffractometer conditions used for analysis.

Parameter used	Setting value
X-Radiation	Cuk_α (NI-Filtered)
X-Ray Tube Voltage and Current	35 KV & 20 m A
Divergent and Anti-scatter slits	1^o
Receiving Slit	0.13 *mm* & 0.3 mm
Goniometer Scanning speed/step width	1^{o}min^{-1}/0.02^o
Rate meter time constant	1 sec.
Detector	Scintillation Counter
Start angle	65^o (2Θ)
Stop angle	3^o (2Θ)

The peak intensity, peak width at half maxima, d –values and Bragg angles were also noted using XRD x ~ y plotter during the step-scan mode. The relative intensities values were calculated for the above materials and presented (Table 2).

Table 2. Relative intensities of spm minerals with KCI.

COMPOUND/MINERAL	RELATIVE INTENSITY (kl $=I_i/I_{kcl}$)
Q	0.85
IL	0.20
T	0.32
G	0.83
CH	0.23
AL	0.36
C A	0.74
HM	0.89
HL	0.65
SP	0.49
MU	0.70
WS	0.16
R	0.27
AN	0.65

Q = Quartz, IL = Illite, T = Talc, G = Gypsum, CH = Chlinochlore, AL = Albite, CA = Calcite, HM = Hematite, HL = Halite, SP = Sphite, MU = Muscovite, WS = Wuscocite, R = Rutile, AN = Autunite.

The suspended particulate matter (SPM) collected from randomly selected sites was strained in order to remove fibrous material. Samples were kept in bottles as such and were passed through two sieves for getting two parts of each sample having particle size less than 53 micrometer and less than 75 micrometer. All the samples were pressed gently in to aluminum/ glass holders before loading each of them on XRPD goniometer. Statistical analysis was carried out using T-Test and results were presented at the relevant place. In this study at least 50 samples covering almost each aspect of the Faisalabad environment for XRPD analysis were randomly selected using SRS Technique and Space Syntax Method. Kimoto high volume air sampler was used along with air condition filters, bucket, dish and sticky tape methods for sample collection. Samples were collected for the period of 12 hours at an average flow rate of 0.8 m^3/minute at a height of 15 feet from ground level ideal for solid aero sols related to selected environment using 20 x 25 centimeter rectangular fiber filter.

RESULTS AND DISCUSSION

The solid aerosols samples collected from various zones of Faisalabad were analysed and results are presented in Table 3 -10 and the variation observed are displayed in Fig. 1- 4.

Table 3. Zone - I (Trafic/Indus Trial Zone).

	R	IL	Q	CH/CL	AN	CA	AL	G/T	HM	HL	SP	MU	WS
2K20	*	*	38.36	*	*	18.32	37.67	5.62	*	*	*	*	*
2K22	*	59.62	5.72	17.03	*	5.69	11.68	15.43	*	*	*	*	*
2K23	*	37.09	*	30.7	*	10	*	4.84	*	*	*	*	*
2K25	*	29.56	*	29.32	*	12.65	19.42	*	*	*	*	*	*
2K27	*	56.68	13.34	15.15	7.06	*	*	*	*	*	*	*	*
2K28	*	34.97	27.82	*	*	3.72	7.74	*	*	*	*	*	*
2K29	*	63.63	14.98	*	*	8.24	5.82	7.34	*	*	*	*	*
2K30	*	*	9.96	14.14	*	7.56	23.54	10.21	*	*	*	*	*
2K33	*	8.28	*	35.28	*	*	22.53	8.54/2 5.35	*	*	*	*	*

* = Not detected i.e. below limits

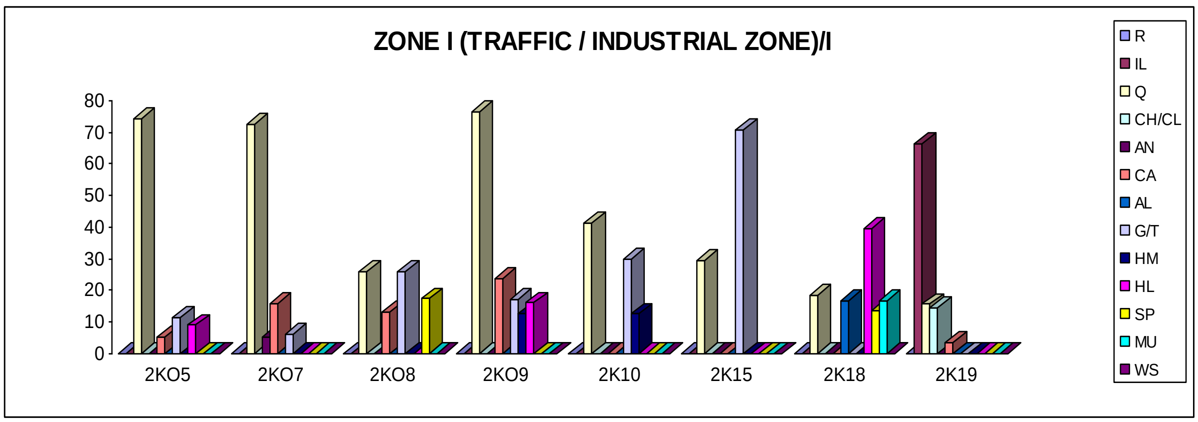

Fig. 1. Solid aerosol taken from Zone-I

Table 4. Zone -II (Trafic /Indus Trial Zone)

Code	R	IL	Q	CH/CL	AN	CA	AL	G/T	HM	HL	SP	MU	WS
2K37	*	38.09	*	33.12	*	*	21.15	7.61	*	*	*	*	*
2K38	*	33.63	*	29.24	*	*	18.67	8.09/10.34	*	*	*	*	*
2K39	*	54.4	4.87	19.92	*	10.27	*	5.51	*	*	*	*	*
2K40	*	59.73	20.37	15.58	*	*	*	4.32	31.52	*	*	*	*
2K41	*	36.83	10.94	33.09	*	6.8	12.31	*	*	*	*	*	*
2K42	*	6.15	14.48	*	*	13.63	34.2	*	19.6	*	*	*	*
2K43	*	48.28	11.35	6.11	*	5.77	28	*	*	*	*	*	*
2K44	*	37.03	8.71	*	*	8.47	20.57	19.60/5.60	*	*	*	*	*
2K46	*	45.82	10.77	16.33	*	8.09	*	7.22/11.73	*	*	*	*	*
2K47	*	9.87	64.02	*	*	14.17	11.93	*	*	*	*	*	*

* = Not detected i.e. below limits

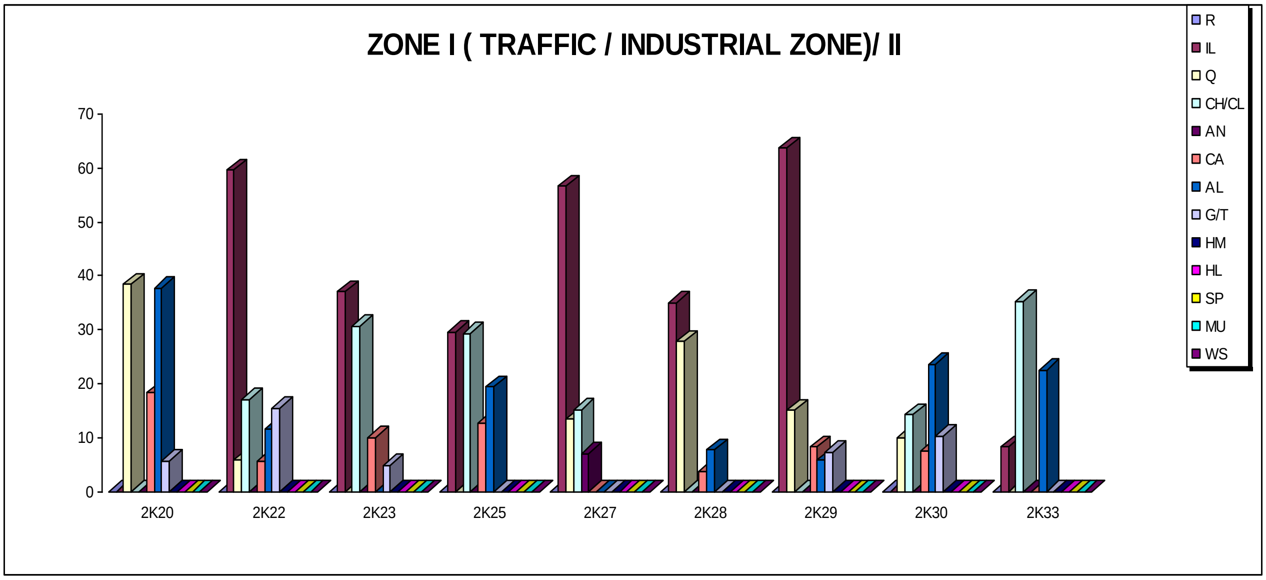

Fig. 2. Solid aerosol taken from Zone II

Table 5. Analysis of samples taken from ZONE - II (SAFE ZONE)

Code	R	IL	Q	CH/CL	AN	CA	AL	G/T	HM	HL	SP	MU	WS
2KO3	*	*	24.42	*	*	21.78	*	19.84	*	*	*	*	33.82
2K12	15.96	*	25.92	*	*	*	*	32.03	*	*	*	*	*
2K21	*	35.46	26.34	21.18	*	17	*	*	*	*	*	*	*

* = Not detected i.e. below limits

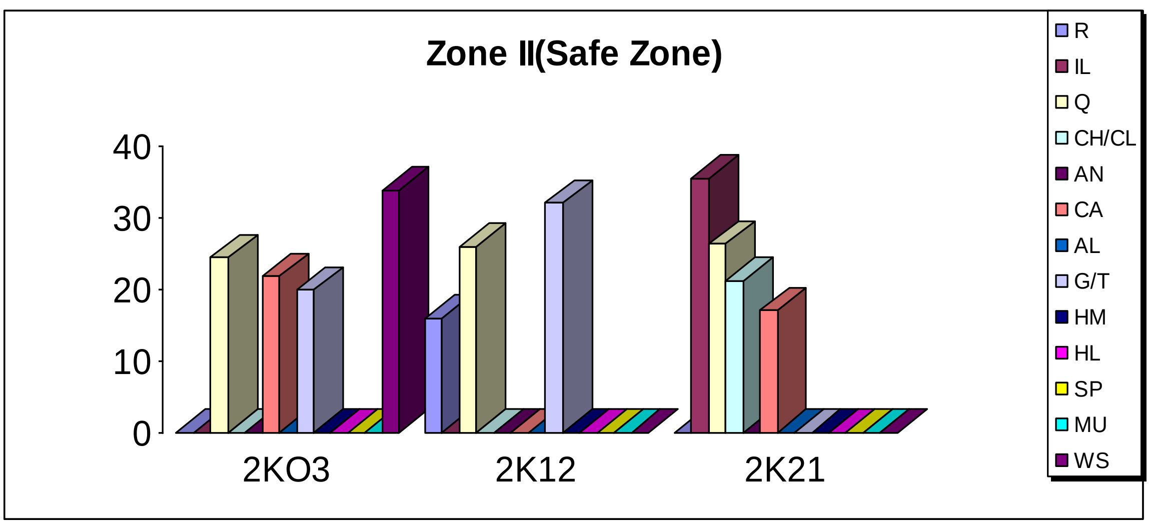

Fig. 3. Variation among the samples taken from safe zone.

Table 6. Zone-III (Residential/Commercial Zone)

Code	R	IL	Q	CH/CL	AN	CA	AL	G/T	HM	HL	SP	MU	WS
2KO1	*	*	66.8	*	5.31	23.23	*	*	*	*	*	*	5.31
2KO2	*	*	29.02	*	*	*	*	28.7	*	11.9	*	30.36	*
2KO4	33.66	*	16.99	*	*	15.06	*	17.88	5.79	*	*	10.6	*
2KO6	*	*	37.8	*	*	28.61	*	15.97	*	12.13	*	5.47	*
2K11	*	*	29.17	*	*	28.38	*	31.39	6.88	*	*	*	*
2K13	*	*	32.03	*	*	35.92	*	20.9	*	*	*	*	*
2K14	*	*	14.57	*	*	64.52	*	*	*	*	*	*	*
2K16	*	*	19.54	*	43.5	17.4	*	19.54	*	*	*	*	*
2K17	*	*	34.02	*	*	*	*	13.64	52.38	*	*	*	*
2K24	*	34.95	25.62	15.16	*	*	*	7.85	*	*	*	*	*
2K26	*	71.85	15.86	15.86	9.34	*	20.5	*	*	*	*	*	*
2K31	*	*	8.68	30.2	*	10.06	20.6	8.96/22.18	*	*	*	*	*
2K32	*	*	6.82	40.41	*	12.56	*	11.18/29.02	*	*	*	*	*
2K34	*	62	14.58	*	*	8.92	6.54	7.94	*	*	*	*	*
2K35	*	52.39	12.32	*	*	1.92	29.1	4.24	*	*	*	*	*
2K36	*	36.5	*	*	*	9.86	21.52	9.32/22.78	*	*	*	*	*
2K45	*	64.21	15.1	11.33	*	*	6.51	2.82	*	*	*	*	*
2K48	*	37.64	19.38	13.34	*	11.98	17.65	*	*	*	*	*	*
2K49	*	29.69	15.74	21.52	*	*	26.39	7.22	*	*	*	*	*
2K50	*	19.66	43.35	10.5	*	16.69	9.77	*	*	*	*	*	*

* = Not detected i.e. below limits

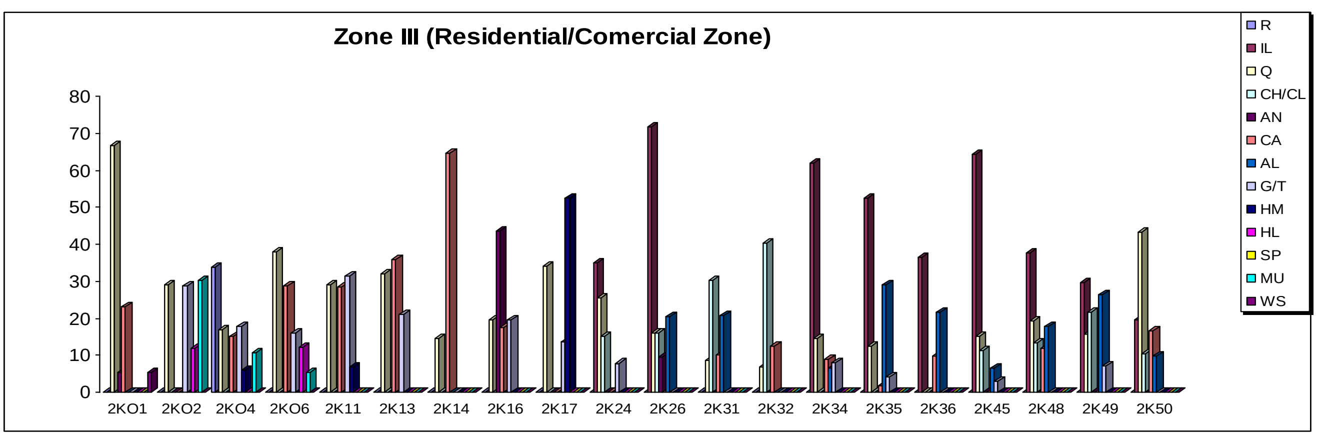

Fig. 4. Variation found among samples collected from Zone III.

Table 7. Statistical analyses of major identified phases

PHASES	MAX	MIN	MEAN	S. D	CV
IL	64.21	6.15	35.18	41.05	116.68
CA	64.52	1.92	33.22	44.26	133.23
G/T	70.58	4.22	37.41	46.90	125.36
Q	64.02	8.68	36.35	39.13	107.64
CH/CL	40.41	6.11	23.26	24.25	104.25
AL	34.20	6.51	20.36	19.57	99.11

Large variations in C. V mean temporal consistency that is stability of the environment for the time being. Any change in the present industrial cum transportational set up may disturb the stability of environment.

Table 8. Chemical analysis of solid aerosols

Oxide	Percent composition of Solid Aerosols
SiO_2	60.4800
Fe_2O_3	9.3000
TiO_2	9.3000
Al_2O_3	9.3000
CaO	7.8000
Na_2O	5.1600
K_2O	2.6666
Loss of Sample was observed	12.0200

Table 9. Comparison of Cell Dimensions of Ice and Minerals Identified in Suspended Particulate Matter

Identified Phase	Crystal System	a (A^o)	c (A^o)	Basal Misfit % age	Prism Misfit % age
ICE	HEXAGONAL	4.490	7.338	-----	-----
QUARTZ	HEXAGONAL	4.913	5.450	9.2	17.8
ILLITE	MONOCLINIC	5.190	20.160	15.4	95.1
CHOLIRIDTE	MONOCLINIC	5.320	14.290	18.3	56.1
CALCITE	HEXAGONAL	4.989	17.062	10.9	71.7
GYPSUM	MONOCLINIC	5.680	6.510	16.3	18.8
TALC	MONOCLINIC	5.287	18.964	17.5	88.0
ALBITE	TRICLINIC	8.144	7.160	81.0	41.7

Table 10. Distribution of the Solid Aerosols at five specially selected sites related to Faisalabad environment.

Sample Code	0.5 – 10 µm %	10 – 20 µm %	20 - 40 µm %	> 40 µm %
S^3I 1	25	5	2	------
S^3I 2	15	5	5	------
S^3I 3	15	5	3	7
S^3I 4	05	5	3	------
S^3I 5	20	5	3	------

Environmental pollution due to solid aero sols is a major problem of the modern civilization. It is being increasingly felt that clean environment is as important as the basic necessities of life such as food, cloth and shelter. Environmental problems in Pakistan are growing at faster rate as compared with growth in the economy. It is evident from massive deforestation, salinity and water logging combined with progressive desertification, extinction of wild life, and degradation of landscape, water and soil resources. Faisalabad is one of the cities of Pakistan where situation is aggravating day by day. Rapid urbanization, an industrial expansion accompanying in the population growth are the major factors responsible for environmental pollution in general and air pollution in particular. The vehicle on city roads have increased many folds and there are a great number of industries in Faisalabad which are contributing heavily to the environmental pollution.

Fig 5

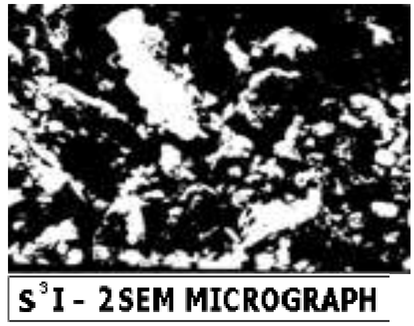

Fig 6

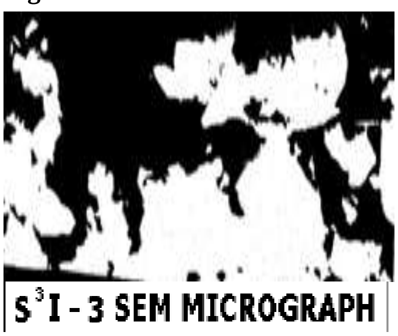

Fig 7

Fig 8

Fig 9

Fig 10

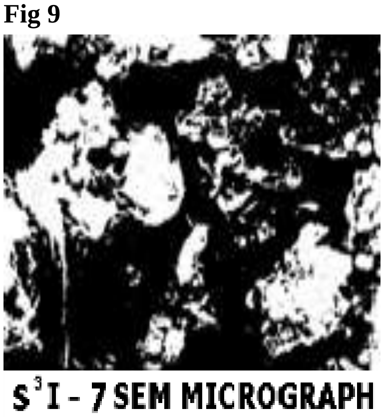

Fig 11

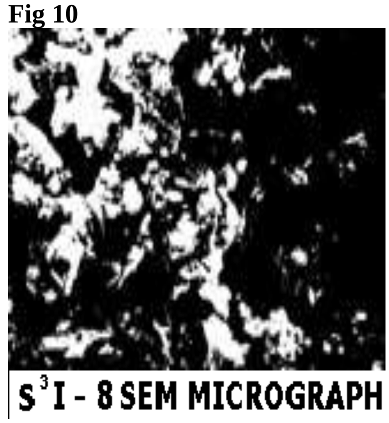

Fig 12

SEM Micrograph (Confirmation of fibrous material)

XRPD studies carried out by matrix flushing method shows that Gypsum and Talc is present in highest amount as indicated by their means (37.41) for each in almost all the samples and Quartz (36.35), Illite (35.18), Calcite (33.22), Clinchlore (23.26) and Albite (20.36) are also found in appreciable amount. The highest presence of Gypsum and Talc gives very interesting results as Faisalabad environment does not contain any source of theses minerals, hence their origin lies at remote areas, the same is true for other such minerals. The detection of R, AN,HN, HL,SP, MU and WS as miner phases or the non existence of theses phases in polluted range is because of their larger size and not due to their existence below critical limits. These phases are of metallic, semi metallic and non metallic nature, there fore their study becomes very important because they when combined with Oxygen Sulphate (SO_4^{-2}) and carbonate (Co_3^{-2}) radicals results the formation of complex compounds which shows the interaction of Industrial and Transportational dust, fumes with solid aero sols and pollute the environment, this aspect is evident from Gray / Black and Yellow color of most of the selected samples along with non identified phases.

Wind direction effect, longitudinal and altitudinal effects on the concentration of solid aerosols shows that N – W direction has maximum load, hence it may be considered as potential danger region for acidic rain but due to Alkaline nature of Carbonates , bicarbonates of Ca, Na, K and Mg this may not happen. S – E direction has minimum load, which favours the non occurrence of acidic rain, so in near future the Faisalabad environment may be considered as safe environment from acidic rain point of view. Latitude and Altitude effects indicate that concentration of solid aero sols follow inverse square law, except some samples collected from sites of special scientific interests (S^3I). This shows the heterogeneous and complex culture of Faisalabad environment. No doubt these results are slightly disagreeable with international standards, but such type of information is very vital to know the geographical and geological set up of concerned environment. Generally an increase in the concentration of dislocations will raise interfacial energy between the ice embryo and the nucleating particulate matter hence decreases its nucleability. A simple theoretical model proposed by was used to study this aspect. The most of the identified phases in the present study have large vales of lattice misfit and they are poor nuclei particularly Quartz, Calcite and Albite which are poor nuclei they remain suspended in the atmosphere for long periods, depending upon their size hence supplement the pollution level of the atmosphere.

The major sources of solid aero sols include Coal burning, Auto mobile exhaust, high temperature Industrial processes, fugitive dust, de-odourization of waste gases, detoxification of dust from steel plants, unpaved roads, municipal waste combustion etc along with some natural processes as forest fires, decaying vegetation, dust storms and volcanic eruptions are almost all are the components of Faisalabad environment.

The size and shape of solid aero sols were examined by transmission scanning electron micro scope from S^3I under 80kv, at $\times$ 1500, $\times$2500 JEOL -1010 Model. The size of the selected samples varies from 0.5 μm to 46 μm i.e. mixed composition of fine and coarse particles, which indicates the complexity of the Faisalabad environment.

In most of the samples identified phases occur as patches rather than single grain, so heterogeneity and aggregation of the Faisalabad environment is a dominating factor in our experimental findings. One possible explanation is that oxidation processes have converted the sulphides of identified phases into a soluble hydrous Sulphate which is confirmed by the Sulphate mineral as Gypsum detected in clay minerals by XRPD technique.

The other possible justification is that due to the presence of fly ash, road dust and pollens present in the Faisalabad environment have interlocked the identified phases into patches, the oval and irregular shapes of the majority of the samples also support our justification. (Confirmation of Presence of Fibrous Material) as shown in the micrographs of SEM (secondary electron microscopy). This state of affairs also confirms the stability of the Faisalabad environment. However further work is suggested to reconcile satisfactorily the techniques used in this study and their co-relationship with Microphological structure studies. It is hoped that this study will be very useful towards the future environmental study programs related to Industrial areas cum commercial areas like Faisalabad (Shahida, 2000 and Tossavainen, 1979).

CONCLUDING REMARKS

It is concluded that the solid aerosols samples collected from various zones in Faisalabad contained steadily the compounds namely Quartz, calcite and Albite as pollution components. The industrial zone have more amounts of quartz than the residential zone the source of these minerals are both local and remote .The approximate size range of the dust particles is from about 1 micron to 46 micron. Such particles remain suspended in the atmosphere for longer periods of times because they are not efficient nuclei of ice. The particles are therefore inhalable and could cause serious health hazards.

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