BEFORE THE NATIONAL GREEN TRIBUNAL, PRINCIPAL BENCH, AT NEW DELHI

IN

I.A No.121 of 2020

IN

ORIGINAL APPLICATION NO.1016 OF 2019

IN THE MATTER OF:

Utkarsh Panwar ....Applicant

Versus

Central Pollution Control Board and Ors. .....Respondent

IN THE MATTER OF:

ZILA INT NIRMATA SAMITI

INDEX

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ADDITIONAL AFFIDAVIT FOR PLACING ON RECORD OBJECTIONS TO CPCB'S REPORT DATED 6/7/2020, ON BEHALF OF U.P ENT NIRMAN SAMITI.

I, Omveer Singh Bhati, Son of Tej Singh aged about 59 years Resident of Devta, P.O Deva, District Gautam Budhh Nagar, U.P, presently at New Delhi, do hereby solemnly affirm and declare that:

1. The present deponent is filing this affidavit acting on behalf of, and in his capacity as President of U.P Ent Nirman Samiti (hereinafter 'the Association).

2. The captioned matter is pending before this Hon'bie Tribunal and is next listed on 15/09/2020. In its order dated 17/03/2020, this Hon'bie Court had directed the CPCB to submit a report on certain issues specified in that order. In compliance with that order the CPCB submitted a

report dated 06/07/2020 before this Hon'bie Tribunal (hereinafter 'the Report').

3. It is submitted that the Report has several glaring and seif-evident errors, inconsistencies and gaps, which render the report unusable for taking any decision affecting the operation of brick kilns. These deficiencies have been pointed out hereinbelow, in no particular order.

I. ASSUMPTION OF 1000 KG EMISSION LOAD IS BASELESS

4. A fundamental assumption, which affects all aspects of the report, is made on page 9 of the report, which is

"Emission load from brick kiins having capacity of 30000 bricks/dayf considering stack PM emission of 250 mg/Nm3 at 17% 02: 1000 Kg/day/'

5. The baselessness of this assumption can be demonstrated in numerous ways, using CPCB's own reports/studies/data. If this assumption is considered true, then emissions from brick kilns atone would account for more than 100% of the total emissions of numerous districts, which is obviously an absurdity.

Some of the brick kiln owners of Haryana after having the report of CPCB in pursuance to the orders of this Hon'ble Tribunal for the purposes of calculating the standard of Air quality approached expert opinion and the same are being given here in below as the geographical situation of Haryana and NCR is same.

This is apparent when one considers this assumption of 1,000 kg emission load in view of Table 3 on page 7 and Table 6(a) on page 10 of the Report. Table 6(a) gives the total PM10 load of various districts in Haryana in different months. Table 3 provides the number of brick kilns operating in each such district.

In the following table, the number of brick kilns for various districts in Haryana have been extracted from table 3 of the Report into column (B), and the actual total emissions for each district in the month of March, 2019 has been extracted from table 6(a) of the Report into column (D). The total emission load coming from brick kilns in each district has been shown in column (C), if each brick kiln is assumed to emit 1,000kg/day load. Column (E) shows percentage of the total emissions of the district, which come from brick kilns, if the assumption of 1,000kg/day emissions is made.

District Name (A)	**Number of brick kilns as per Table 3 of the Report** (B)	**Emissions from all kilns in the district if load assumed to be 1000kg/day per kiln** (C)	**Total Emissions Load in the District in March, 2019 as per table 6(a) of the Report** (D)	**% of the total Emissions load coming from brick kilns** (E)
Bhiwani	142	1,42,000	2,10,232	**67.544%**

Faridabad (Ballabaarh)	85	85,000	96,701	**87.9%**
Gurugram	6	6,000	1,03,785	**5.7812%**
Jhajjhar	387	3,87,000	1,02,704	**376.81%**
Jind	111	1,11,000	1,74,279	**63.691%**
Karnal	92	92,000	1,61,280	**57.044%**
Mahendragarh	42	42,000	1,04,445	**40.213%**
Nuh(Mehwat)	62	62,000	80,625	**76.899%**
Palwal	110	1,10,000	93,895	**117.15%**
Panipat	87	87,000	65,936	**131.95%**
Rewari	76	76,000	1,06,798	**71.162%**
Rohtak	49	49,000	NA	NA
Sonipat	265	2,65,000	1,17,771	**225.01%**
Charkhi Dadri	29	29,000	NA	NA

6. A look at the above table will show that If emission load of each brick kiln is assumed to be 1,000 kg/day, then the emissions from brick kilns alone would exceed the total emissions of the whole district in some cases; in the case of Jhajjar, emissions from brick kilns would be 376.81% of the total district pollution, and this figure would be 225.01% for Sonipat, 117.15% for Palwal and 131.95% for Panipat. For other districts also, this figure is grossly unrealistic, ranging between 40% to 90%.
7. This is contrary to what the Report itself states on page 18,

> "... a study on "Source Apportionment of PM2.s and PM10 of Delhi NCR for identification of major sources" prepared by Automotive Research Association of India (ARAI) and The Energy and , Resources Institute (TERI) for Department of Heavy

Industry, Ministry of Heavy Industries and Public Enterprises, New Delhi, in the year 2016, indicates that that brick kiln industry contributed about 5 & 7% w.r.t, PM10 emissions in Winter and summer respectively, in ambient air of Delhi and NCR . Further reduction of 4% in total PM10 was expected after conversion to Zig-Zag technology, which has now been implemented by brick Kilns in Delhi-NCR."

The contribution of 5% to 7% was made by brick kilns when they were operating at emission standard of 750 mg/nm3 in 2016. Presently, zig-zag brick kilns, which are the only brick kilns allowed to operate in NCR, are operating at less than 250 mg/nm3 as per CPCB itself (See internal page no. 9 of the Report). Therefore, in 2016 brick kilns were expected to contribute only between 1% to 3% of the total emissions after adoption of zig-zag technology. This make sense since the reduction from 750 mg/nmJ to 250 mg/nmJ is an improvement of 300%.

The assumption of 1000 kg/day emission from each brick kiln is thus grossly incorrect.

8. In fact, if emissions of brick kilns are determined by any given reasonable and scientific method, it is found that zig-zaq brick kilns emit less than they are less than 25kg/day, as opposed to the 1,000kg/day assumed in the Report.

9. The present applicant sought the opinion of an expert. Dr, Sameer Maithel, on the question of emission load from

FCBTK and zig-zag high draft brick kilns. Dr. Sameer Maithel is a BE, M Tech and PhD from IIT Bombay, and wrote his PhD thesis on the topic of "Energy Utilization in Brick Kilns" in 1993. He is a Former Fellow & Director, Energy-Environment Technology Division, The Energy and Resources Institute (TERI), New Delhi. He was part of the research team at TERI which assisted CPCB in conducting the technical study leading to the formulation of Emission Standards and Stack Height Regulations for the Vertical Shaft Brick Kiln (VSBK) technology. In recent years, he provided technical assistance to Bihar State Pollution Control Board (BSPCB) for the conversion of FCBTK kilns to zig-zag technology and to the Bureau of Energy Efficiency (BEE), Government of India in the development of the Energy Efficient Enterprise (E3) Scheme for brick industry. He has worked on collaborative research projects on brick industry with various academic institutions including IIT, Bombay, Stanford University, and the University of Illinois. He is the recipient of the prestigious Climate and Clean Air Coalition (CCAC) Award for Individual Achievement in 2017 at Bonn (Germany) for his contributions towards reducing emissions from brick sector in India and other South Asian countries, He is the Founder & Director of Greentech Knowledge Solutions, New Delhi.

10. The opinion of Dr. Maithei was sought on the following question:-

"Can you provide an assessment of Emission Load (kg of PM/day) from an ordinary FCBTK and Zig-Zag High Draught Brick Kiln of 30,000 brick/day production capacity, taking into account data from your studies and those available in public domain from reliable and trusted sources?"

11. Dr. Maithel responded to this request through his opinion dated 30/08/2020 and attached therewith an explanatory note containing reference to three different methods for calculation of emission loads from brick kilns, by relying upon reliable and publicly available information, including a report that CPCB got prepared from PSCT (Punjab Council for Science and Technology), and other peer-reviewed studies/reports published in reputed international journals. The reports and studies that he replied upon were also annexed with his opinion dated 30/08/2020. Opinion dated 30/08/2020 given by Dr. Sameer Maithel to the present applicant, along with its annexures, is annexed herewith as Annexure-A/1.

12. Of the various methods relied upon in the Opinion dated 30/08/2020, of particular note is the simple yet reliabie method discussed hereinafter, which relies on publicly available data from CPCB.

13. Emission load can be simply calculated using the following formula,

Emission Load =Concentration of PM in stack

gases (mg/Nm^3)

x

Volumetric Flow Rate of Stack Gases (Nm3/day)

[where Nm^3=normal meter

cube mg = milligrams

]

Therefore, only two variable are required to be known for this purpose: concentration of PM in stack gases and volume of stack gases.

With respect to the concentration of PM in stack gases - the proposed standard of concentration of PM for brick kilns is 250mg/Nm^3. The actual emissions as the as per CPCB commissioned study conducted by the Punjab State Council for Science and Technology is 49-116 mg/Nm^3, the average of which is 83 mg/Nm^3. Even as per the Report dated 06/07/2020 filed before this Hon'ble Tribunal, the measured emissions from zig-zag bricks are lower than 250mg/Nm^3 (internal page 9 of the report).

Volumetric Flow Rate of Stack Gases for zig-zag brick kilns producing between 30,000 to 60,000 bricks per day has been determined to be ranging between 11377 and 23845 Nm^3/hour as per the same CPCB commissioned study conducted by the Punjab State Council for Science and Technology. The average of 11377 and 23845 Nm^3/hour is 17,611 Nm^3/hour, which is 4,22,664 Nm^3/day and the average brick production is taken to be 45,000 bricks (between 30,000 and 60,000).

With this information, emission load from a zig-zag brick kiln producing 45,000 bricks can be calculated as follow:

Volumetric flow rate Emission load per NrrC

4,22,664 Nm^3/day x 83mg or 0.000083kg = 35kg/day

Proportionally, zig-zag brick kiln producing 30,000 bricks will be 23kg only (35kg x 30,000/45,000).

Even if the variables are revised upwards, within the margin of error and reason, this figure will still be lower than 50kg, and much lower than the 1000kg assumed by CPCB.

14. Even as per other methods (such as calculations based on emission factor, or calculations based on combustion principles}, the emission load for zig-zag brick kilns is stiil in range of 20-25 kg per brick kiln.

15. With this data, if contribution of brick kiins to total PM is calculated, it will be found that brick kilns contribute 1% of the total PM emissions.

II. INADEQUATE AND INCORRECT METHODOLOY FOR DETERMINATION OF CARRYING CAPACITY

16. The method adopted in the Report for determination of carrying capacity of different areas in NCR is inadequate and inconsistent with CPCB's own earlier approach for determination of carrying capacity. It is excessively simplistic and unreliable.

17. In the past, the CPCB in various reports filed before this Hon'ble Tribunal, has relied upon a Box Model for determination of carrying capacity (refer to CPCB's report dated 14/11/2019 in OA no. 681 of 2018 at page 30 of the filing, and CPCB's report filed In compliance of order dated 08/03/2019 in OA no. 568 of 2016 at internal page 2 of that report.

This model takes into account numerous critical factors which affect the carrying capacity of an area, which are completely absent from the Report in the present matter, including meteorological data, such as wind speed. That model takes into account dispersion to determine allowable emissions as well. Even then, the CPCB has acknowledged that this Box Model has several limitations and can be used only for the purpose of demonstrating a framework, preliminary analysis and broad estimates of carrying capacity, the model may provide broad estimates of carrying capacity.

By comparison, the CPCB's approach in the current Report is even more simplistic and unreliable than the box model, since their analysis has no dispersion modelling at all.

18. Therefore, the carrying capacity analysis in the Report cannot be relied upon for any regulatory purposes whatsoever.

III. SKEWED AND ABSENT AIR QUALITY DATA

19. The districts in NCR are very large by area, and in many cases larger than Delhi. For most of these districts, CPCB has only one air quality monitoring station. Some districts don't have even one monitoring station. These monitoring stations are located in urban and industrialized areas of these districts, whereas brick kilns are undisputedly located away from urban centres, in more rural areas (on account of cheapness of land and other logistical reasons).

The data collected from such monitoring stations is highly localised to the immediate area in which these stations are located and cannot be used to determine the air quality of the entire districts.

21. From the data, of CPCB it can be seen that there are 36 monitoring stations for Delhi, which has an area of only 1,484 km^2. The AQI collected for this area ranges from 49 to 132, which is a vast variation. If carrying capacity was calculated by relying upon the data from the monitoring station showing AQI of 132, as against the monitoring station showing AQI of 49, we would get completely different results. This shows that data collected by these monitoring stations Is highly localized and data from any one monitoring station cannot be used to determine the carrying capacity of the entire district/city.

22. This data also shows that monitoring stations are located in urban centers, which are bound to report worse AQI than actually prevailing in that district as a whole. This AQI data can therefore not be used for calculating the total existing emissions in the entire district. AQI data needs to be taken from more locations, including from rural locations in order for this data to be representative of the carrying capacity of the district.

23. Therefore, the carrying capacity assessment made in the Report is liable to be ignored on this ground also.

24. Further, the CPCB has stated on internal page no. 4 of the Report that in respect of districts for which CAAQMS and or AOD (Aerosol Optical Depth) data was not available, data has been extrapolated from other districts. The methodology of this extrapolation has not been explained. The report also does not

indicate the districts for which this extrapolation exercise has been carried out. In view of the unsound methodology and incorrect assumptions made throughout the report, it cannot be presumed that this extrapolation would be correct, without further explanation as to how it was done.

25. Similarly, the data and method used to determine mixing height is missing In the report, which leads the inference that even this is based on assumptions.

Therefore, it is submitted that the Report dated 06/07/2020 submitted by the CPCB before this Hon'ble Tribunal, cannot be relied upon by this Hon'ble Tribunal for the purpose of regulating the operation of brick kilns, or for any other purpose. It is accordingly prayed.

DEPONENT

VERIFICATION

Verified at on this 1st day of October 2020 that the contents of the above affidavit are true and correct to my knowledge, that no part of it is false and that nothing material has been concealed therefrom

DEPONENT

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Greentech Knowledge Solutions Pvt. Ltd.

Sameer Maithel, *PhD*
Director

August 30th,2020

To,
The President
Haryana Pradesh Brick Kilns Owners Association

Sub: Emission Load (kg of PM/day) for an ordinary FCBTK and Zig-Zag High Draught Kiln of 30,000 brick/ day production capacity

Dear Sir,

This has reference to your query regarding the assessment of Emission Load (kg of PM/day) from an ordinary FCBTK and Zig-Zag High Draught Brick Kiln of 30,000 brick/day production capacity.

The explanatory note on the assessment is attached as Annexure 1. The assessment is based on data taken from the Government sources (CPCB & the Bureau of Energy Efficiency) and peer-reviewed scientific papers. The results of the Emission Load calculations are as follows:

a) **FCBTK**: For FCBTK of 30,000 brick per day production capacity, the Emission Load calculated based on measured data as reported in the three studies varies between **72.9 to 107 kg/day**.

b) **High Draft Zig-Zag Kiln**: The Emission Load calculated based on measured data as reported in the two studies varies between **21.6 to 23.0 kg/day**.
Further, theoretical combustion calculations using the Specific Energy Consumption (SEC) data and 250 mg/Nm^3 of PM in flue gases at 17% Oxygen concentration (draft Emission Standards notified by MoEFCC), the calculated Emission Load varies between **27.25 to 38.94 kg/day**.

All the reference papers are also enclosed as Annexures 2-4.

Yours Sincerely,

Sameer Maithel

(Sameer Maithel)

Annexure 1: Note on Emission Load (kg of PM_{10} emitted per day from one brick kiln)

1.1 Introduction

Three studies, including a past CPCB study and two peer reviewed scientific papers on the subject were reviewed to calculate the Emission Load for FCBTK and High Draft Zig-Zag Kiln. The results of a theoretical analysis to calculate Emission Load for the High Draft Zig-Zag Kiln are also presented.

1.2 Reference 1: Presentation "Brick Kilns in India" by Mr J. S. Kamyotra, Director, CPCB at Anil Agarwal Dialogue 2015: Poor in Climate Change, India Habitat Centre, New Delhi, March 11 – 12, 2015. (http://cdn.cseindia.org/userfiles/JS-kamyotra.pdf) accessed on 20th August 2020 and attached as Annexure 2).

The presentation was based on a country-wide study carried out by the Punjab State Council for Science and Technology (PSCST) to measure the environment performance of brick kilns for the Central Pollution Control Board (CPCB).

Page number 18 of the presentation provides the results of the measured volumetric flow rate (Nm^3/hr), measured SPM (mg/Nm^3) and production capacity (bricks/day) for FCBTK kilns operating in North Zone. Similarly, page number 20 of the presentation provides the same results for the Zig-Zag High Draught kilns operating in the North zone. With this data it is now possible to calculate the Emission Load using **Equation 1**. The data referenced from the presentation along with the results of the calculations are shown in Table 1. For the calculations, average values of volumetric flow rate of flue gases and concentration of SPM in flue gases has been used.

Emission Load (kg/day) = Concentration of PM in stack gases (mg/Nm^3) x Volumetric Flow Rate of Stack Gases (Nm^3/day) ……. (Equation 1)

Table 1 Calculated Emission Load based on CPCB presentation

	Volumetric flow rate of flue gases in Stack (Nm^3/h)			Concentration of SPM in flue gases (mg/Nm^3)			Production capacity (brick per day)			Emission Load [A]x[B] x24/10[6]	**Emission Load for 30,000 brick per day capacity**
	Min	Max	**Avg [A]**	Min	Max	**Avg [B]**	Min	Max	Avg.	kg/day	**kg/day**
FCBTK (North India -Coal)	11115	16040	**13,578**	102	688	**395**	32000	40000	**36000**	129	**107**
FCBTK (North India-Biomass)	14487	25938	**20,213**	140	374	**257**	36000	40000	**38000**	125	**98**
High Draft zig-zag kiln (North-Coal)	11377	23845	**17,611**	49	116	**83**	30000	60000	**45000**	35	**23**

Sample calculations

For the High Draft Zig-Zag kiln (North-Coal)

a) Average volumetric flow rate of flue gases in Stack = 13,578 Nm^3/h
b) Average Concentration of SPM in flue gases = 83 mg/Nm^3
c) Emission Load (average production capacity of 45,000 brick/day) = 13578 x 83x 24/1000000 = 35 kg/day
d) Emission Load for average production capacity of 30,000 brick/day = 35 x (30,000)/(45,000) = 23 kg/day

Results

a) In case of FCBTK, the Emission Load for a kiln producing 30,000 bricks per day is calculated to vary between 98-107 kg/day.

b) For High draft zig-zag kilns which are more efficient and less polluting, the Emission Load is much lower compared to FCBTK and is 23 kg/day.

1.3 Reference 2: Research paper published by The Energy and Resources Institute (TERI). R Suresh, Sachin Kumar, Richa Mahtta, Sunit Sharma. Emission Factors for Continuous Fixed Chimney Bull's Trench Kiln (FCBTK) in India. International Journal of advanced Engineering, Management and Science, Vol-2, Issue-6, June-2016, page 662-670 (attached as Annexure 3)

This research paper presents the results of emission monitoring of 10 FCBTKs using coal as fuel located at Varanasi. The main objective of the paper was to estimate the Emission Factor for particulate matter (g of PM/kg of fired brick) for FCBTK. The paper concludes that for the monitored FCBTKs, the Emission Factor for PM emissions derived per kg of fired brick ranged between 0.81- 1.18 g of PM/kg of fired brick. The Emission Factor can be used to calculate the Emission Load and is shown in Table 2.

Emission Load (kg/day) = Emission Factor (g of PM/kg of brick) x Number of bricks produced per day x weight of one brick (kg)/1000 – (Equation 2)

Table 2 Calculated Emission Load based on TERI paper

	Emission Factor (g of PM/kg of fired brick) [A]		Production Capacity [B]	Weight of brick [C]	**Emission Load (kg/day) = [A]x[B]x[C]/1000**	
	Min	Max	(brick/day)	Kg/brick	**Min**	**Max**
FCBTK (10 kilns coal fired at Varanasi)	0.81	1.18	30,000	3.00	**72.9**	**106.2**

The capacity of the kiln is taken as 30,000 brick per day and the weight of fired brick is taken as 3.0 kg/brick.

<u>Sample Calculation</u>

a) Emission Factor (Min) = 0.81g of PM/kg of fired brick
b) Weight of bricks produced in a day = 30000x 3 = 90,000 kg/day
c) Emission Load (kg/day) = 0.81 x 91,000/1000 = 72.9 kg/ day

<u>Results</u>

The Emission Load for FCBTK ranged from 72.9 – 106.2 kg/day which is comparable to the results of the CPCB-PSCST study.

1.4 Reference 3: Research paper published by researchers from University of Illinois (USA), Enzen Global Solutions (India) & Greentech Knowledge Solutions (India).

Uma Rajarathnam, Vasudev Athaly, Santhosh Ragavan, Sameer Maithel, Dheeraj Lalchandani, Sonal Kumar, Ellen Baum, Cheryl Weyant, Tami Bond. Assessment of air pollutant emissions from brick kilns, *Atmospheric Environment,* 98 (2014) 549-553 (attached as Annexure 3)

This research paper presents the results of emission monitoring of 17 brick kilns. Out of which there are 5 FCBTKs using coal as fuel and 3 High Draft zig-zag kilns. Like the TERI paper, the paper presents the results in the form of Emission Factor for particulate matter (g of PM/kg of fired brick). The paper concludes that for the monitored FCBTKs, the mean Emission Factor is 0.89 g of PM/ kg of fired brick and for the High Draft zig-zag kiln the mean Emission Factor is 0.24 g of PM/ kg of fired brick. The Emission Factors can be used to calculate the Emission Load using Equation 2 and the results are shown in Table 3.

Table 3 Calculated Emission Load based on Uma et al paper

	Mean Emission Factor (g/kg)	Production Capacity	Weight of brick	**Emission Load (kg/day)**
FCBTK (5 kilns)	0.89	30,000	3.0	**80.1**
High Draft zig-zag (3 kilns)	0.24	30,000	3.0	**21.6**

The capacity of the kiln is taken as 30,000 brick per day and the weight of fired brick is taken as 3.0 kg/brick.

<u>Results</u>

The Emission Load for PM for FCBTK was calculated as 80.1 kg/day and for High draft zig-zag as 21.6 kg/day for 30,000 brick per day capacity.

1.5 Theoretical Calculations of Emission Load based on Combustion Principles

The presentation by Mr Kamyotra (Reference 1) provides data on the Specific Energy Consumption (SEC) of Zig-Zag kilns to vary between 0.91 MJ/kg to 1.15 MJ/kg. Another report by the Bureau of Energy Efficiency (BEE), Government of India[1], reports SEC of

1 https://beeindia.gov.in/sites/default/files/Brick%20Sector%20Market%20Transformation%20Blueprint_BEE%281%29.pdf

Zig-Zag kilns to vary between 0.95 to 1.3 MJ/kg. Thus, the minimum value of SEC reported is 0.91 MJ/kg while the maximum value is 1.3 MJ/kg.

Let us assume a High Draft zig-zag kiln producing 30,000 brick per day (weight of fired brick taken as 3.0 kg/brick) is using Raniganj coal having Gross Calorific Value (GCV) of 6000 kcal/kg (25.08 MJ/kg). The ultimate analysis of coal is given in Table 4.

Table 4 Ultimate Analysis of Coal Sample and Stoichiometric Air Requirement

Component	**Mass Fraction (% by mass on as received basis)**
Ash	20.6 %
Carbon	58.2 %
Hydrogen	4.8%
Nitrogen	1.1%
Sulphur	0.5%
Oxygen	7.4 %
Moisture	8.0 %
Stoichiometric air requirement[2]	8.051 kg of air /kg of coal

Source: Sameer Maithel (2003). Energy Utilization in Brick Kilns. PhD Thesis. Indian Institute of Technology, Bombay

a) Amount of coal used per day (kg/day)
   - For the minimum SEC of 0.91 MJ/kg = 30,000x3x0.91/25.08 = 3265 kg per day.
   - For the maximum SEC of 1.3 MJ/kg, the coal consumption per day is calculated as 4665 kg per day.

b) Stoichiometric air (kg/day)
   - For SEC of 0.91 MJ/kg = 3265.6 x 8.051 = 26,290.9 kg of air /day
   - For SEC of 1.3 MJ/kg = 4665.1 x 8.051 = 37,558.5 kg of air /day

c) Excess Air at 17% Oxygen Concentration in flue gases: The revised emission standards as draft notified by MoEFCC gives PM concentration as 250 mg/Nm^3 PM at 17% O_2.

   Excess Air for 17% Oxygen concentration (%) = 100 x {(20.9) / (20.9 - O2%) – 1}
   = 100 x {(20.9)/ (20.9 -17) -1}
   = 436%

d) Theoretical quantity of air flow (kg/day) at 17% O2 concentration
   - For SEC of 0.91 MJ/kg = 26,290.9x (4.36+1) = 1,40,919.5 kg of air /day
   - For SEC of 1.3 MJ/kg = 37,558.5 x (4.36+1) = 2,01,313.5 kg of air /day

e) Theoretical volumetric flow rate of air (Nm^3/day) at 17% O_2 concentration

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[2] The theoretical air required to complete combustion of fuel results from the equation of stoichiometry of oxygen/fuel reaction. Stoichiometric air means the minimum air in stoichiometric mixture.

'Normal' refers to normal conditions of 0°C and 1 atm (standard atmosphere = 101.325 kPa)

Density of air at 'Normal' conditions = 1.2992 kg/m^3

- For SEC of 0.91 MJ/kg = 1,40,919.5/1.2992= 1,09,053.9 Nm^3/day of air
- For SEC of 1.3 MJ/kg = 2,01,313.5/1.2992 = 1,55,791.3 Nm^3/day of air

f) Emission Load at 250 mg/Nm3 at 17% Oxygen concentration for Zig-Zag Kilns

- For SEC of 0.91 MJ/kg = 250x 1,09,053.9 / 1000000 = 27.26 kg/day
- For SEC of 1.3 MJ/kg = 250 x 1,55,791.3 /1000000 = 38.95 kg/day

Conclusions

a) **FCBTK**: For FCBTK of 30,000 brick per day production capacity, the Emission Load calculated based on measured data as reported in the three studies varies between **72.9 to 107 kg/day**.

b) **High Draft Zig-Zag Kiln**: The Emission Load calculated based on measured data as reported in the two studies varies between **21.6 to 23 kg/day**. Theoretical calculations based on combustion calculations and assuming 250 mg/Nm^3 of PM in flue gases at 17% Oxygen concentration, the calculated Emission Load varies between **27.26 to 38.95 kg/day**.

Brick Kilns in India

J. S. Kamyotra
Director, Central Pollution Control Board
Delhi, India

BRICK PRODUCTION IN ASIA

1. Very large and traditional industry in Asia
2. Mechanized and fully automated process for brick production is used by Developed countries

	Bangla-desh	India	Vietnam	Nepal	Pakistan	China
No. of brick units	-	1,40,000	10,000	700	>10,000	80,000
Production in billion	17.2	240-260	26.59	3.15	50	800-1000
Labor in '000	1000	9,000	NA	NA	1500	5000
Population in million	149.7	1210	176.5	18.6	176.7	1334
Brick use/ capita	115	215	151	169	283	750

INTERNATIONAL SCENARIO

INTERNATIONAL SCENARIO World over- Tunnel and Hoffman Kilns considered as environment friendly EE technology and is being promoted

	USA/ Europe – Natural gas fired Tunnel Kilns	•High Initial cost (5-10 crores) •Lack of Know-how •Access to finance •Hot environment inside Hoffman kiln
	China – Tunnel/ Hoffman Kiln	
	Vietnam – Coal fired Tunnel Kilns	
	Bangladesh – Hybrid Hoffman Kiln/ Tunnel Kiln	

- Replacement with REBs (perforated bricks, hollow bricks, bricks with internal fuel/ flyash bricks etc).
- Mechanization for clay preparation and molding
- Min. 20-30% savings in fuel and clay.
- In China, upto 80% of total fuel requirement mixed as internal fuel and remaining 20% fuel used during firing process – *Emission reduction from kiln to a large extent.*

HOFFMAN KILN

(Product Stationery and Fire Moving)

Tunnel Kiln

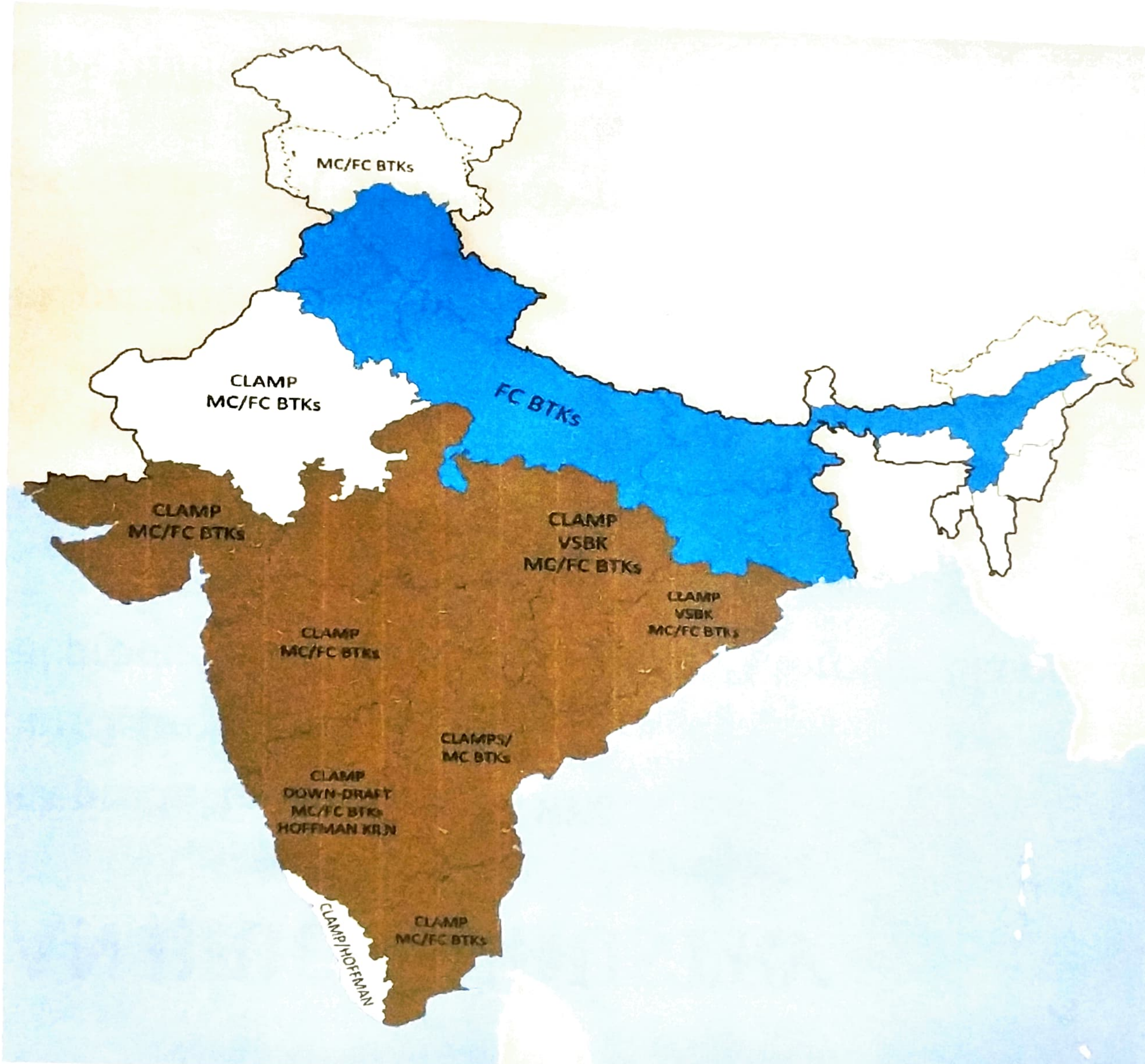
(Product Moving and Fire Stationary)

INDIAN BRICK INDUSTRY

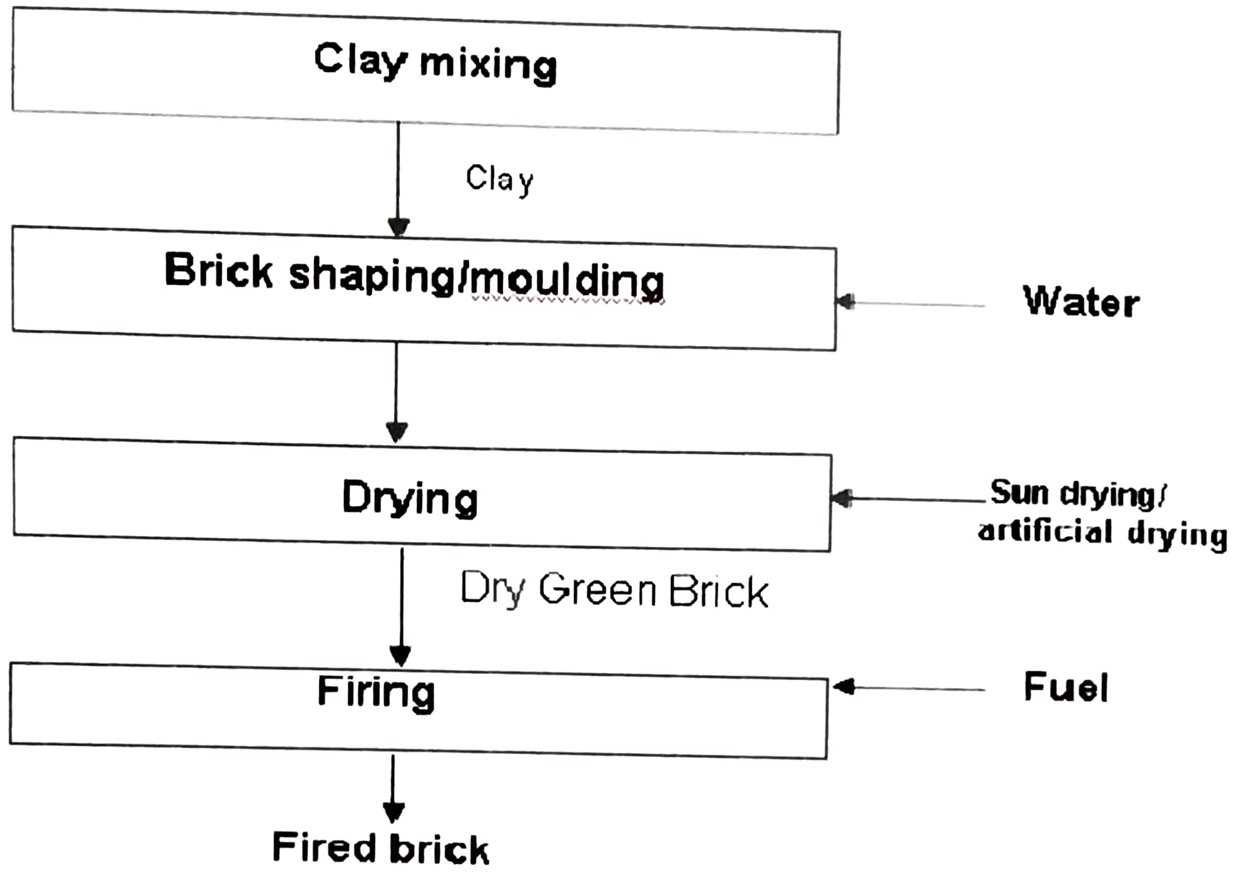
- Annual brick production growth: 5-10%
- 2nd largest brick producer after China.
- 74% of total production through BTKs and 21% through Clamps (100K).

Brick-making enterprises (all types)(no.)	1,40,000
Brick-making fuel used	coal & biomass
Annual brick production	240-260 billion
Coal/biomass consumption (million tce)	35-40
CO_2 emissions (million t)	66
Clay consumption (million m^3)	500
Total employment (million employees)	9-10

Distribution of different type of kilns in India

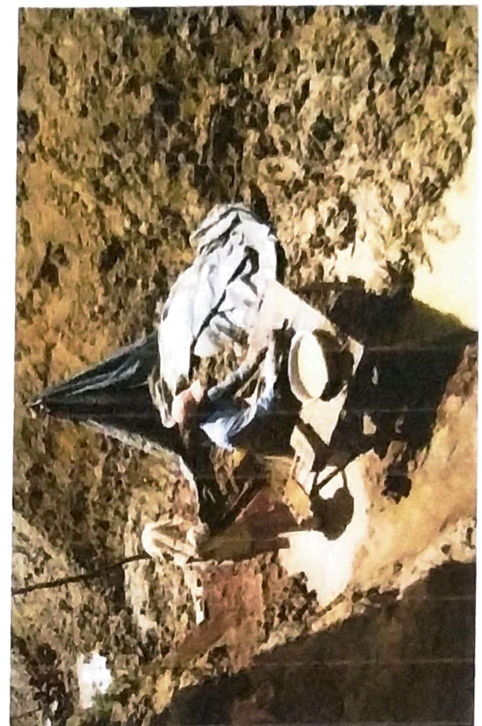


BRICK MAKING PROCESS



- 99% brick production through hand molding
- Use of biomass/biomass waste/flyash with low CV as internal fuel in some areas of Central/East and West zones.
- Clay preparation through pug mills/tractors with mixers in Central/west/south India.

BRICK MAKING PROCESS: MANUAL EXCAVATION & MOULDING

Preparation	**Table moulding**
	
Manual Excavation	**Manual Moulding**
	

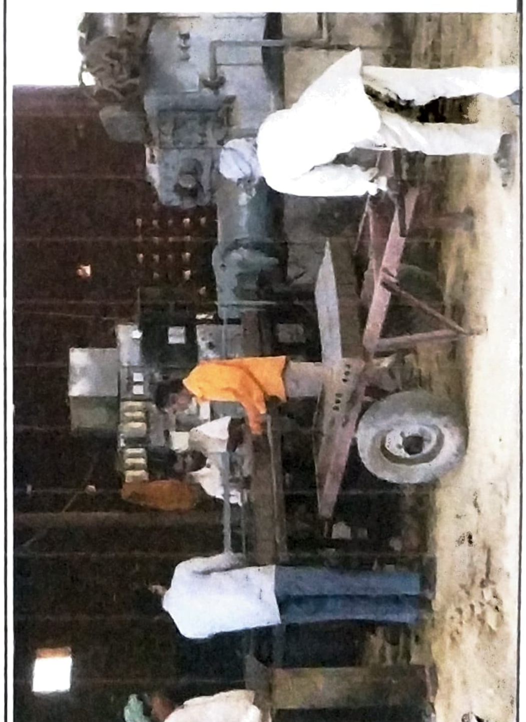
BRICK MAKING PROCESS: MECHANICAL

Box feeder

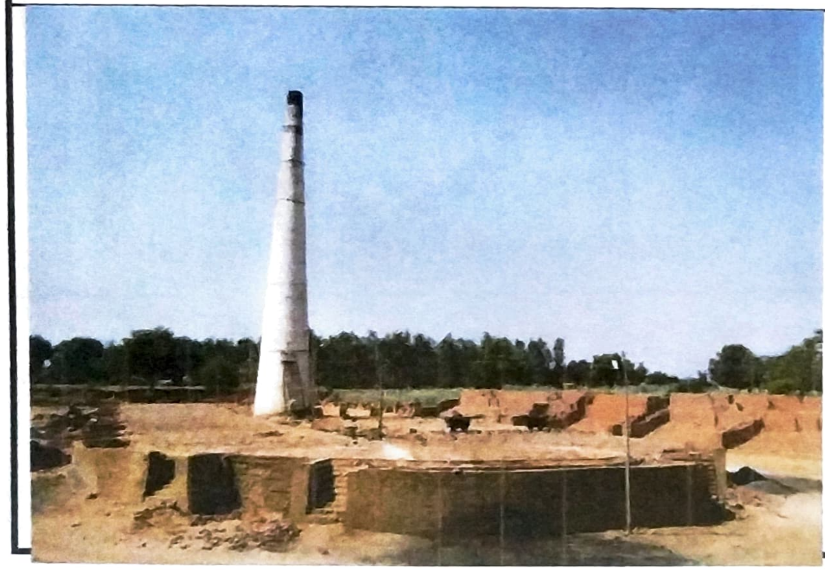
Extruders

Excavation

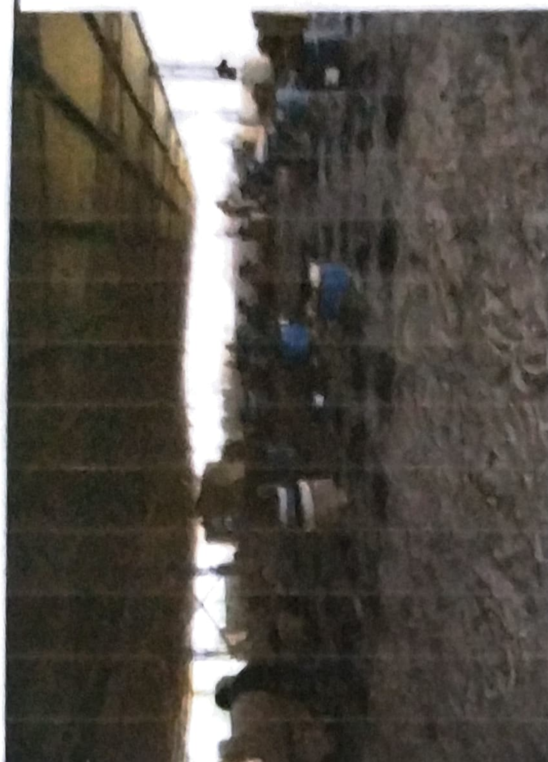
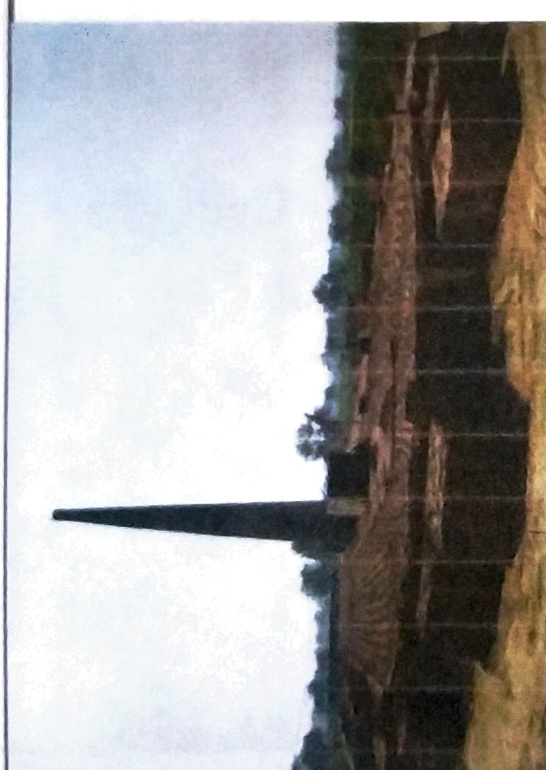
Extruders



Bull's Trench Kilns



EXISTING TECHNOLOGIES

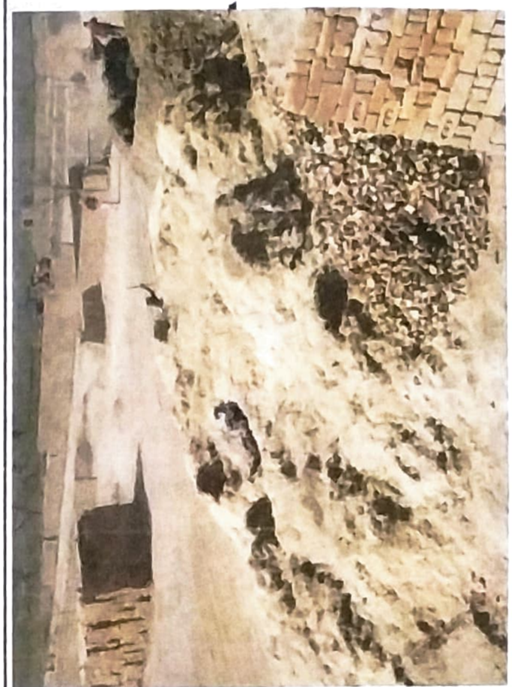
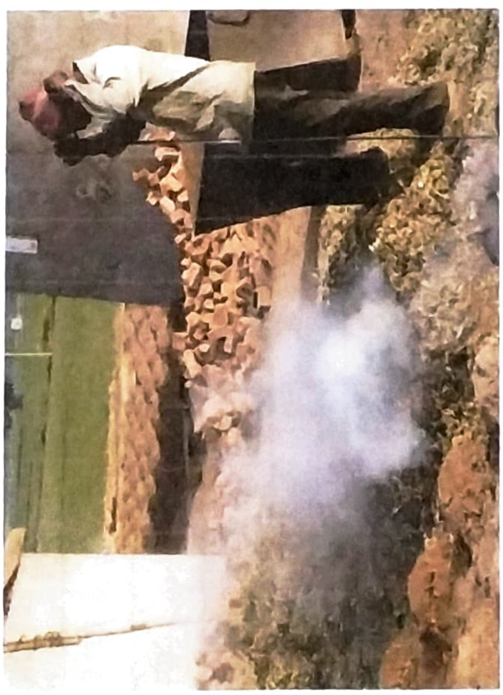
HDK	VSBK
	
FCBTK	**Hoffman**
	

DOWNDRAFT / CLAMP KILNS

SOURCES OF EMISSIONS

- Stack Emission
- Fugitive Emission
  - During charging of fuel
  - Crushing of coal
  - Clay excavation
  - Loading and unloading of bricks
  - Laying and removal of dust/ash layer '*keri*' over brick setting
  - Cleaning of bottom of trench/side flues
  - During high winds

DIFFERENT TYPES OF FUELS USED

Assam coal	Wooden chips, mustard & cotton
	
Cotton straw & wood chips	**Mustard straw**
	

FUEL ANALYSIS

Type of Fuel	Moisture (%)	Ash (%)	Volatile (%)	Fixed Carbon (%)	GCV (Kcal/kg)
Coal					
Assam Coal	0.96-2.99	11.03-26.46	22.84-37.71	37.06-49.88	4864-5603
Chandrapura Coal	3.96-8.36	22.19-37.16	25.07-30.96	33.81-38.49	4077-4867
Indonesian Coal	13.5-16.7	2.82-15.16	42.31-46.29	28.85-35.6	5386-6316
Jharia Coal	0.31-1.48	34.47-46.89	15.83-26.85	33.78-50.06	3520-5034
Raniganj Coal	6.83-8.61	31.3-23.86	25.1-27.41	34.46-42.43	4607-5258
Biomass					
Mustard straw	5.38-9.09	3.1-6.23	70.47-73.79	16.51-17.1	3998-4306
Rice Husk	5.63-19.4	17.4-23.89	48.26-55.95	14.53-14.92	3403-3471
Cotton straw	12.18	3.77	66.75	17.3	4219
Saw Dust	30.61	5.31	53.38	10.7	3235
Internal fuel					
Katni Coal Dust	1.92	45.77	19.66	32.65	3336
Coal Rejects of thermal Power	2.43	68.5	18.09	10.98	2049

FIRING PRACTICES AND PERFORMANCE OF FCBTKS IN FIVE ZONES

Parameters	North		East Zone	Central Zone			West Zone		South Zone
Fuel	Coal	Biomass	Coal	Coal	Biomass	Coal	Coal	Biomass	Coal
No. of columns	23-31	25-27	19-23	22	21-23	19-21	19-26	20-21	12-21.
Trench width (m)	8.2-11.6	9.5-9.94	7-8	7.8	7.6-8.2	6.4-10.4	6.4-8.7	7.8-8.54	3.6-6.4
Daily production capacity	32,000-40,000	36,000-40,000	16700-32000	28,000	19,000-40,000	20,000-26,000	30,000-45,000	35,000-40,000	22,000-27,000
Firing temperature (ºC)	980-1050	940-1020	960-1070	880-980	900-980	960-1016	860-1016	925-973	720-850
SEC in MJ/Kg of fired brick	**1.18-1.32**	**1.33-1.95**	**1.05-1.41**	**1.29**	1.60-172	**1.08-1.16**	**1.13-1.82**	1.7-1.77	**0.95-1.24**
Stack Temperature (ºC)	60-82	52-77	63-118	116	92-95	90-128	80-172	80-90	90-119
Velocity (m/s)	1.2-3.7	1.4-1.9	1.84-2.32	1.54	2.4-2.5	1.49-1.58	2.1-3.65	2.28-2.29	2.8-5.2
Volumetric flow rate (Nm^3/hr)	11115-16040	14487-25938	7597-25938	20373	20610	9115-10600	11843-32284	24462-27984	9600-11100
SPM Charging (mg/Nm^3)	517-1375	268-382	124-865	619	294-330	500	122-422	122-147	75-364
Non-Charging	107-257	83-105	103-301	108	100-115	110-130	78-186	90	42-224
Integrated	102-688	140-374	162-742	566	169-271	357-450	90-384	96-146	55-298
SO_2 (mg/Nm^3)	10-595	5-8	34.1-563.3	10.5	7.9-3.1	13.1-23.6	5.2-943.2	18.3-52.4	0-437.5
CO (mg/Nm^3)	193-1419	2275-2952	282-1748	205	495-1311	147-238	355-3579	2622-5026	269-880
CO_2 %	**0.6-2.85**	2.4-2.6	1.2-2.4	1.2	0.7-1.7	1.7-15	1.0-2.4	1.7-2.0	1.5-2.1

FIRING PRACTICES AND PERFORMANCE OF FCBTKS IN FIVE ZONES

Parameters	North		East Zone	Central Zone			West Zone		South Zone
Fuel	Coal	Biomass	Coal	Coal	Biomass	Coal	Coal	Biomass	Coal
No. of columns	23-31	25-27	19-23	22	21-23	19-21	19-26	20-21	12-21.
Trench width (m)	8.2-11.6	9.5-9.94	7-8	7.8	7.6-8.2	6.4-10.4	6.4-8.7	7.8-8.54	3.6-6.4
Daily production capacity	32,000-40,000	36,000-40,000	16700-32000	28,000	19,000-40,000	20,000-26,000	30,000-45,000	35,000-40,000	22,000-27,000
Firing temperature (^0C)	980-1050	940-1020	960-1070	880-980	900-980	960-1016	860-1016	925-973	720-850
SEC in MJ/Kg of fired brick	**1.18-1.32**	**1.33-1.95**	**1.05-1.41**	**1.29**	1.60-172	**1.08-1.16**	**1.13-1.82**	**1.7-1.77**	**0.95-1.24**
Stack Temperature (^0C)	60-82	52-77	63-118	116	92-95	90-128	80-172	80-90	90-119
Velocity (m/s)	1.2-3.7	1.4-1.9	1.84-2.32	1.54	2.4-2.5	1.49-1.58	2.1-3.65	2.28-2.29	2.8-5.2
Volumetric flow rate (Nm^3/hr)	11115-16040	14487-25938	7597-25938	20373	20610	9115-10600	11843-32284	24462-27984	9600-11100
SPM Charging (mg/Nm^3)	517-1375	268-382	124-865	619	294-330	500	122-422	122-147	75-364
Non-Charging	107-257	83-105	103-301	108	100-115	110-130	78-186	90	42-224
Integrated	102-688	140-374	162-742	566	169-271	357-450	90-384	96-146	55-298
SO_2 (mg/Nm^3)	10-595	5-8	34 1-563.3	10.5	7.9-3.1	13.1-23.6	5.2-943.2	18.3-52.4	0-437.5
CO (mg/Nm^3)	193-1419	2275-2952	282-1748	205	495-1311	147-238	355-3579	2622-5026	269-880
CO_2 %	**0.6-2.85**	2.4-2.6	1.2-2.4	1.2	0.7-1.7	1.7-15	1.0-2.4	1.7-2.0	1.5-2.1

Operating practice	North		East Zone	Central Zone			West Zone		South Zone
Fuel Type	Coal	Biomass	Coal	Coal	Biomass	Coal	Coal	Biomass	Coal
Size of fuel	1/2" to 2"	Chopped 1" to 2"	1/2" to 3"	1" to 6"	Chopped 1" to2" size	Same as coal fired kiln Same as coal fired kiln	1" to 6"	Chopped 1" to 2" size	coal (1" to 6")
Capacity of feeding spoon	Heavy feeding using spoon of 1.0-2.0 kg	With tokris or vehngis	Spoon size: 0.6-1.6 kg	Spoon size 1.5-2.5 kg	Tokri size: 25-30 kg & vehngi size: 45-50 kg		Spoon of size: 0.7-2.0 kg	Tokri size: 25-30 kg & vehngi size: 45-50 kg	With tokris of 25-30 kg capacity
No of rows being fed	Fuel feeding in two lines	Fuel feeding in one line	Fuel feeding in two lines	Heavy feeding in one line	Heavy feeding in one line		Fuel feeding in one or two lines	Heavy feeding in one line	fuel feeding done in two lines
Feeding frequency **Charging**	5-10 mins	Heavy 15-25 mins	7-12 mins	10-15 mins	15-25 mins		8-15 mins	15-25 mins	10-20 mins
Non-Charging	20-40 mins	20-40 mins	20-40 mins	30-50 mins	30-50 mins		30-50 mins	30-50 mins	30-50 mins
Remarks	**Thick smoke during charging period**	**High surface temperatures result in self ignition of biomass at surface only.**	**Coal crushers used in some kilns**	**Thick smoke during charging**	**High surface temperatures result in self ignition of biomass at surface only**		**Resulting in thick smoke due to charging**		***Due to feeding coal lumps the light greyish smoke emitted***

PERFORMANCE OF DESIGNS OF KILNS (OTHER THAN FCBTKs)

Parameters	FCBTK-Zig-Zag East Zone	High Draft Kiln (HDK) North Zone	High Draft Kiln (HDK) East Zone	VSBK East /Central Zone	Down Draft Kiln (DDK) South Zone	Hoffman Kiln South Zone
No. of columns	15,000 bricks/ Chamber	18,000-20,000 bricks/ chamber	10,500-19,500 bricks/ chamber	440 bricks/ batch in 6 layers	Batch process	4,000-5,000 bricks/ chamber
Trench width (m)	5.2-6.6	10-10.4	5.2-8			2.7
Daily production capacity	20,000-30,000	30,000-60,000	15,000-28,000	6000-8800	30,000 bricks /chamber	10,000-12,000
Fuel	Coal/pet coke/ biomass	Coal/pet coke	Coal	Coal	Biomass	Coal/fired wood
Firing temperature (⁰C)	970-1015	970-1020	960-1050	870-915	820-850	650-810
SEC in MJ/Kg of fired brick	**0.92-1.06**	**1.08-1.10**	**1.07-1.15**	0.9	**2.80-3.14**	**1.21-1.52**
Stack Temperature (⁰C)	118-163	107-109	54-146	152-179	181-252	118-128
Velocity (m/s)	2-2.83	3.4-3.99	2.01-3.37	2.55	2.8-4.3	2.04-2.86
Volumetric flow rate (Nm^3/hr)	7390-10008	11377-23845	8971-20761	4444-9285	5036-5498	8200-8500
SPM Charging (mg/Nm^3)	155	119-147.6	145.5-432	452	150-454.5	275-353
Integrated	128-134	49-116	149-316	314-405	75-359	200-315
SO_2 (mg/Nm^3)	393-469	1045-1053	13.1-615.7	84-89	118-975	5.2-7.9
CO (mg/Nm^3)	95-158	332-1027	290-667	951-1440	4398-11309	2931-3518
CO_2 %	2-2.4	1.8-1.9	1.27-2.4	0.6-1.1	8.1-11.9	4-4.4

Parameters	FCBTK-Zig-Zag	High Draft Kiln (HDK)		VSBK	Down Draft Kiln	Hoffman Kiln
Size of fuel	Crushed coal	Crushed coal	Crushed coal	Upto 1"	For first 15-20 hrs fuel feeding rate is 30-400kg/hr whereas for last 8-10 hrs fuel feeding rate is 700-750 kg/hr	
Capacity of feeding spoon	Spoon size: 0.175-0.3 kg	Spoon size : 0.25-1.0 kg	Spoon size : 0.25-0.5 kg	NA		
No of rows being fed	6 chambers	6 chambers	2-3 chambers	Packed within the brick settings	Total firing time 24-30 hrs	3 chambers
Feeding frequency **Charging**	10-15 mins or continuous Charging	7-10 mins or continuous Charging	7-12 mins	NA	Continuous charging is done	Fire wood Charging done for 8-10 mins
Non Charging	5-15 mins	12-15 min	10-12 mins			25-30 mins
Remarks	thin smoke	Thin smoke during fuel Charging		Bloating of fired bricks due to lumps of internal fuel	Thick smoke during last 8-10 hrs of Charging	

INFERENCES - PERFORMANCE OF KILNS IN DIFFERENT ZONES

- **FCBTKs/HDKs**
  - Trench width: 6.4-10.4 mtrs.
  - Min. Production capacity: 22,000 bricks/day
    (trench width of 3.6m in South)
- High stack emissions/ thick smoke in kilns with shorter combustion zone & poor operating practices.
- Excess Air levels of 400-1000% were observed during stack emission monitoring.
- During fuel charging period SPM levels upto 1375 mg/Nm^3 observed in kilns with poor operating practices.
- High CO levels observed in kilns using biomass as fuel.

SPECIFIC ENERGY CONSUMPTION (SEC)

IN MJ/ KG OF FIRED BRICK

FCBTKs-Coal fired	**0.95-1.82**	
FCBTK-Biomass fired	1.33 – 1.95	
HDKs/FCBTK zig-zag	0.91-1.15	Better operating practices
VSBK	0.90	**Limited brick** production and **high initial** cost
Hoffman Kiln	1.21-1.52	Produce hollow block, roof tiles
DDKs	2.8-3.14	
Clamps	1.38-1.92	

ENERGY BALANCE

Basis: 1 Ton of clay brick

Sr. No.	Parameters	FCBTK (coal)		FCBTK (Biomass)		FCBTK (zig-zag)		HDK		VSBK	
	Heat Input										
1	Fuel (coal, biomass, etc.) consumed	in MJ	in %	in MJ	in %	in MJ	in %	in MJ	in %	in MJ	in %
		1134- 1445	100	1364-1772	100	1162	100	1038-1097	100	834	100
	Heat output										
1	Surface heat loss from kiln (Top surface & side walls)	161-424	*14-29*	288-424	*21-24*	236	*20*	150-328	*14-30*	27	*3.2*
2	Heat loss in dry flue gas	35-107	*3-7*	51-153	*3.7-8.6*	71	*6.1*	22-82	*2-7.5*	205	*24.6*
3	Heat required for removing the mechanically held water in green bricks	36-339	*3-23*	33-244	*2.4-13.8*	186	*16*	102-169	*10-15*	68	*8.2*
4	Heat loss due to hydrogen & moisture in fuel	40-80	*3-5*	98-132	*7.2-7.5*	46	*4*	33-49	*3.2-4.5*	15	*1.8*
5	Heat loss due to partial conversion of C to CO	5-28	*0.5-2*	21-75	*1.5-4.2*	4	*0.3*	23-37	*2.2-3.4*	29	*3.5*
6	Sensible heat loss in unloaded bricks	4-20	*0.3-1.4*	20-26	*0.5-1.5*	23	*2*	27-60	*2.6-5.5*	47	*5.6*
7	Other heat component*	477-960	*42-66*	442-1250	*32-70*	596	*51*	440-613	*42-56*	443	*53.1*

Heat required for irreversible chemical reaction & losses such as trench bottom, periodic heating and cooling of kiln structure & due to unburnt carbon in ash

PERFORMANCE EVALUATION OF APCD IN FCBTKs

The particulate removal efficiency of different design of Gravity Settling Chamber (GSC) generally ranged from 20-63%. The stack emission levels at inlet of GSC vary between 592-1495 mg/Nm^3.

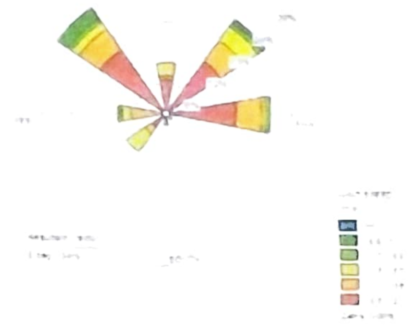
General ambient air QUALITY-brick kilns

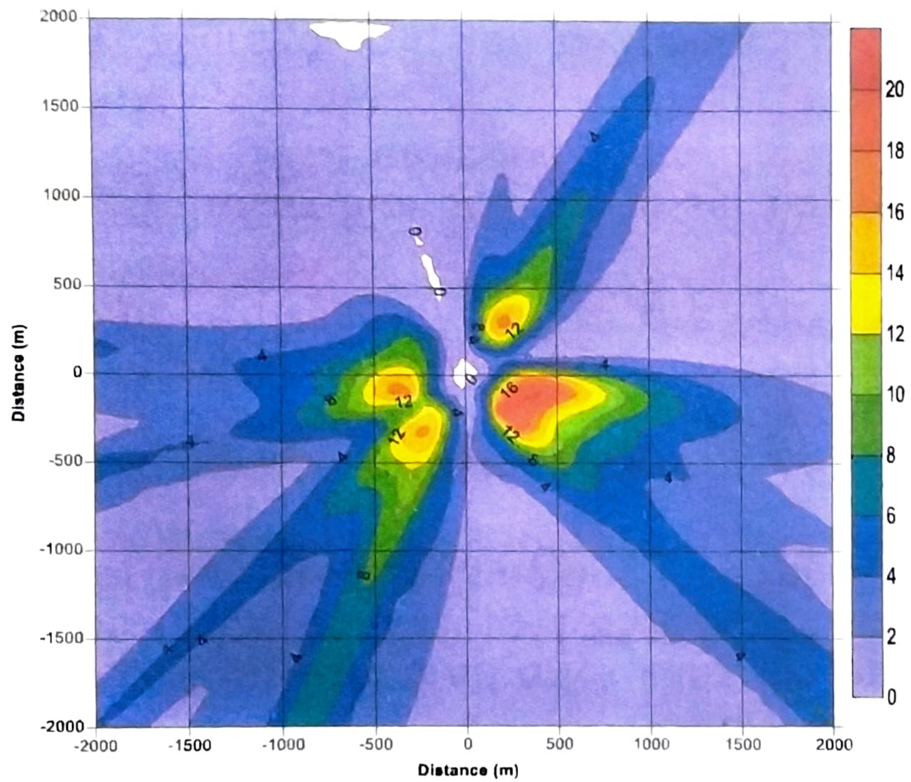
- Impacts not continuous or long term because brick kilns are seasonally operated and operations is cyclic in nature.
- Ambient SO_2 & NOx levels rarely exceeded 25 µg/m3
- The NOx emissions from kiln stacks were also very low and hence its impact on GLCs, the impact of kiln emissions would be insignificant.

AIR POLLUTANT DISPERSION MODELING

- To assess the maximum impact of stack emissions (SO_2 & SPM) on Ground Level Concentration (GLC).
- To formulate stack height guidelines for ensuring the safe impact levels in the context of prescribed Ambient Air Quality Standards.
- To recommend siting guidelines for brick kilns.

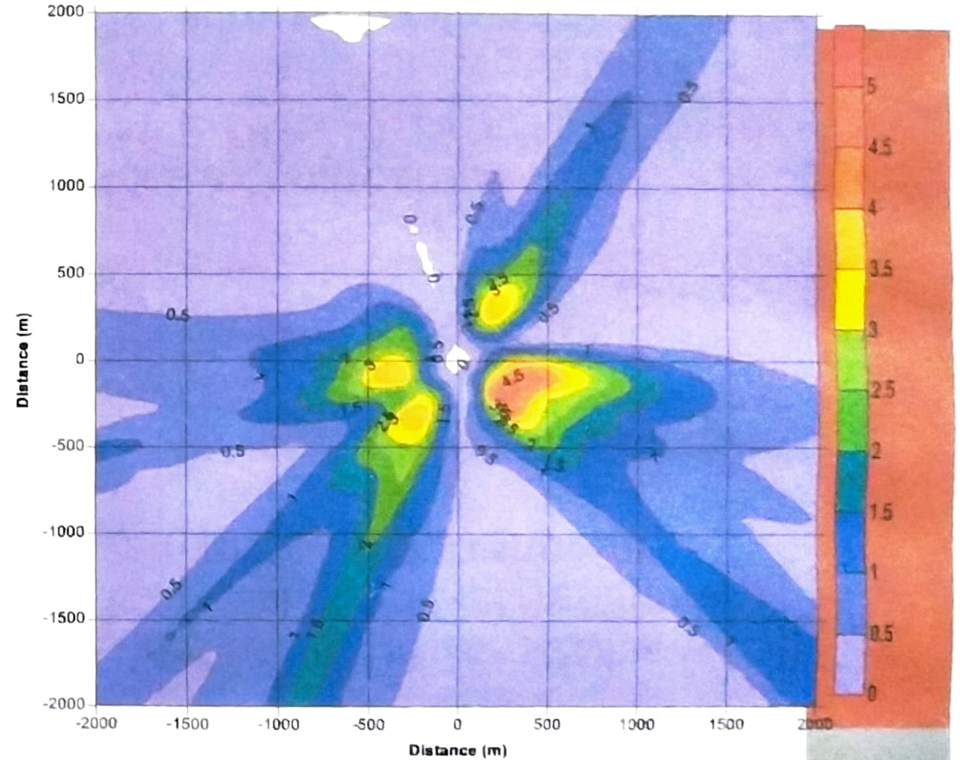
EMISSION DISTRIBUTION PATTERNS IN NORTH ZONE USING ISCST3 MODEL:





Maximum GLC- 21.94 $\mu g/m^3$, co-ordinates (200,-200)

SPM EMISSIONS



Maximum GLC-5.13 $\mu g/m^3$, co-ordinates (400,-200)

SO_2 EMISSIONS

Emission Factor

- The emission factor for SPM & Sulphur Dioxide is mainly due to quality of fuel and its feeding & operating practices.
- In case of coal fired brick kilns the average emission factor for SPM was in the range of 0.79 to 1.85 g/kg of fired bricks in the three zones namely North Zone, East Zone and Central Zone wherein brick firing temperature is above 950^{0}C.
- *Low average emission factor of 0.57g/kg observed in the South Zone which is mainly due to low firing temperature (around 850^{0}C) and feeding of big lumps of coal after longer intervals. Moreover the quality of brick is also comparatively inferior to the bricks produced in North, East and Central Zones.*
- FCBTK using biomass has lesser emission factors as compared to coal fired FCBTKs (SPM emission factor in the range of 0.78 to 1.19 g/kg of fired bricks).
- The average emission factor for SPM in FCBTK with zigzag firing was 0.37 g/kg of fired bricks due to longer combustion zone in comparison to conventional FCBTKs and good combustion practices adopted in the process. The emission factor is almost comparable with High Draft Kiln.

Ctd...

- The emission factor for SPM in High Draft Kiln were in the range of 0.21 to 1.12g/kg of fired brick due to efficient burning of fuel by adopting good firing practices.
- The emission factors for SPM in VSBK was 1.86 to 2.6 g/kg of fired bricks.
- The biomass fired DDK and Hoffman Kiln in South Zone has emission factor of 0.38 to 1.82g/kg of fired bricks.
- Emission factor for SO_2 were mainly due to sulphur content in the fuels used. Low emission factors of 0.03 to 0.23g/kg of fired bricks were observed in biomass fired brick kilns. Whereas, in case of coal fired kilns it varied from 0.04 to 0.67 g/kg of fired bricks.
- The average emission factor for NO_x were generally low and was found in the range of 0.03 to 0.32g/kg of fired bricks.

PROPOSED ACTION PLAN

- Two Fold Strategy proposed:
  1. Long Term Measures
  2. Short term Measures

PROPOSED ACTION PLAN

1. Long Term Measure:

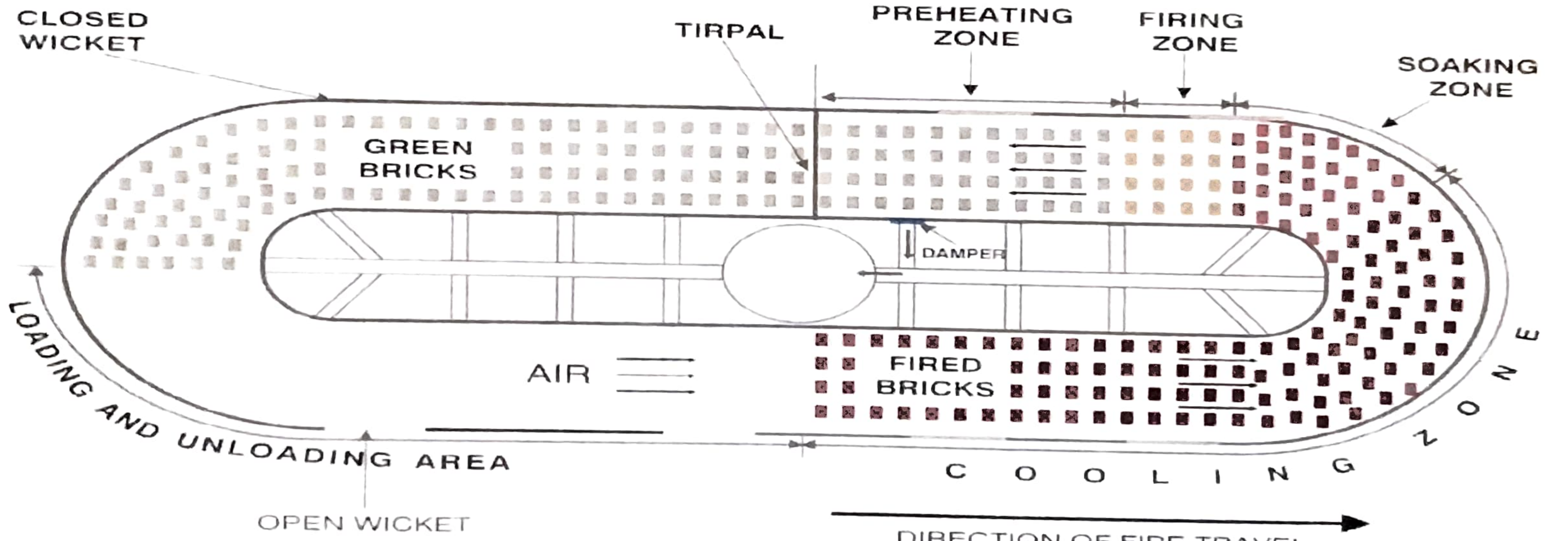
- Effective policies and regulations required for implementing energy efficient technologies like Tunnel Kiln, Hoffman Kilns etc.
- Need for establishing the demand/market for resource efficient products like hollow and perforated bricks, and limiting the production of solid bricks in phases.
- The technologies being capital intensive, requires mechanism for financial support before its replication on large scale.

Short Term Measures

a) Adoption of improved feeding, firing and operating practices in existing FCBTKs

b) Retrofitting of kiln and converting into High Draft Kiln/ Fixed Chimney Bull's Trench Kiln with zig-zag firing.

c) Extensive Capacity Building Program for 'a' above.



ZONES IN BULL'S TRENCH KILN

TECHNOLOGY SELECTION

- Need for initiatives for promotion of EE technologies while framing new Regulations for:
  - Reducing the emissions from brick making process
  - Conserving resource materials and
  - Reducing carbon footprint.
- FCBTK is the most prevailing technology, producing 74% of the country's brick production.
- Need based changes have been incorporated in brick production technology which has improved its EE.
- Use of locally available biomass in FCBTKs has also picked up especially in North and Central Zone.

TECHNOLOGY SELECTION.. Inferences

- However, the smoke emission from the kiln stack, especially during charging time is a cause of concern which can be reduced by only adopting better feeding, firing & operating practices.
- In India, High Draft Kilns (HDKs) and Vertical Shaft Brick Kilns (VSBKs) are comparatively more energy efficient technologies. constraints are
  - need for electricity/power back up in case of HDKs and
  - high initial cost/ low production & non availability of skilled manpower in case of VSBK, these technologies has not been replicated on large scale

Existing Standards for Brick Kilns

Sr. No.	Industry	Parameter	Standards
1	2	3	4
74	Brick Kilns	**i. Bull's Trench Kiln (BTK) Category***	Limiting concentration in mg/Nm3
		Particular matter	
		Small	1000
		Medium	750
		Large	750
		Stack height	minimum (metre)
		Small	22 or induced draft fan operating with minimum draft of 50 mm WG with 12 metre stack height.
		Medium	27 or induced draft fan operating with minimum draft of 50 mm WG with 15 metre stack height.
		Large	30 or induced draft fan operating with minimum draft 50 mm WG with 17 metre stack height.
		*Category Trench width (m)	Production (bricks/day)
		Small BTK <4.50	Less than 15,000
		Medium BTK 4.50-6.75	15000-30000
		Large BTK above 6.75	Above 30000

74	Brick Kilns	**(II) Down-Draft Kiln (DDK) Category****	Limiting concentration in mg/Nm3
		Particular matter small/medium/large	1200
		Stack height	minimum (metre)
		Small	12
		Medium	15
		Large	18
		**Category Production (bricks/day) Small DDK Less than 15000 Medium DDK 15,000-30,000 Large DDK Above 30,000	

74	Brick Kilns	**(iii) Vertical Shaft Kiln (VSK)**		
		Category**		Limiting concentration in mg/Nm3
		Particular matter small/medium/large		250
		Stack height		minimum (metre)
		Small		11 (at least 5.5 m from loading platform)
		Medium		14 (at least 7.5 m from loading platform)
		large		16 (at least 8.5 m from loading platform)
		**Category	No. of shafts	Production (bricks/day)
		Small VSK	1-3	Less than 15000
		Medium VSK	4-6	15,000- 30,000
		Large VSK	7 or more	Above 30000

1. Gravitational Settling Chamber along with fixed chimney of appropriate height shall be provided for all Bull's for all Bull's Trench kilns.
2. One chimney per shaft in Vertical Shaft Kiln shall be provided. The two chimneys emanating from a shaft shall either be joined (at the loading platform in case of brick chimney or at appropriate level in case of metal chimney) to form a single chimney.
3. The above standards shall be applicable for different kilns if coal, firewood and / or agricultural residues are used as fuel."

PROPOSED EMISSION STANDARDS

FIXED CHIMNEY BULL's TRENCH KILN (FCBTK), HIGH DRAFT KILN (HDK) & HOFFMAN KILN

Guidelines for better fuel charging & operating practices in and siting of Bull's Trench Kilns and Clamp Kilns

IMPROVED FUEL CHARGING & OPERATING PRACTICES

(For improving the combustion efficiency and reduce emissions)

- The coal charging in Bull's Trench Kilns should be properly graded and maximum size of coal charged should be limited to 20 mm.
- Fuel charging in Bull's Trench Kilns should be done in minimum 3 rows of brick setting at a time in case of coal and in minimum 2 rows of brick setting at a time in case of firewood and agricultural residues.
- Minimum 3 fuel charging shall be done every hour in Bull's Trench Kilns.
- Internal fuel, such as powdered coal, flyash etc. should be used by mixing with clay during brick making in Bull's Trench Kilns and clamp brick kilns.

PROCESS EMISSION CONTROL

- Crushing of coal should be done in enclosed equipment/ area to avoid process emissions.
- Following measures be adopted to control dust emissions due to airborne ash from the top of brick settings:
  - Raising a 2 feet wind breaker wall along the outer trench wall of bull's trench kilns.
  - Covering of the top ash layer in the preheating zone with sheet in bull's trench kilns.
- The approach road and the road around brick kiln should be paved/stabilized.
- Water should be sprinkled frequently over roads around brick kiln and over the ash layer before its removal and transfer.
- Two or three rows of trees should be planted along the outer periphery of kiln area.

PROCESS IMPROVEMENT

- Use of Temperature gauge in firing zone, flue duct and chimney to monitor and control combustion process.
- Use of double walled insulated feedhole covers packed with insulation material such as ceramic or asbestos fibers to prevent heat loss from fuel charging holes bull's trench kilns.
- Double walled wicket with kiln ash filled in between Bull's Trench Kilns instead of conventional single brick wicket wall with brick on edge which results in leakage.
- Closing of side flue ducts with brick wall (1 ½ brick thick) plastered with a mix of sand clay and cow dung bull's trench kilns or alternatively, shunt system should be used for transferring the gas from side flues to central flue, connected with chimney.
- Minimum 7 inch thick brick kiln ash layer over the brick setting bull's trench kilns to provide heat insulation.
- Placement of fuel in multi-layers during brick stacking in clamp kilns to reduce emissions and to produce better quality bricks

NORMALISATION OF EMISSION STANDARDS IN FCBTK/HDK

- The air supply in a (FCBTK) drawn through the cooling/ fired brick withdrawal zone has following role:
  - Assist in the combustion of the fuel
  - In addition to the combustion, air is needed to carry forward the heat through different zones for transferring the heat (i.e. cooling of hot fired bricks and drying/ pre-heating freshly set green bricks before combustion)

Normalisation of Emission Standards in FCBTK/HDK

Therefore, in addition to air required for combustion, excess air is required for transferring of heat to different zones. Various authors have indicated the total quantity of air as:

- 6-7 times the quantity of air required for the combustion of fuel (Alfred B. Searle, 1956)
- 500% excess air is required in a continuous kiln (Tim Jones, 1996)

Better practices

- Fuel Storage
- Size of Coal
- Fuel quality
- Fuel feeding
- Kiln Maintenance
- Use of internal fuel
- Fugitive Emissions
- Monitoring
- Protection to workers health

Fuel Storage

- The coal should be stacked on a raised platform with pucca flooring and proper drainage arrangements.
- Coal should preferably be stored under shed with proper ventilation
- The height of coal stack should not be more than 1.5 meter otherwise it will loose its heat value due to self ignition under intense heat and pressure.

Size of Coal

- The size of coal should be such that the coal should either be completely burnt or atleast should have caught fire before the next round of feeding. Hence the coal size should be between powder to ¾ inch i.e. properly graded coal. This would help in uniform brick quality as the powdered coal ignites immediately on feeding thereby releasing heat to the top layer of brick setting. Whereas large sized coal particles release heat at the bottom of brick setting.
- Small sized coal improves air-fuel mixing thus accelerating the rate of combustion. Appropriate size of coal can be obtained by screening/ crushing of large sized coal.
- The crushing of coal leads to fugitive emissions. It is advised that coal crushing should be done in enclosed area with high walls so as to avoid cross currents.

Fuel quality

- Use of coal with high ash content will not only lead to high stack emission but will also pose a problem of handling of ash. It is, therefore, recommended that coal with ash content more than 35% should be avoided.
- Coal with high sulphur content (more than 2%) should not be allowed to use in brick kilns especially in the areas in the vicinity of orchards or flower bearing crops.

Fuel feeding

- Feeding of fuel in more number of lines would increase the length of firing zone and would result in more efficient combustion thereby reduction in stack emissions. Besides this the SEC of brick kiln would also improve.

Kiln Maintenance

- Constructing double walled wicket with rapish/keri in between. The conventional practice of single brick wicket wall with brick on edge results in leakage and hence should be avoided.
- Closing side flues with brick wall (1 ½ brick thick) plastered with a mix of sand clay and cow dung.
- Using double walled insulated feedhole covers. The existing feed hole covers are made of single layer steel plate. The insulated feed hole covers consists of double walled steel plates packed with insulation material such as ceramic or asbestos fibres.
- Providing a minimum ash/keri thickness of 7 inch over the brick setting.

- It is also observed that the kiln structure is partially/fully below the ground level in many States. And even the side walls/base of the kiln is unlined. During rainy season, the trench of brick kiln use to be filled with water. As a result, during first cycle of firing, additional fuel to the extent of 40-50% is consumed in order to evaporate the excess moisture present in the kiln structure, thereby emitting dark smoke from the kiln chimney. Besides this the quality of bricks is also severely affected during first cycle. It is, therefore, recommended that:
  - The kiln should always be above the ground level with proper drainage facility.
  - The kiln structure should preferable be covered by providing a shed over the kiln portion. Provision of shed over kiln would save at least 20-30 tons of coal every first cycle. The shed will have a payback period of around 4-5 years depending upon the weather of particular location.
  - Providing shed over the kiln would also improve the ambience of the area and provide shade to the workers working in the kiln.

Use of internal fuel

- Internal fuel such as ash with carbon, powdered coal or other waste with fuel value should be used in clay. Better mixing of fuel in clays can be achieved using mechanical means. Use of internal fuel will reduce the feeding requirement thus leading to reduced emissions.

Fugitive Emissions

- During summer winds/ storms, the ash layer over the top of brick settings, become airborne resulting in fugitive emissions. To minimise this, wind breakers should be raised along the outer trench wall of brick kiln by constructing two feet high brick wall.
- Provision of shed over the kiln structure will also reduce the fugitive emissions.
- Water should be sprinkled over the keri/ ash layer before its removal and transfer.
- The coal crusher should be installed in an enclosed area with minimum 6’ high walls.
- Brick paved/earthen stabilized roads shall be constructed along the outer periphery of brick kiln and approach roads. The water should be sprinkled frequently over these roads.
- Two or three rows of trees with thin leaves should be planted along the outer periphery of kiln area.
- The ash layer in the preheating zone can be covered with plastic sheet/tirpal.

Monitoring

- Since the process of loading, unloading and firing system is totally manual and its performance and efficiency depends on the efficiency and skill of the workers, it is utmost important to monitor the activities, especially the feeding and operating practices in the kiln by using instrumentation, installing monitoring gadgets.
  - It should be made mandatory for a kiln owner to employee a supervisor with minimum 10+2 qualification who will keep the log of temperature in the firing zone, in the side flue and chimney.
  - A temperature gauge shall be installed in the kiln chimney to monitor the temperature of flue gas.

Protection to workers health

- Covering of the kiln top with a continuous layer of bricks or tiles.
- A full face mask is to be provided to workers to protect their eyes, ears and nose.
- Hand gloves are to be provided to workers to protect their hands from ill effects of coal handling and also from hot flue gases coming out of fire hole during the charging.
- Special coat/apron and shoes are to be provided to the workers for their protection against these hazards.

Thanks

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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

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		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/m^3 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

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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

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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)

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

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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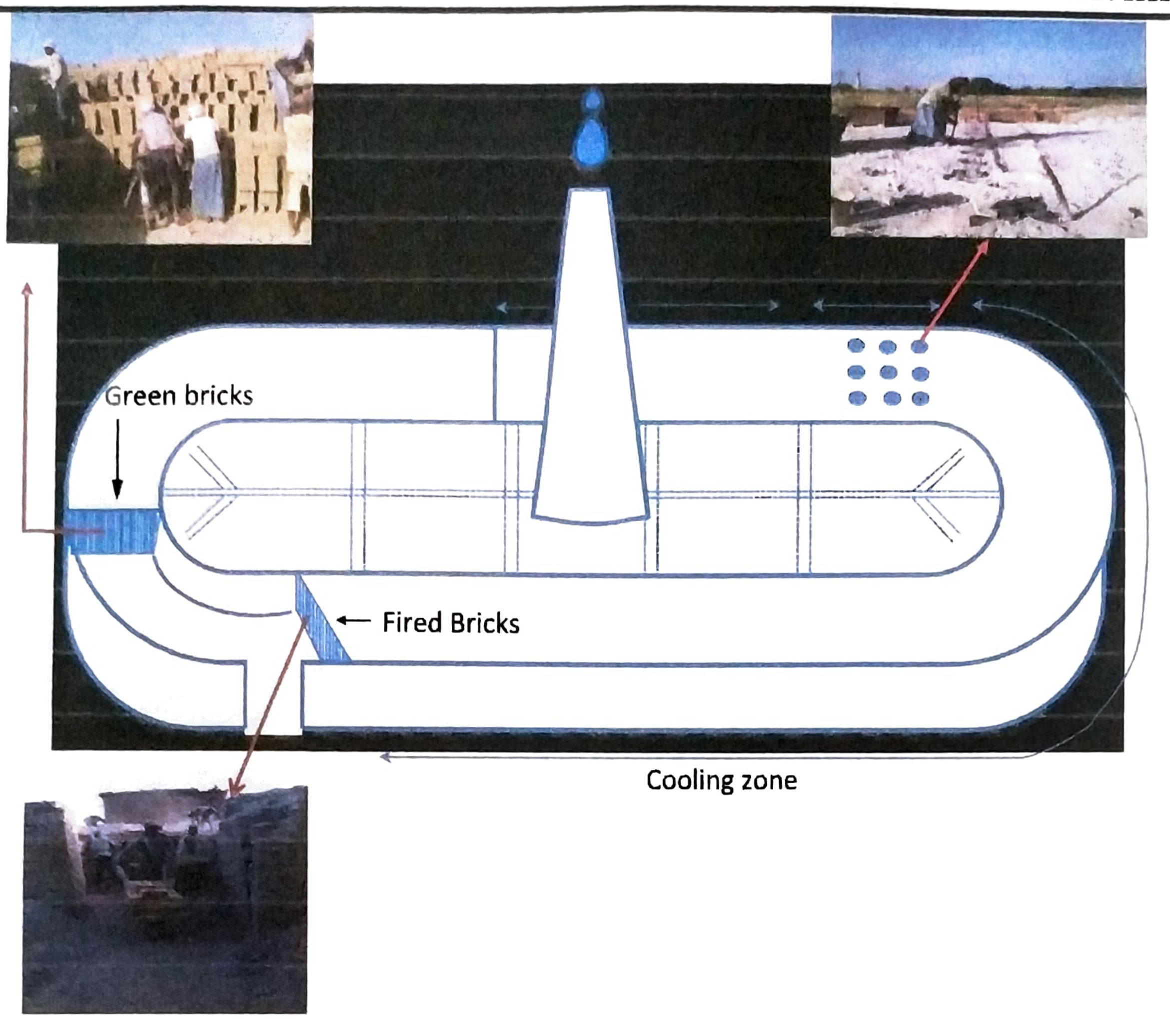

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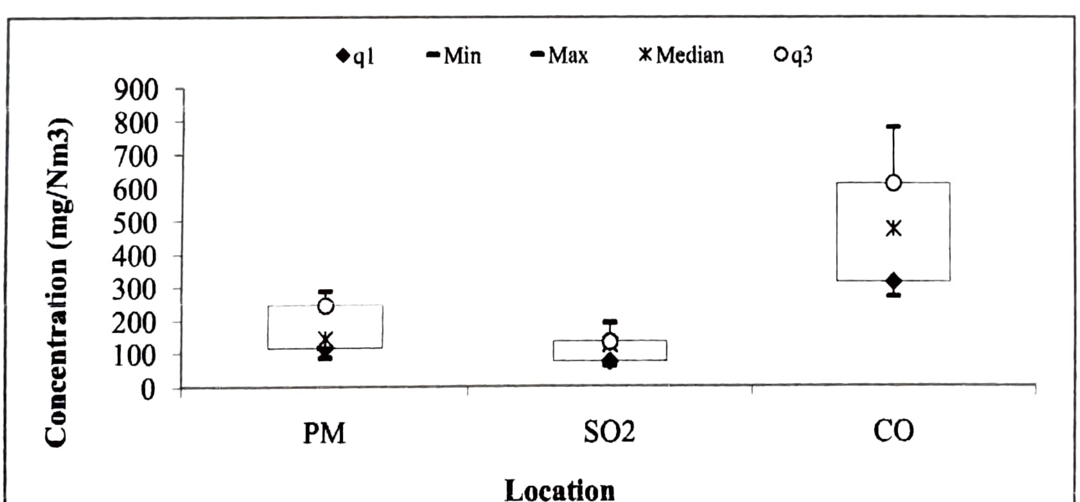

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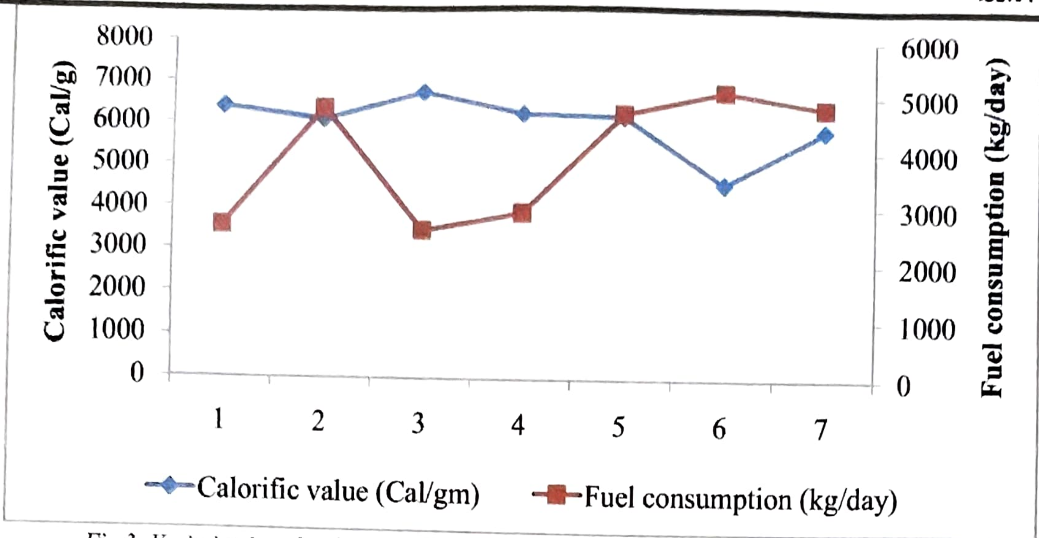

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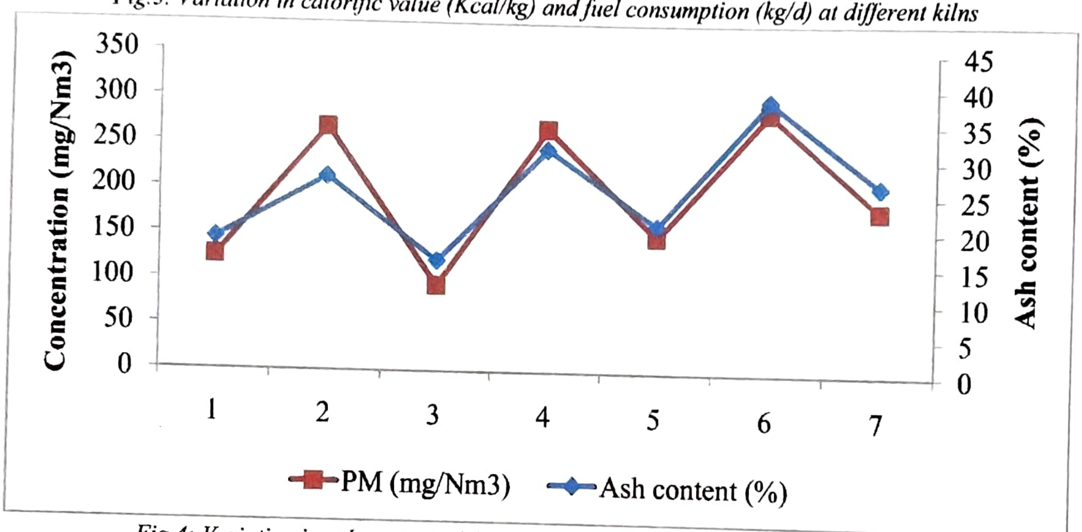

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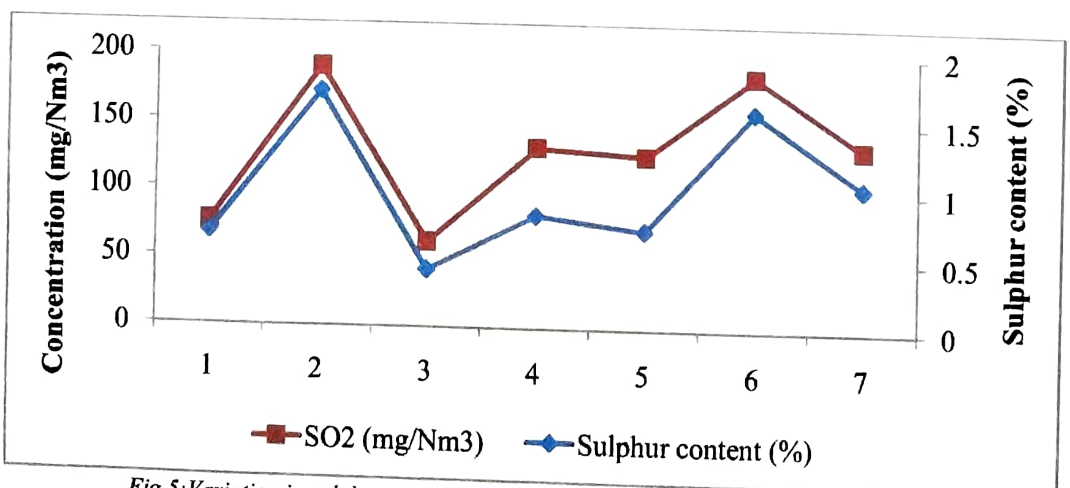

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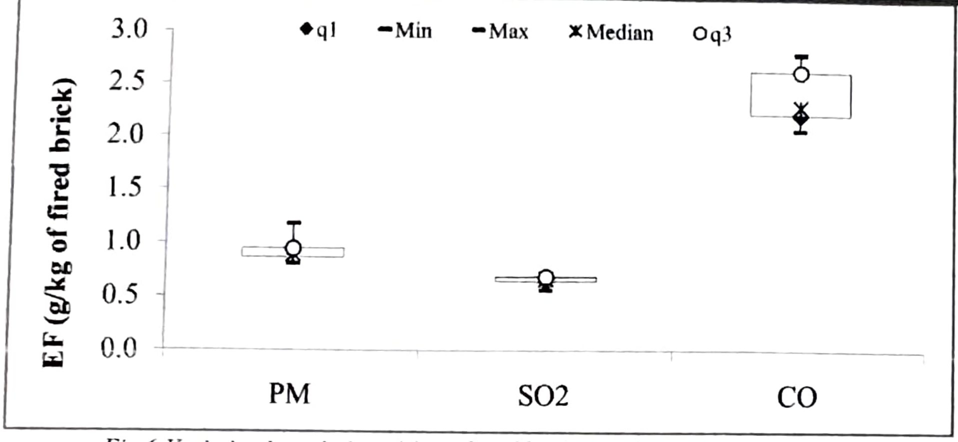

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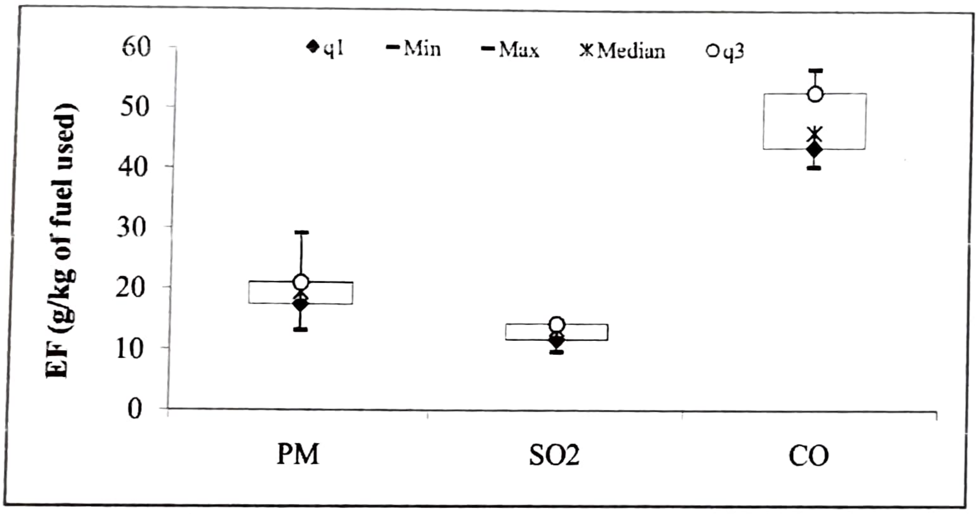

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Technical note

Assessment of air pollutant emissions from brick kilns

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ABSTRACT

India has more than 100,000 brick kilns producing around 250 billion bricks annually. Indian brick industry is often a small scale industry and third largest consumer of coal in the country. With the growing demand for building materials and characterised by lack of pollution control measures the brick industry has a potential to cause adverse effects on the environment. This paper presents assessment of five brick making technologies based on the measurements carried out at seventeen individual brick kilns. Emissions of PM, SO_2, CO and CO_2 were measured and these emissions were used to estimate the emission factors for comparing the emissions across different fuel or operating conditions. Estimated emission from brick kilns in South Asia are about 0.94 million tonnes of PM; 3.9 million tonnes of CO and 127 million tonnes of CO_2 per year. Among various technologies that are widely used in India, Zig zag and vertical shaft brick kilns showed better performance in terms of emissions over the traditional fixed chimney Bull's trench kilns. This suggests that the replacement of traditional technologies with Zig zag, vertical shaft brick kilns or other cleaner kiln technologies will contribute towards improvements in the environmental performance of brick kiln industry in the country. Zig zag kilns appear to be the logical replacement because of low capital investment, easy integration with the existing production process, and the possibility of retrofitting fixed chimney Bull's trench kilns into Zig zag firing.

1. Introduction

Solid fired clay bricks are the most widely-used building materials in India. The bricks are mainly produced locally in small enterprises at the cottage, village and rural scale. The informal, small-scale industry sector, often unlicensed and unregulated manufacturing processes generally lack in the control of pollution and hence lead to negative environmental implications (Co et al., 2009).

Indian brick kiln industry is the second largest brick producer in the world, next to China, having more than 100,000 operating units and producing about 250 billion bricks annually. It employs about 10 million workers and consumes about 25 million tons of coal annually (Gupta and Narayan, 2010; Lalchandani et al., 2012). Coal is the major fuel, apart from coal, a variety of biomass fuels, such as, firewood, dry dung, rice husk bagasse and other agro-residues are used for firing bricks. Typical brick making process in India and other developing countries is of less energy efficient and hence leads to high levels of pollution. In addition to these emissions from combustion, the life cycle of brick making involves significant fugitive emissions.

Building construction in India is estimated to grow at a rate of 6.6% per year between 2005 and 2030. The building stock is expected to multiply five times during this period, resulting in a continuous increase in demand for brick and other building materials (Mckinsey, 2009). With rapid growth of brick production, the environmental aspects of brick making have become a serious concern that needs immediate attention.

1.1. Brick making technologies in India

Based on the firing practice, brick kilns can be grouped under two broad categories namely intermittent kilns and continuous kilns. In intermittent kilns, bricks are fired in batches. Examples of intermittent kiln include Clamp, Scove, Scotch and Down Draft kilns. In a continuous kiln, on the other hand, the fire is always

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burning and bricks are being warmed, fired and cooled simultaneously in different parts of the kiln. Examples of such kilns include Bull's trench kiln (BTK), Hoffmann, Zig zag kilns, Tunnel kiln and vertical shaft brick kiln (VSBK) (Heierli and Maithel, 2008). Majority of the kilns in India are of traditional intermittent and continuous manually operated kiln such as BTK. Table 1 presents the details of kilns in India.

1.2. Regulatory drivers

With growing awareness, environmental issues are of serious concern at all levels of society. Government of India has issued notifications of emission standards for brick kilns. The notification includes maximum allowable norms for Particulate Matter (PM) concentration in flue gases, minimum stack height and proposed ban on the use of moving chimney BTK (CPCB, 1996). Later on, emission standards and stack height regulations for VSBK and Down-Draft Kiln (DDK) were stipulated by The Government of India (GoI, 2009). Summary of emission regulations for various types of brick making technologies in India is presented in Appendix A.

Apart from the environmental concerns, the industry faces other challenges, such as shortage of workers, resulting in an increase in wages and disruption of production; rapid increase in the fuel cost and limited availability of good quality coal; shortage of good quality clay and competition from other walling materials such as concrete blocks. It is expected that these drivers will force the industry to adopt better technologies and mechanization in the future.

The present paper discusses the comprehensive assessment of brick making technologies which were carried out to gain a deeper understanding of the emissions from current technologies as well as technologies that offer the promise of cleaner brick production. The assessment included detailed monitoring of emissions and simultaneous assessment of energy consumption from seventeen kilns representing five technologies: two traditional brick kiln technologies widely prevalent in India – fixed chimney BTK (FCBTK) and DDK and three relatively newer technologies – VSBK, Zig zag kilns, and Tunnel kiln. Brief description of these five brick making technologies is presented in Appendix B.

Among seventeen kilns, two of them are located in Vietnam representing VSBK and Tunnel kiln. Vietnam has demonstrated significant advancement in adoption of efficient technologies such as VSBK and Tunnel kiln and better operating practices such as usage of more internal fuels and partial mechanization. Though these developments are expected in India, the current progress is very slow. During the time of study (2011), proper operating tunnel kiln was almost nil in India. In order to study the performance of better technologies and operating practices, the study included performance monitoring of a tunnel kiln and VSBK in Vietnam. Appendix C presents the details of selected kilns.

Table 1
Types of brick kilns in India.

Kiln technology	Typical production (million bricks/year)	Approximate number of kilns	Main fuel used	Specific energy consumption (MJ/kg of fired product)
Fixed chimney Bull's trench kiln (FCBTK)	3–10	30,000	Coal	1.1–1.4
High draft/Zig-zag kilns	3–5	200	Coal	0.8–1.1
Clamps	<1	>60,000	Biomass, coal and lignite	1.9–2.5, 1.2–1.75
Vertical shaft brick kiln (VSBK)	0.5–4	20	Coal	0.7–1.0

Table 2
Measurement and analysis techniques.

Process variable	Principle of measurement/Analysis	Sample location	Type[a]
Fuel feeding rate	Weighing of fuel taken by the fuel feeding spoon one time and recording the no of spoons fed over the experiment	–	R
Temperature of flue gas	Thermocouple	Monitoring port on stack, Flue gas duct	R
Temperature of bricks and surfaces	K-type Thermocouple, Infrared thermometer	Inside the kiln, Outside surface of kiln	P
Stack velocity[b]	Pitot tube	Monitoring port on stack	P
Oxygen	Electrochemical	Monitoring port on stack, Flue gas duct	R
Carbon dioxide	Inferred from O_2	Monitoring port on stack, Flue gas duct	R
Carbon monoxide	Electrochemical	Monitoring port on stack, Flue gas duct	R
Sulphur dioxide	Barium–Thorin titrimetric method, Electrochemical	Monitoring port on stack	I
Suspended particulate matter	Gravimetric	Monitoring port on stack	I

[a] P – Average of single-point observations, I – Integrated sample taken over many minutes, R – Real-time observations averaged for presentation.
[b] For duct diameter smaller than 0.30 m, standard or modified hemispherical-nosed pitot tube was used, with a minimum diameter of 0.1 m.

2. Methodology

2.1. Measurement techniques

Emissions of gases and particulate matter were monitored in the stack at the height of 10–15 m from the ground level and meeting as per standard BIS/EPA methods with suitable modifications. VSBKs had smaller stacks and the sample was taken two metres above the top layer of bricks. The VSBK measured in India had two stacks and samples were taken from both stacks.

As per the standard method, stack monitoring for particulate matter consists of obtaining representative sample of the particulate matter in an isokinetic manner (BIS, 1985a). The velocity of the stack gas from BTKs and, natural draught Zig zag kilns were very low (In some cases it was less than 1 m/s). Such low velocity could not be measured accurately by the pitot method. Alternatively, the velocity can be derived indirectly from flow rate roughly estimated from fuel consumption, air requirement, fuel analysis and composition of flue gas. Comparison of velocity measured by the pitot method and velocity derived from the estimated flow rate is presented in Appendix D. For such low velocity isokinetic sampling is difficult. Hence, it was decided that for all practical purposes, low velocity conditions can be assumed as still air and sampling was done at low flow rate. Particulates were collected in Glass Fibre (GFC of Whatman make) thimbles and measured gravimetrically.

Gaseous samples were collected in the impinger tube and taken to the laboratory for analysis for SO_2 analysis using titrimetric method as per IS11255 (Part 2): 1985 (BIS, 1985b). Carbon

Table 3
Energy input based emission factor (g/MJ) for various pollutants from different brick making technologies.

	No of kilns monitored	No of samples	PM		SO_2		CO		CO_2	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV
Kilns in India										
FCBTK	5	15	0.66	0.90	0.39	0.92	2.96	0.91	140	0.57
NDZZ	5	15	0.21	0.91	0.06	1.52	0.32	0.97	113	0.30
FDZZ	3	9	0.23	0.84	0.23	1.00	1.96	0.76	92	0.81
VSBK	1	4	0.10	0.18	0.11	0.19	4.39	0.39	126	0.28
DDK	1	3	0.54	0.90	<0.1	0.04	5.17	0.04	181	0.34
Kilns in Vietnam										
VSBK	1	3	0.22	0.16	1.78	0.01	2.93	0.12	146	0.07
TK	1	3	0.21	0.12	0.49	0.03	1.56	0.26	109	0.10

CV – Coefficient of variation is the ratio of standard deviation to mean.

monoxide (CO) and Carbon dioxide (CO_2) measurements were carried out using flue gas analyzer. In addition to these parameters, black carbon (BC) emissions from various brick making technologies were studied in the present study. Methodology and results of BC emissions are presented by Weyant et al. (2014).

At each of the seventeen kilns, minimum of three experiments were carried out. Sampling covered both coal feeding and non-feeding periods. Fuel consumption rate during the experiment was recorded by measuring the quantity of fuel taken by the fuel feeding spoon and rate of fuel feeding during the experiment. In addition, fuel and clay samples from each of the monitored kilns were collected and analysed for calorific value, carbon, nitrogen, sulphur and ash content. Table 2 provides the list of technical parameters that were measured.

2.2. Method for estimation of emission factor

Pollutant emissions vary according to type of kiln, fuel used and kiln operating conditions. Comparing the emissions across different fuel or operating conditions requires normalization, either to unit of fuel consumed or to unit of energy consumed, or a comparison based on brick production. In the present study, emission factors were derived to compare the emissions from different technologies. Emission factors can be derived from emission rate (ER), fuel consumption rate, energy content of the fuel, and production rate (CPCB, 2007).

Emission factor derived from Emission rate and fuel consumption rate

$$ER(g/h) = S \times Q_S$$

where Q_S represents the flow rate of flue gas (m^3/h) and S the concentration of pollutant (mg/m^3).

From the emission rate (ER), fuel unit mass based emission factor (EF_m) in g/kg was calculated as follows:

$$EF_m = ER/F$$

where F is the fuel consumption rate (kg/h).

Energy input based emission factor (EF_e) or emissions per MJ of energy input in g/MJ were calculated as:

$$EF_e = EF_m/EC$$

where EC is energy content in MJ/kg.

Similarly production based emission factor i.e. emissions per kg of fired brick was estimated as

$$EF_p = EF_e \times SEC$$

where SEC = Specific energy consumption in MJ/kg of fired brick.

3. Results and discussions

3.1. Emission factors

Emission factors were estimated for PM, SO_2, CO and CO_2 based on energy input and brick production and presented in Tables 3 and 4. Details on concentration of various pollutants measured in the study can be found in Appendix E.

Average energy input based emission factor for PM varied between 0.10 and 0.66 g/MJ with lowest levels for VSBK in India and highest for FCBTK. Table 4 reveals that mass of brick production based emission factor for PM ranged between 0.09 and 1.56 g/kg of fired bricks with lowest levels for VSBK in India and highest for DDK. Comparison of emission factors among large scale brick making technologies indicate that both mass based and energy input based emission factors are lower for Zig zag technology (NDZZ and FDZZ) than those for FCBTKs and are also comparable to efficient tunnel kilns monitored in Vietnam. Two kilns monitored in Vietnam are of efficient technology (VSBK and Tunnel) and hence PM emissions are relatively low.

Average energy input based emission factor for SO_2 for various technologies monitored in India ranged between <0.01–0.39 g/MJ and average emission factor based on mass of fired brick for various technologies monitored in India ranged between <0.01–0.52 g/kg of fired bricks. Average SO_2 emission factors (both energy input based and mass of brick produced) for kilns monitored in Vietnam are on higher side in comparison with kilns under various technologies monitored in India.

Estimated average CO emission factors based on energy input for various technologies measured in India ranged between 0.32 g/MJ and 5.17 g/MJ of energy input; emission factor based on mass of brick production for various technologies in India ranges from 0.35 to 15.01 g/kg of fired bricks. Lowest CO emission factor is for NDZZ technology and highest for DDK. CO being product of incomplete combustion, the emission factor indicates the efficiency of the technology. Emission factors for carbon dioxide are in the range of 79–526 g/kg of fired bricks and 92–181 g/MJ of energy.

Literature on emission factors for brick kilns is very limited, specially with developing countries perspective. In comparison with the US EPA emission factor for coal fired tunnel kiln, the current study emission factor for CO for tunnel kiln in Vietnam was about five times higher; CO_2 emission factor was comparable and PM emission factor was about half (US EPA, 1997).

3.2. Estimated emissions from brick kilns in South Asia

About 330 billion bricks are being produced annually in south Asia, which contributes approximately 0.94 million tonnes of PM; 3.9 million tonnes of CO and 127 million tonnes of CO_2 per year (See

Table 4
Emission factor based on mass of fired brick (g/kg of fired brick) for various pollutants from different brick making technologies.

	No of kilns	No of samples	PM		SO_2		CO		CO_2	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV
Kilns in India										
FCBTK	5	15	0.89	0.97	0.52	0.98	3.63	0.82	179	0.56
NDZZ	5	15	0.22	0.89	0.06	1.48	0.35	1.05	119	0.32
FDZZ	3	9	0.24	0.84	0.24	0.99	2.04	0.76	96	0.80
VSBK	1	4	0.09	0.18	0.10	0.19	4.14	0.39	118	0.28
DDK	1	3	1.56	0.90	0.00	0.04	5.01	0.04	526	0.34
Kilns in Vietnam										
VSBK	1	3	0.12	0.16	0.97	0.01	1.59	0.12	79	0.07
TK	1	3	0.31	0.12	0.72	0.04	2.28	0.26	149	0.10

CV – Coefficient of variation is the ratio of standard deviation to mean.

Appendix F. for brick production details). India, being major brick producing country in South Asia, the emission contribution from brick kilns in India accounts for about 80% of emissions from brick kilns in South Asia. Shifting from traditional technologies such as clamps, DDK, BTKs to advanced technologies such as VSBK and Zig zag firing can reduce CO and PM emission by 60%–70%.

3.3. Comparison of various brick kiln technologies

Though alternate materials such as fly ash bricks, concrete blocks and cement stabilized solid blocks penetrated the market in the last two decades, fired clay bricks dominate with more than 90% of current market share and expected to continue with a share of about 85% of building material by 2030. Considering the significance, it is imperative to promote cleaner technologies for brick production.

Comparison of five different technologies based on their environmental performance, energy efficiency parameters, quality of bricks produced and economic aspects is presented in Table 5.

The tunnel kiln ranks better in terms of environmental parameters and quality of bricks produced, however the return on investment is low and requires electricity for operation, which may be a constraint in many parts of India as continuous electricity supply is not available. Zig zag firing ranks better than FCBTK with better performance in terms of environmental and efficiency parameters and better return on investment. Among the small kilns, VSBK performs better than DDK in terms of environmental and efficiency parameters, but fast firing may not be suitable for certain clay types.

4. Summary and conclusions

This paper provides assessment of air pollutant emission from different types of commonly used brick making technologies in India and also compares the emission levels of VSBK operated in India and Vietnam. Key findings of the assessment of air pollutants from brick kilns are as follows.

Among the five different technologies evaluated, Tunnel Kiln and Zig-zag firing shows better performance in comparison with FCBTK. Among the small scale production, DDK records poor environmental performance with high PM and CO emission levels.

The estimated emission from brick kiln production in India is about 0.94 million tonnes of PM; 3.9 million tonnes of CO and 127 million tonnes of CO_2 per year. Shifting from traditional technologies such as clamps, DDK, BTKs to advanced technologies such as VSBK and Zig zag firing can reduce CO and PM emission by 60%–70%.

Based on efficiency improvements, emission reduction and low capital investment, conversion of FCBTKs to Zig zag technology appears to be near term solution for reducing emissions from brick kilns.

Table 5
Qualitative assessment of various brick making technologies commonly used in South Asia.

Kiln types	Particulate matter EF	CO EF	Specific energy consumption for firing	Quality of fired product	Ability to fire hollow blocks	Return on investment
DDK	+	+	+	++	++	++
FCBTK	+	++	++	++	++	++
Zig-zag	++	++	++	++	++	+++
TK	+++	++	++	+++	+++	+
VSBK	+++	++	+++	+	+	++

+++ Denotes the best performance in the category.

Considering the significance in terms of energy intensity and growth in the demand of fired bricks, environmental aspects of brick making warrants attention for promotion of cleaner brick making technologies.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.atmosenv.2014.08.075.

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