CSIRO PUBLISHING
www.publish.csiro.au/journals/spjns The South Pacific Journal of Natural Science, 2007, 14, 78-81

Characterization of aerosols generated in a steel processing factory

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ABSTRACT
The levels of total suspended particulates (*TSP*) *within the complex of a steel factory* (*Fletcher Pacific Steel Fiji*) *have been investigated through high volume air sampling. The levels of TSP inside and outside* (*in the ambient environment*) *the factory has been found to be in the range of 121-339 and 33-80 μg m^{-3} respectively. The levels inside the factory exceed the WHO guideline by a factor of 2-4. The management of the factory was very proactive to determine the air quality for records and to safeguard the health and safety of all the employees, contractors, and visitors. At the request of the factory, the exposed filters were analysed by neutron activation and gamma-ray spectroscopy techniques and the results are presented.*

1 INTRODUCTION

Aerosols consist of solid and/or liquid particles of sizes in the range 0.01-100 μm suspended in air, which originate through natural processes such as volcanic eruptions, windblown dust, sea spray, *etc*., or through anthropogenic sources like industrial emissions, automobile exhausts, *etc*. It is generally accepted that the concentration of total suspended particulates (TSP) from natural origins is less than 10 μg m^{-3} (Boubel *et al*. 1994). High levels of TSP in air can reduce atmospheric visibility, irritate eyes and can have long-term effects on human, plant and animal life. The toxic properties of these particles are partly due to biochemical activities of metals and other chemicals present in them. In recent times, particulate matter pollution in urban air has become common and a serious problem in many developing countries (*e.g*., Bilos *et al*. 2001; Salaam *et al*. 2003). The World Health Organisation (WHO) advises that concentration of TSP in air should not exceed the annual average of 60-90 μg m^{-3}, while the air quality guideline in most developed countries is 90 μg m^{-3} annually and 120-150 μg m^{-3} daily (Boubel *et al*. 1994). The choice of these guidelines is mostly influenced by targeted national development goals.

The characteristics of aerosols injected through natural means are well understood. However, it is difficult to properly understand anthropogenic injections, such as industrial aerosol transport from one region to another, as several factors come into effect (type of factory, processing methodologies, fuel used, pollution control measures in place, *etc.*). Thus, characterization of aerosols generated from specific types of industries not only deserves merit, but it also becomes important for reasons of community health. The present work therefore is a study of the elemental abundances in aerosols generated during factory working hours (processing periods) inside the Fletcher Pacific Steel Fiji, steel factory in Walubay. High volume sampling, neutron activation, and gamma-ray spectroscopy techniques have been employed to carry out this task.

2 MATERIALS AND METHOD

2.1 HIGH VOLUME SAMPLING

A high-volume air sampler, with flow rate of 1.0 m^3 min^{-1}, was used to collect aerosols on Whatman-41 filter papers (size 203 × 254 mm^2) inside a steel factory. These filters have a TSP collection efficiency of over 95% (Prospero *et al*. 2003). Further, Whatman-41 filters have very low blank levels of heavy metals and trace elements (EPA 1999). The sampler was run continuously for a week inside the factory during working hours only (8 am – 4 pm) before collecting the filter. A total of 4 filters were collected over a period of one month. About 1300–5000 m^3 of air was drawn through each filter. In addition, 4 weekly filters were collected outside the factory for comparison. The mass of each filter was measured before and after exposure under conditions of constant temperature and humidity, and the TSP masses were determined.

2.2 NEUTRON ACTIVATION ANALYSIS

The neutron activation analysis technique for aerosol characterisation has been described in many monographs (*e.g*., Landsberger 1994). The filters were irradiated in the HIFAR reactor at the Australian Nuclear Science and Technology Organisation (ANSTO), Sydney. For this purpose, (8×1) cm^2 strips of two filters (W1 and W2), which were exposed inside the factory, were folded into a (1×1) cm^2 pellet and heat-sealed in a clean polyethylene bag, which was in turn sealed in another polyethylene bag. Several standard samples from United States Geological Survey (USGS) and International Atomic Energy Agency (IAEA) standard samples, of similar size and mass about 50 mg, were also prepared and stacked together with exposed filter sections and placed in an irradiation can. The standards were intended to serve three purposes: a) to make corrections for the non-uniformity of neutron flux received by the samples during irradiation in the reactor, b) to measure the elemental concentrations in filters by using the comparator method, and c) to cross-check the accuracy and reliability of results by treating some of the standards as unknowns. The can was irradiated in the reactor for 4 hours at a thermal neutron flux of 2.75×10^{12} cm^{-2} s^{-1}.

 10.1071/SP07014

After a waiting time of 3 days, the irradiated samples were flown back to Suva for measurement of induced activities using an HPGe gamma-ray spectrometer (efficiency 24% relative to NaI detector). In the first batch of measurements, which took place immediately after the arrival of the samples in Suva, each sample was measured for 4000 s. Figure 1 shows a typical gamma-ray spectrum obtained for one of the activated filter samples, from which the activities of short-lived nuclides ($T_{½} \leq 7$ d) were obtained. From these, the concentrations of elements arsenic (As), bromine (Br), lanthanum (La), sodium (Na), antimony (Sb) and samarium (Sm) in each filter were determined. A second batch of measurements, for 6000 s on the samples, was carried out 3-4 weeks after irradiation. By this time, most of the short-lived nuclides were nearly extinct, which enabled the long-lived nuclides to be determined with greater accuracy. From this data, elemental concentrations of cerium (Ce), cobalt (Co), chromium (Cr), europium (Eu), iron (Fe), hafnium (Hf), scandium (Sc), strontium (Sr), tantalum (Ta), thorium (Th), ytterbium (Yb) and zinc (Zn) were calculated. These are the only elements that could be measured, since radio-isotopes of other elements were nearly extinct after the samples were flown from Sydney to Suva.

3 RESULTS AND DISCUSSION

3.1 OBSERVATIONS FROM HIGH VOLUME SAMPLING

The TSP levels inside the steel factory were found to be in the range 121–339 μg m^{-3}, averaging 198 ± 97 μg m^{-3}, stated to one standard deviation. This corresponded to about 0.25 g of aerosols collected over weekly periods during factory working hours. This is indeed a very high level. In order to protect themselves, workers in the factory were always wearing gloves and face masks during working hours. Aerosols measured inside the factory comprise of the natural aerosols available in the air, as well as those generated from the various activities at the site. These activities include (but not limited to) burning of used-oil (obtained from automobiles) for furnace operation, cutting, beating and rolling of iron sheets, and heavy automobile operations within the factory yard. Measurements outside the steel factory revealed that TSP levels are in the range of 33-80 μg m^{-3}. This certainly reveals that a great deal of anthropogenic aerosols is generated inside the factory.

Garimella & Deo (2007) have shown that the measured TSP levels in residential, traffic, and industrial areas of Suva are in the range 9-43, 20-50, and 33-91 μg m^{-3} respectively. The levels of TSP measured outside the factory and in the ambient environment conform to their levels stated for industrial areas. The large difference observed between factory TSP levels and the general Suva levels prompt a more thorough and systematic study into the aerosol levels inside industries such as the one studied. Also, as fine aerosols (PM_{10}) are important for community health reasons, characterizing size fractions from such industrial emissions is recommended for future study.

3.2 ELEMENTAL ABUNDANCES IN THE AEROSOLS

A total of 12 elements were measured in filters exposed inside the steel factory. The results are given in Table 1. Since air sampling was conducted inside the factory during processing hours only, it is believed that the analysis of 2 weekly filters is justifiable to determine the levels of different elements in the factory during processing periods. This is largely due to the fact that activities inside the factory, and as well as the factory environment inside do not vary greatly. Approximately 40% by weight of the aerosols present in the filters were studied in the present work. This is due to the high concentration of Fe (47,995 – 51,129 μg m^{-3}) measured in the aerosols. This was clearly expected due to the nature of the factory itself. In comparison, similar work conducted by the authors in the ambient environment of Suva could only characterise 3–5 % of the total aerosols elementally (Garimella & Deo, 2007).

For comparison, Table 1 also lists the elemental analysis of aerosols carried out in residential areas of Suva by (Garimella & Deo 2007), as well as elemental composition of used-oil as determined by various other authors (Cotton *et al*. 1977; Becker & Comeford 1980; U.S. EPA 1984; Mumford *et al*. 1986). Comparison between steel factory and residential measurements reveal that all the elements are greatly enriched inside the steel factory. It is a cause for concern, especially since heavy metals such as arsenic, cobalt and chromium are toxic. The comparison values of used-oil are given, with the belief that emissions due to furnace operation are a major source of most elements characterized in aerosols inside the factory. The presence of sodium in the aerosols is probably due to marine environment in Suva. There is a possibility that concentrations of elements like arsenic, bromine, and zinc in air are heavily influenced by burning of used-oil, but the present study cannot confirm this hypothesis. Since there are different stages of iron processing coupled with various activities in the factory, it is generally difficult to single out sources for the various elements detected. The present work provides a baseline data on the levels and different types of elements present in the air inside the factory. Further work is required to properly understand their dominant sources and temporal variations. Moreover, work on size characterisation and subsequent neutron

Table 1. Elemental analysis of aerosols (μg m^{-3}) from inside the steel factory. The last column on elemental composition of used oil (ppm) has been collated from various authors.

Element	Sample W1	Sample W2	Mean ± SD	Residential Area[GD]	Used Oil
As	12.5	16.01	14.3 ± 2.5	2.3 ± 0.9	17.3[b]
Br	11.2	11.9	11.6 ± 0.5	5.6 ± 2.9	1050 – 2950[c]
Ce	0.72	0.89	0.81 ± 0.12	0.07 ± 0.02	N.D
Co	6.8	6.9	6.85 ± 0.07	0.11 ± 0.06	0.25[d]
Cr	33.5	37.2	35.4 ± 2.6	0.5 ± 0.1	28[b]
Fe	47995	51129	49562 ± 2216	169 ± 65	200.7[a]
La	4.93	4.69	4.81 ± 0.17	0.09 ± 0.05	N.D
Na	1875	3623	2749 ± 1236	2536 ± 1820	114.2[a]
Sb	8.89	9.53	9.21 ± 0.45	0.6 ± 0.3	25[d]
Sc	0.28	0.33	0.31 ± 0.04	0.04 ± 0.01	N.D
Sm	0.125	0.117	0.121 ± 0.006	0.008 ± 0.003	N.D
Zn	1032	1048	1040 ± 11	19 ± 8	1061[a]
Other Characterization of W1 and W2					
Total mass of elements determined (g)			0.229 ± 0.023		
Total aerosols deposited on filter (g)			0.573 ± 0.008		
%TSP resolved elementally			40.0 ± 4.5		

[a] – Cotton *et al*. (1977)
[b] – U.S EPA (1984),
[c] – Becker & Comeford (1980), range of values obtained by the authors are given.
[d] – Mumford *et al*. (1986),
[GD] – Garimella & Deo (2007).

activation analysis of aerosols is much needed as this will provide a complete toxicological assessment of aerosols inside the factory.

4 CONCLUSION

High volume air sampling, neutron activation, and gamma ray spectrometry have been successfully applied to carry out an investigation into the elemental characteristics of aerosols inside a steel factory. The levels of TSP as well as its elemental composition reported here are of interest because such levels have not been reported previously in locations around Suva. The present study also asserts and calls for an immediate systematic study into the aerosols emitted from various other types of industries around the country as well. Such studies would help understand better the particle dosage received by local populations.

5 ACKNOWLEDGMENTS

The authors would like to thank the management and staff of the Fletcher Pacific Steel Fiji for allowing such an investigation to be carried out in their premises. We would also like to thank the Australian Nuclear Science and Technology Organization (ANSTO), Sydney, for irradiating our samples and sending them back to Suva for measurements.

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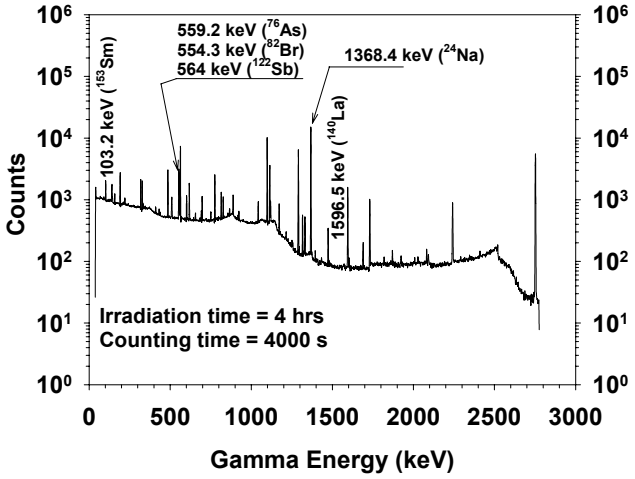

Figure 1. A typical gamma-ray spectrum of short lived nuclides, measured 7 days after irradiation.