Emission Factors for Continuous Fixed Chimney Bull Trench Brick Kiln (FCBTK) in India

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***Abstract*— *Uncertainty in emissions from brick manufacturing is a major concern and more primary monitoring based datasets are required. This study presents latest emission factors for continuous fixed chimney bull trench brick kilns (FCBTK), which is the main technology used for brick production in India. Stack monitoring of kilns in a typical brick manufacturing cluster in India is carried out to monitor emissions of pollutants like PM, SO_2 and CO. Average concentrations of PM, SO_2 and CO in the stacks are measured to be 172±76, 114±47 and 484±198 mg/Nm ^{3}, respectively. Monitored stack concentrations are used to compute emission factors based on brick production and fuel consumption activities in the cluster. The computed emission factors across different kilns ranged between 0.81-1.18, 0.57-0.71 and 2.07-2.80g/kg of fired bricks for PM, SO_2 and CO, respectively. Corresponding emission factors per unit of coal used in brick kilns are found to be in the range of 13-29, 9-15, 40-56 g /kg for PM, SO_2 and CO, respectively. The differences in emission factors are mainly due to variations in the quality of coal used by different kilns. Good correlations were observed between changing calorific values, ash and sulphur content of coal and emissions monitored in the kilns. These new factors can be used for improvement in emission inventories and thereafter modelling results for the region.*

***Keywords*— *Brick Kiln, FCBTK, Emission Factor, India*.**

I. INTRODUCTION

Clay fired brick manufacturing is widely known as a polluting industry contributing to air pollution mainly in developing countries (Skinder et al., 2014; Weyant et al., 2014; Le et al., 2010). Over the years, due to rapid increase in brick production, the corresponding increase in consumption of fuel have resulted in increased emissions of particulate matter (PM) and other gaseous pollutants like sulphur dioxide (SO_2), and carbon monoxide (CO). Brick manufacturing industry is generally unorganized and has limited controls for air pollutant emissions. Old technologies with low combustion efficiencies and limited tail-pipe controls lead to enormous pollutant emissions causing damage to human health at the local, and regional scales (Pariyar et al., 2013; Motalib et al., 2015). Black carbon (BC) which is a constituent of primary PM emitted from incomplete combustion in the brick kilns, is now known to have second highest radiative forcing after carbon dioxide (CO_2) (Bond et al., 2014).

In India, brick manufacturing industry is growing at a rapid rate and there are very few published studies presenting the emission factors for different types of brick kilns. In 2012, GKS (2012) conducted emissions measurement for different pollutants emitted from brick kilns in India. Rajarathnam et al. (2014) also presented the results of emissions from brick kilns employed with various technologies and showed emission reduction potential of zig-zag and vertical shaft brick kiln (VSBK) technologies over FCBTK's that are generally used in India for manufacturing of bricks. Technology-wise emission factors developed in these studies are presented in Table 1.

Table 1 Emission factor (g/kg of fired bricks)for different type of brick kiln technologies

Study	Study area	Technology	Emission Factors (g/kg of fired brick)				
			PM	$PM_{2.5}$	SO_2	CO	CO_2
GKS (2012)	India and Vietnam	FCBTK (Fixed chimney bull trench kiln)	0.86	0.18	0.66	2.25	115
		Zig-zag	0.26	0.13	0.32	1.47	103

		VSBK (vertical shaft brick kiln)	0.11	0.09	0.54	1.84	70
		DDK (down draught kiln)	1.56	0.97	n.d	5.78	282
		Tunnel	0.31	0.18	0.72	2.45	166
Rajarathnam et al. (2014)	South-Asia	FCBTK	0.89		0.52	3.63	179
		NDZZ (Natural draught zig-zag)	0.22		0.06	0.35	119
		FDZZ (Forced draught zig-zag)	0.24		0.24	2.04	96
		VSBK	0.09		0.10	4.14	118
		DDK	1.56		0	5.01	526

Inventorisation of emissions from brick manufacturing industry is very important, especially in the context of developing countries. However, due to regional variations in fuel use and technologies, there is still large uncertainty in emission factors for brick making activity. Zhao et al. (2011) and Bond et al. (2004) discuss the uncertainties in emissions from the sector. This study presents latest results of measurements carried out in northern India for developing emission factor for PM, SO_2 and CO for the FCBTKs brick manufacturing technology. Measurements are presented for a brick manufacturing cluster in the heavily populated and polluted Indo-gangetic plains (Giles et al., 2011) in India. This study is limited to continuous natural draught, traditional FCBTKs, which has the maximum share in the total brick production in India. Findings of this study will be useful in reducing the emission uncertainties from the brick manufacturing sector and improving modelling results for the region.

II. MATERIAL AND METHODS

2.1 Study area

Indian brick industry is highly unorganized and seasonal. Brick making activities are generally carried out after the rice harvest in the months of November-December and continues till the start of rainy season in June. For brick making, clay is the main raw material, and coal and biomass are the major fuels used in the country. However, coal dominates as the fuel used in the sector. India stands second in the overall production of clay bricks in the world after China and there are around 100000 brick kilns in India which has an estimated annual production of about 140 billion bricks (TERI, 2015). Annually, brick industry in India consumes about 25 million tons (mt) of coal and 2.6 million tons of biomass (Rajarathnam et al. 2014; TERI, 2015). Bull's trench brick kiln (FCBTKs) and clamp kilns are the two main brick firing technologies used in India. Other types of firing, which are not significant in terms of production include Hoffman, DDK, VSBK and tunnel kilns. FCBTKs accounts for about 70% of the total brick production in the country (Rajarathnam et al., 2014).

With growing infrastructure and housing demands, the sector is growing at a rapid rate. TERI (2015) projects the consumption of coal used in brick making in India from 39 mt in 2011 to 154 mt in 2031. For control of emissions, the Ministry of Environment, Forests and Climate Change, India has stipulated standards for maximum allowance of PM and a minimum stack height for the brick kilns. It is to be noted that the standard for PM stack emissions from brick kilns in India is 750 mg/m³ with medium and large size category of kilns having production capacity of above 15,000 bricks per day, which is five times the standard for coal based thermal power plants and also more than that of many other industries (Table 2).

Table 2 PM stack emission standard (mg/Nm^3) for different categories in India

Industry	PM Standard (mg/Nm^3)
Cement	30-100
Small boilers	150-1200
Foundries	150-450
Lead glass	50-1200
Soft coke	350
Beehive hard coke oven	150-350
Briquette (coal)	150-350
Boilers using agriculture waste as fuel	250-500
Sponge iron plant	50-100
Thermal power plant	150

Brick kiln	750-1000

This study focuses on a brick making cluster in Varanasi district, one of the most important clusters in terms of brick manufacturing activity in India. The cluster consists of about 226 coal fired natural draft fixed chimney FCBTKs (BEE, 2010), with a production of about 707 million bricks per annum and an annual coal consumption of about 0.126 mt (BEE, 2010). This amounts to 180 tonnes of coal consumption per million bricks (BEE, 2010).

Ten FCBTKs were selected in the study domain for carrying out stack emission measurements and development of emission factors. Basic details of brick manufacturing activity are noted through questionnaire survey and confirmed with visual inspection. Production capacities of the kilns in the study domain varied between 24000-34000 bricks per day with a fuel consumption of about 2160-5180 kg/day. Due to variations in calorific values of the fuel used, specific coal consumption (coal consumption kg/kg of brick) varies between 0.031-0.068, among different kilns. Salient features of the selected kilns are shown in Table 3.

Table 3 Key features of the brick kilns monitored in this study

Kiln No.	Production capacity (bricks/day)	Coal consumption (kg/day)	Specific coal consumption (coal consumption(kg)/kg of brick)
1	26000	2656	0.035
2	32000	4750	0.051
3	32000	3240	0.035
4	24000	2160	0.031
5	30000	3915	0.045
6	26000	2576	0.034
7	26000	2912	0.038
8	32000	4680	0.050
9	34000	5080	0.051
10	24000	4808	0.068

2.2. FCBTK Technology

FCBTKs are horizontal, moving fire kilns in which firing is done continuously throughout the brick making season. Green bricks (molded clay blocks or bricks which are to be fired) are placed in trench (area used for stacking brick in the kiln) and covered with partially fired bricks layer. The whole arrangement is thermally insulated by spreading 3"–5" brick dust (Keri) or ash. The brick-loading end is sealed with metal or jute damper and brick unloading end is kept open for drawing air required for combustion. Fuel is fed manually at a more or less constant rate through feed hole covers provided at the top of the kiln. At any point of time during operation, the kiln can be divided into three distinct zones as shown in Figure 1.Starting from the unloading end, the first zone is brick cooling zone. Air required for combustion enters through unloading end, picks up heat from fired bricks, gets heated up and in turns cools the fired bricks. The next zone is the firing zone in which fuel is fed through feed hole covers. Hot air coming from cooling zone carries out the combustion of fuel in this zone. The third zone is brick preheating zone in which the hot gases coming from combustion zone preheats the green bricks, takes up moisture from them and finally leave as flue gases from the kiln stack. Generally, one or two rows are fired at a time and when firing of one row is complete it is closed and next row is opened. Direction of fire travel in a kiln is same as direction of air travel (generally anticlockwise).

2.3 Methodology

PM, SO_2 and CO concentrations in the flue gas were measured at all the ten selected kilns during April 2015. A minimum of three repetitive monitoring were carried out in each kiln. Measurements were carried out in accordance with the guidelines laid down by Bureau of Indian Standards (BIS)/Central Pollution Control Board (CPCB). Stack sampler (VSS1, Vayubodhan, India) was used to collect samples of the flue gas for PM and gaseous pollutants. Flue gas temperature was measured by thermocouples and velocity was measured using stack velocity monitor. Iso-kinetic sampling procedure was followed for PM sampling followed by analysis using gravimetric technique. Pre conditioned and pre weighed glass fibre thimbles (Whatmann make) were used for PM sampling. The thimbles were accurately weighed using a microbalance of accuracy 1µg before and after the sampling. Sampling was carried out during normal kiln operations under stabilized conditions (excluding the first firing cycle) for a period of 60-80 minutes in all the kilns, which covered both fuel feeding and non-feeding periods.

SO_2 was measured using titrimetric method as per IS11255 (Part2): 1985. CO measurements for the kilns were carried out using flue gas analyzer (Kane-May, KM900 hand-held combustion analyzer). Traverse points as required by standard methods could not be followed in any of the kilns due to the absence of multiple sampling ports, improper access to the location, and safety issues as reported in earlier studies (SSEF, 2012). Hence, monitoring was carried out through the same sampling port, with a minimum of two traverse points in linear direction. The average concentration of PM, SO_2 and CO and flue gas rates at each of the kiln were used for emission estimation using equation (1)

$$Emission\ rate(mg/hr) = Flow\ rate\ of\ flue\ gas(m^3/hr)\ \text{X Pollutant concentation}(mg/m^3) \quad \ldots\ldots (1)$$

Flow rate of the flue gas is calculated from the velocity of the flue gas and area of stack (equation 2).

$$Flow\ rate(m^3/s) = Velocity\ of\ flue\ gas(m/s)\ \text{x Area of stack}(m^2) \quad \ldots\ldots (2)$$

Pollutant emissions vary according to type of kiln/technology, quality of fuel used for firing and also with different operating conditions. Data on production of bricks and fuel used in different kilns is collected through questionnaire surveys and verified through visual inspections. Emission factors (EF) for PM, SO_2 and CO are computed using emission rate, fuel consumption and production datasets using equations 3 and 4.The EFs are developed in two ways- a) pollutant emission per kg of fuel consumed, and b) pollutant emission per kg of fired bricks. EF in terms of per kg of fuel consumed is derived from emission rate and the quantity of coal used for firing the bricks, whereas, EF in terms of per kg of fired brick is derived from emission rate, number of bricks fired and weight of fired brick.

$$\text{EF}(mg/kg\ \text{of fuel}) = \frac{Emission\ rate(mg/hr)}{Fuel\ consumption\ rate(kg/hr)} \quad \ldots\ldots (3)$$

$$\text{EF}(mg/kg\ \text{of fired brick}) = \frac{Emission\ rate(mg/hr)}{\{Rate\ of\ production(no.of\ bricks/hr)\ X\ Mass\ of\ fired\ brick(kg)\}} \quad \ldots\ldots (4)$$

A number of brick samples were used to compute the average weight of brick produced in different brick kilns which varied between 2.65-3.25 kg. Emission factors developed in this study are compared with the previous estimates and discussed.

The emission estimates in this study are also compared and discussed in context of the calorific values, ash content and sulphur content of the fuel used in different kilns. Samples of coal used in different kilns were drawn and calorific values, sulphur content ash content were measured as per standard measurement techniques (ASTM D5865-99a, ASTM D3177-89 (1997) and ASTM D3174-97 for calorific value, sulphur content and ash content respectively).

III. RESULTS AND DISCUSSIONS

3.1 Stack monitoring

Concentrations of pollutants in the flue gas of the monitored FCBTKs are shown in Figure 2. PM concentrations in all the monitored FCBTKs are well within the prescribed limit of 750 mg/Nm^3 for medium and large size brick kilns, as prescribed by the Ministry of Environment and Forests (MoEF), Government of India. Average PM concentrations in the ten monitored FCBTKs ranged between 88- 287 mg/Nm^3,with an average of 172±76 mg/Nm^3. PM levels in this study were found to be low when compared with findings in previous studies. Low PM levels could be attributed to better combustion conditions, as the monitoring in all the kilns has been carried out at normal stabilized condition, excluding the first fuel firing cycle. Earlier studies have reported PM levels in the range 143-766 mg/Nm^3 (SSEF, 2012),148-800 mg/Nm^3 (TERI, 1998; CPCB, 1996) and 113-514mg/Nm^3 (TERI, 2007). These studies reported higher concentrations of PM as monitoring also included the time during the first firing cycle in which the combustion condition at the kiln were not yet stabilized (SSEF, 2012). Incomplete combustion resulting from poor operating practices and wet weather condition caused by unseasonal rain during monitoring period were also reported in earlier study as the possible causes of high PM emissions (SSEF, 2012). Lower PM emission in the current study can also be the results of good operating practices in the kilns; like timely feeding of coal in the combustion zone, proper housekeeping practices, and use of powdered or crushed coal for charging. Quality of coal used for combustion also plays an important role in defining the PM emissions. Calorific values of coal used across different kilns varied between 4568-6726 kcal/kg (Figure 3) with an average of 6000 kcal/kg. All kilns except one showed the use of better quality Grade B category of non-coking coal (calorific value 5600-6200 kcal/kg) as defined by MoC (2015). Figure 3 shows the variation in calorific values and fuel consumption across the kilns. An obvious inverse relationship is observed. Ash content of the coal samples ranged between 15.7-38.6%. Figure 4 shows the variation in ash content of fuel and corresponding change in PM emissions across different kilns. A direct relationship is observed between PM emissions with increasing ash content in the fuel.

Concentrations of SO_2 in the flue gas in different kilns varied between 62-189 mg/Nm^3 with an average value of 116±47 mg/Nm^3. Range of SO_2 levels in this study was also found to be lower when compared with earlier studies. Earlier studies report SO_2 levels in the range of 29-610 mg/Nm^3 (SSEF, 2012). Levels of SO_2 are highly dependent on the sulphur content of the coal used for firing. The sulphur content in the coal samples collected from different kilns was in the range 0.42-1.71%. Figure 6 shows the variation in sulphur content of the fuel and corresponding SO_2 emissions, which again shows a direct positive correlation between the two.

Average levels of CO across the ten monitored kilns ranged from 235-680 ppm with an average CO level of 422±164 ppm. Incomplete combustion of the fuel results in the generation of CO. High levels of CO are observed at the time of feeding of coal. Concentrations of CO were observed to be above 2000 ppm at the time of fuel feeding, which slowly go down to as low as 186 ppm within few minutes after the fuel feeding activity. The time average CO concentrations reported in earlier studies was in the range 1400-1900 ppm (SSEF, 2012), which was again higher than the current study results, mainly on account of differences in fuel quality and time of monitoring.

3.2 Emission Factors

Emission factors for PM, SO_2 and CO were calculated based on equations 1-4 and are shown in Figure 6 and 7. PM emissions derived per kg of fired brick ranged between 0.81- 1.18 g/kg (average 0.93±0.1) and 13.16-29.30 g/kg (average 19.78±4.3) of fuel used. For FCBTK technology, GKS (2012) reported PM emissions of 0.86±0.74 g/kg of fired brick and 14.15±8.91 g/kg of fuel used, while, Rajarathnam et al. (2014) reported an emission factor of 0.89 g/Kg of fired bricks. Despite differences in concentrations measured, PM emission factors derived in this study are in close agreement with the previous estimates. This points to variations in brick production rates and quality of fuels used in previous studies and this work. Present study shows lower standard variations with the mean emission factor values in comparison to previous estimates.

EF derived for SO_2 varied between 0.57-0.71 g/kg (average 0.66±0.05) of fired brick and 9.72-14.99 g/kg (average 13.03±1.75) of fuel used. Average SO_2 EF developed in earlier studies was 0.66±0.55 g/kg of fired bricks and 10.45±7.38 g/kg of fuel used (GKS, 2012). There again the standard variations are found to be lower than previous estimates.

The EF for CO in the current study was estimated to be in the range 2.07-2.80 g/kg (average 2.40±0.25) of fired brick and 40.65-56.83 g/kg (average 48.27±5.82) of fuel used. These estimates are also in agreement with earlier studies findings which reported for CO as 2.25 g/kg of fired brick and 41.14 g/kg of fuel used (GKS, 2012).

IV. CONCLUSION

Brick manufacturing sector is one of the significant contributors to emission loads in many developing countries. Emissions in the process are due to use of primitive combustion technologies and limited tail-pipe controls. This study presents the latest measurements carried out in an important brick manufacturing cluster in India, primarily with an objective to reduce uncertainties in the emission factors. Emission measurements carried out at different kilns shows adherence to the national standards which are presently less stringent than many other industrial categories. However, measurements show significant quantities of uncontrolled emissions released into the atmosphere, as also presented in previous studies. This study presents the latest emission factors both in terms of bricks produced and fuel used in a typical brick manufacturing cluster in India.

Brick manufacturing is increasing at a rapid rate with growth in housing demands and construction activities in countries like India. While there would be some reduction expected in this trend with the influx of alternative construction materials, there would still be significant production of bricks in medium to longer term. This study shows the emissions that could be attributed to brick production activity. Options for control of these emissions lie in technological advancements and introduction of advanced tail-pipe controls. Studies have reported lower emissions from newer technologies like Zig-Zag. There is also a need to carry out cost-benefit analysis of advancement to improved technologies by taking into account the fuel efficiency and health benefits. Low cost tail-pipe treatment technologies also need to be developed which can be adopted by the industry for pollution control. For all this, there is a need to progressively reconsider the stack emission standards for the brick industry.

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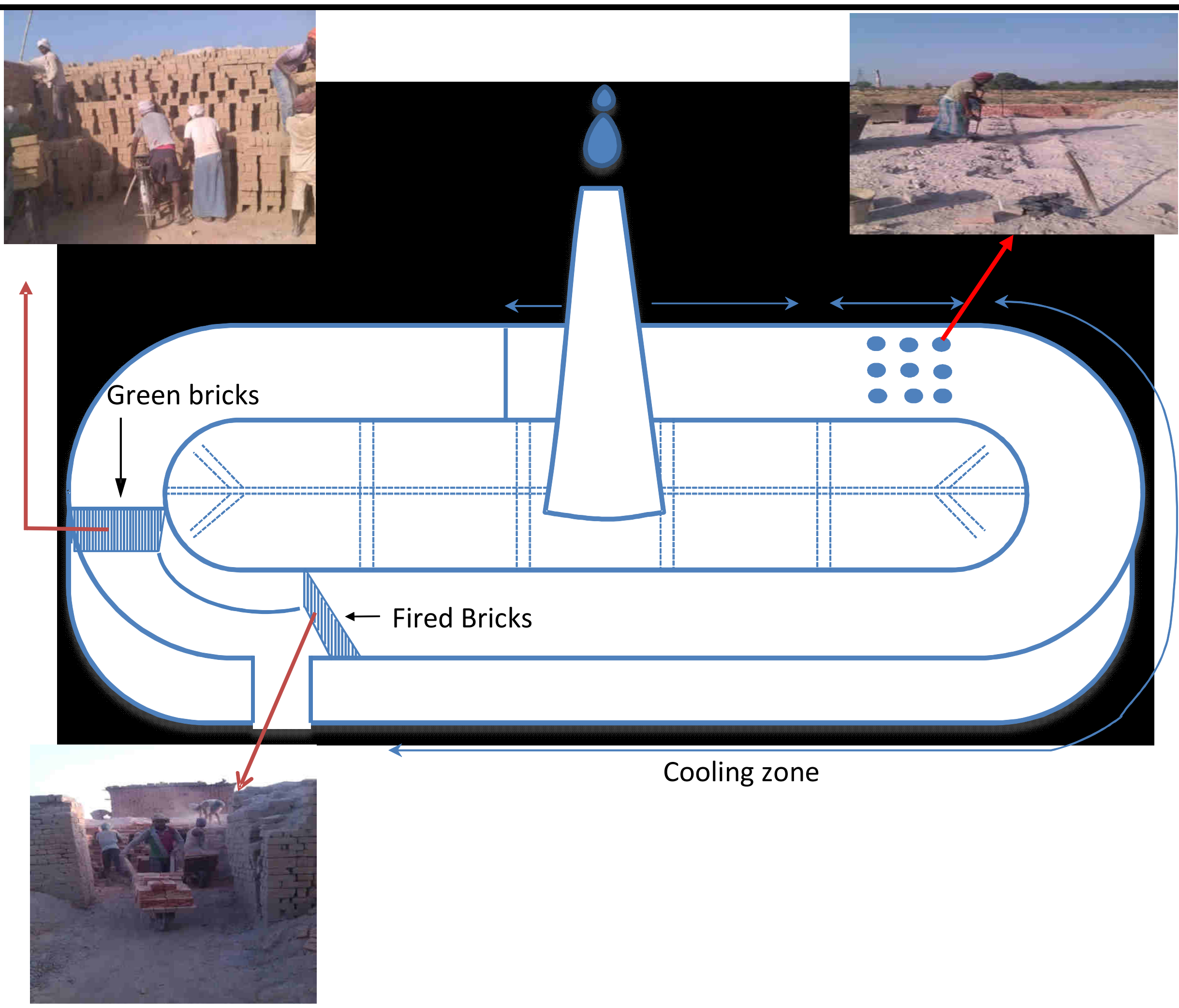

Fig.1:Brick making process in a FCBTK

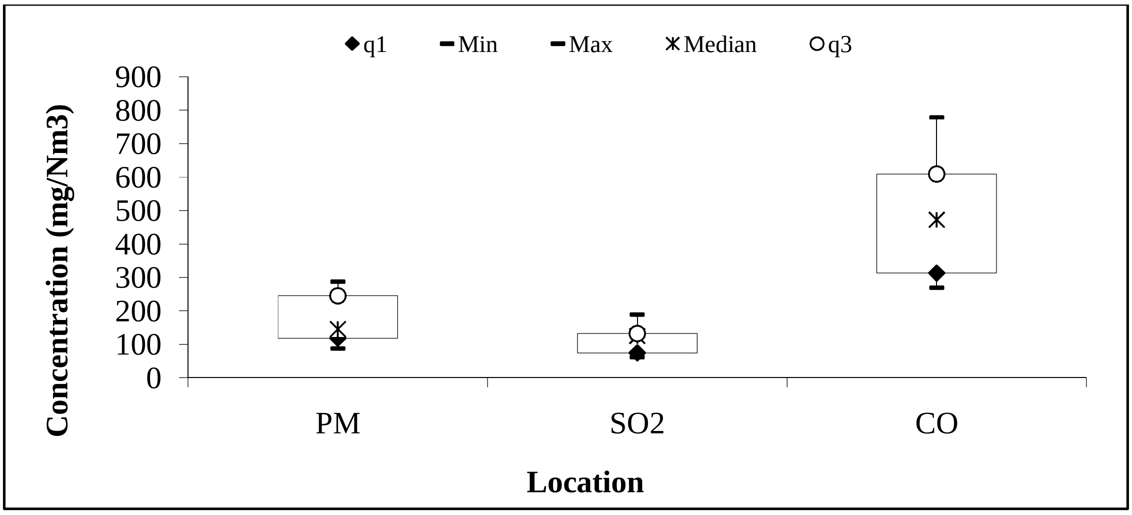

Fig.2:Variation of concentration of PM, SO_2 and CO in flue gas in different kilns

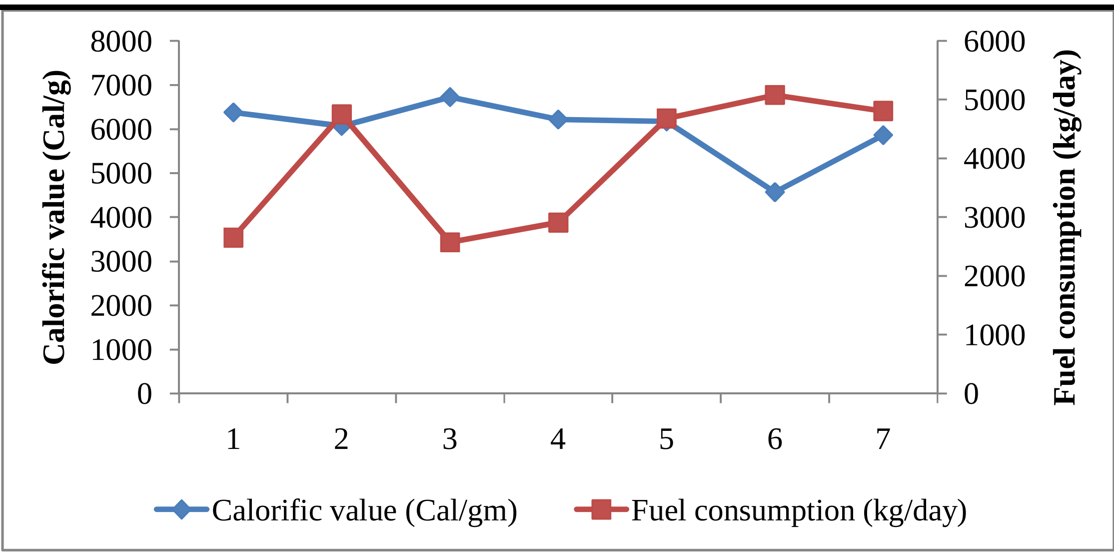

Fig.3: Variation in calorific value (Kcal/kg) and fuel consumption (kg/d) at different kilns

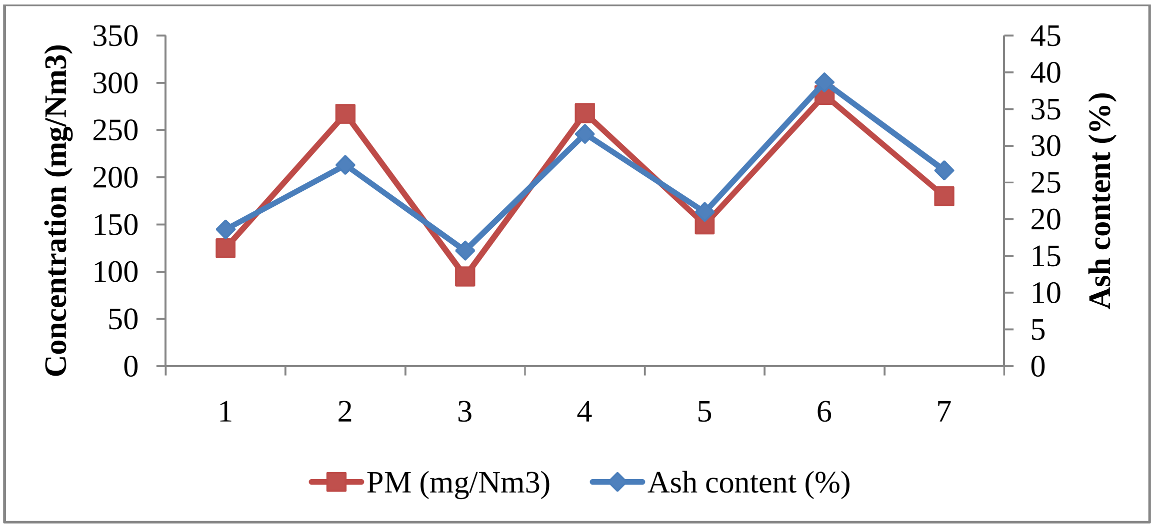

Fig.4: Variation in ash content of the fuel and PM concentrations at different kilns

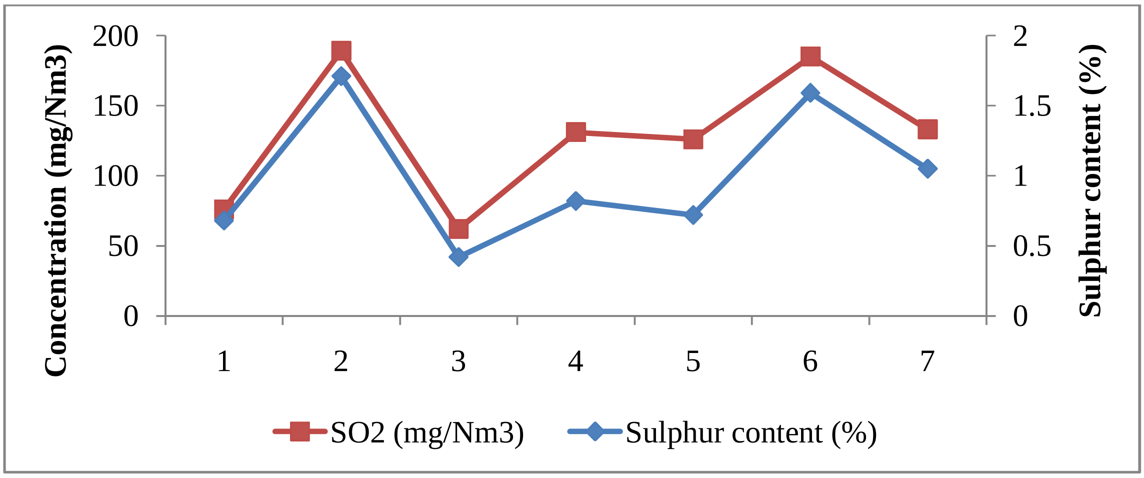

Fig.5:Variation in sulphur content of coal and SO2concentrations at different kilns

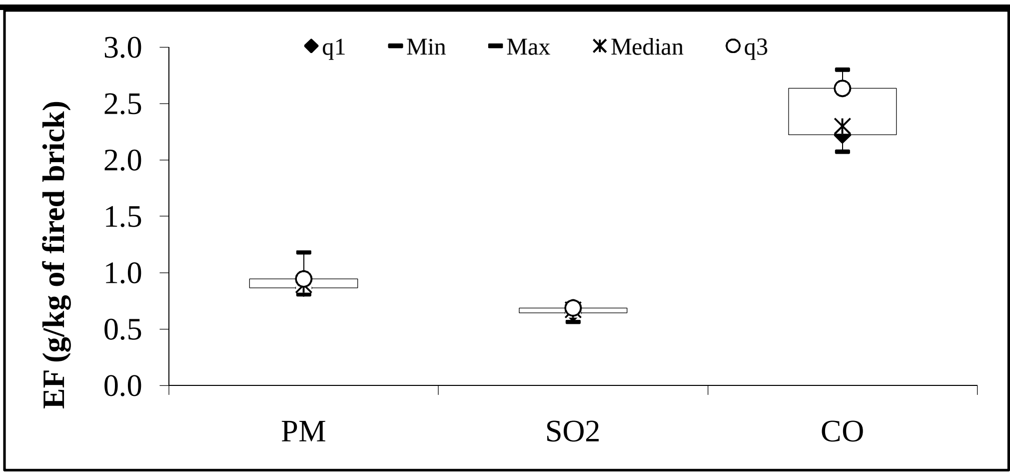

Fig.6:Variation in emissions (g) per kg of fired brick for different brick kilns

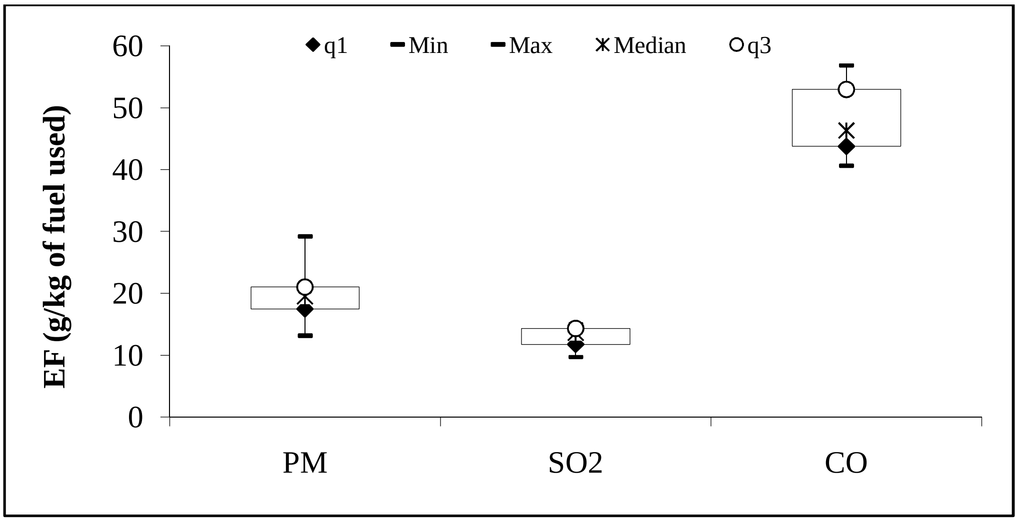

Fig.7:Variation in emission (g) per kg of fuel used in different brick kilns