Zigzag Kiln Performance Assessment - 2012

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A report prepared by

Greentech Knowledge Solutions, New Delhi (India)

In association with

Enzen Global Solutions, Bangalore (India)
University of Illinois, Illinois (USA)
Clean Air Task Force, Boston (USA)

A Shakti Sustainable Energy Foundation Supported Initiative

Project Team

Greentech Knowledge Solutions Pvt. Ltd., New Delhi (India)

Dr. Sameer Maithel, Mr. Dheeraj Lalchandani, Mr. Prashant Bhanware, Mr. Sandeep Ahuja

Enzen Global Solutions Pvt. Ltd., Bangalore (India)

Dr. R. Uma, Mr. Vasudev Athalye, Mr. Santhosh Ragavan, Mr. Rashmin Joshi

University of Illinois at Urbana-Champaign, Illinois (USA)

Dr. Tami Bond, Ms. Cheryl Weyant

Clean Air Task Force, Boston (USA)

Ms. Ellen Baum

A Shakti Sustainable Energy Foundation supported initiative

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For further information, please contact

Dr. Sameer Maithel (sameer@gkspl.in)

Dr. R. Uma (uma.r@enzenglobal.com)

Preface

India is the second largest producer of clay-fired brick in the world, contributing to more than 10% of the global production. India's brick sector is characterized as an *unorganized sector*. It uses traditional kiln technologies, employs more than 10 million migratory workers, consumes around 35 Million tons of coal annually, and creates large amounts of emissions.

Like many traditional unorganized sectors, the clay brick sector has been very slow to adopt new technology and management practices. However, in recent years, a shortage of migratory workers due to the employment guarantee scheme of the government of India, a sharp increase in coal and clay prices, and new regulations on clay mining and environment pollution are putting pressure on the brick sector to adopt new technology and management practices.

With a goal of evaluating various brick kiln technologies and preparing a roadmap for cleaner brick production in India, a team consisting of Greentech Knowledge Solutions (GKSPL), Enzen Global Solutions, Entec AG, and the University of Illinois, with support from the Clean Air Task Force, Shakti Sustainable Energy Foundation, and Climate Works Foundation, conducted a comprehensive technical and financial analysis of five brick firing technologies in 2011.

The assessment concluded that the performance of the zigzag firing technology is superior to the current baseline technology, the fixed chimney bulls trench kiln (FCBTK) on all important technical and financial parameters. The study suggested that the large-scale promotion of zigzag firing and the replacement of all FCBTKs with zigzag fired kilns will be an important step in the transition towards cleaner brick production. With an estimated 35,000 FCBTKs operational in India, conversion to zigzag kilns could result in an estimated annual savings of 2 million tons of coal, 3.9 million tons of avoided CO_2 emissions, and 40,000 tons of avoided black carbon emissions.

Additional energy and environmental measurements of zigzag kilns were made during 2012 to further strengthen and expand the energy and emission database for zigzag kilns. To clearly establish the benefits of retrofitting FCBTKs into natural draught zigzag kilns, monitoring energy and emissions before and after conversion was also initiated.

As a result, energy and emission monitoring (including black carbon monitoring) of four zigzag kilns (two natural draught and two high draught) was conducted in April – May 2012. In addition to the measurements of these operational zigzag kilns, two FCBTKs, whose owners were willing at the time to convert them to natural draught zigzag kilns, were identified and monitored on energy and emission parameters. In 2012 one of them was converted. It will be again monitored on the same parameters in early 2013 for post conversion results.

This report provides the results of the monitoring conducted on these six brick kilns during 2012.

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Chapter I – Introduction

Background

In 2011, a detailed assessment of brick kiln technologies prevalent in India was carried out to gain a deeper understanding of the energy utilization and emissions from current technologies as well as from technologies that offer the promise of cleaner brick production.

The results of the study were based on detailed energy and emission monitoring of nine individual brick kilns pertaining to five brick kiln technologies:

1. Fixed Chimney Bulls Trench Kiln — *Traditional technology*
2. Down Draught Kiln — *Traditional technology*
3. Zigzag Kiln — *Alternate technology*
4. Vertical Shaft Brick Kiln — *Alternate technology*
5. Tunnel Kiln — *Alternate technology*

Apart from measuring energy and environment performance, the financial performance of the individual technologies was also assessed. The assessment concluded that the performance of zigzag firing technology is superior to the current baseline technology of fixed chimney bulls trench kilns (FCBTK) on all three parameters. A comparison of the energy and environment performance is shown in Figure 1.1.

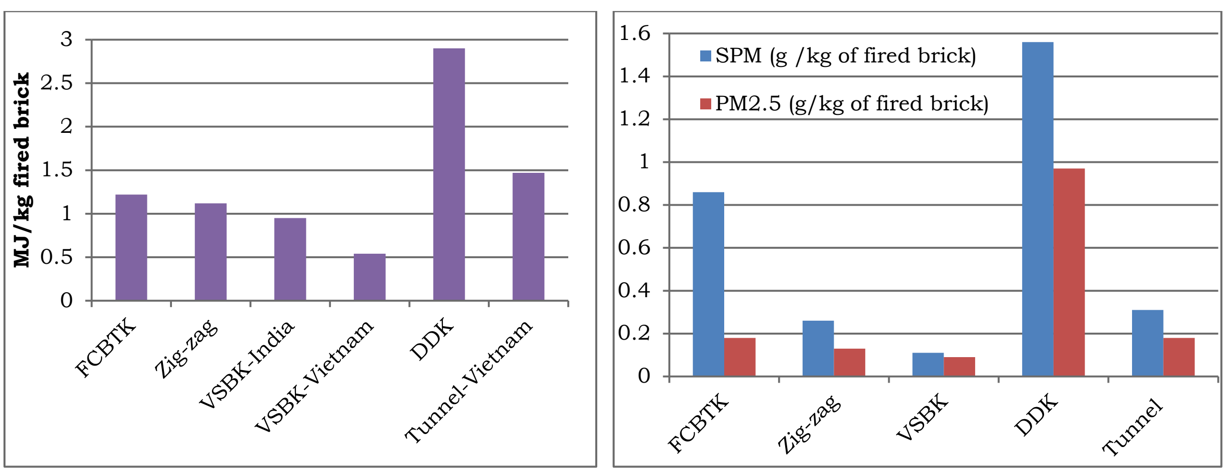


Figure 1.1: Comparison chart of energy and emissions of five brick kiln technologies monitored in 2011

The main benefits of zigzag firing technology as compared to FCBTK are:

1. Around 10% reductions in energy consumption and CO_2 emissions.
2. Significant reduction (~70%) in SPM and black carbon emissions.
3. Substantial increase in the quantity of Class I bricks
   - From 60-70% of the total production for FCBTK to 80-90% of the total production for zigzag kilns.
4. Attractive payback period
   - Payback Period < 1 year in case of retrofitting of an existing FCBTK to natural draught zigzag kiln
   - Payback period of 2 – 3 years in case of a new zigzag kiln

The study suggested that the large-scale promotion of zigzag technology is a way forward to cleaner brick production in India. With an estimated 35,000 FCBTKs operational in India, conversion to zigzag kilns could result in an estimated annual savings of 2 million tons of coal, 3.9 million tons of avoided CO_2 emissions, and 40,000 tons of avoided black carbon emissions.

Additional energy and environmental measurements of zigzag kilns were made during 2012 to further strengthen and expand the energy and emission database for zigzag kilns. To clearly establish the benefits of retrofitting FCBTKs into natural draught zigzag kilns, monitoring energy and emissions before and after conversion was also initiated.

As a result four additional zigzag kilns (2 natural draught and 2 high draught) were monitored for their energy and environment performance in April – May 2012. In addition to the measurements of operational zigzag kilns, two FCBTKs, whose owners were willing at the time to convert them to natural draught zigzag kilns, were identified and monitored on energy and emission parameters. In 2012 one of them was converted. It will be again monitored on the same parameters in early 2013 for post conversion results.

The present report provides the analysis of the results of the measurements of four additional zigzag kilns and two FCBTKs, one of which was converted to a natural draught zigzag kiln.

Objective

The objective of the study was to carry out detailed assessment of zigzag kiln technologies and to clearly establish the benefits of conversion to natural draught zigzag kilns from FCBTK.

Greentech Knowledge Solutions Pvt. Ltd. (GKSPL), Enzen Global Solutions Pvt. Ltd. (Enzen) and the University of Illinois (UoI), with the Clean Air Task Force (CATF), conducted monitoring of brick kilns during April and May 2012.

Monitored Kilns

Four zigzag kilns, two natural draught and two high draught, were monitored on the following parameters:

- Energy performance: Specific Energy Consumption (SEC)
- Environment performance: Emission measurements for particulate matter (PM), black carbon (BC), and selected gaseous pollutants.

To establish the benefits of retrofitting/conversion of FCBTK to natural draught zigzag kilns, a pre and post conversion monitoring of energy consumption and environment parameters was proposed. Two FCBTKs, whose owners were willing at the time to convert them to natural draught zigzag kilns, were identified, and pre conversion monitoring was conducted on the following parameters:

- Energy performance: Specific Energy Consumption (SEC)
- Environment performance: Emission measurements for particulate matter (PM), and selected gaseous pollutants.

The post conversion monitoring will be conducted in early 2013.

The salient features of the monitored kilns are presented in Table 1.1.

Table 1.1 Salient features of brick kilns monitored during 2012

Type of kiln	Number of kilns monitored	Features of monitored kilns	
		Location	Fuel used
Natural Draught Zigzag	2	Varanasi (U.P.)	Coal, Sawdust and Petcoke
		Varanasi (U.P.)	Coal and Sawdust
High Draught Zigzag	2	Howrah (W.B.)	Coal
		Howrah (W.B.)	Coal
FCBTK	2	Varanasi (U.P.)	Coal
		Varanasi (U.P.)	Coal

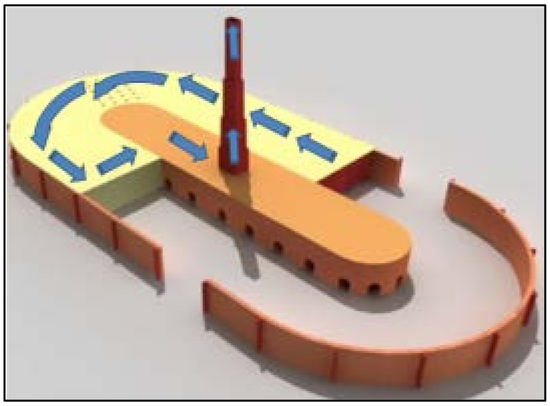
Organization of Report

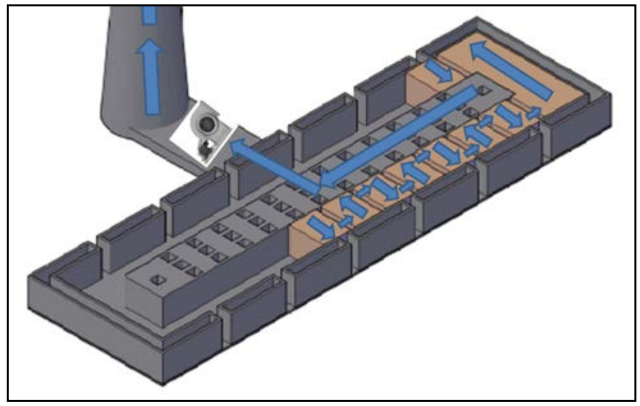
The report is organized as follows: Chapter 2 provides an introduction to the zigzag kiln technology and its types. Chapters 3 and 4 present the analysis and results of the energy and environment assessment of zigzag kilns and FCBTKs. Chapter 5 concludes the study by comparing the consolidated results of Zigzag kilns with the baseline technology of FCBTK.

Chapter 2: Introduction to Zigzag Technology

The Concept

The zigzag kiln is an improvement over the FCBTK due to the benefits of its increased air path.



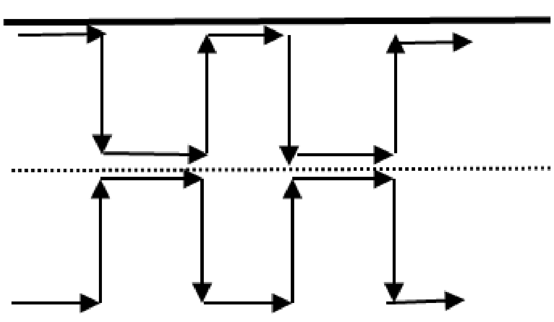


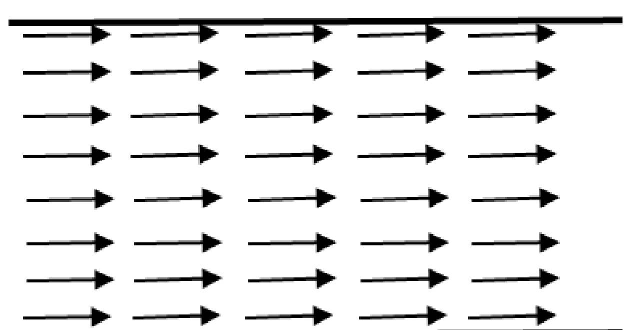
Straight air flow in FCBTK *Zigzag air flow in Zigzag kiln*

Figure 2.1: Concept of Zigzag kiln

Main Differences between Zigzag kilns and FCBTK

1. In a zigzag kiln, air moves in a zigzag path, whereas in an FCBTK, air moves in a straight path. The length of the zigzag air path is around 3 times longer than the straight air path. This longer air path, coupled with turbulence imparted by the zigzag air flow, improves the heat transfer between the bricks and air. The zigzag air path also facilitates the settling of dust particles in the flue gases by gravity.





Air flow in Zigzag kiln *Air Flow in FCBTK*

Figure 2.2: Comparison of air flow in FCBTK and Zigzag kiln

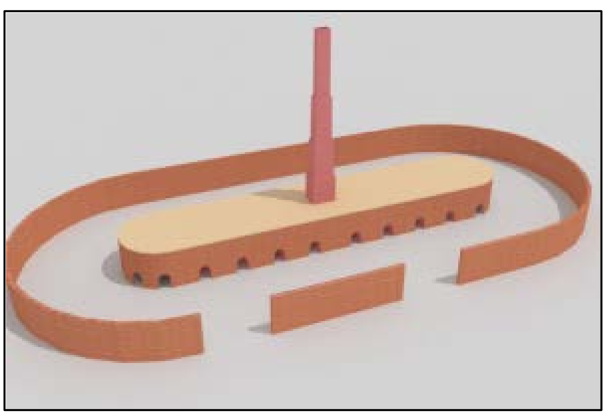
2. In a zigzag kiln, the fuel feeding zone is 2 – 3 times longer than in an FCBTK. This longer firing zone provides more time for mixing fuel and air; turbulence created by the zigzag air movement also facilitates mixing fuel and air. Better mixing of fuel and air results in near complete combustion and lower generation of soot and particulate matter.

Fuel feeding zone in Zigzag Kiln

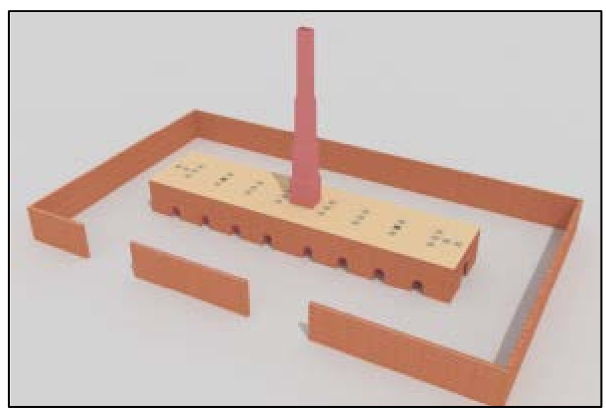
Fuel feeding zone in FCBTK

Figure 2.3: Comparison of fuel feeding zone in FCBTK and Zigzag kiln

3. FCBTK is oval or circular in shape, while zigzag kiln is rectangular.



Oval shape of FCBTK



Rectangular shape of Zigzag kiln

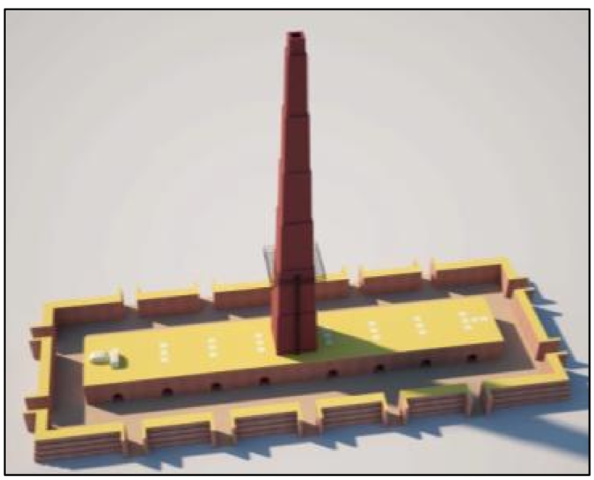
Figure 2.4: Shape of FCBTK and Zigzag kiln

Types of Zigzag Kilns

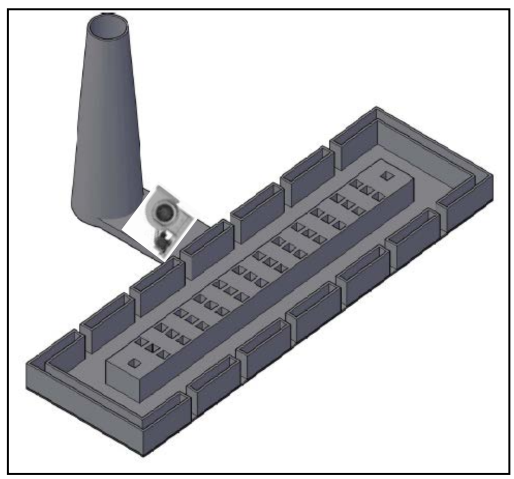
Based on the method of producing a draught, zigzag kilns can be classified as natural draught (in which draught is created by hot gases in the chimney) and high draught (in which draught is created by a suction fan). A comparison of the two types of zigzag kilns is provided in Table 2.1

Table 2.1 Comparison of natural draught and high draught zigzag kiln

Natural draught Zigzag kiln	*High draught Zigzag kiln*
➢ Operates under a draught of 8-12 mm WG, created due to the buoyancy effect of hot gases in the chimney.	➢ Operates under a draught of around 50 mm WG, created with the help of a suction fan.
➢ No electricity or diesel is required for operation of the kiln.	➢ Electricity or diesel is required to operate the fan.
➢ Brick setting is less dense.	➢ Brick setting is very dense.
➢ Height of the chimney is 120 – 130 ft.	➢ Height of the chimney is 50 – 80 ft.
➢ Uses double and triple zigzag paths.	➢ Uses only a single zigzag path.



Natural draught Zigzag kiln



High draught Zigzag kiln

Figure 2.5: Schematic of natural and high draught Zigzag kiln

Chapter 3 - Analysis and Results of Zigzag Kilns

Natural Draught Zigzag Kiln

General Description of Kilns

Two natural draught zigzag kilns, located in Varanasi, were monitored. A description of both kilns is provided in Table 3.1.

Table 3.1: Description of the monitored natural draught zigzag kilns

	Kiln 10_ZigzagND	Kiln 11_ZigzagND
Name & Location	Prayag Clay Products, Ganeshpur,Varanasi, UP	Payal Bricks, Aundi, Varanasi, UP
Monitoring dates	13 – 15 April 2012	16 – 18 April 2012
Description of company	➢ The owner is a second-generation brick maker ➢ Currently the company operates three zigzag kilns, all natural draught. ➢ Family business for last 70 years	➢ The owner is a second-generation brick maker ➢ Currently the company operates two zigzag kilns, both natural draught.
Annual Production	➢ 4– 5 million bricks/ year	➢ 4 – 5 million bricks/ year
Supplying Market	➢ Majority of the market in the radius of 50 km ➢ Varanasi & near-by areas.	➢ Majority of the market in the radius of 50 km ➢ Varanasi & near-by areas.
Operational period	➢ Dry months (December to June) ➢ Operation period is short because the kiln is open to air	➢ Dry months (December to June) ➢ Operation period is short because the kiln is open to air
Kiln Description	➢ Converted from traditional FCBTK to Zigzag natural draught 8 years ago. ➢ Double Zigzag firing ➢ Kiln trench width: 18 ft (5.5 m) ➢ Height of chimney from the platform: 70 ft (21.3 m)	➢ Converted from traditional FCBTK to Zigzag natural draught in 2011. ➢ Double Zigzag firing ➢ Kiln trench width: 22 ft (6.7 m) ➢ Height of chimney from the platform: 125 ft (38.1 m)
Moulding	➢ Hand moulded solid bricks	➢ Hand moulded solid bricks
Firing Fuel	Coal, Sawdust, Petcoke	Coal, Sawdust

Energy Performance

Based on the fuel consumption (kg of fuel consumed per day) and brick production (kg of bricks fired per day), specific energy consumption (SEC) was computed and is shown in Table 3.2.

Table 3.2: Specific energy consumption of the monitored natural draught zigzag kiln

	Fuel Consumption* (kg/day)			Brick Production		SEC (MJ/kg fired brick)
Kiln 10_ZigzagND	*Coal*	*Sawdust*	*Petcoke*	*Bricks/day*	*kg/day*	**1.02**
	2061	644	468	21600	61920	
Kiln 11_ZigzagND	*Coal*	*Mix of Sawdust & Coal*		*Bricks/day*	*kg/day*	**1.02**
	1319	1168		16400	50020	

*Calorific values of the fuels used in the monitored kilns are provided in Annexure I

The SEC for the two natural draught zigzag kilns is identical, at 1.02 MJ/kg of fired bricks. The SEC of the single natural draught zigzag kiln monitored in 2011[1], i.e Kiln 3_Zigzag_ND, was 1.2 MJ/kg fired brick. The higher SEC in 2011 was attributed to the fact that the kiln was monitored during its first cycle[2] of operation when the SEC is highest. The kilns monitored in 2012 were in their last firing cycle, when the SEC is lowest.

In the earlier study FCBTKs reported an SEC in the range of 1.1 - 1.46 MJ/kg fired brick. The lower SEC in natural draught zigzag kilns compared to FCBTKs can be attributed mainly to better heat transfer and almost complete combustion.

The details regarding the fuel mix and fuel feeding practices in the monitored natural draught zigzag kilns are provided in Annexure II.

[1] Brick Kiln Performance Assessment 2011, GKSPL, Enzen Global, University of Illinois & CATF http://www.gkspl.in/FinalBrick.11Aprl%20Print%20version.pdf
[2] The fire in a zigzag kiln moves in a closed circuit. Typically 15-20 days are required for completing one circuit, which is referred here as one cycle. In a firing season of 180-200 days/year, typically 10 to 12 cycles are completed.

Carbon-monoxide (CO) concentration in the flue gas is an indicator of the combustion efficiency of the kiln. Figure 3.1 provides a comparison of CO concentrations in the two monitored natural draught zigzag kilns in 2012 with one of the FCBTKs monitored in 2011.

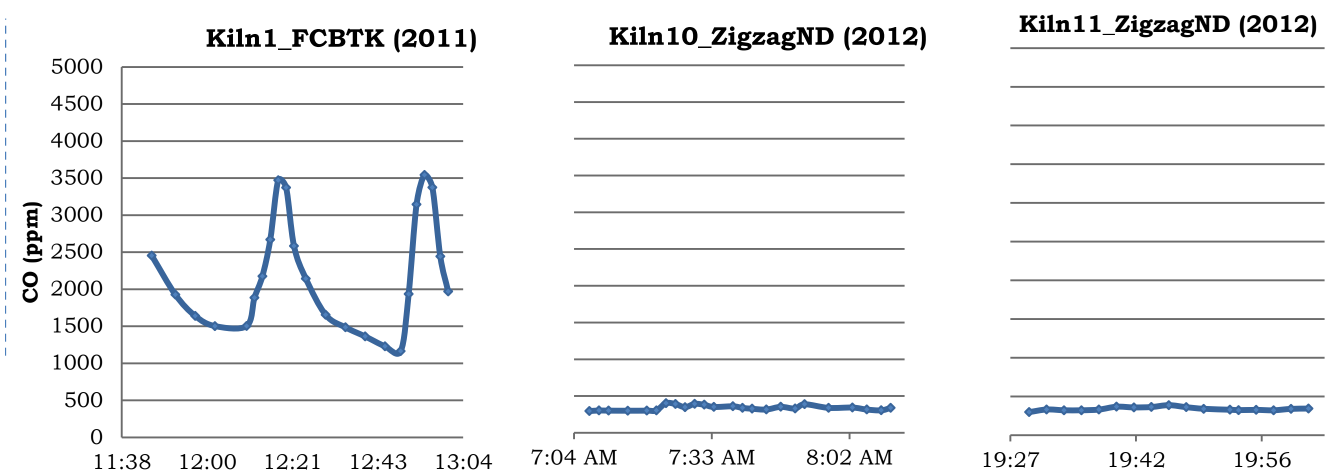


Figure 3.1: Comparison of CO concentration in zigzag kilns (measured at the chimney port) with a typical FCBTK (measured at the bottom of the chimney)

The CO concentrations in FCBTKs show a large variation with time due to the intermittent fuel feeding practice and the short combustion zone. The CO concentrations are higher during the fuel feeding period (reaching a peak of around 3500 ppm) and lower during the non-fuel feeding period (reaching the lowest value of around 1000 ppm). The average (weighted time average) concentration of CO was found to be around 1700 ppm. In a natural draught zigzag kiln, the non-feeding intervals are shorter, with fuel fed almost continuously in small quantities; this along with turbulence and the longer fuel feeding zone results in more uniform and complete combustion. Hence large variations in CO concentration are not observed. In the two natural draught zigzag kilns, the CO concentration was near to 450 ppm, which is ~70% less than the average CO concentration of the FCBTK.

Emissions

A minimum of three samples was collected at each kiln. The samples were collected from the sampling port located at a height of 11 – 20 m above ground level. Sampling was done for a period of 30 to 60 minutes, which includes both coal feeding and non-feeding periods. Prior to sample collection, the temperature and velocity of the flue gases were measured at the sampling port. Iso-kinetic sampling was followed for particulate matter sampling. At the same sampling port, a second sampling kit was used to measure the chemical and optical properties of emitted aerosols and $PM_{2.5}$. Results of the emissions sampling are shown in Table 3.3.

Table 3.3: Emission concentrations in monitored natural draught zigzag kilns

	Kiln 10_ZigzagND	Kiln 11_ZigzagND
Flue gas temperature (^{0}C)	97	95
Concentration of pollutants in the flue gas		
PM (mg/Nm^3)	263 *(176 - 339)*	255 *(227 - 290)*
$PM_{2.5}$ (mg/Nm^3)	15.6 *(13.7 – 18.6)*	108.6 *(96.7 – 124.9)*
SO_2 (mg/Nm^3)	18 *(12 - 26)*	134 *(119 - 149)*
NOx (mg/Nm^3)	39 *(22 - 50)*	19 *(19 - 21)*

Note: The single figure in the table above denotes the simple average of the three samples and the numbers in parentheses provide the minimum and maximum value obtained in three tests.

The average SPM concentration in the two monitored natural draught zigzag kilns is around 260 mg/Nm^3. The emission standard prescribed by the MoEF for a large category kiln is 750 mg/Nm^3. Hence SPM emissions in the two natural draught zigzag kilns are much lower than the prescribed norm of the MoEF.

It may be observed that SPM concentrations for the two kilns are comparable, whereas the concentration of $PM_{2.5}$ in the second kiln is seven times higher than that of the first. This large variation in $PM_{2.5}$ concentrations between the two kilns is explained by the use of different fuel mixes in the front chambers of the firing zone. The first kiln used sawdust, which burns completely at lower temperatures and hence results in lower soot, whereas the second kiln used a mixture of coal and sawdust, which resulted in greater soot formation.

Sulphur content in the fuel mix of Kiln 10_ZigzagND was 0.80%, whereas Kiln11_ZigzagND had 1.52% sulphur. The use of a high sulphur fuel mix in Kiln

11_ZigzagND resulted in higher concentrations of SO_2. The average concentration of NO_X was reported in the range of 19 – 39 mg/Nm³.

Aerosol Properties

Table 3.4 provides measured values of Elemental & Organic Carbon concentrations obtained from the fraction of particles smaller than 2.5 microns in the stack.

Table 3.4: Scattering and absorption for Red λ and elemental and organic carbon concentration results for natural draught zigzag kilns

	Unit	Kiln 10_ZigzagND	Kiln 11_ZigzagND
Scattering	*1/m*	0.03	0.19
Absorption*	*1/m*	N/A	N/A
Elemental Carbon	*mg/Nm³*	4.41 (1.66 – 8.83)	6.67 (5.45 – 8.75)
Organic Carbon	*mg/Nm³*	Not detected	1.3 (0 – 1.97)

* Absorption measurements were not conducted in the two kilns

The scattering measurements performed at the natural draught zigzag kiln in 2011, i.e Kiln 3_Zigzag_ND, were inconsistent and might have been affected by measurement errors. Therefore, present scattering results cannot be compared with 2011 results. The scattering result in kiln 11, like the $PM_{2.5}$ result, was also about 7 times higher than in kiln 10.

The elemental carbon concentrations are within the range of results of the earlier study[3], while the organic carbon concentrations were slightly lower, but within the uncertainty of the analyser (Sunset Laboratory OC-EC Aerosol Analyser).

Emission Factors

Pollutant emissions vary according to type of kiln, fuel used and operating conditions. Comparing the emissions across different fuel/operating conditions requires

[3] Brick Kiln Performance Assessment 2011, GKSPL, Enzen Global, University of Illinois & CATF http://www.gkspl.in/FinalBrick.11Aprl%20Print%20version.pdf

normalization, either to unit of fuel consumed or to unit of energy consumed, or to kilograms of fired brick. All emission factors were derived from emission rate (ER), fuel consumption rate, energy content of the fuel, and production rate.

A summary of the emission factors of various pollutants is presented in Table 3.5.

Table 3.5: Emission factors of pollutants in two monitored natural draught zigzag kilns - 2012

Pollutants			*g/kg fuel*	*g/MJ*	*g/kg fired brick*
Flue Gas Pollutants		CO	4.5	0.22	0.23
		CO_2	2046	101	103
		SO_2	1.93	0.09	0.1
		NOx	0.92	0.05	0.05
Particulate Matter	**SPM**	Total SPM	8.48	0.42	0.43
		$PM_{2.5}$	1.76	0.09	0.09
	Aerosol Properties	Elemental Carbon	0.18	0.01	0.01
		Organic Carbon	0.02	0.001	0.001
			m^2/ kg fuel	*m^2/ MJ*	*m^2/kg fired*
		Scattering (Red λ)	3.85	0.19	0.19
		Absorption (Red λ)	N/A	N/A	N/A

High/Forced Draught Zigzag Kiln

In India, the zigzag firing concept was first introduced in the form of the high draught (HD) kiln. The original design was provided by CBRI. In forty years, many modifications have been made to the original design and several variations of high draught kilns can be found in the field. The monitored high draught kilns of Howrah were of modified design.

The original design consisted of a rectangular shaped annular kiln, having 24 chambers. The draught was created by an induced draught fan with a 15 hp motor. A sketch of the original design is given in figure 3.2 below:

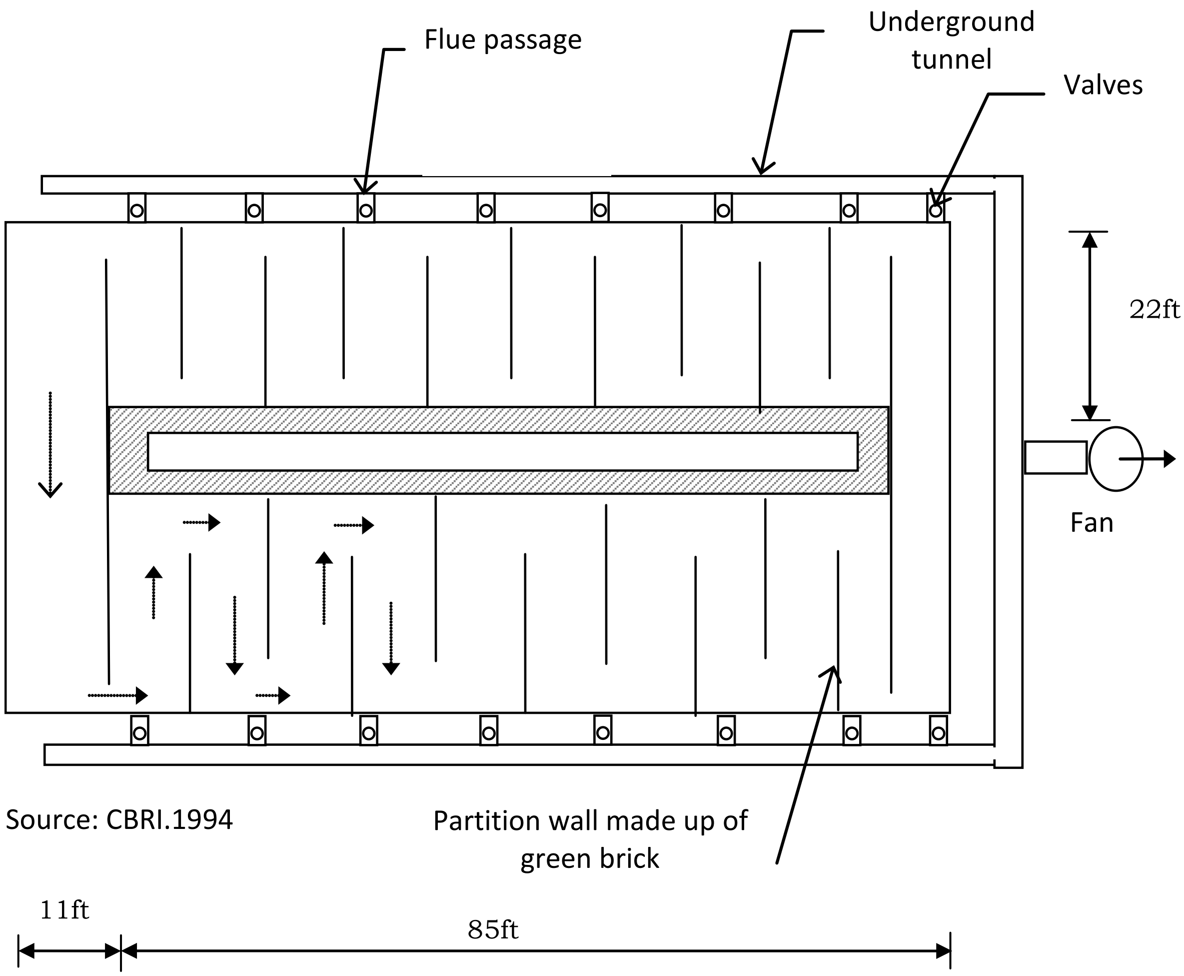


Figure 3.2: Original design of High draught Zigzag kiln, Source: CBRI

The small size of the kiln and issues of leakages from the valves were among the major problems which acted as a catalyst for the modifications in the original design of the high draught kiln.

In the modified design, the length of the kiln has been increased to 192 ft (58.5m) and an underground flue gas duct is constructed on the central island with a shunt mechanism to connect fan with kiln, as in figure 3.3. Figure 3.4 shows the actual kilns that were monitored.

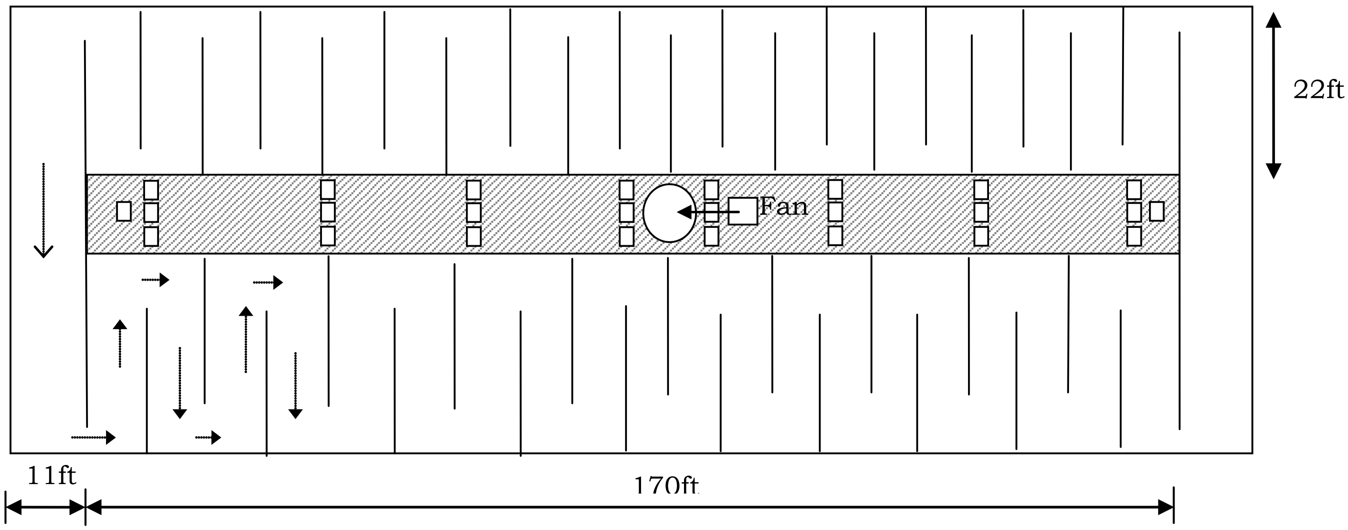


Figure 3.3: Modified design of the monitored high draught zigzag kiln

Figure 3.4 -Monitored Modified High Draught Zigzag kilns, Howrah

General Description of Kilns

Two high draught zigzag kilns, located in Howrah, were monitored. A description of both kilns is provided in Table 3.6.

Table 3.6: Description of the monitored high/forced draught zigzag kilns

	Kiln 12_ZigzagFD	Kiln 13_ZigzagFD
Name & Location	LMB Bricks, Panchpara, Howrah, West Bengal	Bisco Brick Field, Panchpara. Howrah, West Bengal
Monitoring dates	8 – 11 May 2012 (last firing cycle)	12 – 14 May 2012 (last firing cycle)
Description of company	➢ The owner is an experienced brick maker known for his sound technical knowledge of brick making and for innovative management practices	➢ The owner is a second-generation brick maker
Annual Production	➢ 4 – 5 million bricks/ year	➢ 4 – 5 million bricks/ year
Supplying Market	➢ Kolkata, Howrah and near-by areas	➢ Kolkata, Howrah and near-by areas
Operational period	➢ Dry months (December to May) ➢ Operation period is short because the kiln is open to air	➢ Dry months (December to May) ➢ Operation period is short because the kiln is open to air
Kiln Description	➢ Modified high draught design ➢ Kiln is open to air ➢ Kiln trench width: 22 ft (6.7m) ➢ Height of chimney: 135 ft (41.15 m) ➢ Use of shunt type mechanism	➢ Modified high draught design ➢ Kiln is open to air ➢ Kiln trench width: 20.5 ft (6.25m) ➢ Height of chimney: 105 ft (32m) ➢ Use of shunt type mechanism
Moulding	➢ The main raw-material is silt from Hooghly river ➢ Hand moulding o Solid Bricks	➢ The main raw-material is silt from Hooghly river ➢ Hand moulding o Solid Bricks
Firing Fuel	➢ Coal	➢ Coal

Energy Performance

Based on the fuel consumption (kg of fuel consumed per day) and brick production (kg of bricks fired per day), the specific energy consumption (SEC) was computed and is shown in table 3.7.

Table 3.7: Specific energy consumption of the monitored high/forced draught zigzag kiln

	Fuel Consumption (kg/day)	Production		SEC (MJ/kg fired brick)
Kiln 12_ZigzagFD	*Coal*	*Bricks/day*	*kg/day*	**1.11**
	3511	20,800	62,348	
Kiln 13_ZigzagFD	*Coal*	*Bricks/day*	*kg/day*	**0.95**
	3025	15,750	58,768	

The SEC for the two high draught zigzag kilns was measured to be 1.11 and 0.95 MJ/kg of fired bricks respectively. The SEC of the high draught zigzag kiln measured in the previous study[4] of 2011, i.e Kiln 4_Zigzag_FD, was reported to be 1.03 MJ/kg fired brick, which lies in the range of the presently monitored high draught zigzag kilns.

In the earlier study FCBTKs reported an SEC in the range of 1.1 - 1.46 MJ/kg fired brick. The lower SEC of high draught zigzag kilns compared to FCBTKs can be attributed mainly to better heat transfer and almost complete combustion caused by high excess air (draught created by fan) coupled with turbulence created due to zigzag air movement.

Emissions

A minimum of three samples was collected at each kiln. The samples were collected from the sampling port located at a height of 11 – 20 m above ground level. Sampling was done for a period of 30 to 60 minutes, which includes both coal feeding and non-feeding periods. Prior to sample collection, the temperature and velocity of the flue gases were measured at the sampling port. Iso-kinetic sampling was followed for particulate matter sampling. At the same sampling port, a second sampling kit was used to measure the chemical and optical properties of emitted aerosols and $PM_{2.5}$.

[4] Brick Kiln Performance Assessment 2011, GKSPL, Enzen Global, University of Illinois & CATF http://www.gkspl.in/FinalBrick.11Aprl%20Print%20version.pdf

Table 3.8 presents concentrations of the pollutants in the two monitored high draught zigzag kilns.

Table 3.8: Emission concentrations in monitored high draught zigzag kilns

	Kiln 12_ZigzagFD	Kiln 13_ZigzagFD
Flue gas temperature (^{0}C)	54	72
Concentration of pollutants in the flue gas		
PM (mg/Nm^3)	71 *(51 - 92)*	34 *(26 - 46)*
$PM_{2.5}$ (mg/Nm^3)	37.8 (34.9 – 39.5)	18.5 (4.4 – 32.2)
SO_2 (mg/Nm^3)	32 *(17 - 42)*	14 *(11 -15)*
NO_x (mg/Nm^3)	27 *(20 - 37)*	25 *(19 - 34)*

Note: The single figure in the table above denotes the average of the three samples and the numbers in parentheses provide the minimum and maximum value obtained in three tests.

The average SPM concentration in the two monitored high draught zigzag kilns is 71 and 36 mg/Nm^3 respectively. The emission standard prescribed by the MoEF for large category kiln is 750 mg/Nm^3, hence the SPM emissions of high draught zigzag kilns are much less than the prescribed norm of the MoEF.

The earlier study[5] of 2011 reported average SPM concentration of 183 mg/Nm^3 for the only monitored high draught zigzag kiln located in Varanasi. The present kiln, located in Howrah, witnessed a more humid climate than that of Varanasi at the time of monitoring. The recorded relative humidity at the time of monitoring of both the earlier and the present kiln is shown in Figure 3.5. The water content of green bricks loaded in a kiln located in a humid climate is higher than that in a dry climate. Also the flue gas temperature of the earlier monitored high draught zigzag kiln was around 100 – 110 $^\circ$C, whereas in the presently monitored high draught kilns, the flue gas

[5] Brick Kiln Performance Assessment 2011, GKSPL, Enzen Global, University of Illinois & CATF http://www.gkspl.in/FinalBrick.11Aprl%20Print%20version.pdf

temperature is 54 and 72 °C respectively. Low flue gas temperature coupled with high water content in the flue gas results in a large amount of condensed water in the chimney, thereby reducing the SPM emission because of the scrubbing effect.

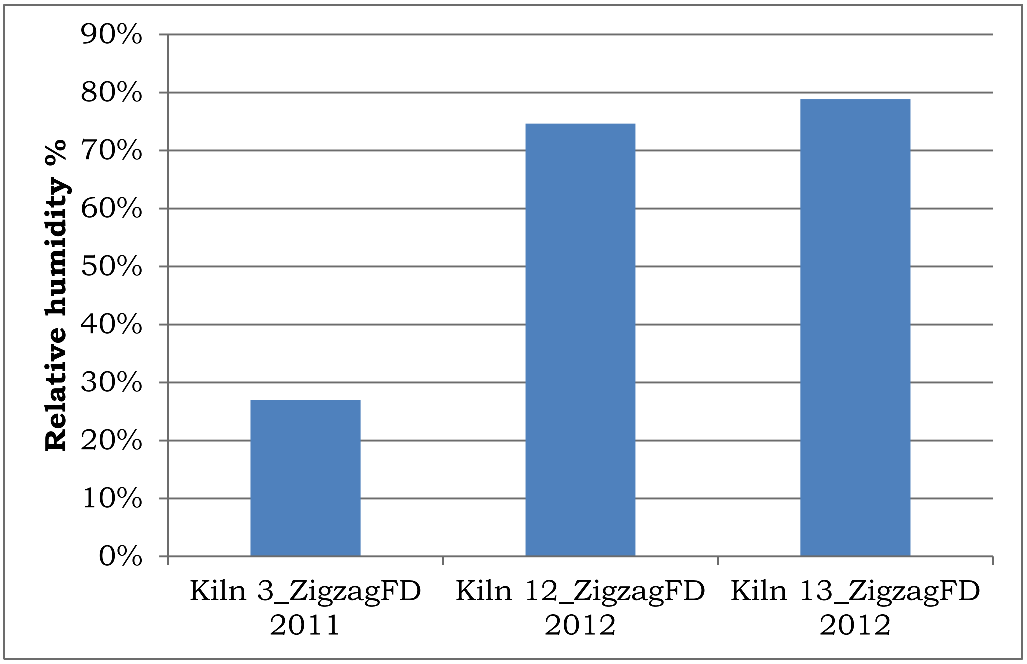


Figure 3.5: Recorded average humidity at the time of monitoring the high draught kilns in 2011 and 2012

Aerosol Properties

Table 3.9 provides measured values of Elemental & Organic Carbon concentrations obtained from the fraction of particles smaller than 2.5 microns in the stack.

Table 3.9: Scattering and absorption for Red λ and elemental and organic carbon concentration results for high/forced draught zigzag kilns

	Unit	Kiln 12_ZigzagFD	Kiln 13_ZigzagFD
Scattering	*1/m*	0.14	0.08
Absorption	*1/m*	0.03	0.02
Elemental Carbon	*mg/Nm³*	5.19	1.14
Organic Carbon	*mg/Nm³*	2.2	0.1

Values of real time measured scattering and absorption concentrations, reported in table 3.9, are in range with the concentrations reported in the earlier study. Due to lower SPM concentrations, elemental and organic carbon concentrations in the monitored high draught kilns are also lower than the earlier study.

Emission Factors

Pollutant emissions vary according to type of kiln, fuel used and operating conditions. Comparing the emissions across different fuel/operating conditions requires normalization, either to unit of fuel consumed, or to unit of energy consumed, or to kilograms of fired brick. All reported emission factors were derived from emission rate (ER), fuel consumption rate, energy content of the fuel, and production rate.

A summary of the emission factors of various pollutants is presented in Table 3.10.

Table 3.10: Emission factors of pollutants in monitored high/forced draught zigzag kilns

Pollutants			*g/kg fuel*	*g/MJ*	*g/kg fired brick*
Flue Gas Pollutants		CO	22.98	1.20	1.25
		CO_2	1894	99	102
		SO_2	1.03	0.05	0.06
		NOx	1.21	0.06	0.06
Particulate Matter	**SPM**	Total SPM	2.36	0.12	0.13
		$PM_{2.5}$	1.11	0.06	0.06
	Aerosol Properties	Elemental Carbon	0.13	0.01	0.01
		Organic Carbon	0.05	0.002	0.003
			m^2/ kg fuel	*m^2/ MJ*	*m^2/kg fired*
		Scattering (Red λ)	4.87	0.25	0.26
		Absorption (Red λ)	1.04	0.05	0.06

Chapter 4 – Analysis and Results of Pre-conversion Monitoring of FCBTK

Two FCBTKs, whose owners were willing at the time to convert them to natural draught zigzag kilns, were identified and monitored before conversion[6]. Monitoring focussed on the energy and environment performance of the FCBTK. The following parameters were assessed for measuring energy and environment performance:

- Energy performance: Specific Energy Consumption (SEC)
- Environment performance: Emission measurements for particulate matter (PM), and selected gaseous pollutants.

A description of both kilns is provided in Table 4.1.

Table 4.1: Description of the monitored FCBTK – Before conversion

	Kiln 14_FCBTK	Kiln 15_FCBTK
Name & Location	TATA Bricks, Varanasi, UP	Shail Bricks, Varanasi, UP
Monitoring dates	4 - 5 May 2012	6 - 7 May 2012
Annual Production	➢ 5 -6 million bricks/ year	➢ 4 – 5 million bricks/ year
Supplying Market	➢ Majority of the market in the radius of 50 km ➢ Varanasi & near-by areas.	➢ Majority of the market in the radius of 50 km ➢ Varanasi & near-by areas.
Operational period	➢ Dry months (December to June) ➢ Operation period is short because the kiln is open to air	➢ Dry months (December to June) ➢ Operation period is short because the kiln is open to air
Kiln Description	➢ Typical FCBTK ➢ Kiln is open to air ➢ Kiln trench width: 22' 10" (6.96m) ➢ Height of chimney: 105' (32m)	➢ Typical FCBTK ➢ Kiln is open to air ➢ Kiln trench width: 20' (6.1m) ➢ Height of chimney: 115' (35.05 m)
Moulding	➢ Hand moulding o Solid Bricks	➢ Hand moulding o Solid Bricks
Firing Fuel	➢ Coal	➢ Coal

[6] As of January 2013, the second identified FCBTK, i.e. Kiln 15_FCBTK, deferred the conversion to natural draught zigzag. Therefore after conversion monitoring can only be conducted in the first kiln, i.e. Kiln 14_FCBTK.

Energy Performance

Based on the fuel consumption rate and brick production (kg of bricks fired per day), specific energy consumptions were computed and shown in Table 4.2.

Table 4.2: Specific energy consumption of the monitored FCBTK – Before conversion

	Fuel Consumption (kg/day)	Production		SEC (MJ/kg fired brick)
Kiln 14_FCBTK	*Coal*	*Bricks/day*	*kg/day*	**1.41**
	5392	27000	77760	
Kiln 15_FCBTK	*Coal*	*Bricks/day*	*kg/day*	**1.39**
	3570	19600	63896	

The pre-conversion SEC for the two FCBTK kiln are 1.41 and 1.39 MJ/kg of fired brick respectively. In the earlier study FCBTKs reported an SEC in the range of 1.1 – 1.46 MJ/kg fired brick. The SEC of the presently monitored FCBTK lies in range of the earlier reported study.

Carbon-monoxide (CO) concentration in the flue gases is an excellent indicator for measuring the combustion efficiency of the kiln. Figure 4.1 provides CO concentration graphs in the monitored pre-converted FCBTKs. It is clearly visible that CO concentrations in pre-converted FCBTKs vary from 500 ppm to 3200 ppm. This large variation in CO concentrations in FCBTK is due to the intermittent fuel feeding practice.

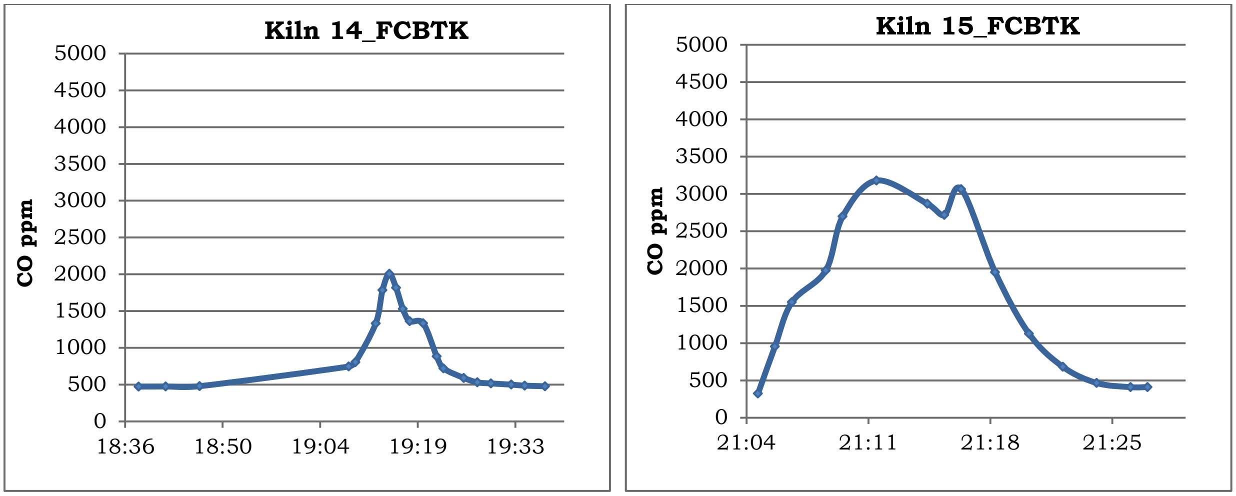


Figure 4.1: CO charts for the FCBTKs monitored in 2012

Emissions

A minimum of three samples was collected at each kiln. The samples were collected from the sampling port located at a height of 11 – 20 m above ground level. Sampling was done for a period of 30 to 60 minutes, which includes both coal feeding and non-feeding periods. Prior to sample collection, the temperature and velocity of the flue gases were measured at the sampling port. Iso-kinetic sampling was followed for particulate matter sampling. Table 4.3 presents concentrations of the pollutants in the two monitored high draught zigzag kilns.

Table 4.3: Emission concentrations in monitored FCBTK – Before conversion

	Kiln 14_FCBTK	Kiln 15_FCBTK
Flue gas temperature (^{0}C)	98	73
Concentration of pollutants in the flue gas		
PM (mg/Nm^3)	1255 (251 - 2740)	316 (218 - 397)
SO_2 (mg/Nm^3)	58 (24 – 96)	284 (157 - 437)
NOx (mg/Nm^3)	14 (14 – 17)	19 (18 – 21)

Note: The single figure in the table above denotes the average of the three samples and the numbers in parentheses provide the minimum and maximum value obtained in three tests.

The SPM concentration in Kiln 14_FCBTK is around 4 times higher than Kiln 15_FCBTK. The SPM concentrations in the flue gases are dependent on excess air in the kiln and the amount of fuel fed during the sampling time. In Kiln 14_FCBTK, the excess air was around 260% and during sampling around 480 kg of coal was fed in to the kiln, whereas in Kiln 15_FCBTK, excess air was 345% and 300 kg of coal was fed during the sampling time. Due to higher excess air and lower amount of coal feeding in Kiln 15_FCBTK, the SPM concentrations are lower than Kiln 14_FCBTK.

Emission Factors

Pollutant emissions vary according to type of kiln, fuel used and operating conditions. Comparing the emissions across different fuel and operating conditions requires normalization, either to unit of fuel consumed or to unit of energy consumed or to kilograms of fired brick. Emission factors for SPM and SO_2 were derived from emission rate (ER), fuel consumption rate, energy content of the fuel, and production rate.

A summary of the emission factors of various pollutants is presented in Table 4.4.

Table 4.4: Emission factors of pollutants in monitored FCBTK – Before conversion

Pollutants	*g/kg fuel*	*g/MJ*	*g/kg fired brick*
CO	27.07	1.16	1.62
CO_2	2510	112	156
SO_2	6.42	0.27	0.37
SPM	25.16	1.18	1.66

Chapter 5 – Conclusion

The 2011 performance assessment study of brick technologies concluded that zigzag kilns are superior to conventional FCBTKs on energy, environment and financial parameters. In 2012, further monitoring of the two zigzag technologies, natural draught and high draught, was conducted to further expand the energy and emission database and strengthen the case for zigzag kilns.

Overall in 2011 & 2012, five FCBTKs, three natural draught zigzag, and three high draught zigzag kilns were monitored for their energy and environment performance. ***A comprehensive assessment on energy, environment and financial performance parameters of zigzag kilns over the conventional FCBTK technology was conducted, based on the results of monitoring of 2011 & 2012***. Subsequent sections of this chapter will discuss the results of the assessment on each of the three performance indicators.

Energy Performance

A summary of the specific energy consumption for the monitored FCBTK and zigzag kilns is presented in Table 5.1. The average SEC of monitored FCBTK is 1.30 MJ/kg fired brick whereas the average for the zigzag is 1.06 MJ/kg fired brick. ***The monitored results reflect that the zigzag kiln consumes ~20% less energy than a conventional FCBTK.***

Table 5.1: Summary of SEC of monitored FCBTK and Zigzag kiln

Year of monitoring	FCBTK		Zigzag Kiln	
	Kiln Identification No	**Specific energy Consumption (MJ/kg fired brick)**	**Kiln Identification No**	**Specific energy Consumption (MJ/kg fired brick)**
2011	Kiln 1_FCBTK	1.46	Kiln 2_zigzag_ND	1.21
	Kiln 4_FCBTK	1.12		
	Kiln 6_FCBTK	1.10	Kiln 3_zigzag_FD	1.03
2012	Kiln 14_FCBTK	1.41	Kiln 10_ZigzagND	1.02
			Kiln 11_ZigzagND	1.02
	Kiln 15_FCBTK	1.39	Kiln 12_ZigzagFD	1.11
			Kiln 13_ZigzagFD	0.94
Average ± Standard deviation	**1.30 ± 0.17**		**1.06 ± 0.1**	

Environment Performance

The SPM emission standard prescribed by the MoEF for a large category kiln is 750 mg/Nm^3. SPM emissions in the monitored FCBTKs range from 143 - 1255 mg/Nm^3, averaging 570 mg/Nm^3, whereas zigzag kiln emissions range from 31 – 263 mg/Nm^3, averaging 140 mg/Nm^3. Table 5.2 provides details of the SPM emissions in the monitored FCBTK and zigzag kilns. There is no other emission standard prescribed by the MoEF for the brick industry. However, other gaseous pollutants like CO, CO_2, SO_2 and NO_x, particulate emissions like $PM_{2.5}$ and Black Carbon were also measured in the monitored kilns.

A large variation is observed in the SPM emissions of FCBTKs as well as of zigzag kilns. The project team attributes these large variations to two main factors:

a) Operating conditions (mainly type of fuel, fuel feeding rate and excess air)
b) Weather conditions (mainly relative humidity).

Table 5.2: SPM emissions in the monitored FCBTK and zigzag kilns

Year of monitoring	FCBTK		Zigzag Kiln	
	Kiln Identification No	SPM (mg/Nm³)	Kiln Identification No	SPM (mg/Nm³)
2011	Kiln 1_FCBTK	766	Kiln 2_zigzag_ND	31
	Kiln 4_FCBTK	143		
	Kiln 6_FCBTK	370	Kiln 3_zigzag_FD	183
2012	Kiln 14_FCBTK	1255	Kiln 10_ZigzagND	263
			Kiln 11_ZigzagND	255
	Kiln 15_FCBTK	316	Kiln 12_ZigzagFD	71
			Kiln 13_ZigzagFD	36
Average ± Standard deviation	**570 ± 446**		**140 ± 107**	

The effect of operating conditions on SPM emissions has already been explained in chapters 3 and 4. The effect of weather can be illustrated by a comparison of SPM emissions between high draught zigzag kilns monitored in Varanasi in 2011 (Kiln 3_Zigzag_FD) and the ones monitored in Howrah in 2012 (Kiln 12_ZigzagFD & Kiln 13_ZigzagFD). The difference between the climates of Varanasi[7] and Howrah is illustrated in Figure 5.1. During the time of monitoring, i.e. during summer months of March to May, Varanasi has a dry climate (RH mostly <60%) while Howrah has a humid climate (RH mostly >60%). The SPM emission in the high draught zigzag kiln (Kiln 3_Zigzag_FD) operating in dry conditions at Varanasi is 183 mg/Nm³, whereas those operating in humid conditions at Kolkata have SPM emissions of 36 and 71 mg/Nm³.

Emission factors of all the measured pollutants are summarized in table 5.3. ***It can be observed that the emission factors of SPM and elemental carbon in zigzag kilns are ~75% and ~85% less than FCBTK respectively.***

[7] As long-term weather data for Varanasi is not available, the weather data for Allahabad which is the nearest town for which data is available is used; similarly data for Kolkata is used for nearby Howrah.

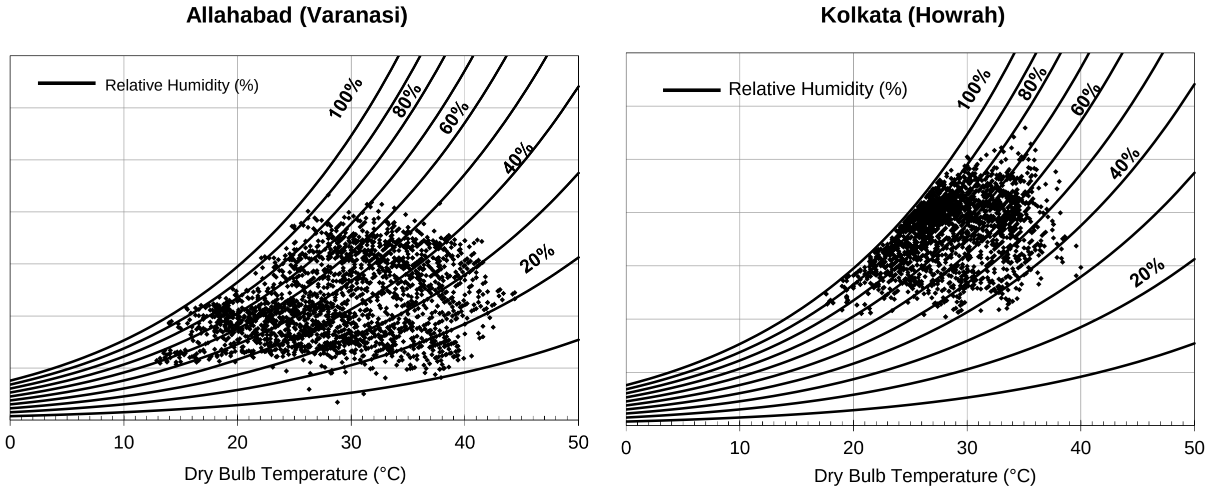


Fig 5.1 Comparison of humidity between Allahabad and Kolkata during March – May[8]

Table 5.3: Summary of emission factors of all the measured pollutants in FCBTK & Zigzag kiln

Pollutants			***FCBTK*** *(g/kg fired brick)*	***Zigzag*** *(g/kg fired brick)*
Flue Gas Pollutants		CO	2.00	0.98
		CO_2	131	103
		SO_2	0.54	0.16
Particulate Matter	**SPM**	Total SPM	1.18	0.27
		$PM_{2.5}$	0.18	0.09
	Aerosol	Elemental Carbon	0.13*	0.02
		Organic Carbon	0.010*	0.008

*Based on the results of monitored FCBTK in 2011. Black carbon monitoring was not carried out on FCBTK monitored in 2012

[8] Based on weather data of Allahabad and Kolkata http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm/region=2_asia_wmo_region_2/country=IND/cname=India

Financial Performance

The financial performance of the zigzag kiln compared to the FCBTK is assessed considering a typical case of a brick enterprise of North India. General data required for conducting the assessments was gathered by interviewing the brick kiln owners operating the respective technologies. Table 5.4 provides details of the financial performance of FCBTK, zigzag natural draught, and zigzag high draught kilns. The capital cost of setting up a zigzag natural draught is equivalent to that of an FCBTK but the zigzag high draught requires a slightly higher capital investment, because of the additional component of a fan. The two significant differences between FCBTK and zigzag kilns are the amount of fuel required and the quality of the bricks produced. Together, these two factors make for a significant improvement in the profitability of zigzag kilns over FCBTKs. Table 5.4 states the assumptions and highlights financial performance assessments.

Table 5.4: Financial performance assessment of Zigzag kiln with FCBTK (Base case)

Type of Kiln	FCBTK (Base Case)	Zigzag Natural Draught	Zigzag High Draught
Type of moulding	Hand	Hand	Hand
Type of brick	Solid	Solid	Solid
Annual Capacity (Million brick/year)	6	6	6
Total Land (Acres)	8	8	8
Capital Cost* (Million Rs)	4.5	4.5	5
Coal Consumption (ton/100,000 brick)	18	13	13
Price of coal @ year 2012 (Rs/ton)	8000	8000	8000
Diesel consumption (Liter/100,000 brick)	Nil	Nil	100
Price of diesel @ year 2012 (Rs/liter)	N/A	N/A	45
Operation Cost (Rs per 1000 bricks)			
Raw Material	400	400	400
Operation	1000	1000	1000
Fuel	1440	1040	1085
Administration & legal	250	250	275
Losses	250	250	250
Total cost/1000 brick	3340	2940	3010
Total operation cost Million Rs/year	20.04	17.64	18.06
Revenue Generated			
Class -I (%)	60%	80%	80%
Class -II (%)	15%	15%	10%
Class -III (%)	25%	5%	10%
Selling Price (as of March 2012)			
Class - I (Rs/brick)	5.0	5.0	5.0
Class - II (Rs/brick)	4.2	4.2	4.2
Class - III (Rs/brick)	2.5	2.5	2.5
Average Selling Price (Rs/brick)	4.26	4.76	4.76
Revenue through sales (Million Rs/year)	25.53	28.53	28.02
Losses and Pilferages (Million Rs/year)	1.5	1.5	1.5
Profit (Million Rs/year)	4.0	9.39	8.46
Operating Profit Margin %	16%	33%	30%

*excluding land cost & working capital

Summary

The performance of the zigzag kiln was found to be superior to the FCBTK in terms of energy, environment and financial parameters. To summarize:

- ***The zigzag kiln consumes ~20% less energy than a conventional FCBTK.***
- ***Emission factors of SPM and elemental carbon in the zigzag kiln are ~75% and ~85% less than in the FCBTK respectively.***
- ***The fuel savings of the zigzag kilns result in a 10 - 12% reduction in the cost of producing bricks, at the same time that an increase in the quality of the bricks produced (that is, a higher percentage of class I bricks) allows for a 10 - 12% increase in the average selling price. Thus, the overall operating profit margin in zigzag kilns is almost double that of FCBTKs.***

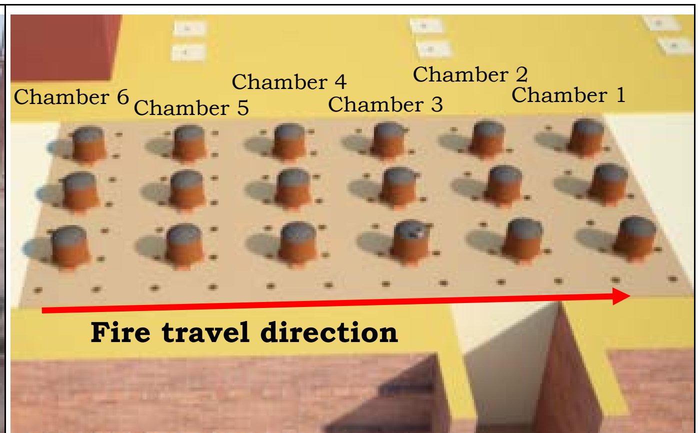
Annexure I – Fuel Analysis of the Monitored Kilns

Table A.1: Fuel Analysis of the monitored kilns

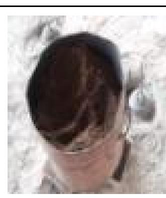
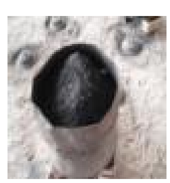
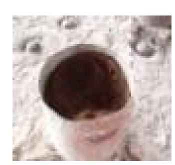
Kiln identification No	Fuel	Ultimate analysis						Proximate analysis				GCV (kcal/kg)
		Ash (%)	Nitrogen (%)	Carbon (%)	Sulphur (%)	Hydrogen (%)	Oxygen (%)	Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	
Kiln 10_ZigzagND	Coal	37.05	0.19	50.22	0.31	2.06	9.71	0.46	37.05	19.22	43.27	**4250**
	Petcoke	1.85	1.0	83.74	3.43	4.31	5.15	0.52	1.85	10.97	86.66	**7854**
	Sawdust	4.7	0.4	45.6	0.5	6.2	42.7	7.30	4.68	68.42	19.59	**4300**
Kiln 11_ZigzagND	Coal	32.83	0.35	53.36	1.14	3.09	5.46	3.77	32.83	22.07	41.33	**4494**
	Mixture of Sawdust & Coal	14.35	0.23	62.7	1.94	3.28	10.68	6.82	14.35	35.71	43.12	**5324**
Kiln 12_ZigzagFD	Coal	28.56	0.18	54.37	0.56	3.35	5.59	7.39	28.56	29.17	34.88	**4717**
Kiln 13_ZigzagFD	Coal	33.16	0.16	50.89	0.29	3.66	1.30	10.54	33.16	23.78	32.52	**4391**
Kiln 14_FCBTK	Coal	32.27	0.36	57.77	2.03	2.68	3.99	0.90	32.27	28.59	38.24	**4867**
Kiln 15_FCBTK	Coal	10.57	0.43	68.2	2.27	3.16	10.84	4.53	10.57	38.75	46.15	**5934**

Annexure II – Best practices in preparation of fuel mix and fuel feeding in Natural Draught Zigzag Kiln

In a zigzag kiln, the firing zone consists of six chambers. The required characteristics of the fuel for each of the chambers are provided in the table below.

	
Six chamber fuel feeding	*Six chambers numbered according to fire travel direction*

Fire travel direction

Chamber No	*Chamber 6*	*Chamber 5*	*Chamber 4*	*Chamber 3*	*Chamber 2*	*Chamber 1*
Temperature	800-845°C	935-1020°C	1035°C	970-1010°C	830-910°C	480-635°C
Fuel Characteristics	High Volatile content and medium calorific value	High Volatile content and high calorific value	Medium Volatile content	Medium Volatile content	High volatile content	Low Ignition temperature
Fuel Used	Mixture of Sawdust & Coal	Coal (High VM)	Coal (Medium VM)	Coal (Medium VM)	Mixture of Sawdust & Coal	Sawdust
						

In the front chambers (chamber 1 and 2) where the temperature is lower, fuel with low ignition temperature i.e. sawdust and a mixture of sawdust and coal is used. Chambers 3, 4 and 5 are the high temperature chambers and therefore coal is used as the fuel. Chamber 6 is the back chamber; it is fed with either coal or a mixture of coal and sawdust.

Fuel feeding is done continuously. A single-man feeding practice is followed. In a typical natural draught zigzag, three sizes of spoons are used. Sawdust requires large spoons because of its low density. Medium spoons are used for the mixture of sawdust and coal and small spoons are used for coal. Usually the fire travels 18 ft (3 chambers) in 24 hours and hence the shunts are shifted only once in 24 hours.

Single man feeding

Large, Medium & Small size spoons

Annexure III – Price trend of Coal

Brick kilns generally purchase coal from the retail market for firing. Coal prices have increased sharply in the last decade. The data collected from brick owners about the purchase price of coal show that, in the last eleven years, coal prices have increased 3-4 times. While, in 2001, coal prices ranged from Rs 950 – 4000 per ton, they rose to Rs 5000 – 13000 per ton in 2012.

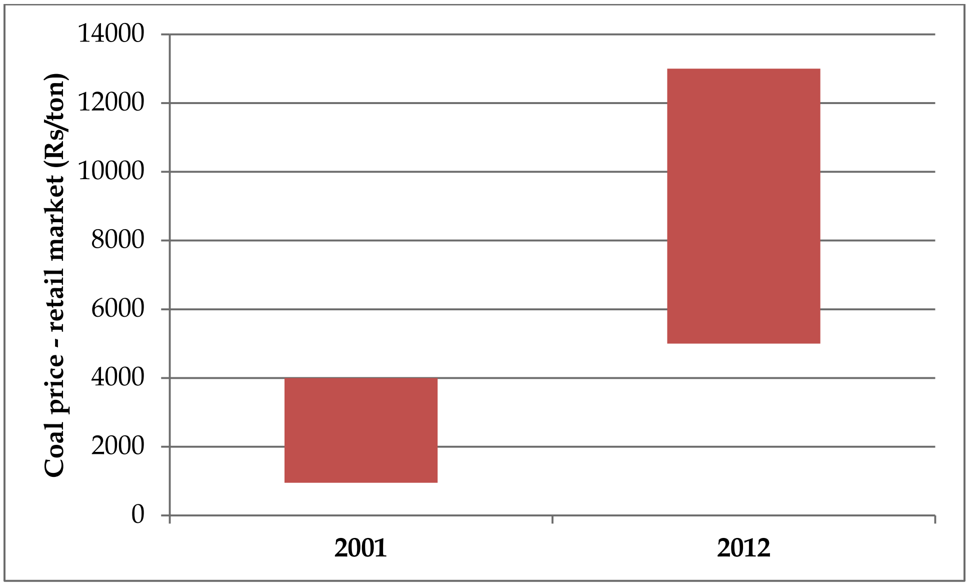


Figure A.3: Price trend of coal 2001 - 2012