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CHARACTERIZATION AND QUANTIFICATION OF COAL FIRED BOILER STACK EMISSIONS AT NATIONAL TYRE SERVICES LIMITED, ZIMBABWE

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ABSTRACT

Boiler stack emissions were characterized and quantified for a tyre manufacturing company over a period of six months. The isokinetic sampling method was used. Variation of pollutant concentration as a function of distance from the emission source was also assessed. Results showed the major pollutants as sulfur dioxide, nitrous oxide carbon monoxide and particulates. Levels of sulfur dioxide ranged between 199mg/m3 and 233mg/m3; nitrogen dioxide between 59 and 99 milligrams per cubic meter (mg/m3); carbon monoxide between 54mg/m3 and 94mg/m3 and particulates between 212mg/m3 and 280mg/m3 during the sampling period. Levels of pollutants generally decreased during the sampling period. There was also a gradual decrease in the concentration of the pollutants with increasing distance from the epicenter with the highest levels being recorded at a distance of 300m for all pollutants.

Keywords: Coal fired boilers; Particulates; Isokinetic Sampling; Stack Emissions

INTRODUCTION

National Tyre Services Limited (NTS), a member of the Dunlop Africa Limited, is a well-established company, primarily engaged in the business of tyre manufacturing and retreading. The company also sales and distributes new and retreaded tyres and allied products. NTS is located in Graniteside, an established commercial and light industrial area, about 3 km south of Harare Central Business District.

During the retreading process, tyres are cured in a steam chamber with the steam coming from the boiler. A boiler is an enclosed devise using controlled flame combustion and having the primary purpose of recovering thermal energy in the form of steam or hot gas (Gao & Sjobrget, 2003). According to the Factories and Works Regulations, a boiler is any apparatus adapted to convert continuously, any liquid into steam, vapor, or gas at a pressure higher than that due to the atmosphere. It is usually made of steel and has a cylindrical stack rising into the atmosphere, which allows emissions from the burnt fuel to escape. The boiler at NTS uses coal as a source of fuel. Coal is a black non-renewable resource, solid in nature and ignites at 400 degrees Celsius and produces thermal heat of about 14,000 degrees Celsius in boilers (Gao & Sjobrget, 2003).

Gaseous emissions from coal combustion include sulfur dioxide, nitrous oxide, carbon dioxide, carbon monoxide, and particulate matter (PM). Emission is defined as the dispersion of gaseous, solid and liquid particles of microscopic size in air. PM2.5 and PM10 denote fine particles with aerodynamic diameter less than 2.5 and 10 microns respectively (World Health Organisation, 1999a). The atmospheric emissions of fine particles is of special importance because they contain toxic substances, have long atmospheric residence times, and are efficiently deposited in the lung (Held & Sivertsen, 1996).

Based on the 2004 Environmental Protection Agency (EPA) Emission Report, conventional coal fired boilers are the largest anthropogenic sources of atmospheric fine particles, sulfur dioxide, and the largest source of nitrogen oxide. In addition, potentially toxic micro elements and heavy metals, naturally occurring radionuclides and potentially carcinogenic organic and inorganic compounds have been identified in the atmospheric discharges from coal-fired boiler stacks (Mengel, 1982).

Air pollution poses serious threats to the health of exposed communities. Graniteside houses thousands of workers and nearer is the overpopulated residential area of Mbare and Sunning Dale which experience a lot of pollution from burning of used tyres, garbage, firewood from the informal sector, homes, as well as burst sewage pipes. People exposed to boiler coal emissions coupled with other sources suffer health effects of inflammation of the nasal passage and airways, respiratory disorders, altered lung function, tissue damage and exacerbated heart diseases (Mengel, 1982; Bobak & Leon; 1992; Seaton, MacNee, Donaldson and Godden, 1995).

Atmospheric levels of sulfur dioxide, nitrogen oxides, carbon monoxide, and suspended particulate matter continues to rise, with current levels in Harare surpassing the World Health Organization's maximum permissible limits (World Health Organisation, 1999b). The city is experiencing a marked increase in levels of suspended particulate matter whose concentration rose from under 25 micro grams per cubic meter(ug/m3) in 1987 to 113 ug/m3 in 1997 (Ngara, 1998).

Boiler emissions are known to cause health and environmental impacts to the receiving environment. The major stack emissions from coal are sulfur dioxide, carbon dioxide, nitrogen oxide, particulate, and non-metal volatile organic compounds. The health effects of these gases and particles are the irritant and reduced lung function, which may cause an increase in respiratory diseases (Bobak & Leon; 1992; Seaton *et al*, 1995). The present efficiency of coal fired industrial boilers in Zimbabwe is 74 % and in some cases 50% (Ngara, 1998).

Based on recent media articles, even in the absence of quantitative measurements, most residents in Harare would agree that their air quality is deteriorating, especially in winter when air inversions tend to trap harmful pollutants in the lower atmosphere. Climatic extremes that have been analyzed show that the monthly highest daily maximum temperatures have increased by about two percent hence, Zimbabwe is undergoing gradual warming (Mengel, 1982).

The extent of air pollution problems is becoming clearer, but there are gaps in knowledge, such as a reliable emissions inventory and data on various impacts of air pollutants. Available information shows that little research has been done on the characterization and quantification of emissions in Zimbabwe. There is a need for reduction of emissions and adoption of the culture for cleaner production, which depends on the nature and amount of the emissions.

The Air Pollution Information Network for Africa (APINA) has started developing a comprehensive regional emission inventory that can be used to predict deposition of air pollutants now and in the future, hence, knowledge of the emission will contribute both to the national and regional inventory. Knowledge of nature and quantities of the emissions will help assure legal compliance and mapping of an operational air quality management plan. In light of these observations, this research endeavors to characterize and quantify stack emissions from a coal fired utility boiler. This will ultimately establish mechanisms and strategies to minimize air pollution.

MATERIALS AND METHODS

The accepted and standard practice of sampling stacks is the Isokinetic method. This method can be used for risk assessment. Isokinetic Sampling is defined in the British Standard (BS3405: 1983) section 2.9 as sampling at a rate such that the average velocity of the gas entering the sampling nozzle is the same as that of the gas in the flue at the sampling point. Isokinetic samples were taken for Sulfur Dioxides (SOx), Nitrous Oxides (NOx), Carbon monoxide (CO) and particulates in the stack, using an Isokinetic sampling train. A temperature/humidity environmental meter (Survey-light SKC Standard ST-8820) was used for temperature measurements. Weighing of filters was done on an Avery Berkel four decimal point analytical balance and wind dynamics were measured using a “Windynamics” (Omen Technology Inc. U.S.A.), a computer based software program and anemometer reading both wind speed in knots and wind direction. The calibration procedure is included with the software. Co-ordinates were determined with a Garmin Geko 101 Global Position System

RESULTS

The following tables show results for the measurement of different parameters (Table 1) and mass low rate (Table2). A summary of source testing results is given in Table 3. Finally, a graph showing monthly average boiler stack emissions during the sampling time is shown in Figure 1.

Table 1: Boiler stack measurements

Parameter	**Measurement** (m)
Stack height	16.200
Stack diameter	0.604
Stack circumference	0.190
Stack nozzle/duct diameter	0.020

Table 2: Stack mass flow rate

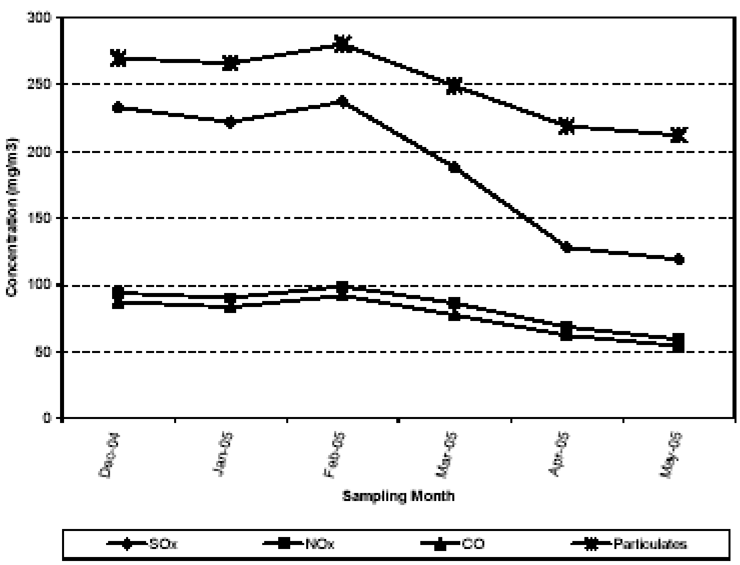
Pollutant	**Mass flow rate**(g/s)
Sulfur dioxide (SOx	0.36-0.38
Nitrogen dioxide (NOx)	0.14-0.15

Carbon dioxide	0.40-0.44
Particulate	0.44-0.49

Table 3 Summary of source testing results

Sampling Parameter	Sampling Month					
	DEC 2004	JAN 2005	FEB 2005	MAR 2005	APR 2005	MAY 2005
Sampling duration (mins)	3	3.2	3.5	3	3.6	3.1
Stack gas velocity (m/s)	3	3.4	3	3.8	10	3.3
Velocity head of water (mm)	2.1	2.3	2.2	2.1	8	2.3
Temperature (°C)	500	600	515	505	570	550
Wind Speed (Knots)	7	4	2.3	7	11	10
Wind Direction	NE	NE	NE	NE	NE	NE

Fig 1 monthly average boiler stack emissions over sampling time



DISCUSSION

Boiler stack emission concentrations over time

Particulates

Concentrations of particulates were in general, constant in December 2004 as well as January 2005, with average values of 270mg/m3 and 266mg/m3 being recorded respectively. During this period the coal was sprayed with water, to coagulate the fly ash particles thereby reducing formation of coal dust and the release of micro particulates during coal burning. However there was an increase in the monthly average concentration to 280 mg/m3 in February 2005. It was noted that during this period the coal grade purchased was of poor quality, containing a great deal of fly ash. It contained a lot of fly ash. With improved coal quality, the month of March 2005 recorded a decrease to 249 mg/m3. Coupled with improved boiler operation there was a continued decrease to 219 mg/m3 in April and to 212 mg/m3 in May 2005.

The presumptive limit value (the level used by the Ministry as a guide to best practice) set for boilers for particulate emissions is 115 mg/m3. The particulate concentrations exceeded the presumptive limit. Such high concentrations of particulate may cause lung irritation, altered immune defense, systemic toxicity, decreased pulmonary functions and stress on the heart (World Health Organization, 2002).

Sulfur Dioxide

In December 2004 the average concentration was 233 mg/m3. The high levels of concentrations reflected that the boiler was operating at a low efficiency. There was a slight decrease in January 2005, to 222 mg/m3 due to reduced volatility of sulfur species by coal wetting. Poor coal quality in February 2005 resulted in a high average concentration of 237 mg/m3. The purchasing of coal with low sulfur content resulted in a significant decrease of concentration to 188 mg/m3 in March followed by continued decrease to 128 mg/m3 in April 2005 and 119 mg/m3 in May 2005.

However these monthly average values exceed the 70 mg/m3 limit. Exposure to high concentration of sulfur dioxide cause respiratory irritation, shortness of breath, impaired pulmonary function, increased susceptibility to infection, illness in the lower respiratory tract (particularly in children), chronic lung diseases, and pulmonary fibrosis (Tolba & El-Kholy, 1992).

Nitrous Oxide

The monthly average concentration of Nitrous oxide was as high as 94 mg/m3 in December 2004. In January 2005 there was a slight decrease in average concentration to 90 mg/m3 followed by an increase in concentration in March to 99 mg/m3. Again this rise was a result of poor coal quality, therefore the release of nitrous oxide was high during combustion (Gao & Sjobrget, 2003). From March to May 2005 there was a continued decrease in the concentration. This was attributed to use of better quality coal, which allowed the volatiles to be concentrated in a small area under the boiler arch resulting in stable ignition, reducing nitrous oxide releases. Nitrous oxide concentrations exceeded the limit of 40 mg/m3. Eye and nasal irritation, respiratory tract disease, lung damage, decreased pulmonary function, and heart stress are caused by exposure to high concentration of nitrous oxide (Tolba & El-Kholy, 1992; Harrison, 1992).

Carbon Monoxide

In December 2004 the monthly average concentration was 87 mg/m3 followed by a decrease in January 2005 to 83 mg/m3 and a significant increase to 99 mg/m3 in February 2005. From March to May 2005, the monthly average concentration of carbon monoxide decreased gradually from 86 mg/m3 to 68 mg/m3 and 59 mg/m3 respectively. This was attributed to the improved effectiveness of the planned and preventive management system. Some of the measures included amongst others, the use of grade ‘A’ washed pea coal with high calorific value and low ash content (Gao & Sjobrget, 2003).

Variation of stack emissions with increasing distance from the source

Particulates

Within 100m from the source, particulate concentrations are above the Threshold Limit Value (TLV) of 0.09 mg/m3. There is an increase in the level of particulate emission as shown on the graph at 200m and the highest of 0.018 mg/m3 at 300m downwind from the epicenter (source). The results around the 200m and 300m radius take into consideration background sources for pollution of stack emission measurements taken by the Air Pollution Control Board, which is under the Ministry of Health. The area has a lot of coal boiler stack emissions from various industrial organizations. From a distance of 400m to 700m the concentrations are still above the threshold limit value. The continued decrease in concentration from 800m to 2500m is within the TVL of 0.09 mg/m3.

Sulfur dioxide

Sulfur dioxide concentrations are above the TVL of 0.09 mg/m3 within a distance of 600m from the stack epicenter. The sulfur dioxide concentration increases at 300m, which is the peak and then there is a gradual decrease with increasing distance. There is continued decrease with increasing distance from the source from 700m to 2500m, which are within the threshold limit value. This is a result of diffusion of emissions into the atmosphere.

Nitrous Oxide

Nitrous oxide concentration increases from the epicenter to 300m and gradually decreases to the distance of 2500m. However the concentrations are above the TVL within the distance of 800m and subsequently are below the TVL of 0.04 mg/m3.

Carbon monoxide

Carbon monoxide levels are constant from the stack epicenter within a 200m distance with an increase at 300m. From 400m onwards the concentrations gradually decrease and are below the TVL of 0.09 mg/m3 starting at 600m to 2500m.

CONCLUSION

Characterization and quantification of stack emissions were done by using the isokinetic sampling method for a period of six months. Data on climatic conditions was measured and analyzed during sampling. There was a gradual decrease of NTS's sulfur dioxide, nitrous oxide, carbon monoxide, and particulates concentrations from the stack over the monitoring period (December 2004 to May 2005. This is attributed to the mitigatory measures that were instituted since the realization that the emissions were well above the legal limits. Continuous improvement of boiler efficiency resulted in reduced products of incomplete combustion, decreasing the stack emissions. However the stack emissions were still above the legal limits. The ground level dispersal effect of the pollutants to the surrounding environment was monitored with increasing distance from the stack source. Results obtained were compared with legal limits and the Threshold Limit Value to determine compliance.

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