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Air Quality Assessment of Industrial Boilers Exhaust and its Impact Upon Workers' Health

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ABSTRACT

Air pollution is a major concern worldwide with human activities being the main contributor and causing serious health impacts. The present study was designed to monitor the amount of gaseous pollutants (CO_2, CO, SO_2, NO_X) and total suspended particulates (TSP) from different industrial boiler's exhaust using three fuel types (coal, natural gas and heavy furnace oil/diesel). These five parameters were measured and compared with the National Environmental Quality Standards (NEQS) of Pakistan. Coal and diesel boilers were emitting more SO_2 (22x) as compared to natural gas. The natural gas boilers were producing more CO (7x) due to inefficient combustion and low mixing of air into gaseous fuel. The concentration of NO_x from all boiler types were within the standard value. TSP values ranged from 82.3 mg m^{-3} to 245.7 mg m^{-3}, which were within the NEQS limits due to the presence of control devices. Workers' health (n=42) was assessed using a questionnaire and health of many workers was found to be compromised (34 %), while most of them were either unaware or were not provided PPEs (37.5%). Consequently, the workers were being exposed to large amounts of hazardous emissions in the industry.

Keywords: *industrial emissions , occupational health, industrial boilers, natural gas, Heavy Furnace Oil, coal*

INTRODUCTION

Air pollution is an invisible killer and a modern-day curse in many cities of the world due to increased urbanization and industrialization. Air pollution levels in Asia, Africa and the Middle East are now much higher than those considered safe by the World Health Organization (WHO) air quality guidelines (*WHO 2016*). Burning of fossil fuels like coal and petroleum generates particulate matter (PM), greenhouse gases such as CO_2, CO, sulfur as SO_2, heavy metals (Hg, As, Se) and hydrocarbons (*Kim et al. 2015; Vallero 2011; 2008*). These air pollutants have also disturbed the chemical composition of atmospheric gases. The chemical composition of the current atmosphere is quite different from the natural atmosphere before the industrial revolution in the 1760s (*Desonie 2007*).

PM, SO_X, and NO_X cause adverse health effects like lung irritation, lower lung cancer, asthma, damage to cell lining of lungs and increased chronic lungs diseases (*Khan et al. 2015; Martinelli et al. 2013; Desonie 2008; Kampa and Castanas 2008; Pope and Dockery 2006*). PM itself is a mixture of various components and contains nitrates, inorganic sulfates, acids, heavy metals, microbial particles (bacteria, spores), pollen, organic carbon and polycyclic aromatic hydrocarbons (*WHO 2000*). PM2.5 (particles with diameter <2.5 µm) are more toxic than PM10 (particles with diameter <10 µm) because they can be inhaled deeper into the lungs' alveoli (*Pope and Dockery 2006*). CO is a very lethal gas as it has 210x more affinity with hemoglobin than O_2 and causes cardiac problems, visual weakening, fatigue, headache, confusion, drowsiness and even death due to lack of oxygen supply to tissues and organs (*Desonie 2008; Khan et al 2015*). SO_2 causes damage to respiratory passage and bronchitis. NO_2 can irritate the lungs and cause chronic bronchitis and emphysema. According to *WHO* (*2016*), both indoor and ambient (outdoor) air pollution are responsible for one in every nine deaths per year in the world. Ambient air pollution alone kills around 3 million people each year and WHO estimates that air pollution would be a main cause of premature deaths by 2050 in the world (*WHO 2016*). Expected environmental causes of air pollution usually include smog, acid rain and global warming (*Kidd and Kidd 2006*).

In developing countries like Pakistan, local effects of the industries are growing rapidly and becoming problematic. There are various types of industries like textile, chemical, food, pharmaceutical, petrochemical and power plants, fertilizers, cement, iron and steel plants etc. in major cities like Lahore, Karachi, Hyderabad and many others in Pakistan (*Ahmed et al. 2016; Niaz and Zhou 2014*). The number of manufacturing units in Lahore alone is 774, making it the second largest industrial hub of the country after Karachi (*BOS 2014*). The poor air quality of the metropolitan has been reported by many researchers (*Colbeck et al. 2018, 2010a, 2010b, 2008; Sidra et al.2015; Sánchez-Triana et al. 2014*). The recent incident of smog in Lahore and other parts of Punjab have threatened several lives and caused various health and environmental issues (*Mukhtar 2017: Qureshi et al. 2012*). Keeping in view of the current pollution packed situation of the metropolitan, the main objective of this study was to evaluate the boiler exhaust from local industries of Lahore, Kasur and Sheikhupura districts and to assess the effect of air pollutants and other industrial hazards on workers' health. While these boilers play a crucial role in industrial processes, it is also noteworthy that they are often poorly managed structures and a major source of various gaseous and solid particle emissions. Moreover, there are very few in-depth studies reporting the role of fuel type in deteriorating the air quality and no such recent studies were also found during literature surveys.

MATERIALS AND METHODS

Sampling sites

The provincial capital of Punjab and the second largest city of Pakistan, Lahore (31°32'N, 74°20' E) is situated along the west bank of River Ravi. The metropolitan has 1,757,691 households and is inhabited by 11,126,285, making it the 27th most populous city worldwide (*Pakistan Bureau of Statistics, 2018*). Moreover, the city has a large motor pool of over 2,400,000 vehicles reported in 2010 and more than 700 industrial units in and around the city contributing significantly towards the poor air quality (*Planning and Development Department 2014*). Similarly the neighboring districts of Kasur and Sheikhupura are also highly industrialized but data on their air quality is unavailable.

The current study was designed to measure and compare the emissions generated by industrial boilers using different fuel types. Various industries were visited to identify the types of boilers present in Lahore, Kasur and Sheikhupura districts. Three fuel types i.e. coal, natural gas, and heavy furnace oil were identified. Industries were selected (n= 7) after obtaining consent from the respective management at each site (**Figure 1**). Among the selected boilers (n= 17), seven were coal powered; five were using natural gas while the remaining five were burning heavy furnace oil (HFO) and diesel.

Measurement of air quality

Carbon monoxide (CO), carbon dioxide (CO_2), sulphur dioxide (SO_2), and oxides of nitrogen (NO and NO_2, NO_x) were measured using Testo 350 Portable Emissions Analyzer (Testo Inc.). Gas concentrations were obtained from the emission stack with a sampling probe. The electrochemical sensors present in the instrument react with the gases, thereby emitting electric signals. The number of electrical signals equals the concentration of gaseous pollutants (*Irfan et al. 2014; Nie et al. 2012; Kaya and Eyidogan 2010; Macor and Pavanello 2009; Karademir 2006*). The instrument has a calibration function for each parameter and is carried out every six months or when required.

The total suspended particulate (TSP) samples for coal boilers only were collected using an iso-kinetic sampling train based on USEPA Method-5 (**Figure 2**). Sample was extracted iso-kinetically and consistently for one hour. The pre-weighed filter was placed in the filter holder by tweezers or disposable surgical gloves. Then, the sampling nozzle was inserted into the boiler exhaust ports/hole. The pump was started, and the flow was adjusted to isokinetic conditions. During sampling, a temperature of 20±14°C was maintained by adding salt and ice at the condenser/silica gel outlet. At the end of the sample run, the probe and nozzle were removed from the stack and was covered to prevent any gain or loss of particulate matter. The filter paper was carefully detached from the holder and placed in a petri dish, then dried and weighed (**Figure 3**). The difference in weight represented the amount of particulate matter collected on filter media (*USEPA year; Nie et al. 2012; Macor and Pavanello 2009; Sippula 2009; Karademir 2006*). The PM concentration was calculated by using following equation:

$$C_s = K_3 . M_n / V_{m\,(std)}$$

where:

C_s = Concentration of particulate matter in stack gas, dry bases, corrected to standard conditions, gm^{-3}

K_3 = 0.001 g/mg for metric units, 0.0154 gm g^{-1} for English units.

M_n = total amount of particulate matter collected, mg.

$V_{m\,(std)}$ = volume of gas sample measured by dry gas meter, corrected to standard conditions m^3

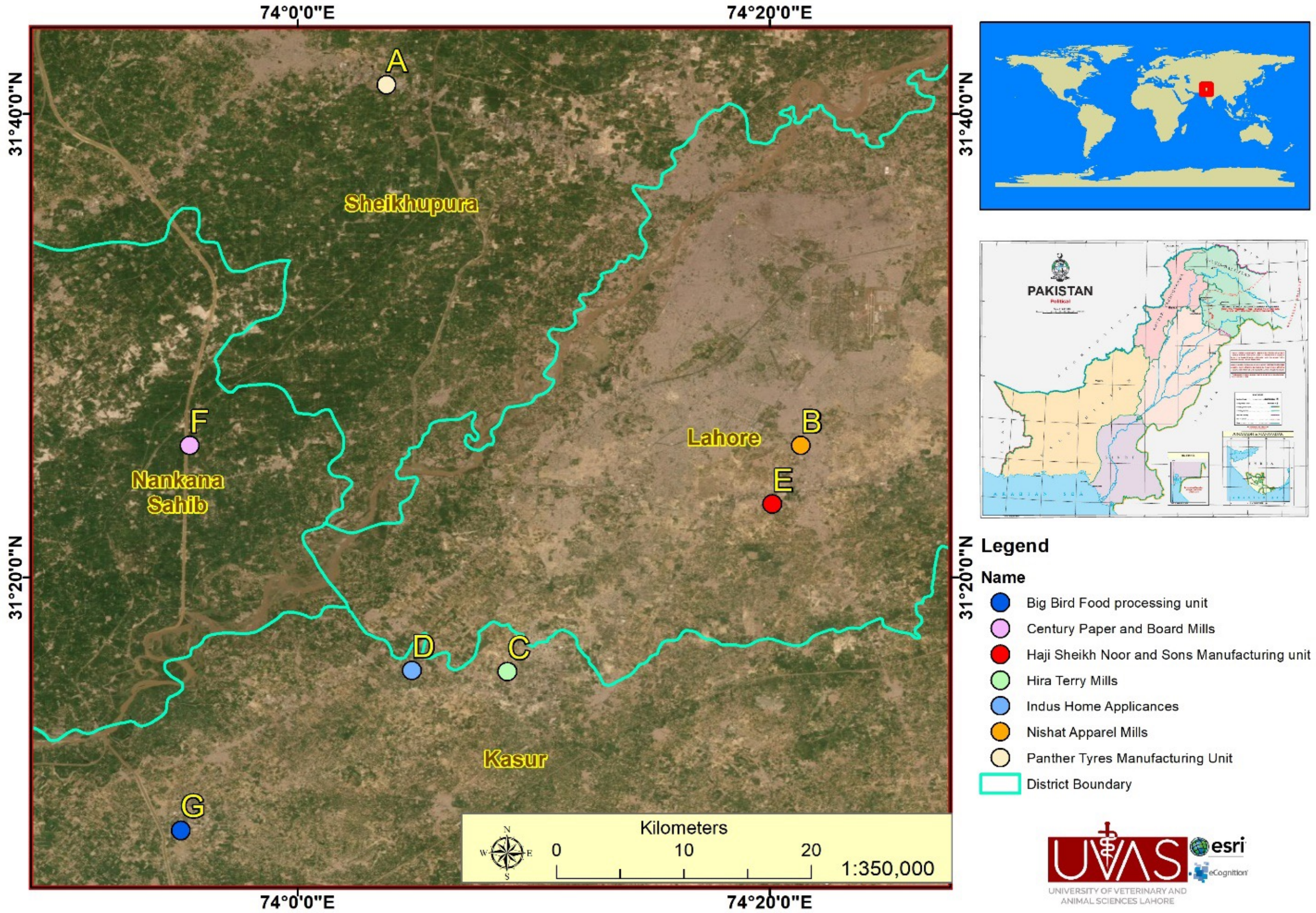

Figure 1. Study area and location of different industries selected for sampling.

Figure 2. Particulate matter sampling by Iso-kinetic instrument.

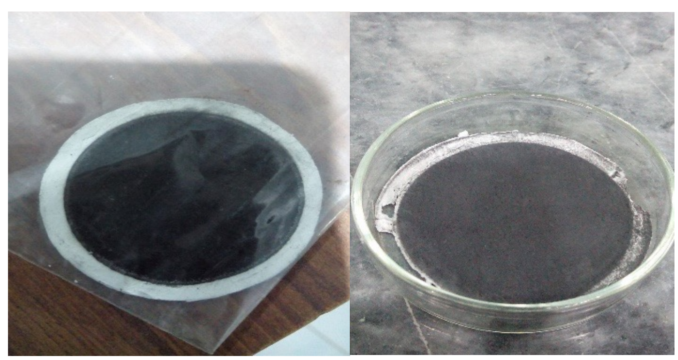

Figure 3: Filter papers recovered.

Assessment of workers health

A questionnaire was designed to obtain information from the workers in the selected sampling sites relating to occupational health and safety, and their well-being as well. The workers were randomly selected and interviewed after obtaining their consent.

RESULTS AND DISCUSSION

Boilers are an integral component of most industries for steam generation (*Barma et al. 2017*). Combustion processes spew variable quantities of gaseous and particulate pollutants into the atmosphere based on the fuel type and quality and coal is the major fuel used in industries (*Dmitrienko et al. 2018*). According to the NEQS devised by Pakistan Environment Protection Agency (Pak-EPA), the industrial emissions released by combustion of different fuel types should not exceed the concentrations (**Table 1**).

The pollutants emitted from the combustion process depend upon the characteristics of the fuel burned, temperature of the furnace, actual air used, and any additional devices to control the emissions. The concentrations of CO released from natural gas boilers ranged between 187.5 mg m^{-3} to 2,952.5 mg m^{-3}, while it varied between 37.75 to 3 85 mg m^{-3} from coal boilers, and HFO boilers emit CO in the range of 37.3 to 443 mg m^{-3} (**Table 2**). It can be seen that natural gas boilers emit higher CO concentrations as compared to the HFO and coal boilers, which is due to low mixing of air in low carbon fuels like natural gas (*Sahoo et al, 2009*). There are small variations in CO_2 emissions ranging between 6.5 to 11.56 mg m^{-3} from all boilers using three types of fuel because other factors like net efficiency of combustion process, fuel quality, presence of control devices etc. determine the amount of pollutants released.

Coal and HFO boilers produced SO_2 emissions in the range of 1478.8 to 2,384.2 mg m^{-3} and 1,233 to 3,866.9 mg m^{-3} as compared to the natural gas boilers 0 to 116.85 mg m^{-3}. Higher sulphur content in the fuel is responsible for higher SO_2 emissions as SO_2 emissions were highest or HFO followed by Coal and Natural gas. Lower SO_2 emissions from some coal boilers is due to the presence of scrubbers in exhaust Chimneys.

The concentration of NOx measured from selected industries were within the NEQs values and variations in values were irrespective of the fuel type (**Table 2**) because generation of NO depends on the temperature in the combustion engine, which converts the N_2 to NO (*Sahoo et al. 2009*). Particulate Matter (PM) emission is of particular concern for boilers using coal. Mostly, PM emissions from oils are lower than those of coal because coal is a slow burning fuel having high ash (incombustible inorganic) content. Coal boilers emit high amounts of particulate matter (PM) (*Alam et al. 2014; Flagan and Seinfeld 1988*). However, in this study TSP concentrations of all boilers are lower than NEQS limit i.e. 500 mg m^{-3} because selected industries have scrubbers and are using good quality anthracite coal.

The estimated average emissions of various gaseous pollutants are given in. The values were calculated using activity data from the organization. The emission factors for CO_2, CO, SO_2, and NO_x are calculated based on the input data, such as chemical composition of the coal used and the actual air used during combustion (**Table 3**). Activity data is calculated by volume or mass i.e. liters of petrol consumed.

Activity Data × Emission Factor = GHG Emissions

The maximum SO_2 emissions were measured from coal boilers followed by HFO and natural gas because it mainly depends on the sulfur content in the coal unlike

Table 1. National Environmental Quality Standards (NEQS) for combustion of different fuel types.

NEQS	coal (mg m^{-3})	natural gas (mg m^{-3})	*HFO (mg m^{-3})
CO	800	800	800
NO_x	1,200	400	600
SO_x	1,700	1,700	1,700
Particulate matter (PM)	500	--	--

*HFO is heavy furnace oil

Table 2. Average concentrations of emissions monitored from the selected industrial boilers.

Fuel type		CO (mg m^{-3})	CO_2 (mg m^{-3})	NO (mg m^{-3})	NO_2 (mg m^{-3})	NO_X (mg m^{-3})	SO_2 (mg m^{-3})	TSP (mg m^{-3})
Coal	Average	185.16	7.10	253.21	15.43	268.64	1,994.6	202.8571
	Std Dev	128.71	0.876	132.08	40.82	143.09	440.47	102.2553
	Max.	385	8.61	411	108	411	2,659	329
	Min.	33.75	6.5	50.8	0	50.8	1,478.8	13
Natural gas	Average	1,383.1	8.864	149.66	8.256	177.76	23.95	82.3
	Std Dev	1,137.20	2.14	108.18	13.79	111.25	51.97	30.41
	Max	2952.5	11.56	328.8	32.18	360.9	116.9	93.4
	Min	187.5	7.1	63.99	0	72.07	0	2
HFO	Average	198.91	8.722	528.13	36.65	564.77	2,981.76	197.4
	Std Dev	218.32	2.38	447.06	58.92	431.40	1,150.66	99.8
	Max	443.5	11.06	1,301.9	140.2	1,301.9	3,921.7	101.45
	Min	0	6.13	223.8	0	242.25	1,233.4	11

High mean values are indicated in bold

Table 3. Estimated Average Emissions of various gaseous pollutants using activity data from the selected industries.

Fuel Type	Fuel Consumed	CO_2 Emission factor	Emission amount of CO_2 per year	SO_2 Emission Factor	Emission amount of SO_2 per year	NO_x emission factor	Emission amount of NO_x per year	Emission factor of CO	Amount of CO emitted per year
Heavy Furnace Oil	2,450 L	2.614 kg L^{-1}	6.404 t	5.544 kg L^{-1}	13.582 t	0.0074 kg L^{-1}	0.181 t	0.839 kg L^{-1}	2.055 t 17.123 t
Natural gas	2,666 kg	0.45 kg kg^{-1}	1.199 t	0.02 kg kg^{-1}	0.0533 t	0.0011 kg kg^{-1}	0.0026t	6.423 kg kg^{-1}	2.292 t
Coal	3,000 kg	2.970 kg $unit^{-1}$	8.910 t	5.723 kg $unit^{-1}$	17.169t	0.0071 kg $unit^{-1}$	0.0213 t	0.764 kg $unit^{-1}$	

the emissions of CO_2 and NO_x, which depends on the operating conditions and the design of the plant. The CO emissions were highest from natural gas boilers as compared to the coal and HFO boilers which is due to the low mixing of air leading to incomplete combustion of gaseous fuel. The variations in NO_x emissions vary from plant to plant regardless of fuel type depending upon temperature of the furnace and air used. However natural gas is still considered a cleaner option owing to lowest emission of particulate matter as compared to other fuels as observed by *Yang et al.* (*2018*) as well.

It has also been noted that the type of equipment using the same fuel may also produce different levels of emissions as observed by *Tian et al.* (*2021*). These were evaluated and compared emission levels from different sources using the same and different fuel types and noted that the levels of emissions caused by a coal fired residential stove and a coal fired industrial boiler varied significantly.

One of the most important factors in air quality studies is the exposure assessment of the people being exposed. In workplaces, occupational health and safety must be the foremost obligation of the employer. While the selected boilers were noted to be releasing harmful pollutants, a questionnaire-based survey was conducted to assess the health and OHS practices in the industries. Forty-two (n=42) workers from selected industries volunteered to participate in this exercise. It was observed that 11 out of 42 workers were suffering from health problems like headache, high blood pressure and respiratory problems (like asthma and allergies); 12 were aware of the exposure to hazards like noise, dust, vibrations and heat. In response to queries related to use of personal protective equipment (PPEs), 20 had access to PPEs but not in good condition while the remaining 12 workers had no access to PPEs. Overall, 34.4% workers were suffering from health problems and 37.5% workers had exposure to health hazards as they were not using PPEs (**Figure 4**).

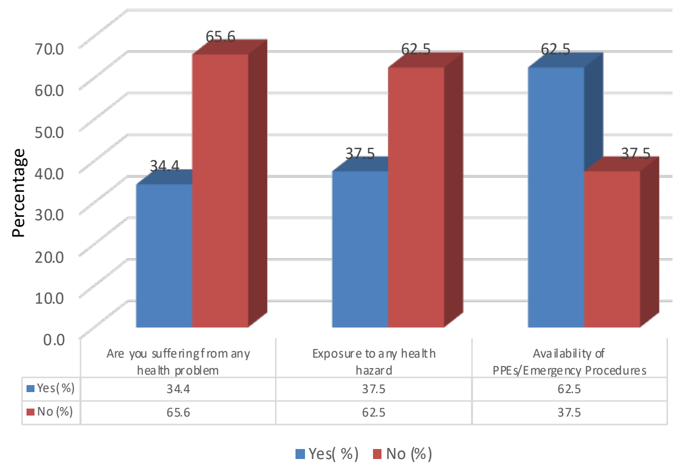

Figure 4. Response of workers regarding OHS practices and health status.

CONCLUSION

This study was aimed to assess the amount of gaseous and particulate matter emissions from coal, heavy furnace oil and natural gas powered industrial boiler's exhaust. Among all the analyzed parameters SO_2 emissions were above the permissible limit from the majority of the coal and HFO boilers, while natural gas boilers release CO beyond the NEQS limits ranged between 493 to 2,952 mg/m^3. Although the TSP emissions from all industries come under the standard values, but the lowest emissions (82 mg/m^3) were observed from natural gas boilers. Similarly, the nitrogen oxides (NO, NO_2 and NO_x) emissions from the selected industries also met the quality standards. This may owe to the fact that different factors like combustion efficiency, furnace temperature, air used, fuel quality, plant design, presence of control devices determine the amount of pollutants released. Hence, it is suggested that good quality fuel and pollution reduction technologies like scrubbers, filters, catalytic converters, etc. should be used by industries to reduce the air pollution.

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