Brick Kilns Performance Assessment

A Roadmap for Cleaner Brick Production in India

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Abstract

Introduction

India is the second largest producer of clay fired bricks, accounting for more than 10 percent of global production. India is estimated to have more than 100,000 brick kilns, producing about 150-200 billion bricks annually, employing about 10 million workers and consuming about 25 million tons of coal annually. India's brick sector is characterized by traditional firing technologies; environmental pollution; reliance on manual labour and low mechanization rate; dominance of small-scale brick kilns with limited financial, technical and managerial capacity; dominance of single raw material (clay) and product (solid clay brick); and lack of institutional capacity for the development of the sector.

In a first of its kind detailed performance assessment, the principal investigating organizations – Greentech Knowledge Solutions Pvt. Ltd., Enzen Global Solutions Pvt Ltd, and University of Illinois – examined the energy, environmental and financial performance and brick maker input for five main brick firing technologies during 2011:

- Fixed Chimney Bull's Trench Kiln (FCBTK - India)
- Zig-zag Kiln (natural and forced draft - India)
- Vertical Shaft Brick Kiln (VSBK – India and Vietnam)
- Down-Draught Kiln (DDK- India)
- Tunnel Kiln (Vietnam)

This study is one of two research components aimed at developing strategies for the introduction and promotion of cleaner walling materials in India.

Results

Energy performance

A large variation was observed in the energy performance of the monitored kilns. DDK (least efficient kiln) consumes four times more energy compared to VSBK (most efficient kiln). The Vietnamese VSBK kiln had the lowest thermal energy requirement, followed by the

Indian VSBK, zig-zag kiln and FCBTKs. The tunnel kiln, which incorporates a dryer, had higher energy use.

Environmental performance

- VSBK had the lowest emissions of Suspended Particulate Matter (SPM) followed by zig-zag kiln, tunnel kiln, FCBTK and down-draught kiln. VSBK also had the lowest Particulate Matter ($PM_{2.5}$) emissions.
- Of the gaseous pollutants measured, variations in the SO_2 concentration were observed, with the lowest levels in the biomass-fueled DDK. This is because sulphur dioxide (SO_2) is dependent on sulphur in coal. Oxides of nitrogen (NO_x) emissions were generally below the detectable levels. The natural draught zig-zag kiln had the lowest carbon monoxide (CO) emissions. CO_2 emissions show similar ranking hierarchy as for energy.
- Both tunnel and VSBK had very low black carbon (BC) emissions, followed by zig-zag. FCBTKs and DDK had the highest BC emissions.

Financial performance

Among cleaner kiln options, zig-zag kilns require lower investments and have shorter pay-back periods. Zig-zag kilns offer easy integration with the existing production process of FCBTKs. The tunnel kiln technology is suitable for large-scale production, requires large capital investment (10-20 times more compared to a zig-zag), and has a long pay-back period. VSBK, being modular in nature, can be used for small- as well as medium-scale production, but has problems of low productivity and poor fired brick quality with certain clays. It is suitable for firing only solid bricks and has a longer pay-back period compared to zig-zag kilns.

Production and selling price vary significantly by regions of the country; profitability of brick enterprises is higher in southern and western India.

Brick sector input

Major issues identified by brick makers that are likely to shape future growth of the brick-making industry include:

- Shortage of labour

- Increase in fuel cost
- Competition from other walling materials
- Multiple barriers to adopting semi-mechanized technologies

The way forward

The study recommends that the efforts to propagate cleaner brick kiln technologies over the next decade should focus on these specific technical measures:

- Adoption of cleaner kiln technologies (principally zig-zag and VSBK)
- Promotion of internal fuel in brick making by mechanizing the brick making process
- Promotion of mechanized coal stoking systems
- Diversifying products (e.g. production of hollow and perforated bricks)
- Promotion of modern renewable energy technologies in brick making

Implementation of these measures can result in annual coal savings of the order of 2.5 to 5.0 million tons/year in brick firing operation and associated CO_2 emission reduction of the order of 4.5 to 9.0 million tons/year; significant reduction in air pollution (including SPM, black carbon, CO); improvement in profitability of brick enterprises; and improvement of working conditions for millions of workers employed in brick kilns.

Implementation of these measures requires a concerted effort by the government of India and the brick industry. On the policy and regulatory front, the government of India may wish to refer to the policies and regulations framed by some of the other developing countries in Asia. Among these, of particular interest are: the sustainable building material policy of Vietnam to promote resource-efficient brick production and the recent environment regulation of Bangladesh proposing a time-bound phasing out of FCBTK technology.

The next immediate steps proposed toward achieving these recommendations include environmental regulation to phase out older, inefficient technologies like FCBTKs, the predominant technology in use today, and to introduce newer cleaner brick firing technologies; and undertaking an Indian brick development programme to support financing, technology transfer, and skill development activities.

Executive Summary

I. Background

The growth in India's economy and population, coupled with urbanization, has resulted in an increasing demand for residential, commercial, industrial, and public buildings as well as other physical infrastructure. Building construction in India is estimated to grow at a rate of 6.6% per year between 2005 and 2030[1]. The building stock is expected to multiply five times during this period, resulting in a very large increased demand for building materials.

Solid fired clay bricks are among the most widely used building materials in the country. India is the second largest producer of clay fired bricks, accounting for more than 10 percent of global production[2]. India is estimated to have more than 100,000 brick kilns, producing about 150-200 billion bricks annually[3].

Brick making in India is characterised by the following features:

- Brick making is a small-scale, traditional industry[4]. Almost all brick kilns are located in the rural and peri-urban areas. It is common to find large brick making clusters located around the towns and cities, which are the large demand centres for bricks. Some of these clusters have up to several hundred kilns.
- The brick production process is based on manual labour, and brick kilns are estimated to employ around 10 million workers. Brick production is a seasonal vocation, as the brick kilns do not operate during the rainy season. Most of the workers migrate with their families from backward and poor regions of the country. Families, including young children, work in harsh, low paying conditions. There is typically a lack of basic facilities, such as access to clean drinking water and sanitation.

[1] McKinsey & Company, 2009. Environmental and Energy Sustainability: An Approach for India. McKinsey & Company, Mumbai, India.
[2] Maithel, Sameer, 2003. Energy Utilization in Brick Kilns. PhD Thesis. Energy Systems Engineering, Indian Institute of Technology, Bombay.
[3] No agency in India keeps records of brick production. The numbers referenced here on brick kilns, total production and coal use are estimates that are often quoted by brick industry associations and experts.
[4] A traditional industry is defined as "an activity, which produces marketable products, using locally available raw material and skills and indigenous technology."

- Bricks are fired to a temperature of 700 -1100 ^{o}C, requiring a large amount of fuel for the firing operation. Brick kilns are estimated to consume roughly 25 million tonnes of coal per year, thus making them among the highest industrial consumers of coal in the country.
- A rapid increase in brick production and the clustering of brick kilns have given rise to environmental concerns:
    - Combustion of coal and other biomass fuels in brick kilns results in the emissions of particulate matter (PM), including black carbon (BC), sulphur dioxide (SO_2), oxides of nitrogen (NO_x), and carbon monoxide (CO). The emission of these pollutants has an adverse effect on the health of workers and vegetation around the kilns. In recent years, the higher cost and a shortage of good quality bituminous coal have resulted in an increased use of high-ash, high-sulphur coal, as well as in the use of industrial wastes and loose biomass fuels in brick kilns. All of these have resulted in new air emission challenges.
    - The use of large quantities of coal in brick kilns contributes significantly to emissions of carbon dioxide (CO_2).
    - Good quality agriculture topsoil is used for brick production. Areas having large concentration of brick kilns suffer from land degradation.
- Apart from the environmental concerns, the industry faces other challenges, including:
    - A shortage of workers, resulting in an increase in wages and disruption of production.
    - A rapid increase in the fuel cost and limited availability of good quality coal.
    - A shortage of good quality clay in some regions and an inability of brick makers to adopt technologies to utilize alternate raw material.
    - Increased competition from other walling materials, such as concrete blocks.
    - New demands resulting from trend towards high-rise construction.

Despite its significance in the construction sector, its importance in the livelihoods of the poor, its large consumption of coal, and its impact on health and environment,, the brick making sector has seen very few development interventions/programmes aimed at improving the industry. Initiatives that have been undertaken are listed in Table 1. The most significant government interventions were the environmental regulations enacted in the 1990's, which resulted in upgradation in the firing technology from moving chimney bull trench kilns to fixed chimney bull trench kilns.

Table 1. Development Programmes/Initiatives in the Indian Brick Industry

	Agency/ Programme	Type of Intervention	Impact
1970's	Central Building Research Institute, Government of India	**Technical**: Introduction of zig-zag firing technology and semi-mechanization process	• Successful in seeding the technologies. • No large-scale adoption.
1990's	Central Pollution Control Board/ Ministry of Environment and Forest (MoEF)	**Regulation:** Air emission regulation for brick kilns	• Large-scale shift (around 30,000 kilns) from moving chimney Bull's Trench Kiln technology to more efficient and less polluting fixed chimney Bull's Trench Kiln technology.
1995-2004	Swiss Agency for Development and Cooperation	**Technical**: Introduction of Vertical Shaft Brick Kiln (VSBK) Technology	• Successful in seeding the technology. • No large-scale adoption.
2009-ongoing	United Nations Development Program - Global Environment Facility (UNDP-GEF)	**Technical**: Introduction of hollow bricks and other resource-efficient bricks.	• Not known

II. Objective

The objective of the study was to carry out a comprehensive assessment of brick making technologies to gain a deeper understanding of the energy utilization and emissions from current technologies as well as technologies that offer the promise of cleaner brick production.

To address these objectives, Greentech Knowledge Solutions Pvt. Ltd (GKS), Enzen Global Solutions Pvt Ltd (Enzen) and University of Illinois (U of I), with Entec AG (Entec), Hanoi Center for Environmental and Natural Resources Monitoring and Analysis (CENMA), and the Clean Air Task Force (CATF) conducted a detailed monitoring study from February to May 2011 examining five brick kiln technologies: two traditional brick kiln technologies widely prevalent in India – fixed chimney Bull's Trench Kilns (BTK) and Down Draught Kilns and three relatively newer technologies – Vertical Shaft Brick Kilns (VSBK), Zig-Zag Kilns, and Tunnel Kilns. Nine individual brick kilns were monitored for the following parameters:

- Energy performance: Specific Energy Consumption (SEC)
- Environment performance: Emission measurements for particulate matter (PM), black carbon (BC), and selected gaseous pollutants.
- Financial performance: Capital investment, cost of production, pay-back period.

The study also collected data on the current status of the brick industry in the brick making clusters visited by the project team.

The assessment of the technologies and the industry were used to make recommendations for strategies promoting cleaner brick production technologies. The results were also used as inputs in a parallel study[5] undertaken to assess multiple types of walling materials, including clay fired bricks.

III. Methodology

Details of the monitored kilns are provided in Table 2. Of the nine kilns, seven are located in India, and two – a tunnel kiln and a modified VSBK – in Vietnam, as neither is in operation in India. Both these kilns rely to a large extent on internal fuel[6] and were expected to have a lower environmental footprint, especially in terms of emissions. The selection of Indian kilns was intended to cover major kiln types and fuel combinations prevalent in the country.

Table 3 provides the list of technical parameters that were measured. In addition, fuel and clay samples were collected and analyzed from each of the monitored kilns. Business and process related information were collected through personal interviews with kiln owners.

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[5] For details please refer to the report "Strategies for Cleaner Walling Material in India" prepared by Enzen Global Solutions Pvt Ltd and Greentech Knowledge Solutions Pvt Ltd as a part of the project funded by Shakti Sustainable Energy Foundation in November 2011.

[6] The practice of internal fuel is widely prevalent in China – the largest producer of brick in the world, accounting for almost 50% of the production – and Vietnam. In this process, powdered coal is added during the brick forming operation and serves as a fuel during firing.

Location of the monitored kilns is shown in Figure 1.

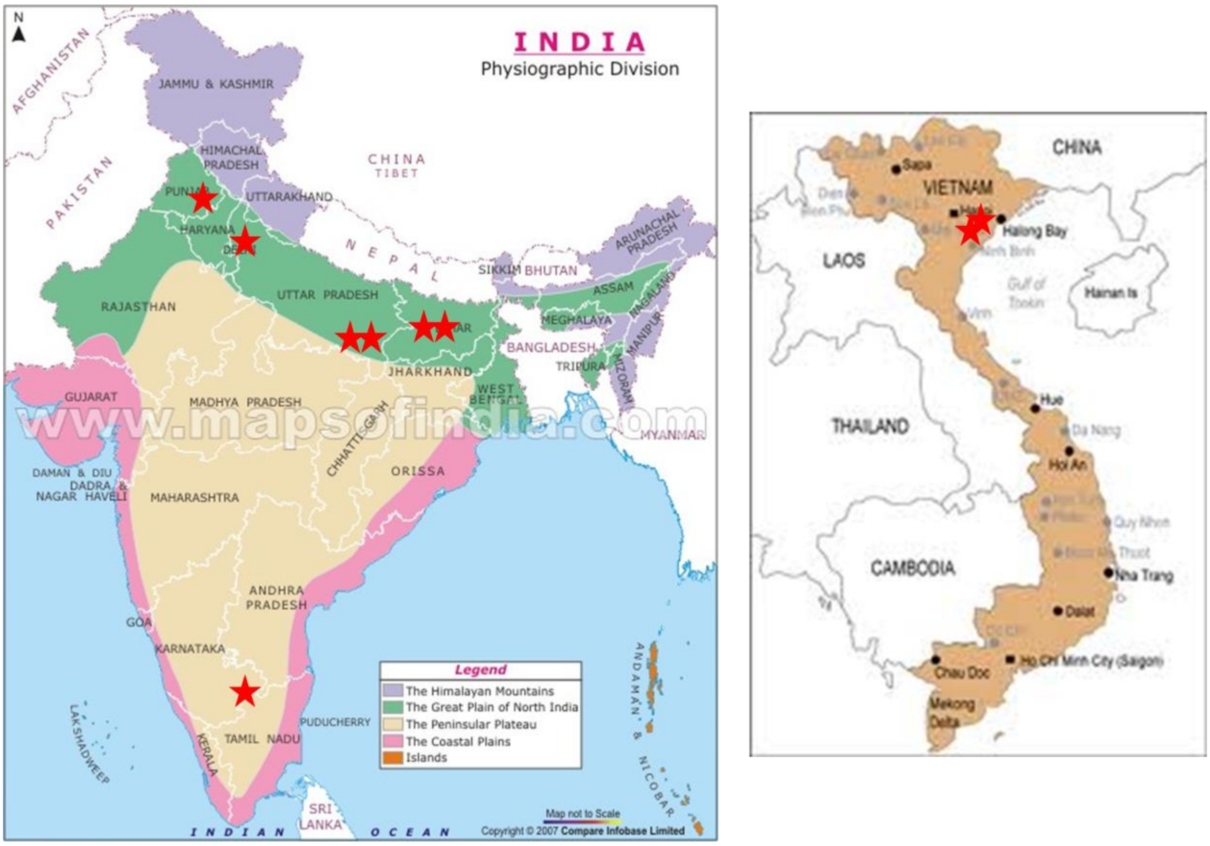

Figure 1: Location of Monitored Kilns in India & Vietnam

Table 2: Information on Monitored Brick Kilns

Type of kiln	Number of kilns monitored	Features of Monitored kilns			Remarks
		Place	Kiln size	Fuel used	
Fixed Chimney Bull's Trench Kiln (FCBTK)	3	Garh Mukteshwar (U.P)	Large	Coal (High volatile & high calorific value); rubber tyres; wood logs	➢ Accounts for more than 70% of total brick production in India. ➢ More than 30,000 FCBTKs currently operational in India. ➢ Emissions from a FCBTK are significantly affected by the fuel used and operating practice.
		Ludhiana (Punjab)	Large	Coal (High volatile & high calorific value)	
		Arah (Bihar)	Medium	Coal (Low volatile and medium calorific value)	
Zig-zag	2	Varanasi (Natural Draft)	Large	Coal (Two types) Biomass (Sawdust)	➢ Improved firing technology as compared to FCBTK in terms of environment emissions & energy consumption. ➢ Traditionally uses a fan for creating draft. ➢ Recently natural draft (using a chimney) has been successfully used in zig-zag kilns.
		Varanasi (Forced Draft)	Large	Coal (Mixture of two types of coal) Mixture of high volatile & high calorific value and low volatile & medium calorific value	
Vertical Shaft Brick Kiln (VSBK)	2	Arah (Bihar)	Small	Coal (Two types) ○ Steam coal ○ Coal Slurry (Internal)	➢ An estimated 100 VSBKs have been constructed in India. ➢ Considered most efficient kiln technology in terms of energy use. ➢ Improved VSBK technology is extensively used in Vietnam ➢ More than 300 VSBK enterprises in Vietnam.
		Hung Yen province (Vietnam)	Medium	Coal (Two types) ○ Coal powder (Internal) ○ Coal Slurry (Internal)	
Down-Draught Kiln (DDK)	1	Malur (Karnataka)	Small	Biomass ○ Fresh eucalyptus branches	➢ Improved version of a clamp kiln ➢ Popular in Malur cluster in Karnataka ➢ Malur cluster has roughly 450 DDK.
Tunnel kiln	1	Nam Dinh province (Vietnam)	Large	Coal ○ Coal powder	➢ Tunnel kiln is the main technology for firing bricks in developed countries, as well as several developing countries e.g. China, Vietnam ➢ India does not have a well-functioning tunnel kiln for clay brick firing; Vietnam has more than 500 operational tunnel kilns

Table 3: List of Technical Measurements

Process variable	Principle of measurement or analysis	Sample Location	Type *	Responsible organization**
Fuel feeding rate	Weighing of fuel and time measurement	Fuel	P	GKSPL
Temperature of flue gas	Thermocouple	Stack/ flue duct	R	GKSPL/ Enzen
Temperature of bricks & surfaces	K-type Thermocouple/ Infrared thermometer	Inside the kiln/ outside surface of kiln	P	GKSPL
Stack flow***	Pitot tube	Stack	P	Enzen
O_2	Electrochemical	Stack/flue duct	R	GKSPL/CENMA
CO_2	Inferred from O_2	Stack/ flue duct	R	GKSPL/CENMA
	Infrared absorption	Diluted exhaust	R	U of I
CO	Electrochemical	Stack/ flue duct	R	GKSPL/CENMA
	Electrochemical	Diluted exhaust	R	U of I
SO_2	Barium-Thorin titrimetric method	Stack	I	Enzen/CENMA
NO_x	Gaseous sampling followed by colorimetry using phenoldisulfonic acid	Stack	I	Enzen
Suspended Particulate Matter (SPM)	Gravimetric	Stack	I	Enzen
HF	Electric potential methods using ion selective membrane electrode	Stack	R	CENMA
PM2.5	Gravimetric	Diluted exhaust	I	U of I
Elemental and organic carbon	Thermal-optical analysis	Diluted exhaust	I	U of I
Light absorption	Filter transmittance	Diluted exhaust	R	U of I
Light scattering	Scattering sensor	Diluted exhaust	R	U of I
Size-resolved carbon particles	Cascade impactor plus thermal-optical analysis	Diluted exhaust	I	U of I

Notes:

* Average of single-point observations (P); Integrated sample (I) taken over many minutes; Real-time observations (R) averaged for presentation.

** CENMA: Hanoi Centre for Environmental and Natural Resources Monitoring and Analysis, Vietnam. GKSPL: Greentech Knowledge Solutions Pvt. Ltd. U of I: University of Illinois.

*** 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. For low velocity (less than 3m/s) differential manometer was used.

IV. Energy & Environment Performance

Energy Performance

The Specific Energy Consumption (SEC) is the amount of thermal energy required to fire 1 kg of brick. Lower SEC signifies efficient operation of the kiln. The SEC for the monitored kilns are presented in Table 4. The improved VSBK kiln from Vietnam had the lowest SEC requirement at 0.54 MJ/kg of fired brick, followed by the zig-zag kilns (1.12 MJ/kg of fired brick) and FCBTKs (1.22 MJ/kg of fired brick). The tunnel kiln, which incorporates a dryer, had a higher SEC of 1.47 MJ/kg of fired brick. The DDK had the highest SEC (2.9 MJ/kg of fired brick), and it consumed 4-5 times more energy than a VSBK.

Table 4: SEC of the Monitored Kilns

Firing Technology	Process	SEC-Thermal energy (MJ/kg fired brick)*	Electricity/ mechanical power used in the production process **
FCBTK	Manual moulding & sun-drying	1.22	• None
Zig-zag	Manual moulding & sun-drying	1.12	• None in case of natural draught • 36 lt diesel/day (SEC: 0.015 MJ of primary energy/kg of fired brick primary energy) for operating the fan in the forced draught kiln
VSBK	Indian VSBK: Manual moulding & sun-drying Vietnam: Extruder moulding & shade-drying	0.95 0.54	• Indian VSBK: 10 lt diesel/day (SEC: 0.03 MJ of primary energy/kg of fired brick) for operating the conveyor (for 1-shaft operation). • Vietnamese VSBK: 15 kWh/1000 bricks (SEC: 0.1 MJ of primary energy/kg of fired brick) for operating the extruder, lifting of bricks, operation of unloading mechanism.
Down draft	Manual moulding & shade drying	2.9	• None
Tunnel– Vietnam – Internal Fuel	Extruder moulding, shade-drying, & tunnel-drying	1.47 ***	• 40 kWh/1000 bricks (SEC: 0.3 MJ of primary energy/kg of fired brick) for operating the extruder, tunnel dryer, tunnel kiln, etc.

Notes:
*The SEC values for FCBTK and zig-zag are a simple average of the three FCBTKs and two zig-zag kilns respectively; for all the other kiln types, the data is for a single kiln.
**Energy/fuel used for producing heat for firing and drying processes.
*** The kiln and the dryer are interconnected. The SEC also includes the energy required in the tunnel dryer.

Environment Performance

The environmental performance results are presented below.

Suspended Particulate Matter

Suspended Particulate Matter (SPM) is a term used for airborne particles of diameter less than 100 µm. The emission factor in terms of g/kg of fired brick for SPM is presented in Table 5. VSBK had the lowest SPM emission factor, followed by zig-zag kiln, tunnel kiln, FCBTK and DDK, respectively. Due to the addition of powdered fuel with the clay and steady-state combustion conditions, VSBK and tunnel kilns were among the lowest emitters of SPM. Better combustion conditions resulted in lower SPM in properly operated zig-zag kilns compared to FCBTK

Particulate Matter ($PM_{2.5}$)

Emission norms in India do not address $PM_{2.5}$ specifically, but it is frequently monitored because of its environmental and health effects. Fine particulate matter (diameters less than 2.5 µm) can penetrate more deeply into lungs than larger particles. It also has a longer atmospheric lifetime and a disproportionately greater effect on visibility and climate, relative to larger particles. VSBK technology had the lowest $PM_{2.5}$ emissions, and DDK had the highest $PM_{2.5}$ emissions.

Gaseous Pollutants

Kilns were monitored for sulphur dioxide (SO_2), oxides of nitrogen (NO_x) carbon monoxide (CO) emissions and carbon dioxide (CO_2). Table 5 provides the emission factors for various pollutants monitored in the study, normalized to grams of pollutant/kg of fired brick.

SO_2 emissions stem from the sulphur content of fuel; therefore significant variations in the SO_2 concentration were observed in the monitored kilns. SO_2 concentration was lowest in the down draft kiln, which uses biomass fuel with negligible sulphur content.

NO_x emissions were generally very low and below the detectable levels.

Emissions of carbon monoxide (CO) are an indication of incomplete combustion of fuel. Zig-zag kilns had the lowest CO emissions. Within the zig-zag technology, the monitored natural draught zig-zag kiln had much lower CO emissions as compared to the monitored forced draught zig-zag kiln. Good fuel-feeding and operating practices support this improvement.

CO_2 emissions are directly related to the SEC and carbon content of fuels being used in the kiln. Hence the CO_2 emissions show a similar ranking hierarchy to SEC.

Table 5: Emission Factors for the Monitored Kilns

Technology	Emission Factors (g/kg of fired brick)				
	SPM	PM2.5	SO_2	CO	CO_2
FCBTK	0.86	0.18	0.66	2.25	115
Zig-zag	0.26	0.13	0.32	1.47	103
VSBK	0.11	0.09	0.54	1.84	70
DDK	1.56	0.97	n.d	5.78	282
Tunnel	0.31	0.18	0.72	2.45	166

Notes:

The emission factors for FCBTK, zig-zag and VSBK are a simple average of the three FCBTKs, two zig-zag kilns and two VSBK kilns respectively; for all the other kiln types, the data is for a single kiln.

n.d. = not detectable (measurement below detection limit)

Black and Organic Carbon

Black carbon (BC) is a combustion product predominantly composed of strongly bonded graphitic-like carbon rings. This composition causes black carbon to be thermally stable at high temperatures and to strongly absorb visible light, causing warming. Organic carbon (OC) comprises all carbon species that are neither black nor carbonate carbon.

This study represents the first-ever measurements of BC from brick kilns, despite the fact that brick kiln upgrades have been targeted as a strategy to reduce BC. In November 2011, the United Nations Environmental Program in its assessment, *Near-term Climate Protection and Clean Air Benefits: **Actions for Controlling Short-Lived Climate Forcers,*** proposed replacing traditional brick kilns with more efficient ones, particularly VSBKs, as a measure to reduce BC.

Two methods were used in this study to measure light-absorbing carbon.

1. Thermo-optical analysis measured "elemental carbon" which is stable at high temperatures and is considered a synonym of BC. This analysis also measured OC.
2. Particle light absorption measured in units of square meters (m^2), together with scattering measurements, can be used to calculate the effect of particles on visibility and radiative transfer. The single scattering albedo[7] is a measure of particle lightness, with pure BC having a value of about 0.22, polluted urban air about 0.7, and pure white particles 1.0.

Results of elemental and organic carbon measurements; absorption and single scattering albedo, are shown in Table 6.

Table 6: Results of Thermo-optical and Light Absorption/Scattering measurements

Technology	Elemental Carbon (g/kg fired brick)	Organic Carbon (g/kg fired brick)	Absorption (m^2/kg fired brick) *	Single Scattering Albedo *
FCBTK	0.13	0.01	0.22	0.67
Zig-zag	0.04	0.02	0.16	0.64 **
VSBK	0.002	0.06	0.06	0.77
DDK	0.29	0.09	1.13	3.5
Tunnel	n.d.	n.d.	n.d.	0.13

Notes:

The results for FCBTK, zig-zag are VSBK are a simple average of the three FCBTKs, two zig-zag kilns and two VSBK kilns respectively; for all the other kiln types, the data is for a single kiln.
n.d. = not detectable (measurement below detection limit)
*At red wavelength (660 nm)
** Excludes natural draught zig-zag kiln, where scattering measurements were spurious and may be affected by measurement error, as the readings are much higher than expected for the measured levels of particulate matter.

Both tunnel and VSBK had very low BC emissions, as indicated by low values for elemental carbon and high values for single scattering albedo. In the tunnel kiln, the BC emissions were

[7] Single scattering albedo – the ratio of scattering efficiency to total extinction efficiency (which is also termed "attenuance", a sum of scattering and absorption). Most often it is defined for small-particle scattering of electromagnetic waves. A single scattering albedo of unity implies that all particle extinction is due to scattering; conversely, a single scattering albedo of zero implies that all extinction is due to absorption. (http://en.wikipedia.org/wiki/Single_scattering_albedo)

below the detection level. The low BC emissions in the tunnel and the VSBK can be attributed to the steady-state combustion conditions in these kilns and the use of internal fuel. FCBTKs and DDK had the highest BC emissions. In both of these kilns, fuel feeding is intermittent, and combustion conditions show large variation with time. The results show that large BC emissions take place around fuel feeding intervals. Improved combustion conditions in zig-zag kilns, in the form of continuous feeding of fuel in small quantities and better mixing of fuel and air, lowered BC emissions compared to FCBTKs.

The BC emission factors of brick kilns may also be compared with other BC emitting sources. Figure 2 compares BC emission factors from this study, with emissions from other types of coal combustion and from mobile sources.

Emissions from coal combustion can vary widely depending on the quality of the combustion. The figure shows that well-operating power plants, with emission controls, have very low emissions BC, industrial stoker boilers have detectable emissions, and heating stoves – which have no control of emissions or airflow within the stove – have quite high emissions. (Heating stoves are not used in India.) The difference in emissions is not caused by the fuel, but rather is attributable to the management of the fuel-air mixing and proper handling of the exhaust products. Emissions of the kilns measured in this project fall between those of industrial boilers and heating stoves, as could be expected based on the combustion management.

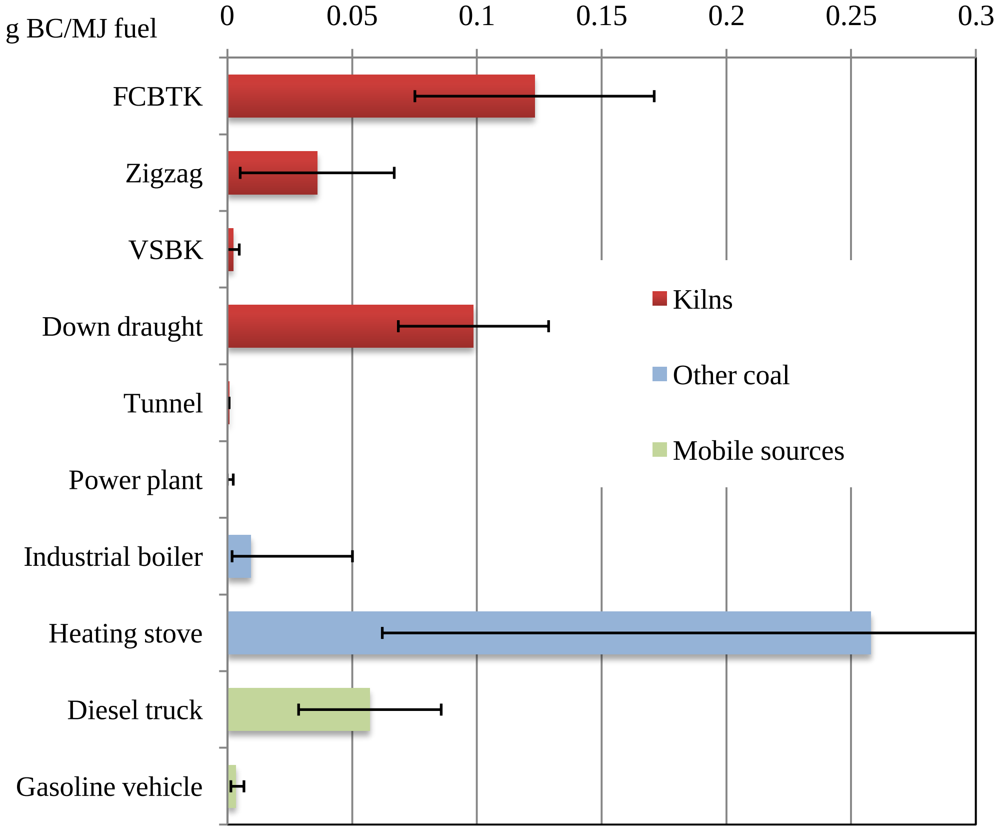

Figure 2: Comparison of BC Emitted from Kilns in this Study to Other Coal Sources and Mobile Sources[8].

V. Financial Performance & Quality of Fired Bricks

Capital Cost

A comparison of the financial performance of various technologies is presented in Table 7. FCBTK and zig-zag kilns require lower investments and have shorter pay-back periods. The tunnel kiln technology is suitable for large-scale production and requires large capital investment (10-20 times more than other kiln types). VSBK, being modular in nature, can be used for small- as well as medium-scale production. It has a longer pay-back period than FCBTK and zig-zag kilns.

[8] Values presented for mobile sources are approximate emission rates for unregulated vehicles.

Table 7: Comparison of Kiln Technologies (Financial Performance)

Technology	Features	Approx. Capital Cost* (US $)	Production Capacity (million bricks/year)	Typical simple pay-back period under Indian conditions
FCBTK	• Chimney height 27 to 30 m; kiln circuit capacity 0.5 to 1 million bricks.	40,000 - 60,000	4-8	< 2 years
Zig-zag	• Natural draft kiln with a chimney height of 30 m.	40,000 - 60,000	4-6	< 2 years
	• Kiln of 24-36 chambers; induced draft fan operated by a 15-20 hp motor; valve system in the flue ducts	60,000 - 80,000	4-6	< 2 years
VSBK	• Two-shaft Indian VSBK with a conveyor system for lifting the brick.	60,000	1.0 -1.5	2-3 years
	• Four-shaft Vietnamese VSBK: higher height; electrical lift; extruder for making internal fuel bricks; drying shade; hydraulic jack and fork-lift truck for unloading bricks	400,000	3.5-4.5	3-4 years
Tunnel	• Vietnamese tunnel kiln plant; daily production capacity: 40,000 to 50,000 bricks per day; tunnel kiln, tunnel dryer, drying shed, extruder for firing bricks	1-2 million	15-20	> 3 years

Note: * excluding the cost of land; simple pay-back assuming 100% capacity utilization

Production Cost and Selling Price

Data was collected on production cost and revenue. Typical production and selling price of bricks for different regions in the country are shown in Table 8. The profitability of brick enterprises is higher in southern and western India, due to the higher selling price of bricks.

Table 8: Typical Production and Selling Price Data

Indo Gangetic Plains (Punjab, Haryana, UP, Bihar)	Production cost: Rs 2.00- 2.50 / brick	Selling Price: Rs 3.00 – 4.00/ brick
Southern and western India	Production cost: Rs 2.50 -3.50/ brick	Selling Price: Rs 4.50 – 8.00/ brick

Figure 3 shows the typical break-up of production cost for a FCBTK in Indo-Gangetic plains and illustrates that fuel is the largest cost component followed by operations (mainly manpower) cost. The production cost of natural draught zig-zag kiln is 15% lower than that of FCBTK.

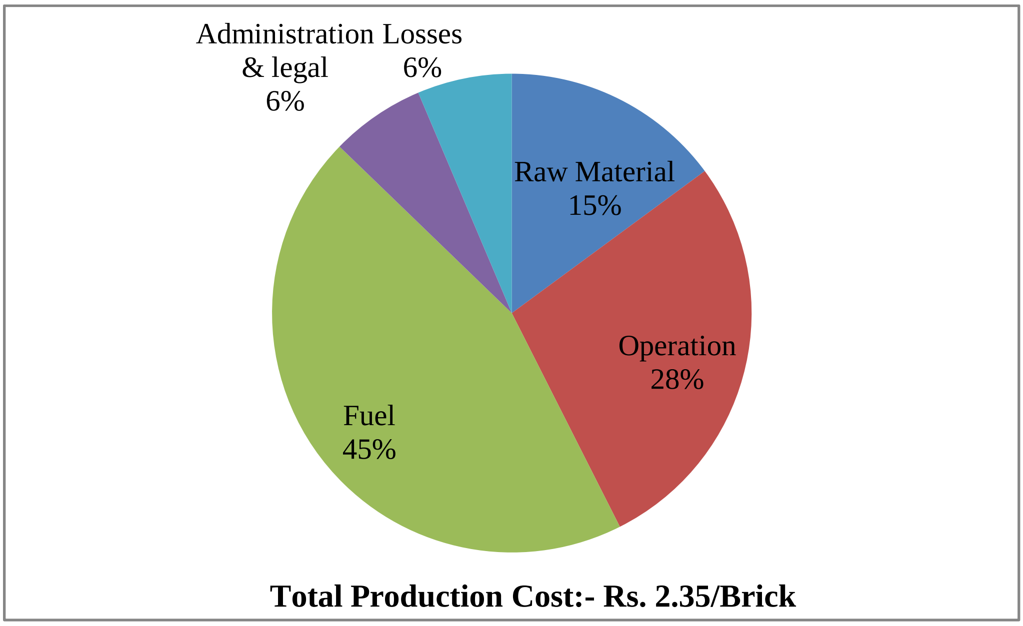

Figure 3: Average Production Cost Break-down Data for Monitored FCBTKs in Indo-Gangetic Region

Quality of Fired Bricks

The quality of fired brick depends both on the quality of green bricks as well as on the firing process.

The tunnel kiln is ranked best in terms of fired brick quality. Factors contributing to this improved quality include:

1. Fine control over the drying and firing process
2. The ability to achieve uniform temperature distribution in the firing zone

3. Mechanization of brick production.

Both the VSBKs had problems with brick quality, with the quality lower in the Indian VSBK. This is due to a variety of factors:

1. High static and dynamic load on the lower brick stacking in the shaft results in damage to the bricks.
2. Fast heating up and cooling down of bricks in the kiln can cause firing and cooling cracks in the bricks.
3. Some damage is also caused by excessive handling of bricks during lift-up to the kiln top and in the loading process.

Due to the lower density and lower compressive strength of hand-moulded bricks, the problem in brick quality are more pronounced when hand-moulded bricks are fired in VSBK. From the experience of Vietnam, it was evident that the firing of machine-moulded bricks results in improvement in quality.

The FCBTK and zig-zag have slow heating and cooling rates that generally do not cause the formation of firing and cooling cracks. The FCBTK does not have a uniform temperature distribution in the firing zone and hence only 60-70% of the bricks are properly fired; the remaining production is either under- or over-fired. The zig-zag has a more uniform temperature distribution, and hence 80-90% of the bricks are properly fired.

VI. Brick Sector Scenario

Input from prominent brick makers was sought via interviews during monitoring and two stakeholder workshops. The main objective of these interviews/interactions was to get better understanding of the current status of brick making and future trends.

Main findings are as follows:

Shortage of workers: The brick industry is facing a severe worker shortage, which resulted in a decrease in brick production of up to 30% in several important brick making clusters during 2011. The worker shortage was first noticed in 2007 with the first implementation phase of the Mahatma Gandhi National Rural Employment Guarantee Act[9]. Most of the brick kiln owners want to reduce dependency on workers through semi-mechanization[10] of the production process.

Rapid increase in the fuel cost: Fuel prices have risen 100-175% over the past five years. Management of fuel cost is an important consideration for brick makers, resulting in shifts to cheaper fuels. The majority of the brick makers do not have practical knowledge and skills to adopt energy conservation measures. There are no intermediaries to help brick makers implement energy conservation measures.

***Competition from other walling materials*:** Clay brick makers are facing competition from other walling materials. This is particularly true in southern and western India.

Barriers in adoption of new technologies for semi-mechanization

- The majority (>90%) of brick kilns in the Indo-Gangetic plains are located on leased land. This is expected to be a large barrier in making investments in the construction of new facilities and machinery. A shift to new technologies would require investment in land or renegotiating lease agreements. Due to the high price of land around cities, brick enterprises are likely to relocate further from towns and cities.
- Limited or no access to grid-electricity: Semi-mechanization of the brick production process requires electricity. Most of the existing brick kilns either do not have access to grid electricity or are located on rural electricity feeders, which are prone to power outages and poor power quality. This is a significant barrier in adopting new technologies. Adopting new technologies requires investments in captive power generation facilities by brick makers.
- Low profit margins for machine-moulded bricks: Machine-moulded bricks have a higher production cost and face stiff competition from lower-priced manually produced bricks.
- Financing: The capital investment in any robust and reliable semi-mechanization brick making package ranges from Rs 10-200 million. The majority of brick makers have little or no access to bank credit.

[9] The Mahatma Gandhi National Rural Employment Guarantee Act (MNREGA) aims at enhancing the livelihood and security of people in rural areas by guaranteeing a hundred days of wage-employment in a financial year to a rural household whose adult members volunteer to do unskilled manual work.

[10] Here semi-mechanization means use of machinery for moulding bricks using an extruder or a soft-mud moulding machine and partial mechanization of the material handling.

- Lack of availability of off-the-shelf technology packages and technology providers: Standard technology packages are not available. The know-how of the zig-zag firing is limited to a handful of brick makers. For VSBK technology there is only one active technology provider. The manufacturing of machinery for brick making is concentrated in a few small-scale enterprises. Recently some European brick-making machinery manufacturers have entered the market and are involved in field trials on India-specific technology packages.
- Lack of availability of trained manpower**:** Operation of any new technology requires trained manpower, which is in short supply. The VSBK monitored during the study was operating at 50% of its rated capacity, mainly because of a worker shortage. Similarly, the poor operation of the zig-zag forced draft kiln can be attributed to absence of trained manpower for its operation. Currently, there is no system in place to train manpower for the brick industry.

VII. A Road Map for Cleaner Brick Production in India

India’s brick sector is characterized by traditional firing technologies, with high emissions; reliance on manual labour and low mechanization rate; dominance of small-scale brick kilns with limited financial, technical and managerial capacity; and dominance of a single raw material (clay) and product (solid clay brick).

This report suggests that development of a cleaner brick production industry in India over the next ten years should aim at:

Adoption of cleaner kiln technologies: The FCBTKs and DDKs should be replaced with zig-zag, VSBK or other cleaner kiln technologies by 2020.

- Zig-zag kilns appear to be the logical replacement for FCBTKs, because of low capital investment, easy integration with the existing production process, and the possibility of retrofitting FCBTKs into zig-zag firing. The zig-zag kiln performance strongly depends on the kiln operation practices; also, the zig-zag natural draught kiln appears to perform better than the zig-zag forced draught kiln. These aspects need further study before finalizing recommendations and formulating a large-scale dissemination programme for zig-zag kilns.

- VSBK appears to have a limited market, mainly because of its inability to produce good quality bricks from all types of clays and its low productivity under the Indian conditions. Incorporation of features of Vietnamese VSBKs into Indian VSBKs may help in improving the VSBK technology package. VSBK dissemination needs to be properly targeted.
- The tunnel kiln technology is capital intensive, and the current technological know-how and experience is limited in India. Adoption of the tunnel kiln also requires extensive modifications in brick moulding, drying and material handling. Widespread adoption of tunnel kiln technology is not foreseen in the immediate future.

Promotion of internal fuel in brick making by mechanizing the brick making process; Internal fuel addition significantly reduces SPM and BC emissions. Cheaper fuels, such as coal slurry, coal dust, charcoal dust, and sawdust can be used as internal fuels and can help reduce fuel cost. Management of internal fuel addition is extremely difficult in the manual molding process. Semi-mechanization of moulding needs to be promoted to support the use of internal fuels. Semi-mechanization of the brick moulding process would have other benefits, including an ability to use inferior clay resources and wastes, reduction in drudgery and better working conditions for workers, and the potential to produce hollow and perforated bricks.

Promotion of mechanized coal stoking systems: High PM and BC emissions in FCBTKs occur during the period of fuel feeding. Continuous feeding of properly sized fuel, using a coal stoker in an FCBTK or a zig-zag kiln, can reduce the emissions significantly.

Diversifying products (e.g. hollow and perforated bricks): Hollow and perforated bricks require less clay and fuel as well as provide better thermal insulation of walls and hence need to be promoted.

Promotion of modern renewable energy technologies in brick making: Apart from the CO_2 emissions caused by firing coal in brick kilns, the current brick making practice has a very low carbon footprint. Any mechanization of the brick making process, as proposed above, would require the use of electricity. Captive power generation using diesel fuel is expensive and has a high carbon footprint. Renewable electricity generation options using biomass gasifiers and solar PV need to be promoted. Semi-mechanization of the brick moulding process also requires artificial drying, which may increase the coal consumption in brick making. There is a need to develop more efficient drying systems based on the use of modern solar thermal and biomass energy technologies.

To achieve these goals, recommendations to the government of India, include:

Modification in environmental regulations to phase-out FCBTKs:

Environmental regulations can be amended to phase-out FCBTKs and replace them with cleaner brick firing technologies. Any action on environmental regulations needs to be supported by complementary supporting actions, which may include:

- Preparation of standard zig-zag and other cleaner kiln technology knowledge packages (containing design, construction and operation guidelines).
- Training and certifying a cadre of technology providers in cleaner brick firing technologies.
- Educating/training brick kiln owners, supervisors and workers in cleaner brick firing technologies
- Supporting a modest R&D programme to consider improvements in the zig-zag firing package, e.g. mechanical stoking of fuel; replacement of ash layer on the top of the kiln.
- Conducting environment monitoring of kilns to gain further understanding and guide the policy action.

Launching an Indian brick development programme

There is a strong case for a national programme for the development of the brick sector. The programme should address issues related to:

- *Planned relocation of brick industry clusters*: Identify sites for relocation of brick industry, based on factors such as clay resource mapping, mapping of waste sources appropriate for brick making, access to electricity and distance from demand centers.

- *Technology transfer and dissemination*: Support for technology transfer/demonstration/field testing of semi-mechanized and cleaner firing technology packages.
- *Skill development*: Develop a cadre of local technology providers, who can also provide service and train supervisors and the workforce.
- *Financing*: Provide access to financing.
- *Advocate for policy change.* Work with appropriate partners to enact environmental policies to transform the industry.

Implementation of these measures can result in annual coal savings of the order of 2.5 to 5.0 million tons/year; significant reduction in air pollution; improvement in profitability of brick enterprises; and improvement of working conditions for millions of workers employed in brick kilns.

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Chapter 1. Introduction

1.1. Background

The Indian economy has been growing at a rate of 7-8% since 2001. The 11th five year plan (2007-2012) targets a higher economic growth of around 9% with an objective to double real per capita income in the next 10 years[11]. The growth in the economy, population, and urbanization imply an increasing demand for residential, commercial, industrial and public buildings and other physical infrastructure. Various studies indicate that, out of the total constructed area existing in India in 2030, about 70% will have been constructed between 2010 and 2030. Building construction in India is estimated to grow at a rate of 6.6% per year[12] during the period 2005 to 2030. The building stock is expected to multiply five times during this period (Figure 1-1), resulting in a continuous increase in demand for building materials. Building materials production processes are generally energy intensive and have a large environmental footprint, due to the use of natural resources, as well as to emissions associated with energy use.

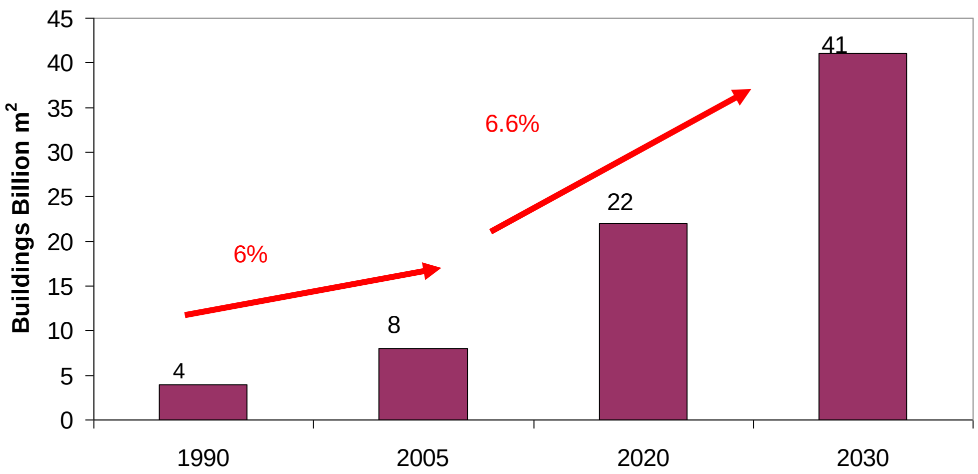


Figure 1-1: Projected increase in building area in India

Source: Environmental and Energy Sustainability: An Approach for India, McKinsey & Co, August 2009

[11] Planning Commission, 2006: Towards faster and more inclusive growth – an approach paper for the 11th five year plan.
[12] Environmental and Energy Sustainability: An Approach for India, McKinsey & Co, August 2009

The new construction will require building materials such as cement, brick, steel, stone, and sand in massive quantities. It is well known that building materials production processes are generally energy-intensive and have a large environmental footprint due to use of natural resources, as well as to emissions associated with energy use.

Bricks are one of the most important walling materials used in India. India is the second largest producer of bricks, representing more than 10 percent of global production. India has more than 100,000 brick kilns producing about 150-200 billion bricks annually[13].

Brick making in India is characterised by the following features:

- Brick making is a small-scale, traditional industry[14]. Almost all brick kilns are located in the rural and peri-urban areas. It is common to find large brick making clusters located around the towns and cities, which are the large demand centres for bricks. Some of these clusters have up to several hundred kilns.
- The brick production process is based on manual labour, and brick kilns are estimated to employ around 10 million workers. Brick production is a seasonal vocation, as the brick kilns do not operate during the rainy season. Most of the workers migrate with their families from backward and poor regions of the country. Families, including young children, work in harsh, low paying conditions. There is typically a lack of basic facilities, such as access to clean drinking water and sanitation.
- Bricks are fired to a temperature of 700 -1100^{o}C, requiring a large amount of fuel for the firing operation. Brick kilns are estimated to consume roughly 25 million tonnes of coal per year, thus making them among the highest industrial consumers of coal in the country.
- A rapid increase in brick production and the clustering of brick kilns have given rise to environmental concerns:
    - Combustion of coal and other biomass fuels in brick kilns results in the emissions of particulate matter (PM), including black carbon (BC), sulphur dioxide (SO_2), oxides of nitrogen (NO_x), and carbon monoxide (CO). The emission of these pollutants has an adverse effect on the health of workers and vegetation around the kilns. In recent years, the higher cost and a shortage of

13 No agency in India keeps record of brick production. The numbers on brick kilns, total production and coal use are estimates that are often quoted by brick industry associations and experts.

14 A traditional industry is defined as "an activity, which produces marketable products, using locally available raw material and skills and indigenous technology."

good quality bituminous coal have resulted in an increased use of high-ash, high-sulphur coal, as well as the use of industrial wastes and loose biomass fuels in brick kilns. All of these have resulted in new air emission challenges.
    - The use of large quantities of coal in brick kilns contributes significantly to emissions of carbon dioxide (CO_2).
    - Good quality agriculture topsoil is used for brick production. Areas having large concentration of brick kilns suffer from land degradation.
- Apart from the environmental concerns, the industry faces other challenges, including:
    - A shortage of workers, resulting in an increase in wages and disruption of production.
    - A rapid increase in the fuel cost and limited availability of good quality coal.
    - A shortage of good quality clay in some regions and an inability of brick makers to adopt technologies to utilize alternate raw material.
    - Increased competition from other walling materials, such as concrete blocks.
    - New demands resulting from the trend towards high-rise construction.

Despite its significance in the construction sector, importance in the livelihoods of the poor, its large consumption of coal, and its impact on health and environment, the brick making sector has seen very few development interventions/programmes aimed at improving the industry. Initiatives that have been undertaken are listed in Table 1-1. The most significant government interventions were the environmental regulations enacted in the1990's, which resulted in upgradation in the firing technology from moving chimney bull trench kilns to fixed chimney bull trench kilns.

Table 1-1 Development Programmes/Initiatives in the Indian Brick Industry

	Agency/ Programme	Type of Intervention	Impact
1970's	Central Building Research Institute, Government of India	**Technical**: Introduction of zig-zag firing technology and semi-mechanization process	• Successful in seeding the technologies. • No large-scale adoption.
1990's	Central Pollution Control Board/ Ministry of Environment and Forest (MoEF)	**Regulation:** Air emission regulation for brick kilns	• Large-scale shift (around 30,000 kilns) from moving chimney Bull's Trench Kiln technology to more efficient and less polluting fixed chimney Bull's Trench Kiln technology.
1995-2004	Swiss Agency for Development and Cooperation	**Technical**: Introduction of Vertical Shaft Brick Kiln (VSBK) Technology	• Successful in seeding the technology. • No large-scale adoption.
2009-ongoing	United Nations Development Program - Global Environment Facility (UNDP-GEF)	**Technical**: Introduction of hollow bricks and other resource-efficient bricks.	• Not known

Source: Greentech Knowledge Solutions Analysis

Brief details of the brick making process and the types of brick kilns are provided in Annexure I and Annexure II respectively.

The brick industry in the Gangetic Plains differs from the brick industry in peninsular and coastal India. The Gangetic Plains of North India account for about 65% of total brick production. Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal are the major brick producing states in this region. Brick kilns, generally of medium and large production capacities (2–10 million bricks per year), are located in clusters around major towns and cities. Coal is the main fuel used for firing bricks. The availability of fertile alluvium soils in

North India has caused the fringe areas of cities in this region to be dotted with brick kilns and consequently is a significant force in bringing about land use/ land cover changes around cities[15]. Peninsular and coastal India account for the remaining 35% of brick production. In this region, bricks are produced in numerous small units (production capacities generally range from 0.1 to 3 million bricks per year). Gujarat, Orissa, Madhya Pradesh, Maharashtra, and Tamil Nadu are important brick producing states in the peninsular plateau and coastal India. Apart from coal, a variety of biomass fuels such as firewood, dry dung and rice husk are also used for firing bricks.

Table 1-2 provides the details about the various types of firing technology currently prevalent in India. Currently, Fixed Chimney Bull's Trench Kiln (FCBTK) is the leading technology for firing bricks. FCBTK accounts for around 70% of the total brick production in India and is prevalent in the Indo-Gangetic plains, as well as in some pockets in the rest of the country. Clamps are used widely all over peninsular India. Down-draught kilns, Vertical Shaft Brick Kilns (VSBK), Hoffmann kilns, and zig-zag fired kilns make up less than 5% of all kilns.

Table 1-2: Brick kiln technologies currently prevalent in India

Kiln Type	Regional spread	Approximate contribution in brick production
Clamps	Central, West and Southern India	25%
Fixed chimney BTK	Indo-Gangetic plains (North and East India) and several clusters in South and West India	70%
Zig-zag	West Bengal, a few clusters in North India	2-3%
VSBK	Central India	1-2%

Source: Greentech Knowledge Solutions Analysis

It is quite evident that the brick industry in India, particularly when seen in the light of future demand, could have long-lasting implications in terms of future energy demand, local pollution, contribution to greenhouse gas emissions, and the socio-economic conditions of a significant number of low-income workers. It is thus important to gain a deeper

[15] Lakshmi Singh, A. and Md. S. Asgher. 2005. "Impact of brick kilns on land use/landcover changes around Aligarh city, India." Habitat International 29 (2005) 591–602.

understanding of the technologies used for brick production and identify technological options to promote cleaner brick production.

1.2. Objective

The objective of the study was to carry out a comprehensive assessment of brick making technologies to gain a deeper understanding of the energy utilization and emissions from current technologies as well as technologies that offer the promise of cleaner brick production.

To address these objectives, Greentech Knowledge Solutions Pvt Ltd (GKS), Enzen Global Solutions Pvt Ltd (Enzen) and University of Illinois (U of I), with Entec AG (Entec), Hanoi Center for Environmental and Natural Resources Monitoring and Analysis (CENMA), and the Clean Air Task Force (CATF) conducted a detailed monitoring study from February to May 2011 examining five brick kiln technologies: two traditional brick kiln technologies widely prevalent in India – fixed chimney Bull's Trench Kiln (BTK) and Down Draught Kiln and three relatively newer technologies – Vertical Shaft Brick Kiln (VSBK), Zig-Zag Kilns, and Tunnel Kilns. Nine individual brick kilns were monitored for the following parameters:

- Energy performance: Specific Energy Consumption (SEC)
- Environment performance: Emission measurements for particulate matter (PM), black carbon (BC), and selected gaseous pollutants.
- Financial performance: Capital investment, cost of production, pay-back period.

The study also collected data on the current status of the brick industry in the brick making clusters visited by the project team.

The assessment of the technologies and the industry were used to make recommendations for strategies promoting cleaner brick production technologies. The results were also used as inputs in a parallel study undertaken to assess multiple types of walling materials, including clay fired bricks.

1.3. Selection of kilns for Monitoring

Nine brick kilns were selected for the monitoring. These kilns cover a range of brick making technologies, fuels and operation practices. The details of the monitored kilns are provided in Table 1-3 and Figure1-2 shows the location of the monitored kilns on the maps of India and Vietnam.

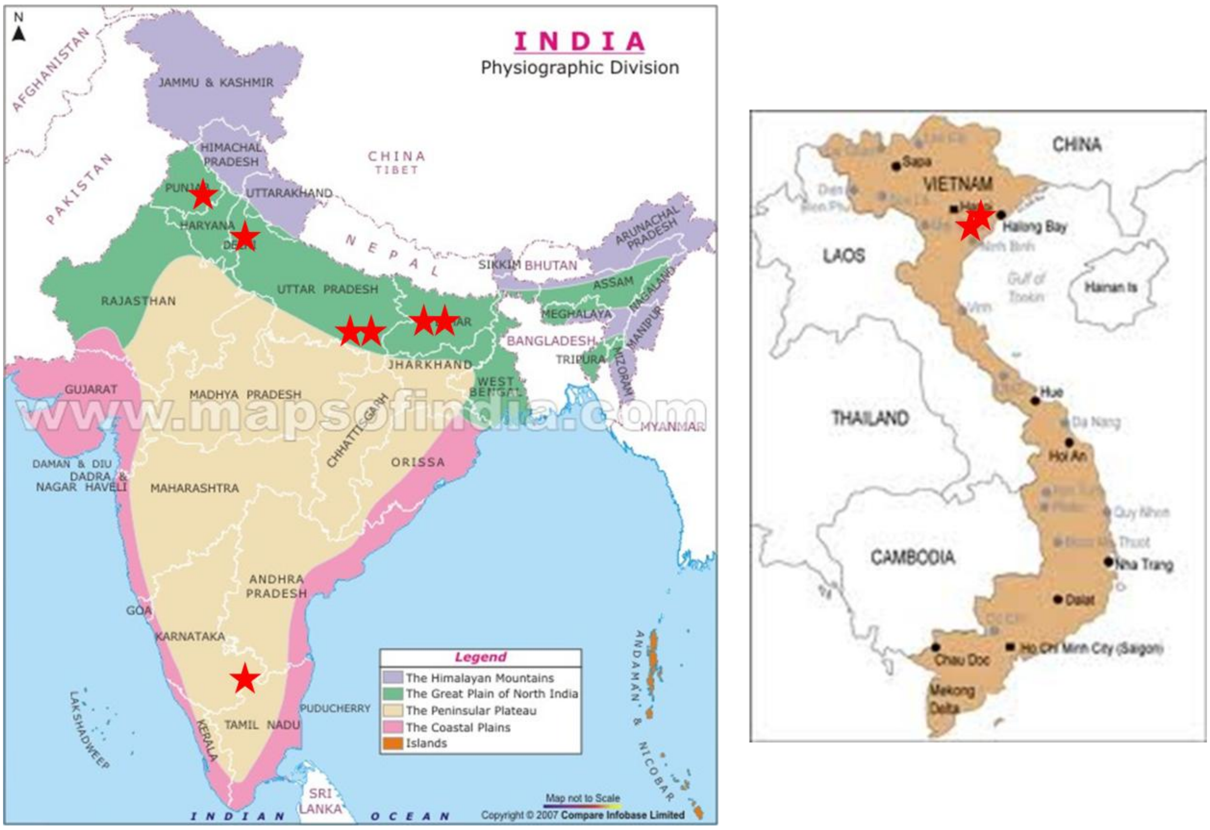


Figure 1-2 Location of monitored kilns in India & Vietnam

Table 1-3 Information on monitored brick kilns

Type of kiln	Number of kilns monitored	Features of Monitored kilns			Remarks
		Place	Kiln size	Fuel used	
Fixed Chimney Bull's Trench Kiln (FCBTK)	3	Garh Mukteshwar (U.P)	Large	Coal (High volatile & high calorific value); rubber tyres; wood logs	➢ Accounts for more than 70% of total brick production in India. ➢ More than 30,000 FCBTKs currently operational in India. ➢ Emissions from a FCBTK are significantly affected by the fuel used and operating practice.
		Ludhiana (Punjab)	Large	Coal (High volatile & high calorific value)	
		Arah (Bihar)	Medium	Coal (Low volatile and medium calorific value)	
Zig-zag	2	Varanasi (Natural Draft)	Large	Coal (Two types) Biomass (Sawdust)	➢ Improved firing technology as compared to FCBTK in terms of environment emissions & energy consumption. ➢ Traditionally uses a fan for creating draft. ➢ Recently natural draft (using a chimney) has been successfully used in zig-zag kilns.
		Varanasi (Forced Draft)	Large	Coal (Mixture of two types of coal) Mixture of high volatile & high calorific value and low volatile & medium calorific value	
Vertical Shaft Brick Kiln (VSBK)	2	Arah (Bihar)	Small	Coal (Two types) ○ Steam coal ○ Coal Slurry (Internal)	➢ An estimated 100 VSBKs have been constructed in India. ➢ Considered most efficient kiln technology in terms of energy use. ➢ Improved VSBK technology is extensively used in Vietnam ➢ More than 300 VSBK enterprises in Vietnam.
		Hung Yen province (Vietnam)	Medium	Coal (Two types) ○ Coal powder (Internal) ○ Coal Slurry (Internal)	
Down-Draught Kiln (DDK)	1	Malur (Karnataka)	Small	Biomass ○ Fresh eucalyptus branches	➢ Improved version of a clamp kiln ➢ Popular in Malur cluster in Karnataka ➢ Malur cluster has roughly 450 DDK.
Tunnel kiln	1	Nam Dinh province (Vietnam)	Large	Coal ○ Coal powder	➢ Tunnel kiln is the main technology for firing bricks in developed countries, as well as several developing countries e.g. China, Vietnam ➢ India does not have a well-functioning tunnel kiln for clay brick firing; Vietnam has more than 500 operational tunnel kilns

1.4. Organization of the Report

This report is organized as follows. *Chapter 2* describes the methodology followed for monitoring the energy, emissions, socio-economic and financial parameters. *Chapters 3 through 7* present the results of the monitored kilns; the chapters are named according to the firing technology of the monitored kilns. *Chapter 8* acts as a synthesis chapter and provides the main conclusions of the monitoring. *Chapter 9* offers recommendations for achieving a more sustainable brick sector in India.

Chapter 2. Methodology for Monitoring & Measurements

2.1. Introduction

Table 2-1 provides the list of parameters that were measured. In addition to these parameters, fuel and clay samples were collected and tested in laboratory. The business and process related information was collected through interviews.

Table 2-1: List of parameters measured

Process variable	Principle of measurement or analysis	Sample Location	Type *	Responsible organization**
Fuel feeding rate	Weighing of fuel and time measurement	Fuel	P	GKSPL
Temperature of flue gas	Thermocouple	Stack/ flue duct	R	GKSPL/ Enzen
Temperature of bricks & surfaces	K-type Thermocouple/ Infrared thermometer	Inside the kiln/ outside surface of kiln	P	GKSPL
Stack flow***	Pitot tube	Stack	P	Enzen
O_2	Electrochemical	Stack/flue duct	R	GKSPL/CENMA
CO_2	Inferred from O_2	Stack/ flue duct	R	GKSPL/CENMA
	Infrared absorption	Diluted exhaust	R	U of I
CO	Electrochemical	Stack/ flue duct	R	GKSPL/CENMA
	Electrochemical	Diluted exhaust	R	U of I
SO_2	Barium-Thorin titrimetric method	Stack	I	Enzen/CENMA
NO_x	Gaseous sampling followed by colorimetry using phenoldisulfonic acid	Stack	I	Enzen
Suspended Particulate Matter (SPM)	Gravimetric	Stack	I	Enzen
HF	Electric potential methods using ion selective membrane electrode	Stack	R	CENMA
PM2.5	Gravimetric	Diluted exhaust	I	U of I
Elemental and organic carbon	Thermal-optical analysis	Diluted exhaust	I	U of I
Light absorption	Filter transmittance	Diluted exhaust	R	U of I
Light scattering	Scattering sensor	Diluted exhaust	R	U of I
Size-resolved carbon particles	Cascade impactor plus thermal-optical analysis	Diluted exhaust	I	U of I

Notes:

* Average of single-point observations (P); Integrated sample (I) taken over many minutes; Real-time observations (R) averaged for presentation.

** CENMA: Hanoi Centre for Environmental and Natural Resources Monitoring and Analysis, Vietnam. GKSPL: Greentech Knowledge Solutions Pvt. Ltd. U of I: University of Illinois.

*** 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. For low velocity (less than 3m/s) differential manometer was used.

2.2. Energy and Combustion Process Parameters

Table 2-2 provides the measurement methodology for the measurement of the energy and combustion process parameters.

Table 2-2: Measurement methodology

Objective	Measurements
Determination of specific energy consumption (SEC) in MJ/ kg of fired bricks	• Measurement of the quantity of fuel used during a specified time period (generally 24 hours). In case of Down Draught Kiln, measurement of fuel fed during one complete kiln firing. • Number of bricks fired in case of FCBTK and zig-zag during the specified time period of fuel measurement; number of fired bricks produced in VSBK and tunnel kiln during the specified time period of fuel measurement; Total number of bricks loaded in case of Down Draught Kiln. • Determination of calorific value of all the fuel samples in the lab. • Measurement of weight of 20 randomly selected fired bricks, to determine average weight of the fired brick.
Understanding temperature profile of the kiln (temperature plotted along the length of the kiln) and temperature distribution in the firing zone	• Sample temperature measurements inside the kiln using K-type thermocouples.
Determination of excess air, flue gas loss and understanding combustion	• Flue gas analysis in the chimney or the duct connecting the kiln with the chimney to measure CO, O_2, SO_2 and temperature of flue gas. • Ultimate and proximate analysis of fuel samples in the lab.
Heat loss in fired bricks	• Measurement of temperature of fired bricks at the unloading point.
Radiation and Convection heat loss from kiln structure	• Measurement of temperature of outer surface of kiln walls and roof.

Objective	Measurements
Heat used for drying of bricks	• Moisture content in green bricks at the time of loading into the kiln.
Heat required for completing irreversible chemical reactions during firing of bricks	• Chemical analysis of clay samples in the lab.

2.3. Environmental Parameters

Environmental parameters, including emissions of gases and particles, were monitored in the chimney stack. All kilns except Kiln 2-Natural draft Zig-Zag kiln lacked permanent sampling arrangements such as sampling platform, port hole in the chimney, and ladder. Temporary platforms using wood and bamboo were erected for stack emission monitoring.

Measurements with two separate sets of equipment (Enzen/GKSPL and U of I) were done, as outlined in Table 2-1. Because there was only one sampling port at each kiln, these measurements could not occur simultaneously. In addition, the size-resolved particle measurements were done separately from all the rest. Because of process variability, measurements that were not made simultaneously may disagree. These discrepancies highlight the uncertainties that are inherent in sampling any time-varying source.

Enzen/GKSPL monitored the gaseous composition of Sulphur dioxide (SO_2) and Nitrogen Oxides (NO_x). This stack emission monitoring was carried out as per standard BIS/EPA methods and using Vayubodhan Stack Sampler 1 (VSS1). At the seven kilns located in India, SO_2 was measured using titrimetric method as per IS11255 (Part2): 1985 and NO_x was measured using colorimetric method as per IS11255 (Part 7): 2005 and IS 5182 (Part VI): 1975. CO and CO_2 measurements for the kilns in India were carried out using flue gas analyzer. Measurement of gaseous pollutants at the two kilns in Vietnam was carried out using flue gas analyzer as per TCVN 6192-2000 methodology. Free Ammonia, water-soluble cations & fluorides may interfere with SO_2 monitoring; some studies have reported condensation of SO_2 into sulphuric acid under the conditions in stack gases. For NO_x measurements, biased results might be expected under high SO_2 concentrations (above 2000 ppm), but all NO_x measurements were quite low.

Enzen/Greentech also measured Suspended Particulate Matter (SPM). Particulate matter sampling was done under iso-kinetic conditions. At each of the nine kilns a minimum of three experiments was carried out. Traversing as required by standard methods was not followed in all sampling. Reasons included small stack diameter, multi-port unavailability, improper access to the location, and safety conditions.

Fine particulate matter ($PM_{2.5}$), carbonaceous particle composition, and particle optical properties were measured by another sampling train developed by the University of Illinois. A cyclone was included in this stream to exclude particles greater than 2.5µm. This stream was operated at near isokinetic conditions. The small size of the targeted particles made isokinetic sampling less important. These measurements were conducted after dilution from the stack gas, and gaseous carbon (CO and CO_2), as well as measurements of sampled and diluted flow, were used to assess dilution rates.

Particulate matter mass and samples for analysis of carbon content were collected on filters. Mass was measured using the gravimetric method with a balance in a temperature and humidity controlled environment, and thermo-optical analysis (TOA) was used to measure elemental and organic carbon content of particles. In this sample stream, light absorption and light scattering by particles were measured in real time. Light absorption was measured with a three-wavelength Particle Soot Absorption Photometer (PSAP, Radiance Research). Light scattering CO, and CO_2 were measured with a modified Portable Emission Measurement System (PEMS, Aprovecho Research). Multi-point calibrations of light scattering, CO, and CO_2 sensors were done before and after the field testing.

Analysis of the collected $PM_{2.5}$ was done to determine the content of carbonaceous particles. Samples for thermal-optical analysis were collected on quartz filters (QAT-2500 UP) that had been baked for at least 4 hours at 550^{o}C. The filters were analyzed with a Sunset thermal-optical transmittance analyzer with a maximum temperature of 870^{o}C in the Helium atmosphere and 890^{o}C in the Helium-oxygen atmosphere. Quartz filters were also sampled downstream of Teflon filters collected for gravimetric analysis, and these filters were also analyzed with the TOA method and used to correct for artifacts caused by adsorption of gaseous organic gases.

Black carbon is a combustion product that is predominantly composed of strongly bonded graphitic-like carbon rings. This composition causes black carbon to be thermally stable at high temperatures, and to strongly absorb visible light. Because of its unusual chemical composition and optical behavior, it affects visibility and climate differently than other particulate species. Organic carbon, in atmospheric science, means all carbon species that are neither black nor carbonate carbon. Much organic carbon does not absorb light. Fine particles may contain other components, such as mineral matter, and these were not measured here. Two of the methods described here respond to these properties of black carbon, although neither is a perfect measure of black carbon. TOA identifies carbon that is stable at high temperatures, which is similar to BC. The BC-like carbon measured by this method is known as elemental carbon. In this method, organic carbon is the remainder of the carbon that is not classified as elemental carbon. A second measure of absorbing carbon is particle light absorption measured in units of square meters (m^2). This measure is approximately proportional to BC concentration.

Although the particles were expected to be largely combustion-generated and thus should appear at submicron sizes, this fact has not been confirmed. For that reason, size-resolved measurements of the particles were conducted at several of the kilns.

2.4. Business Related Information

A detailed format for collection of business related data was prepared. The questionnaire was filled in during the interview with the owner. The format was designed to investigate the typical cost economies of the monitored kiln as well as the dynamics of the kiln cluster. The questionnaire consists of information about the land requirement, land prices, labor cost & availablility, market, fuel cost & supply, transportation, losses due to rain and any other unforeseen circumstances, etc.

Chapter 3. Fixed Chimney Bull's Trench Kiln

3.1. Fixed Chimney Bull's Trench Kiln (FCBTK)

FCBTK is a continuous, cross-draught, annular, moving fire kiln operated under a natural draught, which is provided by a chimney. Its origin lies in the Hoffman kiln, which was patented in 1858. A British engineer, W. Bull is credited with introducing the Bull's Trench Kiln (BTK) to India in 1876.

It is a moving fire kiln, in which the fire moves through the bricks, which are stacked in the annular space formed between the outer and the inner wall of the kiln. Green bricks are loaded in front of the firing zone, and cooled fired bricks are removed from behind. The kiln is generally of oval or circular shape.

The FCBTKs are built above the ground, by constructing permanent sidewalls. Unlike the original form of BTK, which employed a moving metallic chimney, FCBTK has a fixed chimney at the centre of the kiln. Figure 3-1 below shows a sketch of a FCBTK.

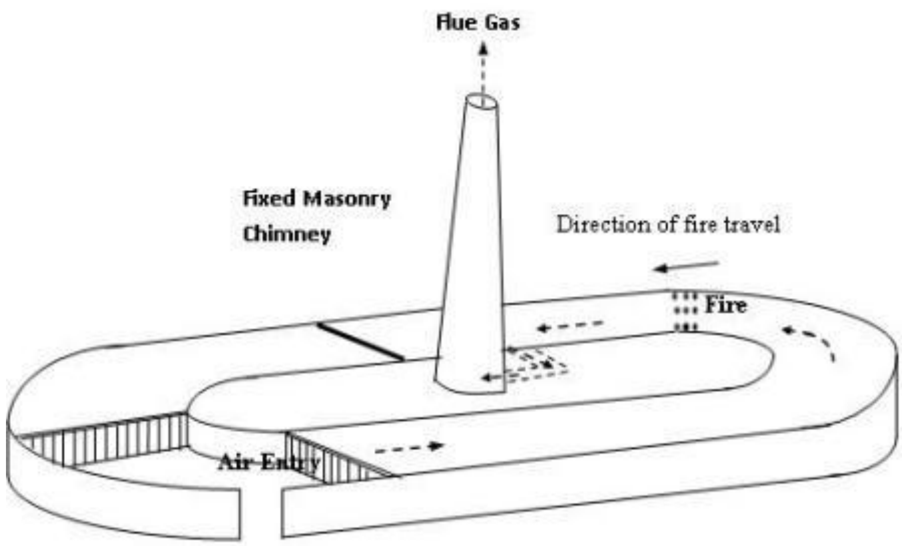


Figure 3-1: General Sketch of Fixed Chimney BTK

Green bricks to be fired are placed in the annular space and covered with a layer of partially fired or green bricks forming a temporary roof. A layer of ash and brick dust is spread over the top to seal the kiln and to provide thermal insulation. The bricks are stacked in a column and blade brick arrangement. The brick-unloading end is kept open for air entry into the kiln. The brick-loading end is sealed with a metal, cloth, paper or plastic damper.

At any given point of time, three distinct zones can be identified in a FCBTK. Proceeding from the brick-unloading end, the first zone is the brick cooling zone. In this zone, air entering from the unloading end picks up heat from fired bricks, resulting in heating of air and cooling of fired bricks. The next zone is the fuel feeding zone (combustion zone), in which the fuel is fed from the feedholes provided on the roof of the kiln. Generally 2-3 rows are fed at a time. Some of the coal fed into the kiln accumulates on the ledges (provided at 4-5 levels) and the rest of the coal falls to the kiln floor. Coal comes in contact with hot gases, and combustion takes place in this zone. The last zone is the brick-preheating zone; in this zone, heat available in the flue gases is utilized for preheating of green bricks. In the kiln, fire movement takes place in the direction of air travel. When the firing of a row is over, it is closed, and the next line is opened. The fire typically travels at a rate of 6-10 m/day. Once in 24 hours, the damper is shifted forward by the same distance (bringing in a new batch of green bricks in the kiln circuit), the next flue duct in the direction of fire travel is opened, and the previous one is closed. Once lit at the beginning of the brick making season, the kiln generally remains lit throughout the season (usually for 4-6 months).

Three FCBTK kilns were selected for monitoring. The salient features of these kilns are given in table 3-1. The locations of the three kilns are marked on the Indian map (Figure 3-2).

Table 3-1: Salient Features of the three monitored FCBTKs

Kiln Identification No	Location	Production Capacity		Fuel	Time of Monitoring	
		Bricks/day	Million Bricks/yr		Date	Comment
Kiln 1_FCBTK	Hapur (UP)	35,000	6 - 8	➢ Assam & Jharia Coal ➢ Rubber tyres ➢ Fuel wood	5th – 7th March 2011	Early in the first firing cycle
Kiln 4_FCBTK	Ludhiana (Punjab)	38,000	6 - 8	Assam Coal	9th - 11th April 2011	Second round of firing cycle
Kiln 6_FCBTK	Arrah (Bihar)	20,000	2.5 - 4	Jharia coal	15th – 18th April 2011	Mid season

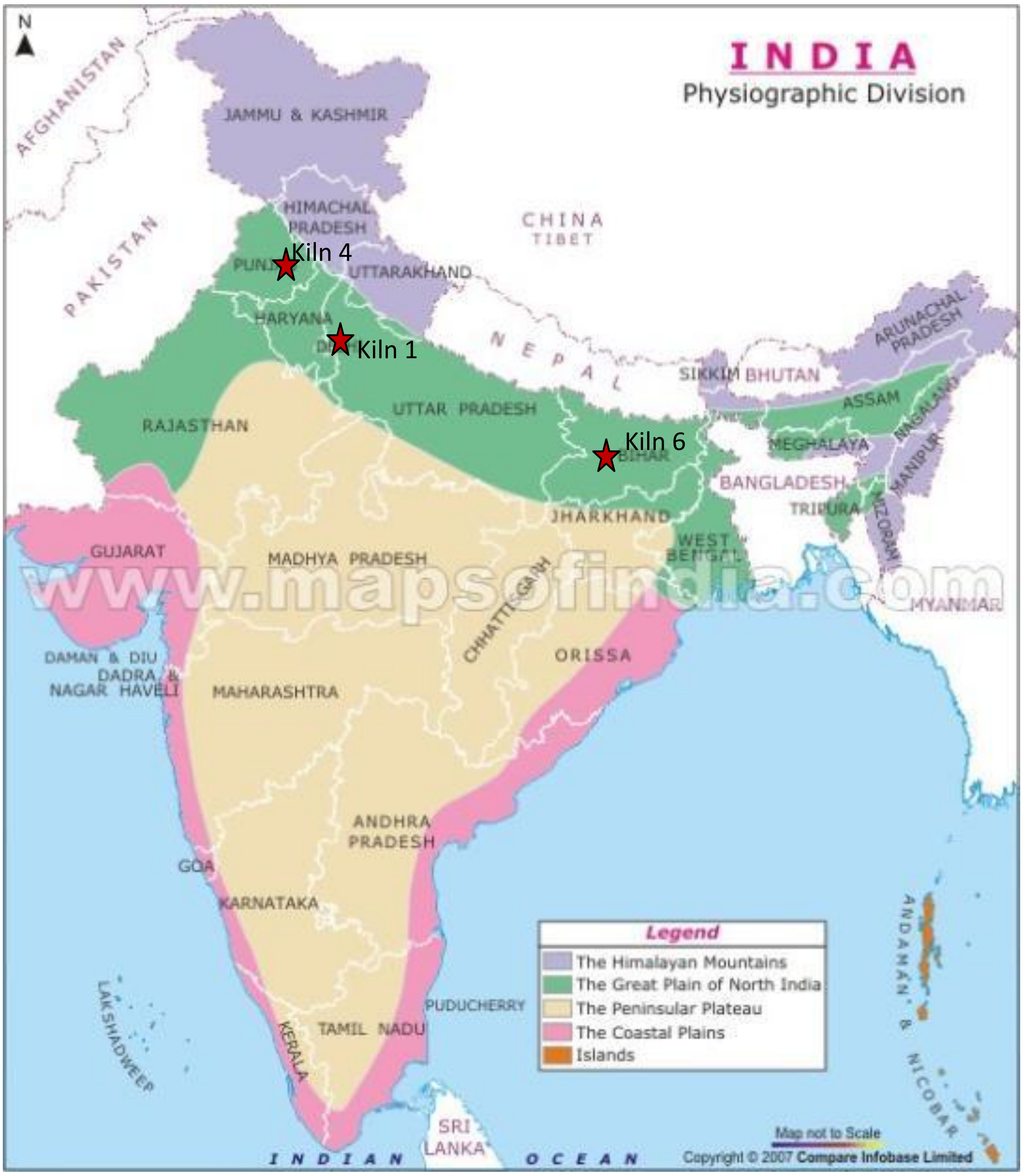


Figure 3-2 Locations of Monitored FCBTKs

3.2. General Description of the Monitored FCBTKs

Table 3-2: Description of three FCBTKs monitored

	Kiln 1_FCBTK	Kiln 4_FCBTK	Kiln 6_FCBTK
Location	Hapur, UP	Ludhiana, Punjab	Arah, Bihar
Description of company	➢ The owner is a second-generation brick maker ➢ Family business for last 70 years ➢ Currently the company operates three kilns (all are FCBTKs)	➢ The owner is a third-generation brick maker ➢ Family business for last 70 years ➢ Currently the company operates two kilns (all are FCBTKs)	➢ The owner is a second-generation brick maker ➢ Largest brick maker in the region ➢ Currently the owner operates four kilns (all are FCBTKs)
Annual Production	➢ 6 – 8 million bricks/ year	➢ 6 – 8 million bricks/ year	➢ 2.5 – 4 million bricks/ year
Supplying Market	➢ In the radius of 50-70 km ➢ Delhi (National Capital Region) & near by areas.	➢ In the radius of 25 km ➢ Ludhiana & near by areas.	➢ In the radius of 25 km ➢ Arah and near by areas.
Operational period	➢ Dry season only (usually from December to June).	➢ Dry season only (usually from February to June & October to December).	➢ Dry season only (usually from January to June).
Kiln Description	➢ Traditional FCBTK ➢ Modifications in flue gas duct operation mechanism, use of shunt system [a]	➢ Traditional FCBTK ➢ Kiln structure is old and needs repairs (possibility of leakages from the structure) ➢ Modifications in flue gas duct operation mechanism, use of shunt system [a]	➢ Small sized traditional FCBTK ➢ Kiln structure is old and needs repairs (possibility of leakages from the structure)
Moulding	➢ Hand moulding ○ Solid Bricks	➢ Hand moulding ○ Solid Bricks	➢ Hand moulding ○ Solid Bricks

	Kiln 1_FCBTK	Kiln 4_FCBTK	Kiln 6_FCBTK
	○ Accounts for 90% of production ➢ Machine Moulding – Extruder [b] ○ Perforated bricks ○ Only 10% of production		
Drying	➢ Drying Shade [c] ○ Extruded bricks are dried under shade ➢ Open drying ○ Most of the hand moulded bricks are dried in open air	➢ Open drying under sun	➢ Open drying under sun
Firing Fuel	➢ Primary fuel: Coal ○ Mixture of Assam [d]& Jharia coal [e] ○ Contributes70% of total thermal energy input ➢ Other fuels: wood and used rubber tyres	➢ Coal ○ Assam [d] coal	➢ Coal ○ Coal slurry ○ Steam Coal

[a] A shunt is a metal duct, which is used to connect the central duct of the chimney with the side ducts. The use of a shunt reduces the possibility of air leakage and improves the working condition of firemen.
[b] The extruder has been manufactured locally and has been installed with the intention of increasing the production and reducing the dependence on moulding labour. The extruder can make both solid as well as perforated bricks.
[c] Drying under shade avoids direct exposure to the sun and hence reduces the possibility of drying cracks and protects the green bricks from unseasonal rains.
[d] Assam coal is a high volatile, high sulphur and high calorific value bituminous coal
[e] Jharia coal is a medium to high ash content, medium volatile bituminous coal.

3.3. Energy Performance

Fuel feeding practice

Typically in FCBTKs, the fuel is fed in 2 to 3 rows. This practice was followed by the three FCBTKs monitored in the study. The details of the fuel feeding practice is given in Table 3-3.

Table 3-3: Fuel feeding practice in FCBTKs

Kiln Identification No	Fuel feeding Practice
Kiln 1_FCBTK	➢ Fuel was fed in three rows. ➢ Fuel was fed by two firemen intermittently. ➢ Coal was crushed to small size in a coal crusher before feeding. ➢ Wood logs were fired mainly in the feed holes situated near the side walls of the kiln or in newly opened rows, where the temperature at the bottom of the brick setting was in the range of 450-650^{o}C. Wood has a lower ignition temperature than coal; hence the main purpose of feeding wood is to raise the temperature so that coal feeding can be initiated. ➢ Rubber tyres used to supplement coal. ➢ Temperature in the firing zone ranged between 975 - 1000^{o}C.
Kiln 4_FCBTK	➢ Fuel was fed in three rows. ➢ Coal was crushed to small size in a coal crusher before feeding. ➢ Fuel feeding was irregular, and the supervision of firing operation was poor. The time between two consecutive coal feedings was generally more than 20 minutes and sometime even stretched to 1 hour. As a result, a large quantity of coal was being fed in a short interval of time. ➢ Temperatures in the firing zone ranged between 990 - 1040^{o}C.
Kiln 6_FCBTK	➢ Fuel was fed in two rows ➢ Fuel was fed intermittently by two firemen during the day and one fireman at night (due to shortage of firemen). ➢ Poor operating practice, i.e., large quantities of fuel fed in short duration of time ➢ Temperature in the firing zone ranged between 1000 - 1060^{o}C.

Energy performance

Flue gas measurements were taken at regular intervals at a central duct connecting to the chimney of FCBTK. Results of three FCBTKs are presented in Table 3-4.

Table 3-4: Flue gas analysis of FCBTKs measured at the central duct

	Kiln 1_FCBTK	Kiln 4_FCBTK	Kiln 6_FCBTK
Time average O_2 (%)	15.8	16.8	16.7
Time average CO_2 (%)	3.3	3.5	3.85
Time average CO (ppmv)	1900	1400	1700
Average Excess Air (%)	285	379	368
Average temperature of flue gas (^oC)	56.4	62.6	77.2

Figures 3-3, 3-4, 3-5 show the variation in the concentration of O_2, CO and CO_2 over 30 to 75 minutes period. The coal feeding periods are marked on the graphs.

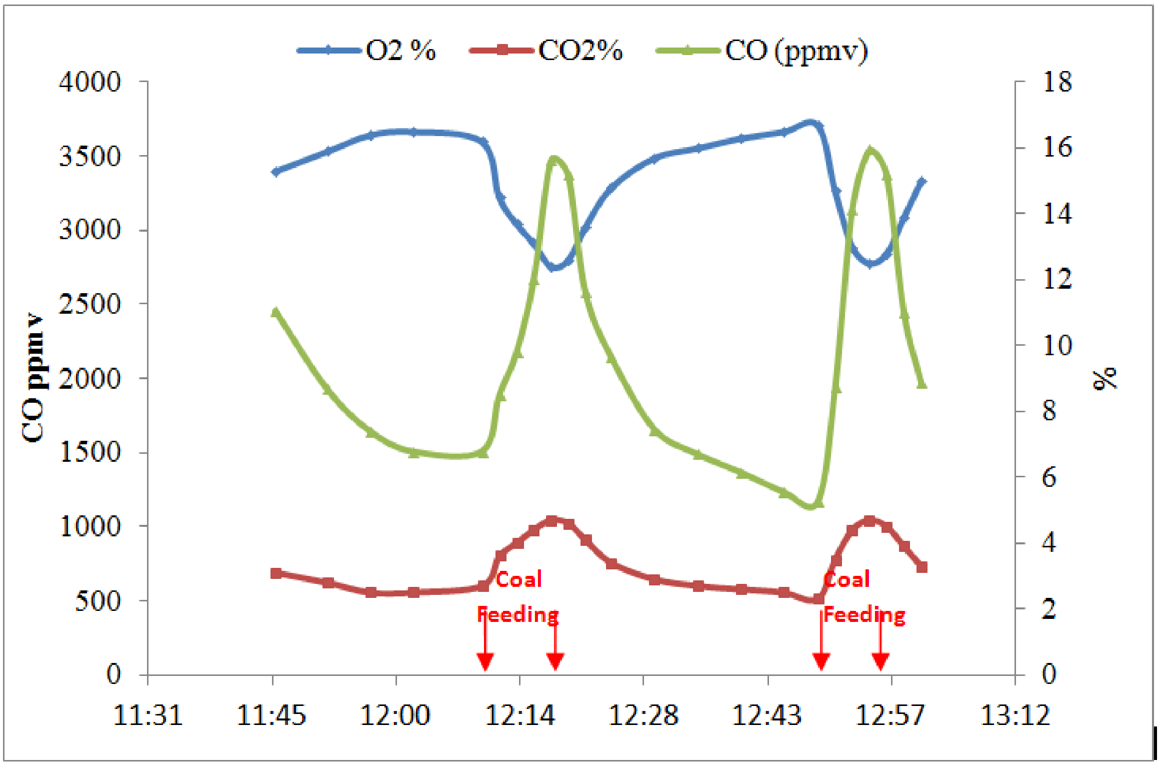


Figure 3-3: Variation in CO, O_2 and CO_2 during coal feeding and non-feeding period at Kiln 1_FCBTK

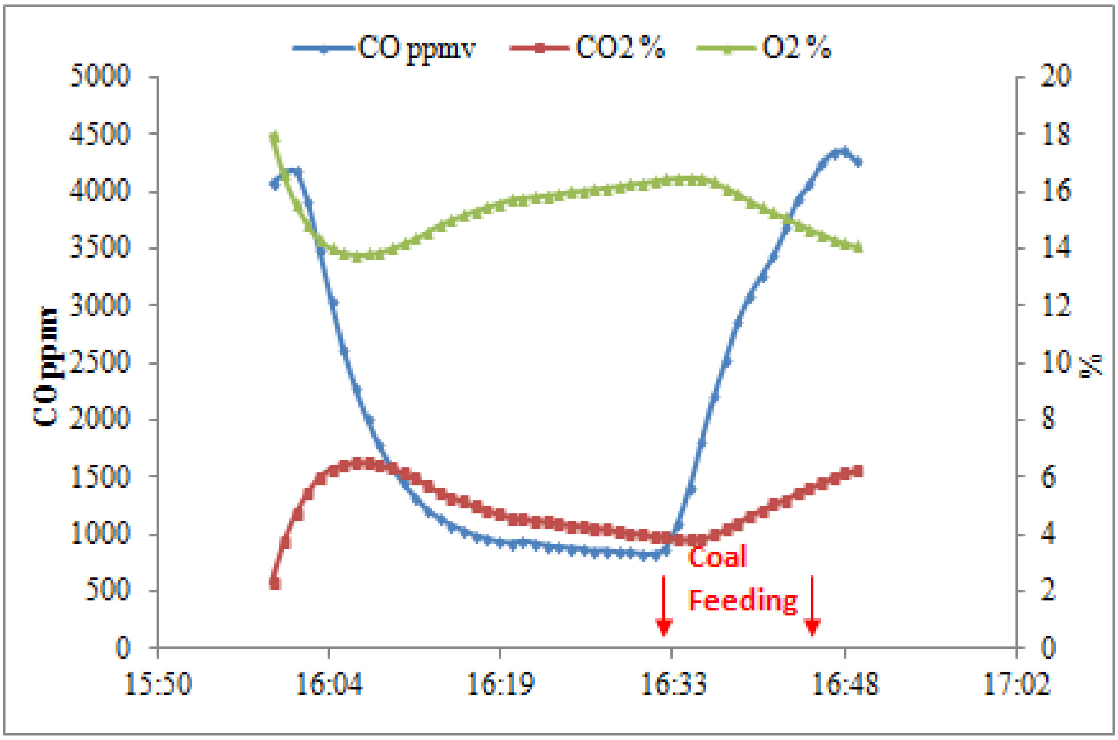


Figure 3-4: Variation in CO, O_2 and CO_2 during coal feeding and non-feeding period at Kiln 4_FCBTK

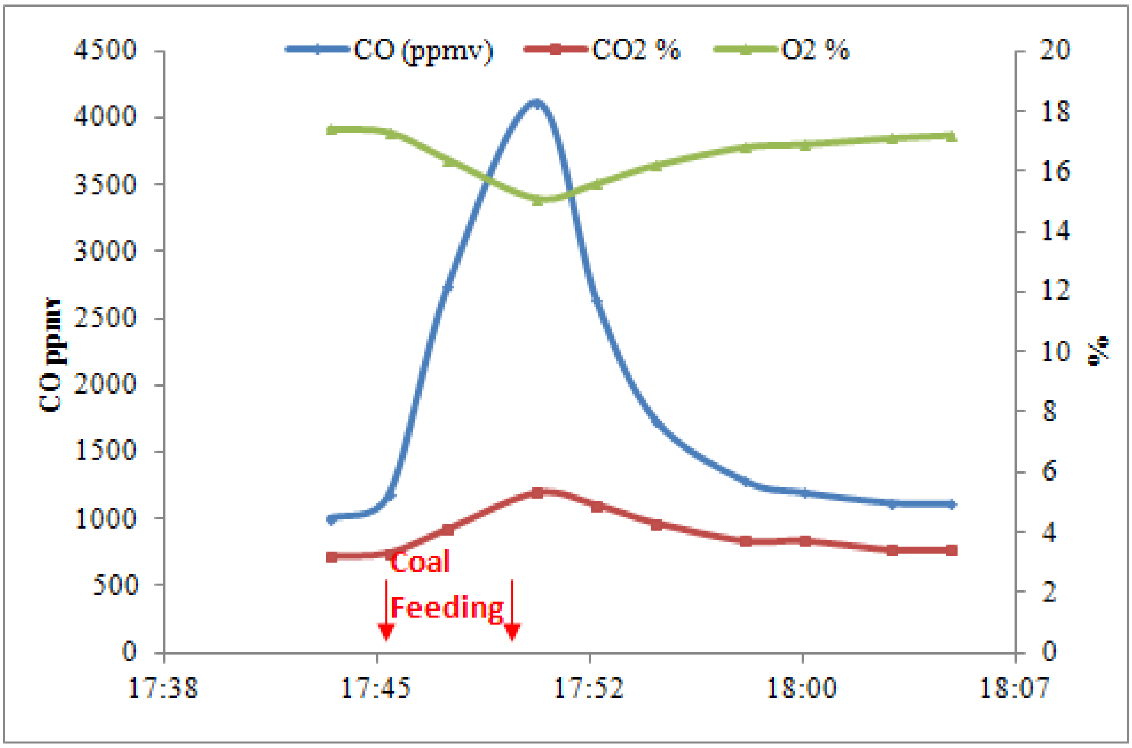


Figure 3-5: Variation in CO, O_2 and CO_2 during coal feeding and non-feeding period at Kiln 6_FCBTK

It can be observed that the initiation of fuel feeding results in a rapid increase in CO and CO_2 concentrations along with a decrease in O_2 concentrations. The CO and CO_2 concentrations peak immediately after stopping the fuel feeding.

Poor operating practice, such as irregular, intermittent fuel feedings, were observed in all three FCBTKs monitored. Average excess air computed for three FCBTKs monitored are in the range of 285% to 379%. Among the three FCBTKs monitored, excess air levels were highest at Kiln 4_FCBTK, which indicates possible air leakages in the kiln or flue ducts.

Specific energy consumption and heat balance

Based on the fuel consumption rate and brick production (number and weight in kg of bricks fired per day), specific energy consumptions were computed and shown in the Table 3-5.

Table 3-5: Specific Energy Consumption of monitored FCBTKs

	Fuel Consumption (kg/day)			Production		SpecificEnergy Consumption (SEC) (MJ/kg fired brick)
Kiln 1_FCBTK	*Coal mix*	*Wood*	*Tyres*	*Bricks/day*	*Kg/day*	1.46
	4808	2000	450	34800	97440	
Kiln 4_FCBTK	*Coal (Assam)*			*Bricks/day*	*Kg/day*	1.12
	4236			37750	109852	
Kiln 6_ FCBTK	*Coal Slurry*	*Steam Coal*		*Bricks/day*	*Kg/day*	1.1
	1809	1809		21280	71075	

The SEC for the three FCBTKs are in the range of 1.10 to 1.46 MJ/Kg of fired bricks, and are comparable to the SEC reported in earlier studies (Maithel, 2003[16]; TERI, 1995[17]). Among the three FCBTKs, the SEC of kiln 1_FCBTK is on the higher side. This is also due to the fact that the kiln was in its first firing round of the season. The SEC of this kiln is expected to

[16] Maithel S. Energy Utilization in Brick Kilns. PhD Thesis, Indian Institute of Technology, Bombay (2003)
[17] TERI. Energy Audit of Bull's Trench Brick Kilns, TERI Report No 94 IE 58, Tata Energy Research Institute, New Delhi, India (1995)

reduce by 10 – 15% as the season progresses. Table 3-6 presents the heat balance for the three FCBTKs monitored in the study.

Table 3-6: Heat balance of the monitored FCBTKs

	Kiln 1_FCBTK	Kiln 4_FCBTK	Kiln 6_FCBTK
Dry flue gas heat loss	4.2 %	5.1 %	6.7%
Sensible heat loss in unloaded bricks	4.0 %	5.0 %	4.9%
Moisture Removal	19.4 %	14.0 %	9.8%
Heat loss due to incomplete combustion	3.9 %	2.3 %	2.5%
Other heat components	68.6 %	73.6 %	76.1%
Total	100 %	100 %	100 %

Energy efficiency improvement measures

All three FCBTKs have potential for improvement in energy efficiency by adopting better operating practices and reducing the leakages. The overall potential for energy savings through better kiln operation and maintenance is expected to be 10-15%. Table 3-7 summarizes the measures which may lead to better energy performance of the kilns.

Table 3-7: Energy efficiency measures for the monitored FCBTKs

Kiln 1-FCBTK	➢ Around 15% reduction in heat loss ○ Adopting proper fuel preparation and good fuel feeding practices ○ Better upkeep of the kiln, which includes periodic maintenance of the kiln walls, chimney, and ducts ○ Improved supervision of the firing operation, which consists of ensuring leak-proof wicket walls and uniform 4-6 inch ash layer on the top with no holes, proper closing of the duct opening covers, and proper placement of the shunts.
Kiln 4-FCBTK	➢ Around 10% reduction in heat loss ○ Adopting proper fuel preparation and good fuel feeding practices ○ Better upkeep of the kiln, which includes periodic maintenance of the kiln walls, chimney, and ducts ○ Improved supervision of the firing operation, which consists of ensuring leak-proof wicket walls and uniform 4-6 inch ash layer on the top with no holes, proper closing of the duct opening covers, and proper placement of the shunts.
Kiln 6 –FCBTK	➢ Around 10% reduction in heat loss ○ Adopting proper fuel preparation and good fuel feeding practices ○ Better upkeep of the kiln, which includes periodic maintenance of the kiln walls, chimney, and use of shunt ○ Improved supervision of the firing operation, which consists of ensuring leak-proof wicket walls and uniform 4-6 inch ash layer on the top with no holes, proper closing of the duct opening covers, and proper placement of the shunts.

3.4. Emissions

A minimum of three experiments was conducted at each kiln, and samples were collected from the sampling port located at the height of 11 - 20m from the ground level. Sampling was done for a period of 45 to 60 minutes, which includes both coal feeding and non-feeding periods. Prior to sample collection, flue gas temperature and velocity 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 $PM_{2.5}$

Table 3-8: Flue gas characteristics and emission concentrations in FCBTKs

	Kiln 1_FCBTK	Kiln 4_FCBTK	Kiln 6_FCBTK
Flue gas temperature (°C)	55 (52 – 60)	56 (50 - 65)	76 (70 - 80)
Maximum flue gas velocity (m/s)	2.2	2.8	2.6
Concentration of pollutants in the flue gas			
PM (mg/Nm^3)	766 *(407 - 1164)*	143 *(90 - 249)*	370 *(282 - 414)*
$PM_{2.5}$ (mg/Nm^3)	160	48	74
SO_2 (mg/Nm^3)	610 *(582 - 637)*	29 *(16 - 42)*	326 *(193 - 404)*

Average SPM concentrations in the monitored FCBTKs range from 143 to 766 mg/Nm^3. The average concentration of SPM in the Kiln 1_FCBTK is 766 mg/Nm^3, which exceeds the Indian emission standard of 750 mg/Nm^3 prescribed by the MoEF for large and medium category of BTKs[18]. High particulate matter concentration reflects incomplete combustion resulting from a combination of factors, namely poor operating practices and wet weather conditions (unseasonal rains during the monitoring days). The poor environmental performance of Kiln 1_FCBTK is also an indication that the combustion conditions at the kiln were not yet stabilized, as the monitoring was done during the first firing cycle. SO_2 levels were also high in Kiln 1_FCBTK. SO_2 is result of sulphur content in coal and rubber tyres used as fuel. NOx levels were generally low (below the detection limit in a few cases) in monitored FCBTKs.

Aerosol properties

Aerosol optical properties (scattering and absorption) are measured in real time for a period of 25 to 45 minutes. Three tests were conducted in each kiln. These measurements have two purposes: Firstly, to measure scattering and absorption quantities that are directly relevant to visibility and climate; secondly, to measure real time optical properties in order to determine the effect of fuel charging on particulate emissions. In addition to real time measurement of scattering and absorption, particles collected on filter papers were analysed for organic and

[18] "*G.S.R. 543 (E) MoEF Notification*", Ministry of Environment and Forests, New Delhi, 2009.

elemental carbon. Results of measured aerosol optical properties and organic and elemental carbon are presented in Table 3-9.

Table 3-9: Scattering & absorption for Red λ and elemental and organic carbon concentration results for FCBTKs

	Unit	Kiln 1- FCBTK	Kiln 4-FCBTK	Kiln 6- FCBT
Scattering	*1/m*	0.25	0.68	0.16
Absorption	*1/m*	0.11	0.31	0.23
Elemental carbon	mg/m^3	130	68	42
Organic carbon	mg/m^3	5.05	2.79	3.03

Particle absorption measurements were taken at three wavelengths; blue (467nm), green (530nm), and red (660nm). Results at red wavelength are presented here, and the results from other wavelengths were used to calculate the absorption angstrom exponent. The results are presented in Table 3.10

Table 3-10: Particle Absorption Measurement for Red Wavelength in FCBTKs

	Kiln 1_FCBTK	Kiln 4_FCBTK	Kiln 6_FCBTK
Single Scattering Albedo (Red λ)	0.71	0.66	0.79
Absorption Angstrom exponent[1]	0.42	0.22	0.23
Elemental Carbon %	96%	96%	93%

[1]Between blue and red wavelengths

In the optical results, the single scattering albedo in the red wavelength can be compared to that of pure black carbon, which has a value of 0.226 at 500nm[19]. The results indicate that these particle emissions are less absorbing than pure black carbon, but are still quite dark.

[19] Conant, W. C., J. H. Seinfeld, J. Wang, G. R. Carmichael, Y. Tang, I. Uno, P. J. Flatau, K. M. Markowicz, and P. K. Quinn (2003), A model for the radiative forcing during ACE-Asia derived from CIRPAS Twin Otter and R/V *Ronald H. Brown* data and comparison with observations, *J. Geophys. Res.*, *108*(D23), 8661, doi:10.1029/2002JD003260

The absorption angstrom exponent for all the three FCBTK kilns are lower than 1. This indicates that the particles absorb light over the entire visible spectrum, and possibly that the particles are larger than black carbon from other emission sources.

The results of the thermal optical analysis reveal that elemental carbon was the dominant aerosol emission. It is also observed from the optical results that these carbon particles are not as light absorbing as pure black carbon. While elemental carbon is sometimes considered a near equivalent to black carbon, non-volatile organic carbon may constitute a significant amount of the EC fraction in this case.

The following charts display the real-time optical data collected at the three FCBTK kilns over three tests. All these tests are presented on the same scale. The variations in absorption measurements are due to fuel feeding. Black carbon is usually emitted during flaming combustion that occurs soon after fuel is added. Scattering (blue line), which represents total particles, always increases when absorption does at Kiln 1 and Kiln 6. However, there are also periods of high scattering when absorption is very low, likely due to smouldering combustion where fuel reacts and releases volatile material without flames. These occur especially at Kiln 4.

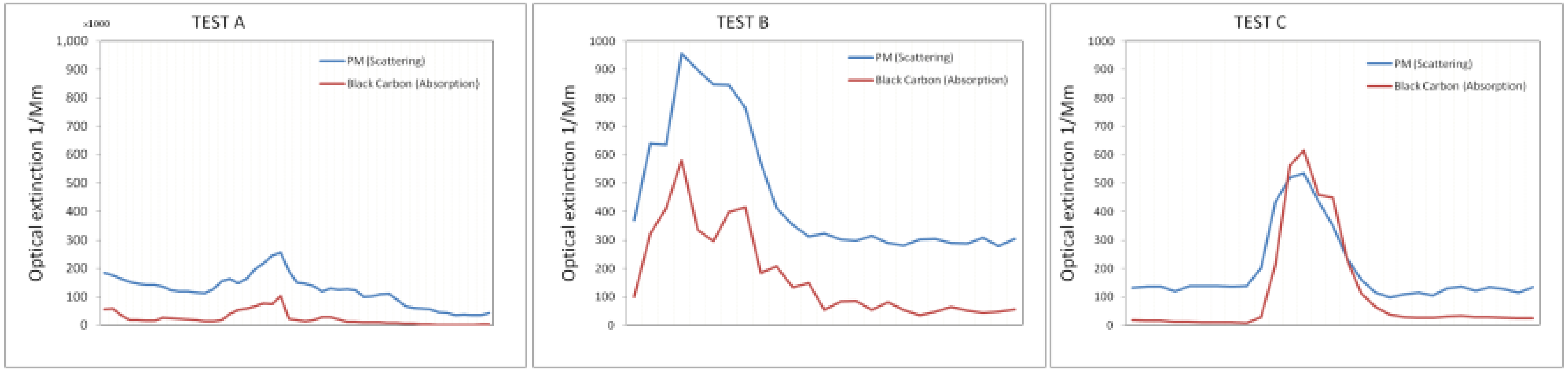


Figure 3-6 Real time optical data collected at Kiln 1_FCBTK

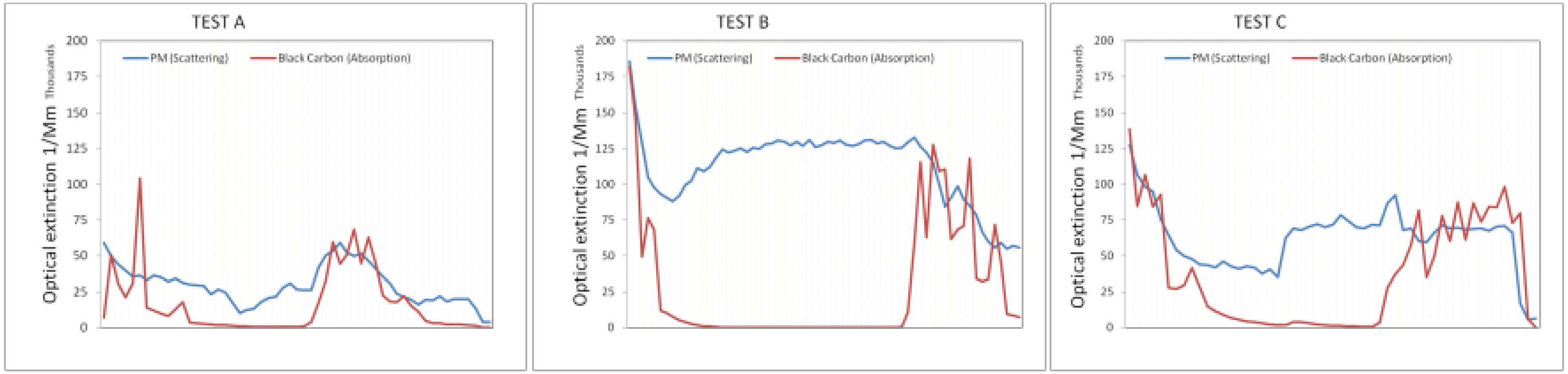


Figure 3-7: Real-time optical results of Kiln 4_FCBTK

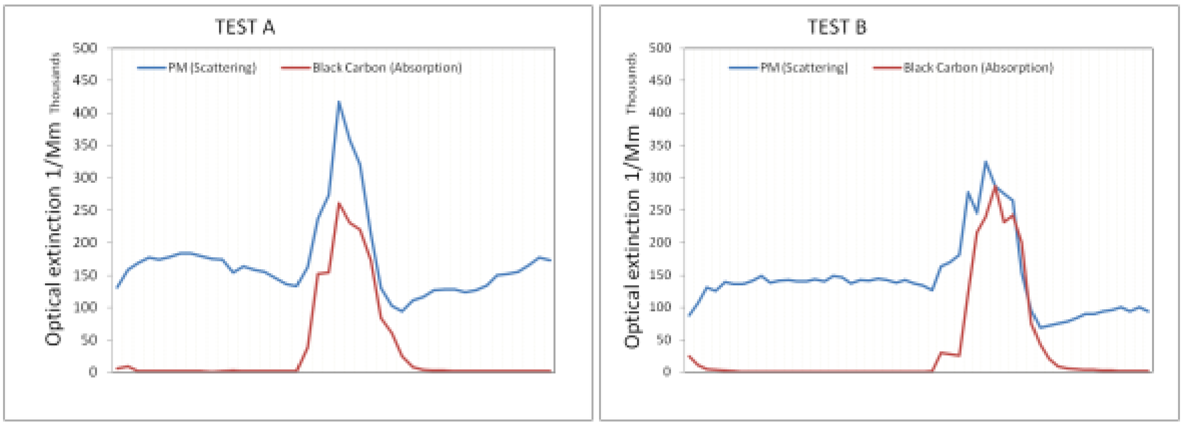


Figure 3-8: Real-time optical results of Kiln 6_FCBTK

In addition to above measurements, an impactor test with cut sizes at PM $_{10}$ and PM $_{2.5}$ was performed at Kiln 4 and 6 in order to get the particle size distribution of organic and elemental carbon. These particles were collected on quartz filters in a MOUDI three stage impactor. Table 3-11 and Figure 3-9 summarize the particle size distribution of organic and elemental carbon in kiln 4_FCBTK & kiln 6_FCBTK.

Table 3-11: Particle size distribution of EC & OC in Kiln 4 & Kiln 6

	Kiln 4_FCBTK		Kiln 6_FCBTK	
	Total Carbon fraction (%)	EC in Total Carbon fraction (%)	Total Carbon fraction (%)	EC in Total Carbon fraction (%)
>PM 10	1.1%	18%	0.24%	61%
PM 10	2.7%	90%	0.93%	80%
PM $_{2.5}$	0.75%	78%	10%	95%
Fines	95%	96%	88%	96%

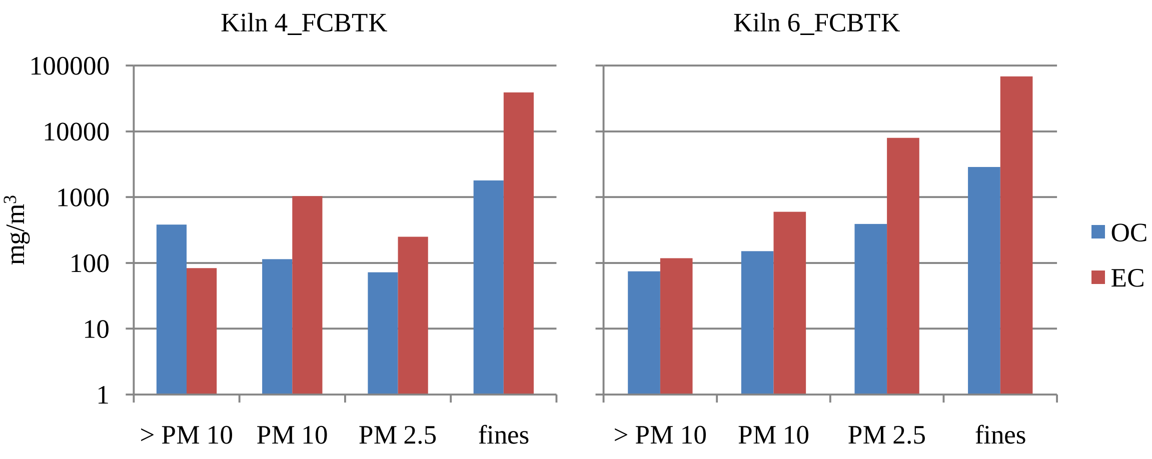


Figure 3-9 Particle size distribution of organic & elemental carbon at Kilns 4 and 6_FCBTK

Submicron aerosols dominated the particulate emissions in these FCBTKs with an average of 92% of the carbon measured in the fine impact or stage. Black carbon is usually emitted in particles smaller than $PM_{2.5}$, so the high elemental carbon to total carbon ratios in the $PM_{2.5}$ and fines sizes is expected.

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 a comparison based on brick production. Emission factors for PM and SO_2 were derived from emission rate (ER), fuel consumption rate, energy content of the fuel, and production rate. Another method – namely the carbon balance method (described in Annexure-III) – was used to estimate $PM_{2.5}$, CO, CO_2 and black carbon emission factors. Summary of emission factors of various pollutants are presented in Table 3-12.

Table 3-12: Emission factors of particulate matter and flue gas pollutants in FCBTKs

Pollutants			*g/kg fuel*	*g/MJ*	*g/kg fired brick*
Flue Gas Pollutants		CO	41.14	1.78	2.25
		CO_2	2182	92	115
		SO_2	10.45 ± 7.38	0.5 ± 0.38	0.66 ± 0.55
Particulate Matter	SPM	Total SPM	14.15 ± 8.91	0.65 ± 0.49	0.86 ± 0.74
		$PM_{2.5}$	3.03	0.14	0.18
	Aerosol Properties	Elemental Carbon	2.44	0.10	0.13
		Organic Carbon	0.12	0.005	0.01
			m^2/ kg fuel	*m^2/ MJ*	*m^2/kg fired brick*
		Scattering (Red λ)	11.19 ± 3.66	0.52 ± 0.16	0.67 ± 0.22
		Absorption (Red λ)	3.77 ± 1.99	0.17 ± 0.09	0.22 ± 0.13

3.5. Summary

Three FCBTKs of different capacities, using different fuels were monitored. A summary of the energy and emission results is shown below. A significantly large variation is observed in both the energy and environmental performance. The results show that the choice of fuels, climatic conditions, and operating practices has a large influence on the energy consumption and environmental emissions of the kiln.

Energy and process

- The average specific energy consumption (SEC) for the three kilns varied between 1.1 to 1.46 MJ/kg of fired brick.
- The operating practices at all the kilns offer opportunity for improvement. In all the cases, 10-15% reduction in fuel consumption is possible through improved operating practices.
- Under the current management practice of brick kilns, the owners are unable to enforce (through better supervision and the use of monitoring equipment) or incentivise (providing incentives to the firemaster/firemen) better operating practices. There is a strong case for semi-mechanization of the fuel preparation and feeding system in FCBTKs or shifting to more efficient brick firing systems.

Emissions

- Average SPM concentration of the three monitored FCBTKs ranged between 143 mg/Nm^3 to 766 mg/Nm^3. SPM results of three FCBTKs monitored in the present study are in agreement with the earlier reported results of 148 mg/Nm^3 to 800 mg/Nm^3 (TERI, 1998[20], CPCB 1996[21], Aslam et al 1993[22]). The results show that the average SPM concentration in FCBTKs, under normal operating practices, are able to meet the Indian emission standard of 750 mg/Nm^3.
- Significant variation in the SO_2 concentration (29 – 610 mg/Nm^3) was observed in three monitored kilns. SO_2 concentration is heavily dependent on the sulphur content of the fuel.
- NOx emissions were low in all three of the FCBTKs.

Aerosol properties

- The average emission factor for $PM_{2.5}$ (for the three monitored kilns) was 3.03g/kg fuel. Kiln 1 had the highest $PM_{2.5}$, as well as SPM concentrations.
- The relationship between scattering and absorption gives an indication of the atmospheric effects of source emission. The single scattering albedo ranged from 0.79 to 0.66. The highest percentage of scattering particles was found in kiln 6 and the highest percentage of absorbing particles was in kiln 4. But these variations are slight. There are greater variations within each kiln during feeding and non-feeding periods, and the results from each kiln are not significantly different.
- Filter based elemental carbon measurements averaged over the tests were 3.8, 3.24 and 1.46 g EC/kg fuel for the three kilns.
- Elemental carbon constitutes more than 93% of the total carbon deposited on the filters. But, this chemically measured carbon is not as absorbing as pure black carbon and may differ from the black carbon that is measured from other sources.
- Due to intermittent fuel feeding, the particle emissions vary significantly with time. In some cases, stack concentrations of absorbing particles were found to be about 12 times higher during fuel charging periods than during non-charging periods. Kiln 4

[20] TERI. 1998. Stack emission and energy monitoring of fixed chimney brick kilns. New Delhi: Tata Energy Research Institute

[21] Central pollution control board (1996), Comprehensive industry document with Standards/Guidelines for pollution control in brick kilns, Series: COINDS/16/1995-96, Delhi

[22] Aslam, M, (1993) Environmental concerns in brick industry, Brick & Tile News, New Delhi, pp 33-39

had a lower effect of charging. All kilns have a continuous emission of non-absorbing particles, which increases somewhat during charging.

Chapter 4. Zig-zag kilns

4.1 Zig-zag kilns

In a zig-zag kiln, the fire follows a zig-zag path (Figure 4.1) instead of the straight path followed in a FCBTK.The zig-zag kiln is considered an improvement over the FCBTKs and results in:

a) Higher heat transfer rates between the air and bricks due to higher velocities and turbulence caused by the frequent change in direction of air/flue gas.
b) Improved combustion due to better mixing of air and fuel in the combustion zone and longer time available for volatiles in the combustion zone.
c) Shorter length of the kiln and hence smaller footprint of the kiln.

The zig-zag firing concept was first used in the Buhrer Kiln (patented in 1868). The Buhrer kiln was similar to a Hoffmann kiln in construction. The main innovation was the zig-zag path to increase the length of the firing channel and accelerate the firing through a flue gas fan. Zig-zag kilns were widely used in Germany between the first and Second World Wars. They were also popular in Australia. The zig-zag kiln was introduced in India by the Central Building Research Institute during the early 1970's in the form of a high draught kiln. Several hundred zig-zag kilns are believed to be operational, mostly in the eastern region of the country. All but a few kilns use a fan to create draft (and hence are called forced draught zig-zag kilns). The requirement of an electricity supply 24/7 for the continuous operation of a forced draught zig-zag kiln is an important barrier to wide scale adoption. In recent years, some of the brick makers have modified the brick setting and practices and have successfully operated the kiln with natural draught.

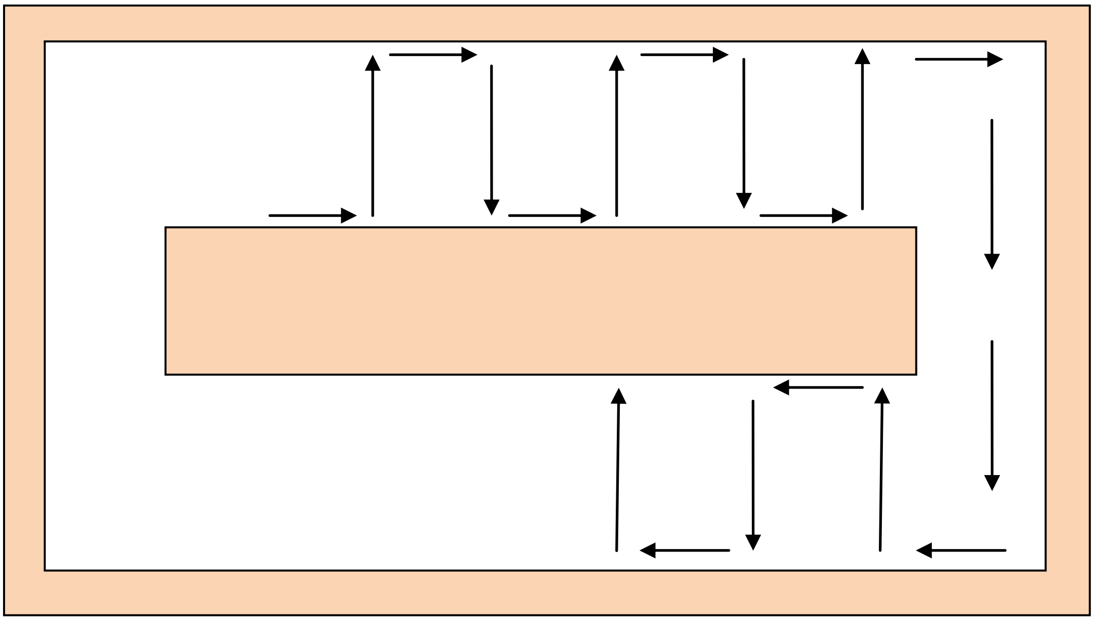


Figure 4-1: Air Flow in a single zig-zag kiln

Green bricks to be fired are placed in the annular space and covered with a layer of partially fired or green bricks. Similar to a FCBTK, a layer of ash and brick dust is spread over the top to seal the kiln and provide thermal insulation. The brick-unloading end is kept open for air entry into the kiln. The brick-loading end is sealed with the help of a metal, cloth, paper or plastic damper. Fuel is fed manually in the feed holes provided on the top of the kiln. Fuel feeding is intermittent.

Comparison between natural draught zig-zag and forced draught zig-zag kilns

Natural draught zig-zag	*Forced draught zig-zag*
➢ Draught is created naturally with the help of a chimney.	➢ Draught is created artificially with the help of a fan.
➢ Operates under a negative pressure of 8 – 10 mm water column.	➢ Operates under a negative pressure of around 50 mm water column.
➢ Brick setting is less dense to reduce pressure drop so as to operate with natural draught.	➢ Brick setting is very dense.
➢ Height of Chimney is around 120 – 130 ft.	➢ Height of the chimney is around 55 – 60 ft.
➢ No electricity/diesel is required for operation of the kiln.	➢ Electricity /Diesel is required for operation of the kiln.

At any given point of time, three distinct zones can be identified in a zig-zag kiln. Proceeding from the unloading end, the first zone is the brick cooling zone. In this zone, air entering from the unloading end picks up heat from fired bricks, resulting in the heating of air and the cooling of fired bricks. The next zone is the fuel feeding zone (combustion zone), in which coal is fed from the feedholes provided on the roof of the kiln. Coal comes in contact with hot gases, and combustion takes place in this zone. The last zone is the brick-preheating zone; in this zone heat available in the flue gases is used to preheat green bricks. In the kiln, fire movement takes place in the direction of air travel. When the firing of a chamber is completed, it is closed and the next chamber is opened. Generally fuel feeding takes place in 1-3 chambers at a time.

Two zig-zag kilns were selected for monitoring. The salient features of these kilns are given in the table below. The locations are marked on the Indian map (Figure 4-2), both are located near Varanasi.

Table 4-1: Salient features of the monitored zig-zag kilns

Kiln Identification No	Location	Production Capacity		Fuel	Time of Monitoring	
		Bricks/day	Bricks/yr (Million)		Date	Comment
Kiln 2_zig-zag_ND	Varanasi (UP)	45,000	6 - 8	➢ Assam & Jharia Coal ➢ Saw Dust	9th – 11th March 2011	first firing cycle
Kiln 3_ zig-zag_FD	Varanasi (UP)	30,000	5 - 6	Coal	13th – 14th March 2011	

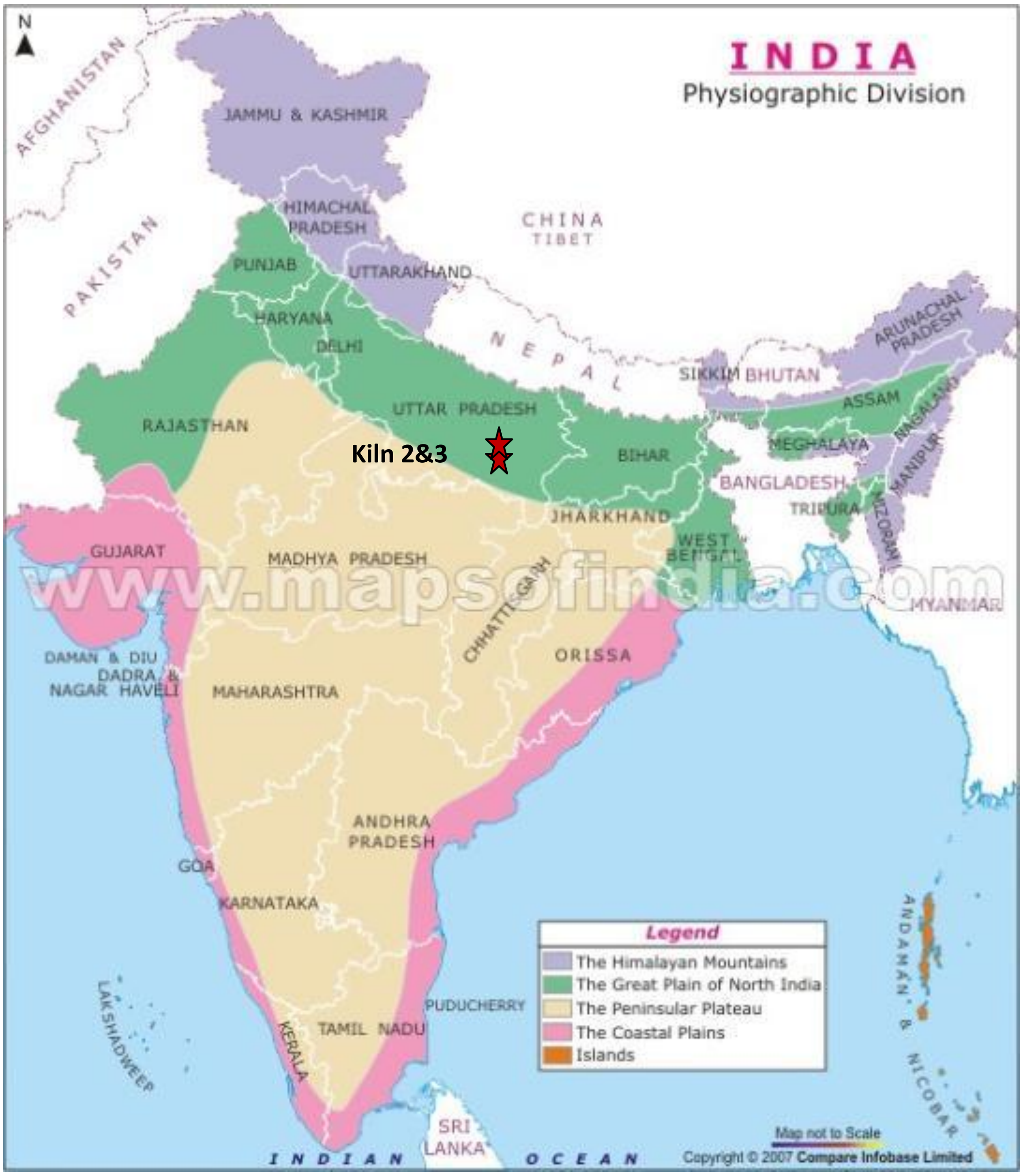


Figure 4-2: Locations of monitored zig-zags

4.2 General Description of the Monitored Kilns

Table 4-2 Description of the monitored zig-zag kilns

	Kiln 2_zigzag_ND	Kiln 3_zigzag_FD
Location	Varanasi, UP	Varanasi, UP
Description of company	➢ The owner is a second-generation brick maker ➢ Family business for last 70 years ➢ Currently the company operates three kilns	➢ The owner is an experienced brick maker ➢ Is in business for last 20 years
Annual Production	➢ 6 – 8 million bricks/ year	➢ 5 – 6 million bricks/ year
Supplying Market	➢ Majority of the market in the radius of 50 km ➢ Varanasi & near by areas. Some of the bricks are sold up to a distance of 200 km.	➢ In the radius of 50 km ➢ Varanasi & nearby areas.
Operational period	➢ Dry months (Mainly December to June) ➢ The kiln is covered, so potentially can be operated for longer period. This is the first year kiln has had shade.	➢ Dry months (December to June) ➢ Operation period is short because the kiln is open to air
Kiln Description	➢ Converted from traditional FCBTK to zig-zag natural draught around 7 – 8 years ago. ➢ Triple zig-zag firing ➢ Kiln is covered with shade ➢ Kiln trench width 10m ➢ To operate on natural draught, the brick setting has been made less dense compared to a normal forced draught zig-zag kilns ➢ Chimney height similar to FCBTK	➢ Typical high draught kiln single zig-zag firing ➢ Kiln is not covered ➢ Trench width 8 m ➢ Kiln structure is old and needs repairs (possibility of leakages from the structure & valves) ➢ Chimney height smaller than FCBTK because the necessary draught is generated using a fan. ➢ Draft is induced through a 5 hp fan ➢ Flue gas duct operation is based on valve system

	Kiln 2_zigzag_ND	Kiln 3_zigzag_FD
	➢ Modifications in flue gas duct operation mechanism, use of shunt system[a]	
Moulding	➢ Hand moulding ○ Solid Bricks	➢ Hand moulding ○ Solid Bricks
Drying	➢ Drying Shade[b] ○ Machine moulded bricks are dried under shade ➢ Open drying under sun	➢ Open drying under sun
Firing Fuel	➢ Coal ○ Assam[c] coal ○ Jharia coal[d] ➢ Saw dust	➢ Coal ○ Mixture of Assam[c] & Jharia[d] coal

[a] A shunt is a metal duct, which is used to connect the central duct of the chimney with the side ducts. The use of shunt reduces the possibility of air leakage and improves the working condition of firemen.
[b] A drying shade avoids direct exposure to the sun and hence reduces the possibility of drying cracks and protects the green bricks from unseasonal rains.
[c] Assam coal is a high volatile, high sulphur and high calorific value bituminous coal
[d] Jharia coal is a medium to high ash content, medium volatile bituminous coal.

4.3 Energy performance of the monitored kilns

Fuel feeding practice

The details of the fuel feeding practice are given in Table 4-3. Table 4-4 presents the chamber wise fuel feeding practice observed in Kiln 2_zigzag_ND.

Table 4-3: Fuel feeding practice in the monitored zig-zag kilns

Kiln Identification No	Fuel feeding Practice
Kiln 2_zigzag_ND	➢ Fuel was fed in 6 chambers. ➢ Fuels were fed by one fireman almost continuously. ➢ Depending on the amount of fuel required, an appropriate spoon was used. ➢ The coal was crushed to a small size in a coal crusher before feeding. ➢ Saw dust was used in the newly opened chamber where the temperatures were in the range of 480 – 635^{o}C. ➢ Assam & Jharia coals were being used in the middle of the firing zone having a temperature range of 970 – 1035^{o}C.
Kiln 3_zigzag_FD	➢ Fuel was fed in 1 chamber at a time. ➢ Fuels were fed by two firemen intermittently. ➢ Coal was crushed to a small size in a coal crusher before feeding. ➢ Fuel feeding was irregular and unsupervised. ➢ A large spoon (250g) was used for feeding in the front row and a small spoon (150g) was used for the back row. ➢ Temperatures in the firing zone were in the range of 1000 - 1030^{o}C.

Table 4-4: Fuel mix in the chambers in firing zone in kiln 2_zigzag_ND

Chamber 1 (towards the green bricks end): Newly opened chamber. Temperature at the bottom chamber is 480-635 °C. Saw dust having low ignition temperature is fed.	**Chamber 2**: Temperature at the bottom chamber is 830-910 °C. Saw dust mixed with Jharia coal is fed.	**Chamber 3**: Temperature at the bottom chamber is 970-1010 °C. Jharia coal is fed.	**Chamber 4**: This chamber has the highest temperature. Temperature at the bottom chamber is 1035-1036 °C. Jharia coal is fed.	**Chamber 5**: Temperature at the bottom chamber is 935 -1020°C. Assam coal, which has high volatile matter is fed. The volatiles released are carried forward and burned in the forward section.	**Chamber 6 (towards the fired bricks end)**: Temperature at the bottom chamber is 800-845 °C. Saw dust mixed with Jharia coal is fed before the chamber is closed.

Energy performance

Flue gas measurements were taken at regular intervals at a central duct connecting to the chimney on Kiln 2_zigzag_ND and on the monitoring port in the chimney on kiln 3_zigzag_FD. The results of the two zig-zag kilns are presented in Table 4-5.

Table 4-5: Flue gas analysis of zig-zag kilns

	Kiln 2_zigzag_ND	Kiln 3_zigzag_FD
Time average O_2 (%)	14.3	18.1
Time average CO_2 (%)	4.7	2.6
Time average CO (ppmv)	645	1700
Average Excess Air (%)	203	587
Average temperature of flue gas (°C)	77.5	102.4

Figure 4-3 shows the variation in the concentration of O_2, CO and CO_2 over 45 minutes period for kiln 2_zigzag_ND.

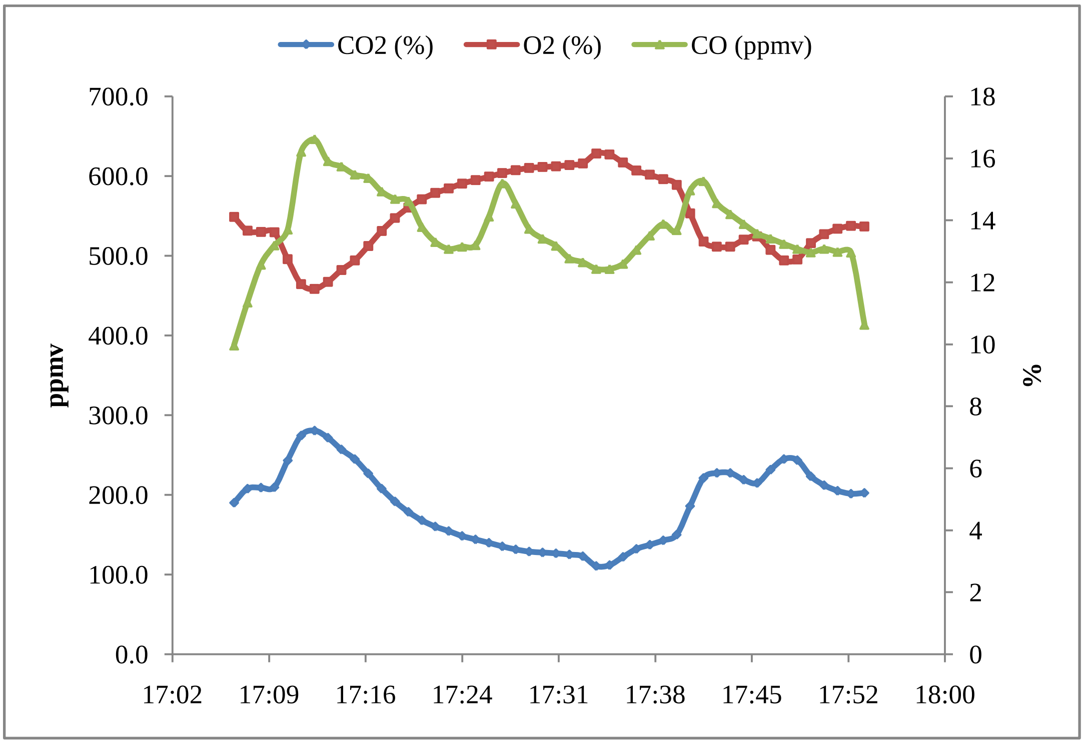


Figure 4-3: Variation in CO, O_2 and CO_2 at kiln 2_zigzag_ND

It can be observed that in the case of Kiln 2_zigzag_ND, the variation in the concentration of CO, CO_2 and O_2 is small (as compared to FCBTKs, please refer to Figures 3-3 to 3-5); this is primarily due to the practice of continuous feeding of fuel in small quantities. Further, adoption of good operating practice in the kiln (continuous feeding, feeding of sawdust and appropriate fuel mix in different chambers depending on the temperature, feeding fuel in small quantities) results in better combustion of fuel. As a result, the average CO concentration is 645 ppmv, which is much lower than the CO concentrations of 3000-5000 ppmv during coal feeding in FCBTKs. The average excess air is 203%, which is ideal for a natural draught, annular kiln; the average flue gas temperature is 78°C, which indicates almost full recovery of energy in the kiln.

Figure 4-4 show the variation in the concentration of O_2, CO, and CO_2 over 35 minutes period for Kiln 3_zigzag_FD.

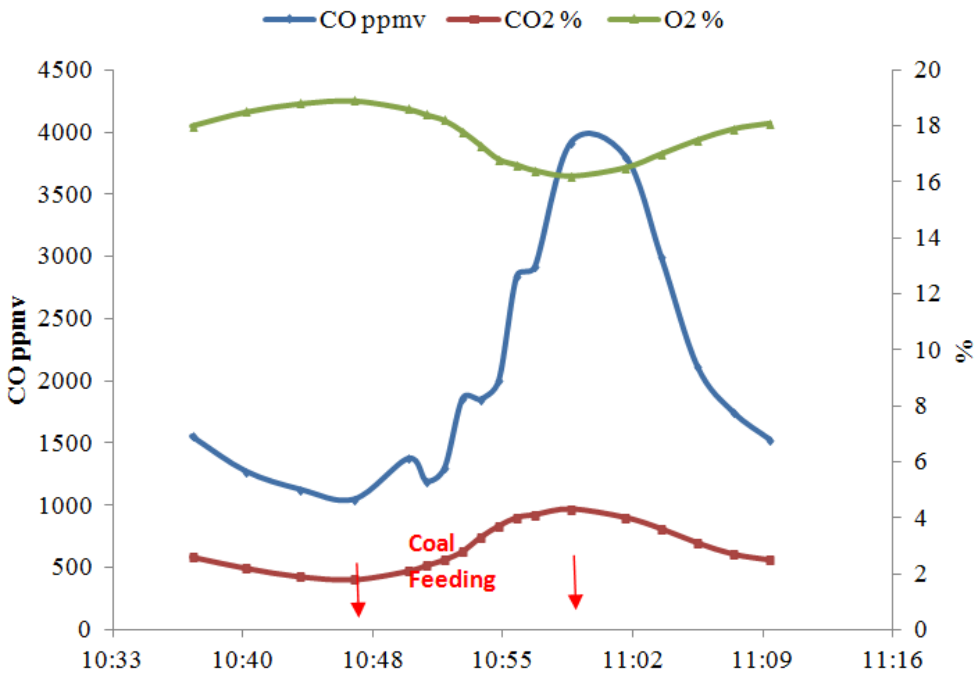


Figure 4-4 Variation in O_2, CO, and CO_2 at kiln 3_zigzag_FD

The kiln 3_zigzag_FD shows an increase in CO concentration from 1000 ppm (coal non-feeding) to 4000 ppmv (peak CO concentration during coal feeding). The variations are large and are quite similar to that observed in FCBTK, as the Kiln 3_zigzag_FD has a similar coal feeding pattern (5-10 minutes of coal feeding, followed by 15-20 minutes of non-feeding).

Average excess air for Kiln 3_zigzag_FD is computed as 587% . High excess air levels in Kiln 3_zigzag_FD indicate high leakages in the kiln.

<u>Specific energy consumption and heat balance</u>

Based on the fuel consumption rate and brick production (kg of bricks fired per day), specific energy consumptions were computed and shown in Table 4-6.

Table 4-6: Specific energy consumption of the monitored zig-zag kilns

	Fuel Consumption (kg/day)			Production		SpecificEnergy Consumption (SEC) (MJ/kg fired brick)
Kiln 2_zigzag_ND	*Coal Assam*	*Coal Jharia*	*Sawdust*	*Bricks/day*	*kg/day*	1.21*
	1836	3884	1488	44400	121656	
Kiln 3_zigzag_FD	*Coal (Mix)*			*Bricks/day*	*kg/day*	1.03**
	3494			28875	81139	

*Based on GCV and assuming 8% moisture content in Assam and Jharia Coal and 15% moisture content in the saw dust.
**Based on GCV and assuming 8% mosisture content in Coal (Mix).

The SEC for the two zig-zag kilns are in the range of 1.03 to 1.21 MJ/kg of fired bricks. The SEC of Kiln 2_zigzag_ND is higher than expected; this may primarily be due to the fact that the kiln was in its first firing round after the start of the season. The SEC of the kiln is expected to reduce by 10-15% and approach 1 to 1.1 MJ/kg of fired bricks as the season progresses.

Table 4-7 presents the heat balance for the two zig-zag kilns monitored in the study.

Table 4-7: Heat balance of the monitored zig-zag kilns

	Kiln 2_zigzag_ND	Kiln 3_zigzag_FD
Dry flue gas heat loss	5.24 %	16.1%
Sensible heat loss in unloaded bricks	4.88 %	7.5 %
Moisture removal	21.2 %	23.7%
Heat loss due to incomplete combustion	0.86 %	3.6 %
Other heat components	67.8 %	49 %
Total	100 %	100 %

Energy efficiency improvement measures

The Kiln 3_zigzag_FD has potential for improvement in energy efficiency by adopting better operating practices and reducing leakages. The owner reported the problem of bricks being too hot at the unloading point. Upon inspection of the kiln by the project team, an air leakage was detected in the main central valve of the flue duct, which was causing air flow to bypass the cooling region of the kiln, and hence resulting in less cooling of bricks in the cooling zone. Managing leakages is an important issue in forced draught zig-zag kilns. Moving to the continuous feeding of coal is another possible improvement. The overall potential for energy savings by better kiln operation and maintenance is expected to be 10-15%.

4.4 Emissions

Measurements of SPM, SO_2, and NO_X emissions were carried out in the chimney as per the methodology described in Chapter 2. The sampling port at Kiln 2_zigzag_ND was 15 m from the ground level. The sampling port at Kiln 3_Zig-Zag_FD kiln was 8 m from the ground level. Three experiments were conducted at each kiln to measure the concentration of PM, $SO_{2,}$ and NO_X. Sampling time for each experiment ranged from 45 to 50 minutes, covering both the coal feeding and non-feeding period. Prior to thecsample collection, flue gas temperature and velocity were measured at the sampling port. Iso-kinetic sampling procedure was followed for particulate matter sampling. Table 4-8 presents the results of environmental monitoring.

Table 4-8: Flue gas characteristics and emission concentrations in the zig-zag kilns

	Kiln 2_zigzag_ND	Kiln 3_zigzag_FD
Flue gas temperature (°C)	65 - 80	100 – 110
Flue gas velocity (m/s)	0.6	2.4 – 2.9
Concentration of pollutants in the flue gas		
SPM (mg/Nm^3)	31 *(13-49)*	183 *(122-247)*
SO_2 (mg/Nm^3)	85 *(65 – 106)*	202 *(129 – 308)*

SPM concentrations in the Kiln 2_zigzag_ND ranged between 13 to 49 mg/Nm^3; the average SPM concentration was 31 mg/Nm^3. SPM concentrations in Kiln 3_zigzag_FD ranged between 122 to 247 mg/Nm^3; the average SPM concentration was 183 mg/Nm^3. In general, SPM emissions in zig-zag kilns were found to be lower compared to FCBTKs and also significantly lower than the Indian emission standard of 750 mg/Nm^3 prescribed by the MoEF for large and medium category BTKs.

In Kiln 2_zigzag_ND, concentrations of SO_2 ranged from 65 mg/Nm^3 to 106 mg/Nm^3 with the average being 85 mg/Nm^3. In the Kiln 3_zigzag_FD, concentrations of SO_2 ranged from 129 mg/Nm^3 to 308 mg/Nm^3 with the average being 202 mg/Nm^3. SO_2 concentrations were higher in the forced draught zig-zag than in the natural draught zig-zag, which is mainly due to the higher sulphur content of the coal mix used in the former kiln. Concentrations of NO_X were found to be below the detection limit in each of the kilns.

Aerosol properties

Aerosol optical properties (scattering and absorption) were measured in real time for a period of 25 to 45 minutes. Three tests were conducted in each kiln. The results of scattering and absorption are presented in Table 4-9. It should be noted that the scattering measurements at kiln 2 were spurious and may be affected by measurement error, as the readings are much higher than expected for the measured levels of particulate matter. Therefore, extreme caution should be used in drawing conclusions about this scattering signal, including the value of single scatter albedo.

Table 4-9: Scattering and absorption for red λ and elemental and organic carbon concentration results for zig-zag kilns

	Unit	Kiln 2_zigzag_ND	Kiln 3_zigzag_FD
Scattering	*1/m*	1.03*	0.18
Absorption	*1/m*	0.046	0.10
Elemental Carbon	*mg/m^3*	15	23
Organic Carbon	*mg/m^3*	6	16

*Value is questionable

Particle absorption measurements were taken at three wavelengths; Blue (467nm), Green (530nm), and Red (660nm). Results at red wavelength are presented here, and the results from other wavelengths were used to calculate the absorption angstrom exponent. The results are presented in the Table 4-10.

Table 4-10: Particle absorption measurement for red wavelength in zig-zag kilns

	Kiln 2_zigzag_ND	Kiln 3_zigzag_FD
Single Scattering Albedo (Red λ)	0.96**	0.64
Absorption Angstrom exponent*	0.44	0.55
Elemental Carbon %	64%	60%

* Between blue and red wavelengths
**Value is questionable

In the optical results, the single scattering albedo in the red wavelength can be compared to that of pure black carbon, which has a value of 0.226 at 500nm[23]. An aerosol that does not absorb any light has a single scattering albedo of 1.0. The results indicate that these particle emissions are less absorbing than pure black carbon.

The absorption angstrom exponent for both the zig-zag kilns is lower than 1. This indicates that the particles absorb light over the entire visible spectrum, and possibly that the particles are larger than black carbon from other emission sources.

The results of the thermal optical analysis indicate that elemental carbon was about half of the total aerosol emission. It is also observed, from the comparison between elemental carbon and absorption, that the EC is not as light absorbing as pure black carbon, with about half the absorption per mass. While elemental carbon is sometimes considered a near equivalent to black carbon, non-volatile organic carbon may constitute a significant amount of the EC fraction in this case.

Figures 4-5 and 4-6 display the real-time optical data collected at the two zig-zag kilns over three tests. All tests are presented on the same scale. The variations in absorption measurements are due to intermittent fuel feeding. Black carbon is usually emitted during

[23] Conant, W. C., J. H. Seinfeld, J. Wang, G. R. Carmichael, Y. Tang, I. Uno, P. J. Flatau, K. M. Markowicz, and P. K. Quinn (2003), A model for the radiative forcing during ACE-Asia derived from CIRPAS Twin Otter and R/V *Ronald H. Brown* data and comparison with observations, *J. Geophys. Res.*,*108*(D23), 8661, doi:10.1029/2002JD003260

flaming combustion that occurs soon after fuel is added. Absorption during charging periods is about three times higher than that of non-charging periods for natural draught zig-zag, and six times higher for forced draught zig-zag. Scattering (blue line), which represents total particles, always increases when absorption does at the monitored kilns. As mentioned above the scattering signal in the natural draught zig-zag kiln could be questionable, so no conclusions will be drawn from these data. At the forced draught zig-zag, scattering was about three times higher during charging than non-charging periods.

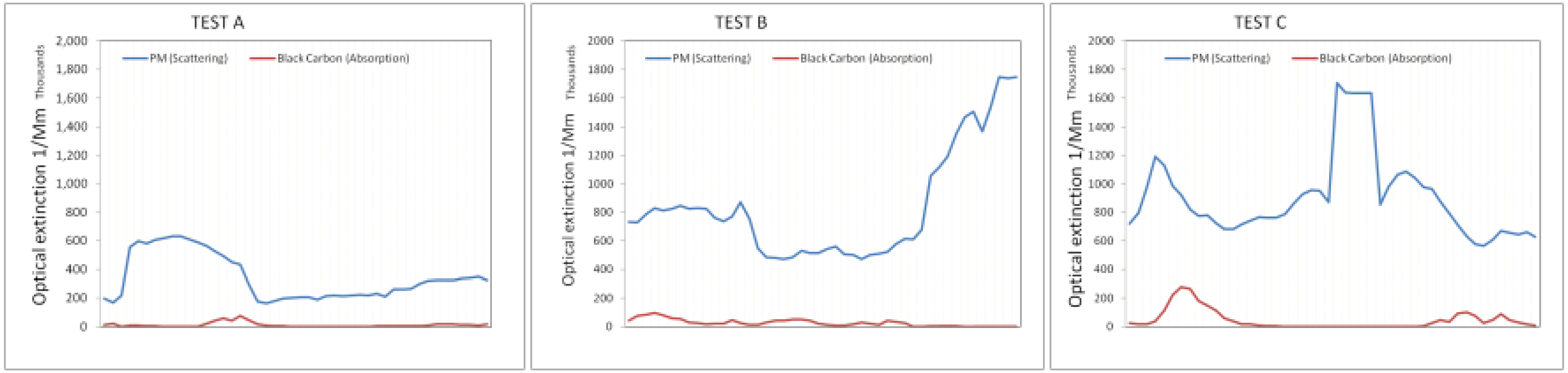


Figure 4-5 Real-time optical data collected at Kiln 2_zigzag_ND

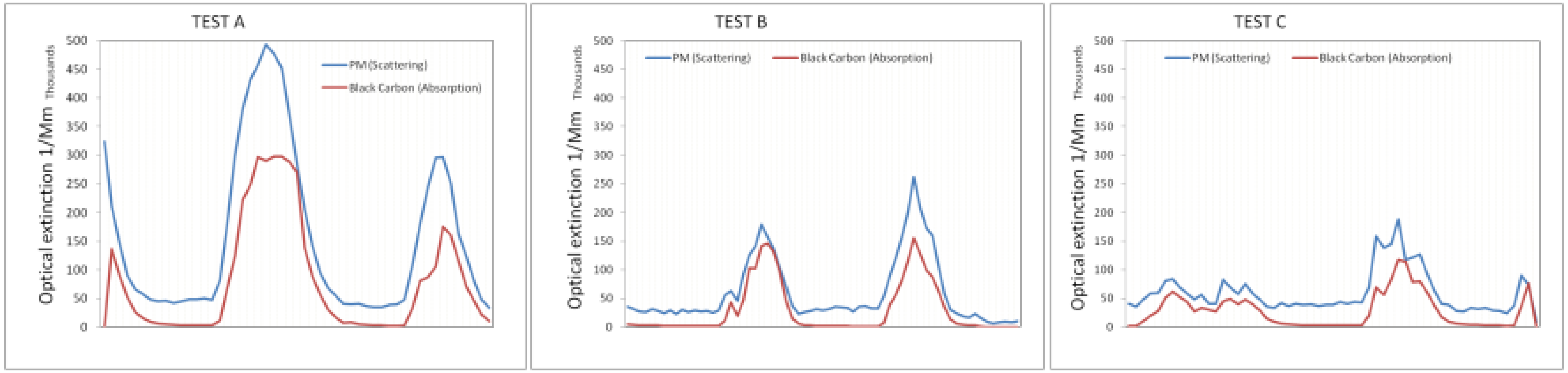


Figure 4-6 Real-time optical data collected at Kiln 3_zigzag_FD

In addition to the above measurements, an impactor test with cut sizes at PM_{10} and $PM_{2.5}$ was performed to get the particle size distribution of organic and elemental carbon. Table 4-11 & Figure 4-7 summarize the particle size distributions of organic and elemental carbon. These particles were collected on quartz filters in a MOUDI three stage impactor.

Table 4-10: Particle size distribution of EC and OC in kiln 2 and kiln 3

	Kiln 2_zigzag_ND		Kiln 3_zigzag_FD	
	Total Carbon fraction (%)	EC in Total Carbon fraction (%)	Total Carbon fraction (%)	EC in Total Carbon fraction (%)
>PM 10	0.66%	1.4%	9%	13%
PM 10	0.82%	1.9%	22%	15%
PM $_{2.5}$	12%	7%	96%	81%
Fines	87%	90%	91%	77%

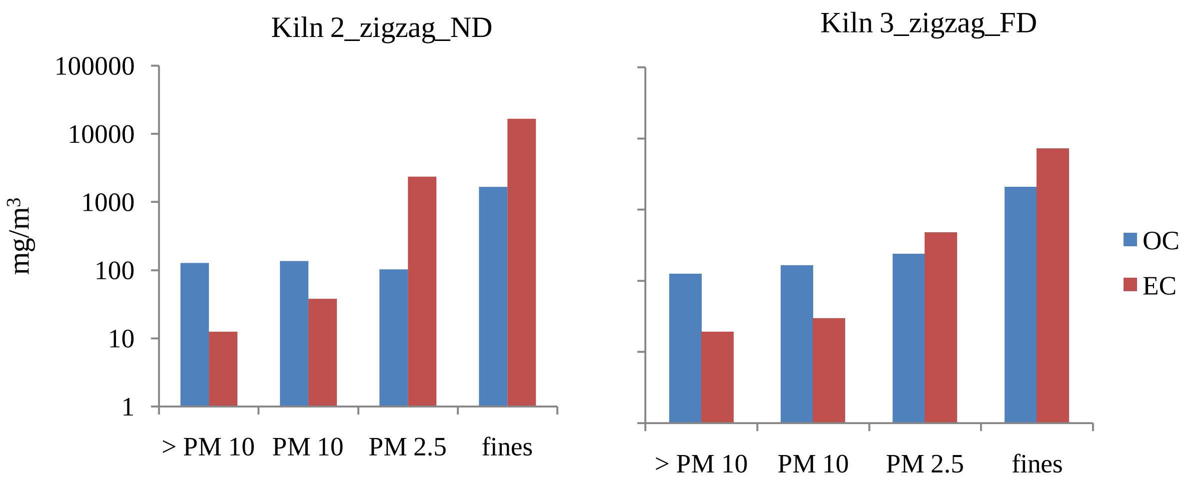


Figure 4-7 Particle size distribution of organic & elemental carbon at kilns 2 and 3

Submicron aerosols dominated the carbon emissions in these zig-zag kilns with an average of 89% of the carbon measured in the fine impact or stage. Black carbon is usually emitted in particles smaller than PM $_{2.5}$, so the high elemental carbon to total carbon ratios in the PM $_{2.5}$ and finer sizes confirms the same.

Emission factors

Pollutant emissions vary according to type of kiln, fuel used and operating conditions. Comparing the emissions across different fuel/operating conditions requires normalizing to either unit of fuel consumed or to unit of energy consumed, or a comparison based on brick production. Emission factors for PM and SO_2 were derived from emission rate (ER) and fuel consumption rate, energy content of the fuel, and production rate. Another method, namely the carbon balance method (described in Annexure -III), was used to estimate $PM_{2.5}$, CO, CO_2 and black carbon emission factors. A summary of emission factors of various pollutants for zig-zag kilns is presented in Table 4-12.

Table 4-11: Emission factors of particulate matter and flue gas pollutants in zig-zag kilns

Pollutants			*g/kg fuel*	*g/MJ*	*g/kg fired brick*
Flue Gas Pollutants		CO	32.4	1.39	1.47
		CO_2	2017	91	103
		SO_2	3.86 ± 4.34	0.3 ± 0.28	0.32 ± 0.28
Particulate Matter	SPM	Total SPM	5.82 ± 6.07	0.25 ± 0.25	0.26 ± 0.26
		$PM_{2.5}$	2.66	0.12	0.13
	Aerosol Properties	Elemental Carbon	0.83	0.04	0.04
		Organic Carbon	0.53	0.02	0.02
			m^2/ kg fuel	*m^2/ MJ*	*m^2/kg fired brick*
		Scattering (Red λ)	16.76	0.78	0.91
		Absorption (Red	3.57	0.15	0.16

4.5 Summary

Energy and Process

- The average specific energy consumption (SEC) for the two kilns was 1.03 and 1.21 MJ/kg of fired brick. Better heat transfer and improved combustion in zig-zag kilns result in lower fuel consumption.
- Better heat distribution in the kiln, resulting in uniform temperature across kiln cross-section, results in a higher class-I brick output (> 85% in the case of the natural draught zig-zag kiln).

Emissions

- The average SPM concentration for the two zig-zag kilns was 31 and 183 mg/Nm^3. The forced draught zig-zag kiln has poor operating practices and reported higher SPM emissions.
- The SPM emission factor for the poorly-operated forced draft zig-zag kiln was ten times higher than for the well-operated natural draft zig-zag kiln.
- There is not much information available on the emission characteristics of zig-zag kilns. The only reported results are from a study by Teri (1998)[24], which had reported SPM emission level of 14-37 mg/Nm^3 for a natural draught zig-zag kiln and 151 mg/Nm^3 for a forced draught zig-zag kiln, which are comparable to the results obtained in this study.
- Concentrations of SO_2 in the two zig-zag kilns monitored ranged from 65 mg/Nm^3 to 308 mg/Nm^3 with average levels of 85 mg/Nm^3 for the natural draught zig-zag kiln and 202 mg/Nm^3 for the forced draught zig-zag kiln.
- NO_x levels in the two zig-zag kilns monitored were below detection limit.

Aerosol Properties

- Emission factors for $PM_{2.5}$ were 1.97 and 3.36 g/kg of fuel. The forced draft kiln had the higher $PM_{2.5}$ emissions.
- Scattering emission factors were 10.62 m^2/kg of fuel in the forced draft kiln, but the measurement in the natural draft kiln was questionable. Average absorption emission factors measured were 1.03 in the natural draft and 6.11 m^2/kg fuel in the forced draft kiln. The single scattering albedo was 0.64 in the forced draft kiln.
- Filter based elemental carbon measurements reported emission factors of 0.33 g EC/kg of fuel in the natural draft and over four times higher in the forced draft (1.34 g/kg of fuel).
- Among the monitored zig-zag kilns, the forced draught kiln appears as a higher emitter of black carbon and light absorption particles.

Of the two types of zig-zag kilns monitored during the study, the zig-zag natural draught kiln has better operation and control over the firing process as reflected in lower emissions and better quality of fired bricks. The zig-zag forced draught kiln has lower

[24] TERI. 1998. Stack emission and energy monitoring of fixed chimney brick kilns. New Delhi: Tata Energy Research Institute

SEC, but, because of poor operation, it lagged in terms of quality of fired bricks and had higher emissions. Overall in terms of energy consumption, emissions, and the quality of fired bricks, the zig-zag kilns perform better than FCBTK. A detailed study is required to further investigate and understand the performance of zig-zag kilns and suggest appropriate zig-zag technology as a possible replacement to FCBTKs.

Chapter 5. Vertical Shaft Brick Kiln

5.1. Vertical Shaft Brick Kiln

The evolution and initial development of the Vertical Shaft Brick Kiln (VSBK) technology took place in rural China. The first version of VSBK in China originated from the traditional updraft intermittent kiln during the 1960's. In the next decade, the kiln became popular in several provinces. In 1985, the Chinese government commissioned the Energy Research Institute of the Henan Academy of Sciences at Zhengzhou, Henan, to study the kiln and improve its energy efficiency. The institute came up with an improved design of VSBK in 1988. The improved design had a higher shaft height and also a provision for a pair of chimneys. In 1996, several thousand VSBKs were reported to be operating in China. Since then the technology has been transferred (under various development projects) to several countries, including India, Nepal, Afghanistan, Vietnam, Pakistan, Sudan, and South Africa. Among these countries the technology has gained wide-spread popularity in Vietnam only; in other countries the dissemination of the VSBK technology is still limited to a small number of enterprises.

VSBK has a vertical shaft of rectangular or square cross-section. The shaft is located inside a rectangular brick structure; the gap between the shaft wall and outer kiln wall is filled with insulating materials – clay, fly ash and rice husk. Some of the kilns in Vietnam have also used modern insulating materials like glass wool. The kiln works as a counter current heat exchanger (Figure 5-1), with heat exchange taking place between the air moving up (continuous flow) and bricks moving down (intermittent movement). Green bricks are loaded from the top in batches; the bricks move down the shaft through brick pre-heating, firing and cooling zones, and are unloaded at the bottom. The combustion of powdered coal (put along with bricks at the top), takes place in the middle of the shaft. Air for combustion enters the shaft at the bottom, and gets preheated by the hot fired bricks in the lower portion of the shaft before reaching the combustion zone. Hot flue gases preheat the green bricks in the upper portion of the shaft before exiting from the kiln through the shaft or the chimney.

The brick setting in the kiln is supported on bars at the bottom of the shaft. Brick unloading is carried out from the bottom of the shaft using a trolley. For unloading, the trolley is lifted (using a screw mechanism or chain pulley blocks) until the rectangular beams placed on the trolley touch the bottom of the brick setting, and the weight of bricks is transferred on to the trolley. The support bars, now freed of the weight of bricks, are removed. The trolley is then lowered by one batch (four layers of bricks). Support bars are again put in place through the holes provided in the brick setting for the purpose. With a slight downward movement, the weight of the brick setting is again transferred back on the support bars. The trolley (with one batch of fired bricks on it) is further lowered till it touches the ground and is pulled out of the kiln on a pair of rails. In traditional operations, every 2-3 hours one batch is unloaded at the bottom and a batch of fresh green bricks is loaded at the top. At any given time, there are typically 8 to 12 batches in the kiln.

Two chimneys located diagonally opposite to each other are provided for the removal of flue gases. Sometimes, a lid is also provided on the top opening of the shaft. The lid is kept closed during normal operation and hence flue gases do not pollute the working area on the top of the kiln.

In this study, two VSBKs were monitored. The location and salient features of these kilns are given in Table 5-1. The locations of the Indian and Vietnamese VSBK kilns are mapped in Figures 5-2 and 5-3.

Table 5-1: Salient features of the monitored VSBK kilns

Kiln Identification No	Location	Production Capacity			Fuel	Time of Monitoring
		Bricks/day	Bricks/yr (Million)	No. of Shafts		
Kiln 5_VSBK	Arah (Bihar)	7600	1 – 1.5	2	➢ Steam Coal ➢ Coal Slurry	13th – 15th April 2011
Kiln 9_VSBK	Hung-yen Province (Vietnam)	21600	4 – 4.5	4	➢ Coal Ash ➢ Coal Powder	12th – 14th May 2011

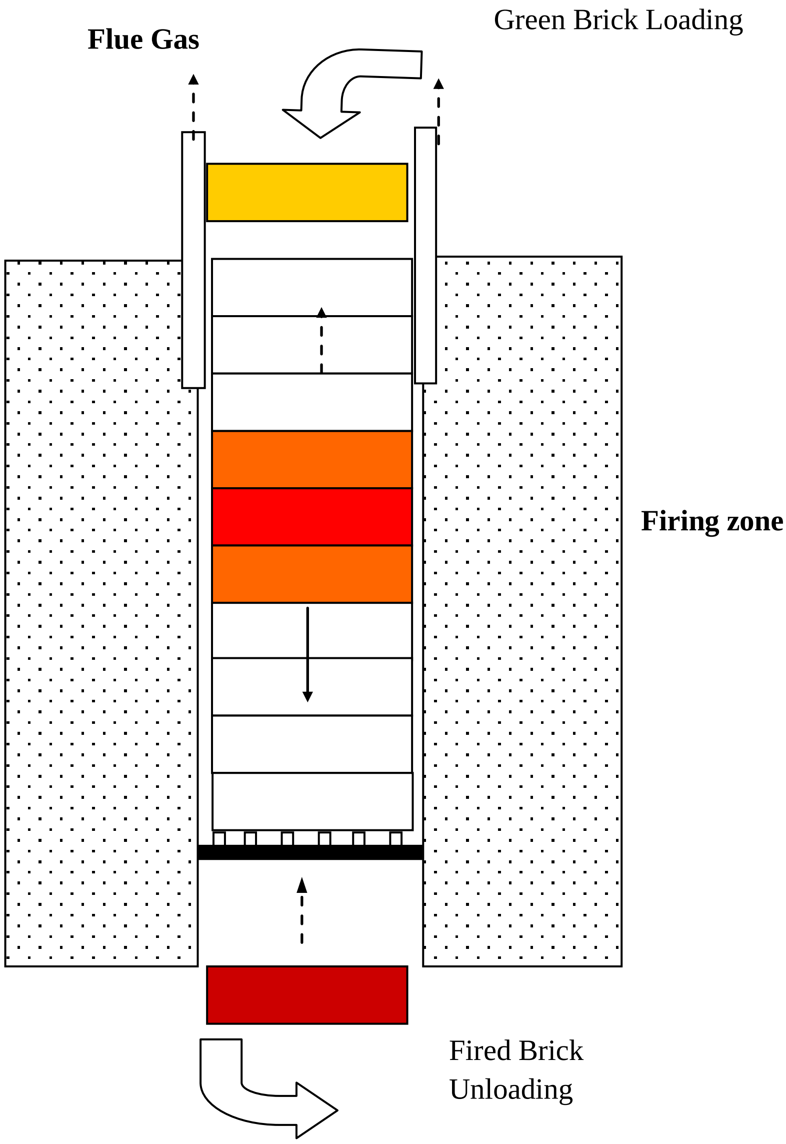


Figure 5-1: Schematic of VSBK with one shaft

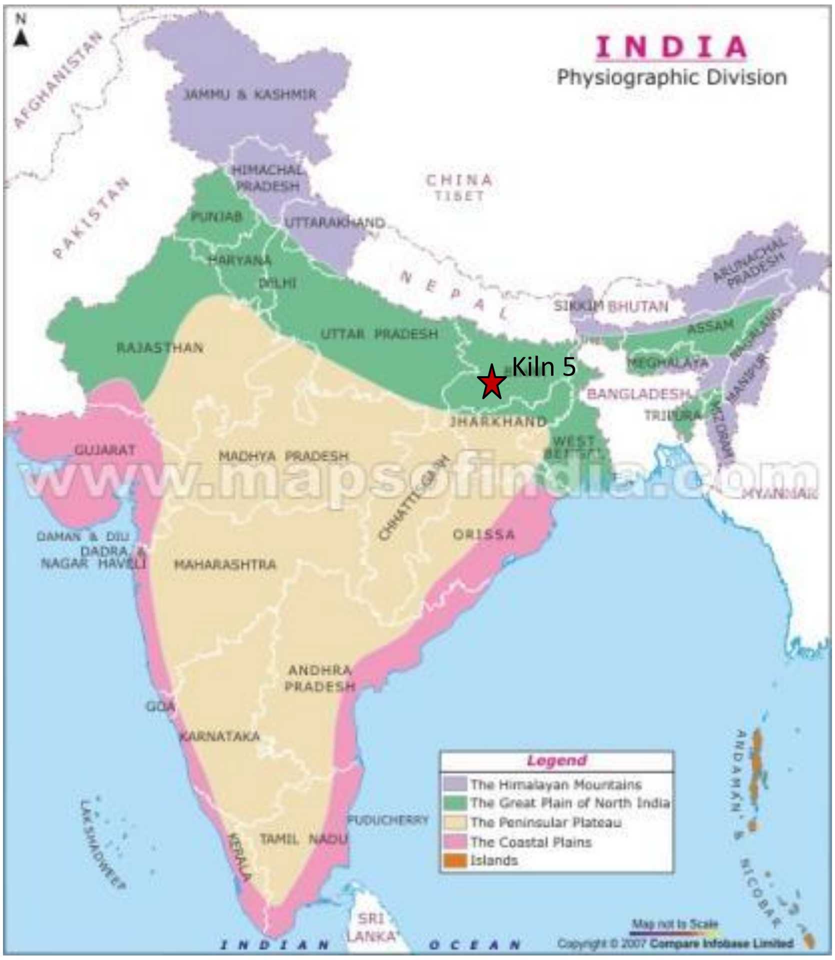


Figure 5-2: Location of monitored Indian VSBK

Figure 5-3: Location of monitored Vietnamese VSBK

5.2. Salient Features of the Monitored Kilns

Table 5-2: Description of the monitored VSBKs

	Kiln 5_VSBK	Kiln 9_VSBK
Location	➢ Arah, Bihar, India	➢ Hung Yen, Vietnam
Description of company	➢ The owner is a first-generation brick maker ➢ New in the business of brick making	➢ The owner is a very experienced brick maker ➢ The owner has modified the design of VSBK for improved performance
Annual Production	➢ 1 –1.5 million bricks/ year	➢ 4 – 4.5 million bricks/ year
Supplying Market	➢ In the radius of 15 – 20 km ➢ Arah & near by areas.	➢ In the radius of 20-40 km ➢ Hung Yen province & nearby areas.
Operational period	➢ Dry months (Mainly December to June) ➢ Operation period is short because there is no covered drying space.	➢ 10 months a year ➢ The kiln is closed or operates at partial capacity during the rainy period.
Kiln Description	➢ 2 shaft VSBK. ➢ Conveyer belt for transporting green bricks from ground to the working platform. ➢ Shaft cross-sectional area: 1.9m x 1.12 m Shaft height: 7.2 m ➢ Production: 6 batches of 476 bricks/day/shaft : 7600[a]bricks/day for the two shafts ➢ Each shaft has 2 chimneys diagonally opposite to each other. ➢ Use of internal & external fuel ○ 42% thermal energy from internal fuel	➢ Improved VSBK consisting of 4 shafts ➢ Lifts for transporting green bricks to working platform ➢ Shaft cross-sectional area: 1.33m x 2.06m ➢ Shaft height: 9.6 m ➢ Production: 3 batches of 1850 bricks/day/shaft : 22200 bricks/day for 4 shafts ➢ 2 chimneys, each chimney connected to two shafts. The height of the chimney was 10 m above the working platform. ➢ Use of internal fuel ○ Almost 100 % of the thermal energy is supplied

	Kiln 5_VSBK	Kiln 9_VSBK
		from internal fuel ➢ External fuel in the form of briquettes is used in very small quantities to ensure uniform temperature in the firing zone and uniform shrinkage throughout the cross-section of the shaft
Moulding	➢ Hand moulding ○ Solid Bricks	➢ Machine moulding ○ Solid Bricks via extruder
Drying	➢ Open air drying	➢ Drying shade[b] ○ All the bricks are dried under a shade
Firing Fuel	➢ Internal Fuel ○ Coal Slurry ➢ External fuel ○ Steam Coal	➢ Internal Fuel ○ Coal powder ○ Coal Ash ➢ External fuel ○ Briquettes

[a] At the time of monitoring only one shaft was operational due to a labor shortage. Hence the production was half of the above stated quantity.
[b] Drying shade avoids direct exposure to the sun and hence reduces the possibility of drying cracks and protects the green bricks from unseasonal rains.

5.3. Energy Performance of the Monitored Kilns

Brick setting and fuel feeding practice

The details of the fuel feeding practice and the brick settings being followed for the two monitored kilns are provided in Table 5-3.

Table 5-3: Fuel feeding practice and brick setting in the monitored VSBKs

Kiln Identification No	Fuel feeding Practice
Kiln 5_VSBK	➢ Coal slurry was being used as an internal fuel[25]. ○ 75 kg of coal slurry per 1000 bricks. ➢ Steam coal was added between the layers of the bricks in every batch ○ 84 kg of steam coal per 1000 bricks. ➢ Each batch contained six layers ➢ Temperature in the firing zone ranged between 875-900°C.
Kiln 9_VSBK	➢ Coal ash & coal powder used as an internal fuel. ○ Almost 100% thermal energy from internal fuel ○ Internal fuel added in the clay mix before the extruder; complete mixing ensured in the extruder. ○ 80 kg of coal powder per 1000 bricks ○ 200 kg of coal ash per 1000 bricks ➢ Briquettes were used in small quantities as external fuel ○ External fuel was used to produce uniform shrinkage across the cross section of the shaft ○ Briquettes were added from the fuel feeding chambers located in the middle of shaft ➢ Each batch contained 4 layers of bricks, 3 layers were densely packed and last layer was loosely packed. ○ Three densely packed layers: ○ 300 bricks with coal ash as internal fuel ○ 82 bricks with coal powder as internal fuel ○ 84 bricks with no internal fuel ○ One loosely packed layer: ○ 290 bricks with coal ash as internal fuel ○ 90 bricks with coal powder as internal fuel ○ 72 bricks with no internal fuel

[25] The internal fuel is mixed with clay during clay preparation (prior to green brick moulding) and external fuel is fed between the layers of bricks while loading the batch in the shaft.

Energy performance

Flue gas measurements were taken at regular interval in the chimneys of VSBK kilns. The results of the two VSBKs are presented in Table 5-4.

Table 5-4: Flue gas analysis of VSBKs measured in the chimney

	Kiln 5_VSBK	Kiln 9_VSBK
Average O_2 (%)	16.31	16.99
Average CO_2 (%)	4.18	4.3
Average CO (ppmv)	4300	1700
Average Excess Air (%)	330	400
Average temperature of flue gas (^oC)	202	67

As VSBK is an up-draught kiln and fuel is added either within the bricks (internal fuel) or added in layers with green bricks, the CO and other volatiles released during the preheating of bricks bypasses the combustion zone to mix directly with the flue gases, resulting in higher CO concentration.

Specific energy consumption and heat balance

Based on the fuel consumption rate and brick production (kg of bricks fired per day), specific energy consumptions were computed and are shown in Table 5.5.

Table 5-5: Specific energy consumption of the monitored VSBKs.

	Fuel Consumption (kg/day)		Production		SpecificEnergy Consumption (SEC) (MJ/kg fired brick)
Kiln 2_zigzag_ND	*Coal slurry*	*Steam coal*	*Bricks/day*	*kg/day*	0.95**
	286	318	3808	13975	
Kiln 3_zigzag_FD	*Coal ash*	*Coal powder*	*Bricks/day*	*kg/day*	0.54*
	2856	324	22200	39960	

*Based on GCV and assuming 8% moisture content in coal ash and coal powder.
**Based on GCV and assuming 4% moisture content in coal slurry & steam coal.

The SEC for the two VSBKs are in the range of 0.54 to 0.95 MJ/Kg of fired bricks. The SEC of Kiln 9_VSBK is the lowest SEC ever reported for a VSBK. Table 5-6 presents the heat balance for the two VSBKs monitored in the study.

Table 5-6: Heat balance of the monitored VSBKs

	Kiln 5_VSBK	Kiln 9_VSBK
Dry flue gas heat loss	24.0%	8.1%
Sensible heat loss in unloaded bricks	9.0%	13.3%
Moisture removal	25%	46.5%
Heat loss due to incomplete combustion	5.4%	2.8%
Other heat components	27.7%	15.6%
Total	100%	100%

The high dry flue gas loss in Kiln5_VSBK is due to a high flue gas temperature of around 200^{o}C. The high flue gas temperature is primarily due to the firing zone located in the upper part of the firing shaft and not in the centre.

5.4. Emissions

Measurement of PM, SO_2, and NO_X emissions at Kiln 5_VSBK, India was carried out in the chimney through a sampling port made at the height of 2 m above platform level. This VSBK has two shafts and each shaft has two chimneys. As per the guidelines stipulated by MoEF, each shaft should have a single chimney. However, most of the VSBKs in India have two chimneys for each shaft as in the case of Kiln 5_VSBK. During the monitoring period, only one shaft was in operation. Sampling and measurements were done in both chimneys of the shaft in operation. Two samples were collected from each chimney. Sampling time ranged from 55 to 90 minutes. Before collecting the samples, the temperature and velocity of the flue gases were measured at the sampling port.

Kiln 9_VSBK has four shafts; each pair of shafts is connected to a centrally located oval chimney. Out of the two chimneys, monitoring was done at only one (which was connected to the shaft being monitored). A port hole was made at a height of 2 m from the platform, and three experiments were conducted to measure pollutant emissions. Concentration of SPM was measured with the stack monitoring kit. SO_2 and NOx were measured using a flue gas analyser from the CENMA laboratory. Sampling was carried out for 30 to 35 minutes. Prior to sample collection, the flue gas temperature and velocity were measured at the sampling port. The following sections present the results of monitoring and estimated emission factors.

Table 5-7: Flue gas characteristics and concentration of pollutants in monitored VSBKs

	Kiln 5_VSBK	Kiln 9_VSBK
Flue gas temperature (°C)	135 - 200	60 – 70
Flue gas velocity (m/s)	1.9 – 2.5	1.2 – 1.7
Concentration of pollutants in the flue gas		
SPM (mg/Nm^3)	101 *(84 – 119)*	114 *(98 – 134)*
$PM_{2.5}$ (mg/Nm^3)	53 *(37-102)*	90 *(43-131)*
SO_2 (mg/Nm^3)	112 *(97 – 136)*	933 *(664 – 1413)*
NOx (mg/Nm^3)	0.08 *(0.02 – 0.09)*	Not available

SPM levels for Kiln 5_VSBK ranged from 84 mg/Nm^3 to 119 mg/Nm^3 with an average of 101 mg/Nm^3, which is lower than the Indian emission standard of 250 mg/Nm^3 prescribed by the MoEF for small, medium, and large category VSBKs[26]. The SPM concentration for Kiln 9 –VSBK Vietnam ranged from 98 mg/Nm^3 to 134 mg/Nm^3. The average concentration of SPM in the kiln was 114 mg/Nm^3.

Concentrations of SO_2 for Kiln 5_VSBK India ranged from 97 mg/Nm^3 to 136 mg/Nm^3 with average levels of 112 mg/Nm^3. For kiln 9_VSBK, Vietnam, average concentration of SO_2 was 933 mg/Nm^3. The maximum NO_X concentration measured in the Indian VSBK was 0.09 mg/Nm^3 .

Measurement of hydrogen fluoride (HF) was done at the VSBK in Vietnam using the instrument of CENMA laboratory as per TCVN 7243-2003 method. The average HF concentration of the eight experiments carried out at the kiln was 11.2 mg/Nm^3. The HF concentration is less than the Vietnamese emission standard of 50 mg/ Nm^3.

Aerosol properties

Aerosol optical properties (scattering and absorption) were measured in real time for a period of 41 to 54 minutes. Three tests were conducted in each kiln. In addition to real-time measurement of scattering and absorption, particles collected on filter papers were analysed for organic and elemental carbon. Kiln 9 had very low particle emissions and in order to capture a larger particle sample size, the dilution rate was reduced, which resulted in a high moisture content, thereby overwhelming the scattering signals. Therefore, the results of scattering for Kiln 9 are errorenous and will not be presented here. The remaining results of scattering and absorption are presented in Table 5-8.

26 "*G.S.R. 543 (E) MoEF Notification*", Ministry of Environment and Forests, New Delhi, 2009.

Table 5-8: Scattering and absorption for red λ and elemental and organic carbon concentration results for VSBKs

	Unit	Kiln 5_VSBK	Kiln 9_VSBK
Scattering	*1/m*	0.23	-
Absorption	*1/m*	0.066	0.0018
Elemental carbon	*mg/m^3*	2.0	0.42
Organic carbon	*mg/m^3*	33	Not detected

Particle absorption measurements were taken at three wavelengths; blue (467nm), green (530nm), and red (660nm). Results at red wavelength are presented here, and the results from other wavelengths are used to calculate the absorption angstrom exponent. The results are presented in the Table 5-9.

Table 5-9: Particle absorption measurement for red wavelength in VSBKs

	Kiln 5_VSBK	Kiln 9_VSBK
Single scattering albedo (Red λ)	0.77 ± 0.15	-
Absorption angstrom exponent*	3.19 ± 0.40	1.1 ± 0.36
Elemental carbon %	6%	100%

*Between blue and red wavelengths

The results indicate that these particle emissions produce less elemental carbon and are less absorbing than the FCBTK and zig-zag kilns.

The absorption angstrom exponent for both VSBK kilns is higher than 1. Especially high value of absorption exponent at kiln 5 indicates that the particles absorb light most strongly in blue wavelengths, and thus appear to be "brown carbon" rather than black carbon. This could explain the high ratio between absorption and elemental carbon; another light absorber is present that is not EC.

The results of the thermal optical analysis reveal that organic carbon was the dominant aerosol emission in the Indian VSBK. Elemental carbon was the dominant aerosol in the

Vietnam VSBK, but the absolute concentrations were quite low, indicating that the burnout of aerosol product in this kiln was successful, leaving only traces of elemental carbon behind.

Figures 5.4 and 5.5 display the real-time optical data collected at both VSBK kilns over three tests. These tests are presented on the same scale. The figures show that there are long periods where absorption and scattering are very low (for example, all of Test B at kiln 5). Scattering (blue line) is consistently higher than absorption at all times, even during high-emission periods (end of Test C at kiln 5). The high absorption angstrom exponent in kiln 5, and the relatively high scattering, is consistent with the idea that the aerosol is released from pyrolysis, when volatile material escapes without flaming. For kiln 9, only absorption is shown, and the levels are much lower than those from other kilns. In both kilns, small emitting events occur, but the large charging spikes as apparent in some other kiln types are not observed.

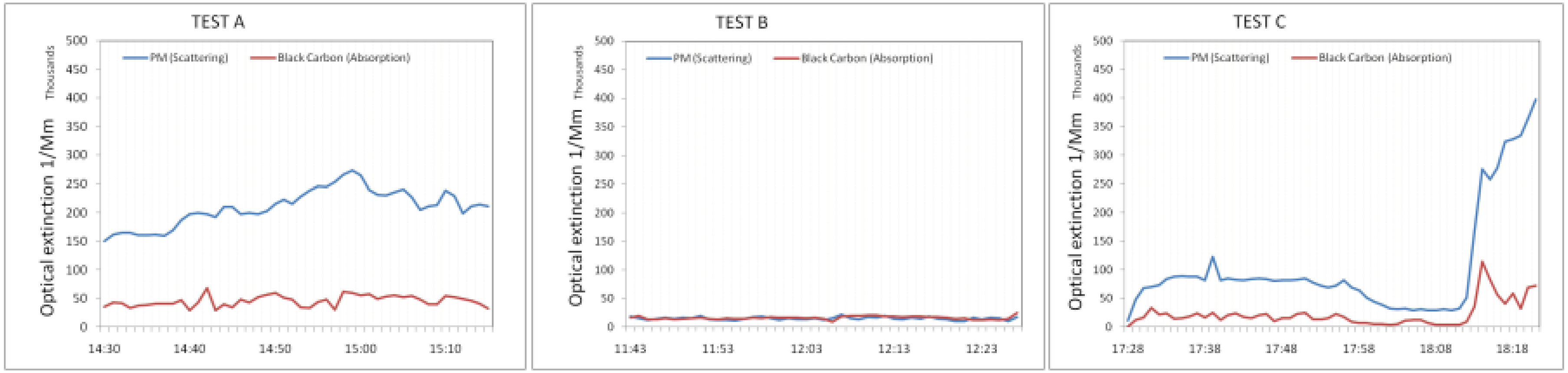


Figure 5-4: Real time optical data collected at Kiln 5_VSBK

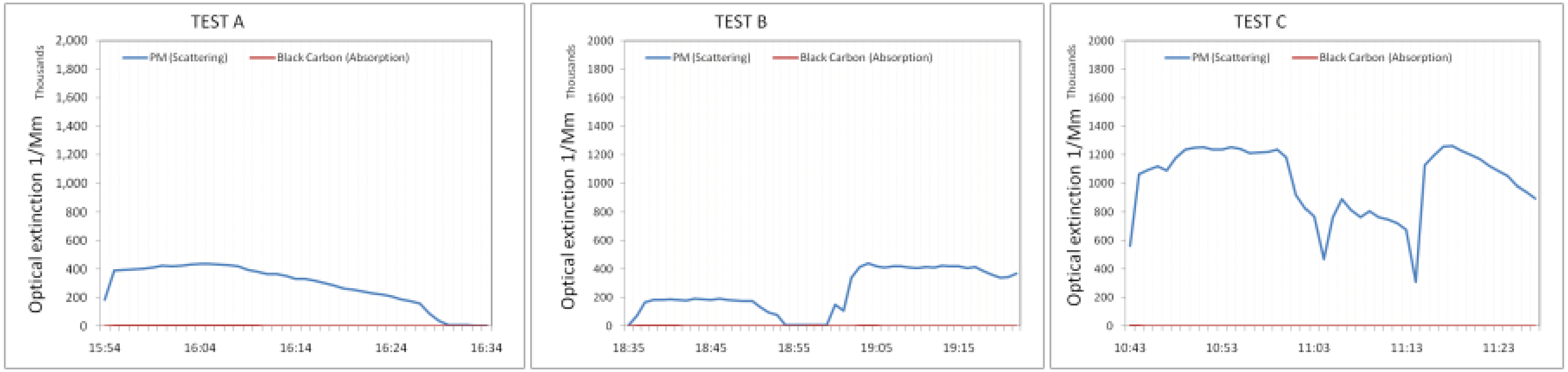


Figure 5-5: Real time optical data collected at Kiln 9_VSBK

In addition to the above measurements, an impactor test with cut sizes at PM_{10} and PM $_{2.5}$ was performed at Kiln 5_VSBK in order to get the particle size distribution of organic and elemental carbon. These particles were collected on quartz filters in a MOUDI three stage impactor. Figure 5-6 and Table 5-10 summarize the particle size distribution of organic and elemental carbon in kiln 5_VSBK. This impactor test was not performed at kiln 9_VSBK.

Table 5-10: Particle size distribution of EC and OC in Kiln5_VSBK

	Kiln 5_VSBK	
	Total Carbon fraction (%)	EC in Total Carbon fraction (%)
>PM 10	0.8%	11%
PM 10	1.4%	29%
PM $_{2.5}$	1.6%	9%
Fines	96%	1.2%

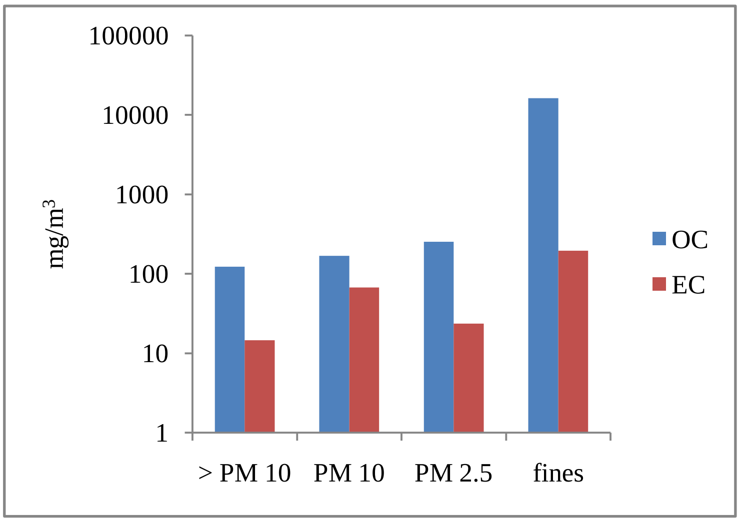


Figure 5-6: Particle size distribution of organic and elemental carbon at Kilns 5_VSBK

Submicron aerosols dominated the particulate emissions in the VSBK kiln with an average of 96% of the carbon measured in the fines cut of impactor stage. Elemental carbon composed 1.76% of the total carbon measured over all particle sizes in kiln 5_VSBK. The difference between this value and the 6% estimate for fine particles in kiln 5_VSBK could be caused by temporal variability, because the two tests were not done at the same time.

Emission factors

Pollutant emissions vary according to type of kiln, fuel used and operating conditions. For comparing the emissions across different fuel/operating conditions, it should be normalized either to unit of fuel consumed or to unit of energy consumed, or a comparison based on brick production. Emission factors for PM and SO_2were derived from emission rate (ER), fuel consumption rate, energy content of the fuel and production rate. Another method, namely the carbon balance method (described in Annexure-III), was used to estimate $PM_{2.5}$, CO, CO_2 and black carbon emission factor. Summary of emission factors of various pollutants for VSBK kilns are presented in Table 5-11.

Table 5-11: Emission factors for monitored VSBKs

Pollutants			*g/kg fuel*	*g/MJ*	*g/kg fired brick*
Flue Gas Pollutants		CO	39.9	2.28	1.84
		CO_2	1375	99	70
		SO_2	7.86 ± 5.89	0.95 ± 0.92	0.54 ± 0.47
Particulate Matter	SPM	Total SPM	1.93 ± 0.44	0.16 ± 0.07	0.11 ± 0.02
		$PM_{2.5}$	1.8	0.13	0.093
	Aerosol Properties*	Elemental Carbon	0.046	0.0023	0.0020
		Organic Carbon	1.4	0.063	0.059
			m^2/ kg fuel	*m^2/ MJ*	*m^2/kg fired brick*
		Scattering (Red λ)	11	1.1	0.66
		Absorption (Red λ)	1.4	0.064	0.060

* These measurements only include Kiln 5_VSBK

5.5. Summary

Two VSBKs of different capacities, using different fuels were monitored. A summary of the energy and emission results is shown below.

Energy & Process

- The SEC for the Indian VSBK was 0.95 MJ/kg of fired brick, while for the Vietnamese kiln it was 0.54 MJ/kg of fired brick. The results confirm that VSBK has the best performance in terms of energy among all kilns. The improved VSBK in Vietnam has one of the lowest SEC ever recorded for a brick kiln. The results indicate that the savings in energy compared to the FCBTK could range between 20 to 50%.
- Both VSBKs monitored had problems with brick quality. The problem was more severe in the Indian VSBK. The unsatisfactory quality can be attributed to a combination of factors:
    - The fast heating and cooling of bricks in the kiln can cause cracks in the bricks.
    - Due to the nature of the process, the high static and dynamic load on the lower part of the brick stacking results in damage to the bricks.
    - Some damage is also caused by the excessive handling of bricks during lifting-up to the kiln top and loading process.

  Due to the lower density and lower compressive strength of hand-moulded bricks, the problems in brick quality are more pronounced when hand-moulded bricks are fired in VSBK (like in India). From the experience of Vietnam, it was evident that the firing of machine-moulded bricks results in improvement in quality.

- VSBK has a limitation in terms of variety of clay products that can be fired in its present configuration; it is well suited for firing solid bricks. It can be used to fire bricks with perforations, but is not suitable for firing hollow bricks or thinner products like roofing tiles.

Emissions

- The average SPM concentration of the two monitored VSBKs was 84 mg/Nm^3 (kiln 5) and 134 mg/Nm^3 (kiln 9). SPM concentration of the kiln 5_VSBK is comparable with the SPM values (77 to 250 mg/Nm^3) of four VSBKs monitored in India (TERI, 2003). The average SPM concentrations from the Entec[27], (2004,) study carried out at VSBKs in Vietnam ranged between 50 to 160 mg/Nm^3. Present study results for the kiln 9 are comparable to those reported in the earlier study.
- SPM concentrations in the kiln 5 were less than the Indian emission standard of 250 mg/Nm^3 and those in the Kiln 9 were less than the Vietnamese emission standard of 400 mg/Nm^3.
- Average SPM emission factors ranged from 0.09 to 0.12 g/kg of fired bricks. The average production based emission factors in the present study are lower than the earlier reported study by TERI, 2003[28] (0.11 to 1.05 g/kg of fired bricks). This can be attributed to the use of a large percentage of internal fuels in both the VSBKs monitored in this study, while the kilns monitored in the earlier study mostly used external fuel.
- Concentration of SO_2 from the kiln 5_VSBK ranged from 97 mg/Nm^3 to 136 mg/Nm^3 whereas for Kiln 9_VSBK it ranged from 646 mg/Nm^3 to 1375 mg/Nm^3. In terms of emission factor, the average SO_2 emission factor for VSBK, India was 0.10 g/kg of fired brick and 0.97 g/kg of fired brick for VSBK, Vietnam.
- NO_X values of VSBKs monitored were less than 21 mg/Nm^3, which is less than emission norms for NO_X in Vietnam.
- The average HF concentration measured at the VSBK in Vietnam was 11.2 mg/Nm^3, which is less than the Vietnamese emission standard of 50 mg/Nm^3.

Aerosol properties

- Emission factors for $PM_{2.5}$ were higher (2.29 g/kg of fuel) in the VSBK measured in India and lower (1.24 g/kg of fuel) in the Vietnam kiln.

27 Entec, (2004), "*Vietnam sustainable brick making project: Environmental Report*", Entec consulting and engineering, Hanoi, 2004

28 TERI, (2003), "*Development of Emission Standards and Stack Height Regulations for the Vertical Shaft Brick Kilns (VSBK) vis-à-vis Pollution Control Measures*", Report Prepared for Central Pollution Control Board, TERI, 2003.

- Scattering emission factors were 10.14 m^2/kg of fuel in the Indian VSBK and 12.3 m^2/kg of fuel in the Vietnam based kiln. Average absorption emission factors measured were 2.85 m^2/kg fuel in India and 0.03 m^2/kg fuel in Vietnam.
- Filter based elemental carbon measurements, averaged over the tests, were 0.09 g EC/kg of fuel in India and 0.01 g EC/kg of fuel in Vietnam. Elemental carbon composed roughly 6% of the total carbon and was too low to be determined in the Vietnam VSBK.
- The VSBK kilns have significantly different combustion processes as compared to the FCBTK and zig-zag kilns, and the optical and chemical analyses of the aerosols indicate low black carbon emissions.

Chapter 6. Down-Draught Kiln

6.1. Down-Draught Kiln

The down-draught kiln (DDK) is an intermittent kiln. In an intermittent kiln, one batch of bricks is fired at any given point of time. The kiln is first filled with green bricks. It is then fired and the batch is heated up to the maximum temperature and left to cool, before being drawn out from the kiln. In the process of heating, the kiln structure also gets heated-up, and while cooling, the stored heat in the structure is lost into the atmosphere. In an intermittent kiln, the heat recovery from the hot exhaust gases is only partial, resulting in high exhaust gas losses. Thus, intermittent kilns, though being suitable for small-scale production, are not fuel efficient.

In a down-draught kiln, fuel is burnt in external fuel-boxes, provided on the outer periphery of the kiln. The hot gases from burning fuel rises to the roof of the kiln. Gases after being deflected from the roof, flow down through the brick setting and in the process warm and fire the bricks. The bricks rest either upon an open-work support of previously fired bricks or upon a perforated floor, through which the flue gases flow down into an underground channel which is connected to the chimney and are exhausted out of the kiln. The warm gases rising through the height of the chimney provide sufficient draught to pull the hot gases down continually through the stack of green bricks.[29]

In India, the Malur cluster located near Bangalore, in the state of Karnataka has hundreds of down-draught kilns. Other than Karnataka, down-draught kilns are also found in Andhra Pradesh and Kerala. These kilns are generally constructed with red bricks, with an inner layer of refractory bricks. The thickness of the wall is about 5 feet. The total cycle time required from loading green bricks to cooling fired bricks is about 7 days. Production capacity of typical down-draught kilns ranges between 20,000 to 40,000 bricks per batch operation. There are about 12 fireboxes in a down-draught kiln, with 6 fireboxes located on each side.

The typical operation sequence of a down-draught kiln in Malur cluster is as follows:

- Stacking of dry bricks in the kiln. Generally, no gap is provided between bricks and the wall of the kiln.

[29] ILO: Small-Scale Brick Making, 1984

- The kiln doors are closed with bricks and sealed.
- Firing is initiated by feeding fuel (Eucalyptus branches/twigs and leaves) in the kiln's firebox.
- Fuel feeding rate is increased, and fuel feeding is continued till the bricks have attained the firing temperature – around 500-600^{o}C in Malur. The firemen judge the temperature by observing the colour of the fire from peek-holes provided in the kiln.
- Upon reaching this temperature, the fire boxes are shut off.
- The kiln is left to cool for 2-3 days before it is opened for unloading the fired bricks.

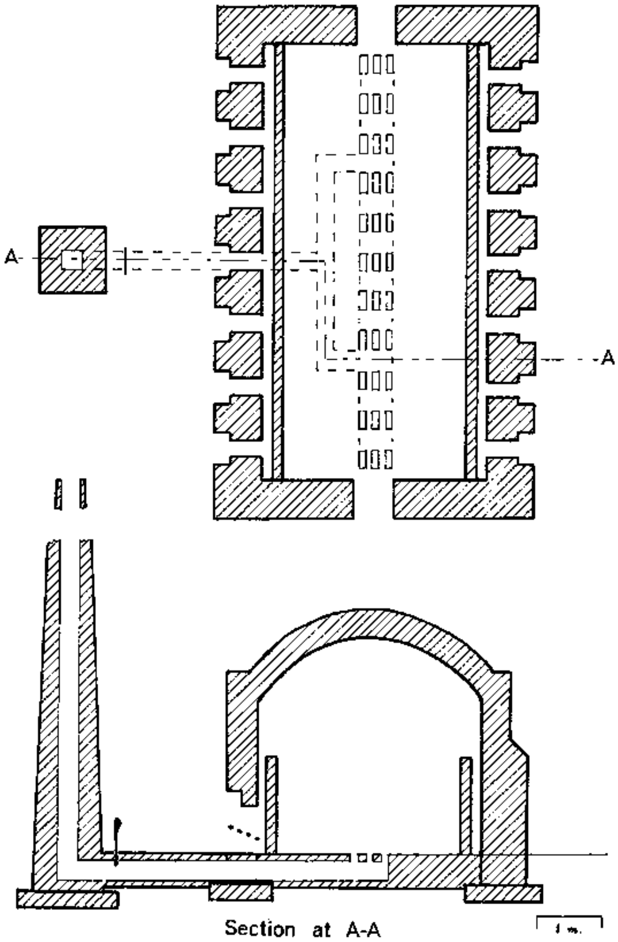


Figure 6-1 Sketch of a down-draught kiln [ILO, 1984]

One down-draught kiln was monitored. The location and salient features of this kiln are given in the table below. The location of the kiln is marked on the Indian map (Figure 6-2).

Table 6-1: Salient features of the monitored down-draught kiln

Kiln Identification No	Location	Production Capacity		Fuel	Time of Monitoring
		Bricks/batch	Kg Bricks/batch		
Kiln 7_Down-draught	Malur (karnataka)	20,000	64,200	Eucalyptus twigs and leaves	28th- 29th April 2011

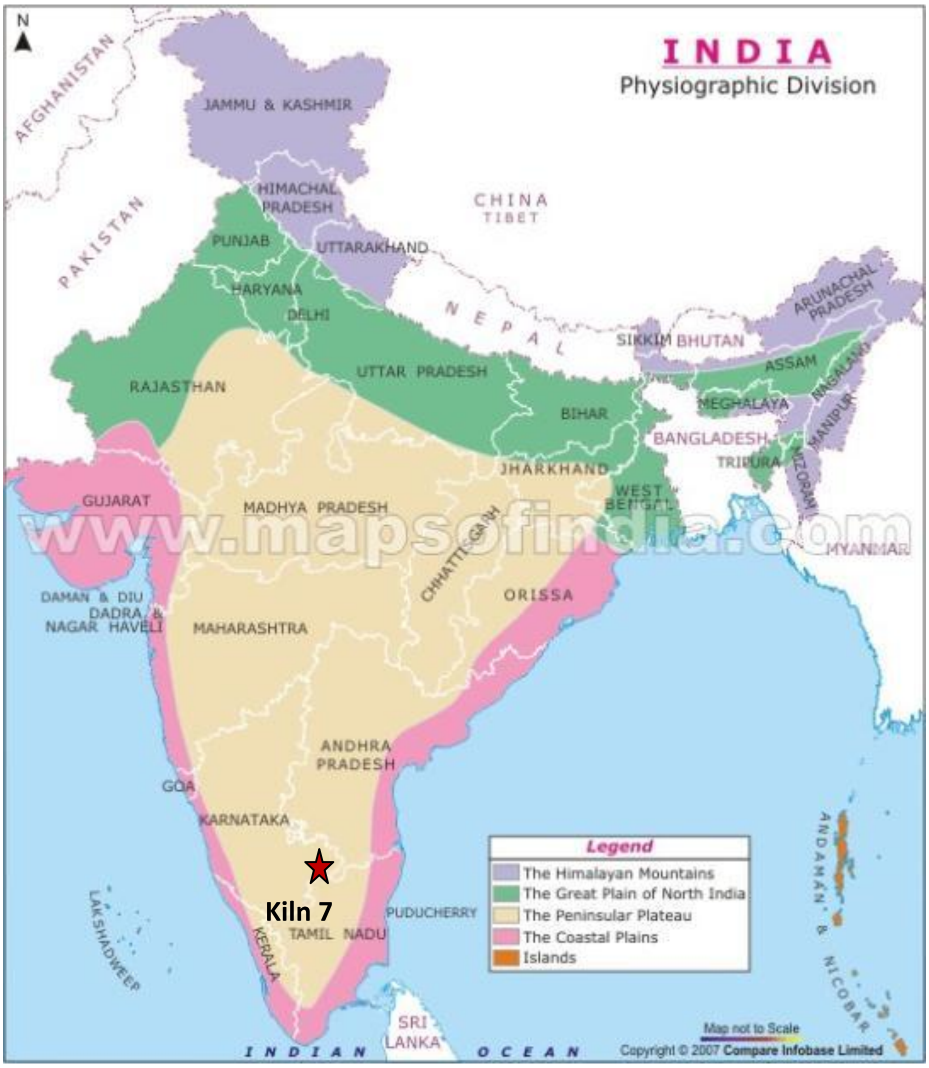


Figure 6-2 Location of monitored down-draught kiln

6.2. Salient features of the monitored kiln

Table 6-2: Description of the monitored down-draught kiln

	Kiln 7_Down-draught
Location	Malur, Karnataka
Description of company	➢ The owner is a very experienced, second-generation brick maker
Supplying market	➢ A large proportion of the bricks produced are supplied to Chennai market, which is around 300 km from Mallur.
Operational period	➢ Year-round operation
Kiln description	➢ Traditional down-draught kiln. ➢ Capacity of 20,000 bricks. ➢ Three feeding holes on each side of the kiln. However only one side of the kiln was being used for feeding. ➢ Feeding done manually by 2 firemen. ➢ The feeding continued for 31 hrs, following which the feeding holes were closed, and bricks were allowed to cool down.
Moulding	➢ Hand moulding ○ Solid Bricks
Drying	➢ Drying shade[a] ○ Green bricks dried under shade
Firing fuel	➢ Eucalyptus tree twigs and leaves[b]

[a] Drying shade avoids direct exposure to the sun and hence reduce the possibility of drying cracks and protects the green bricks from unseasonal rains.
[b] Fresh eucalyptus tree branches have high volatile content and burn rapidly with flames.

6.3. Energy Performance of the Monitored Kilns

Fuel feeding practice

The fuel (eucalyptus twigs and leaves) is fed in 3 fire-boxes provided on one side of the kiln by 2 firemen. The feeding of fuel is intermittent; one or two bundles of fuel are fed in each fire-box. After the fuel has burned completely, the next feeding is undertaken. In this particular case the fuel feeding was continued for 31 hours. During this duration, 12 tons of eucalyptus twigs and leaves were burned in the kiln. Figure 6-3 shows the temperature profile of the kiln during the heating-up of the kiln cycle of 31 hours.

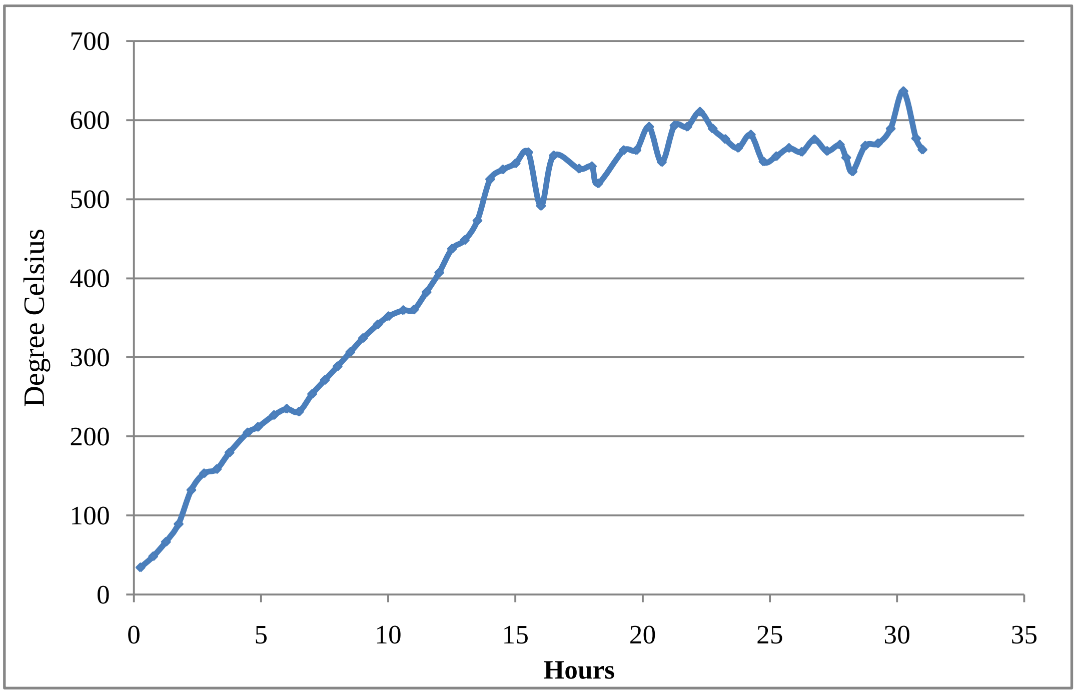


Figure 6-3 Temperature profile of the down-draught kiln during the feeding cycle

Energy performance

Flue gas measurements were taken at regular intervals at the chimney of the down-draught kiln. Results of monitored kiln are presented in Table 6-3.

Table 6-3: Flue gas analysis of down-draught kiln measured at the chimney

	Kiln 7_Down-draught
Average O_2 (%)	11.59
Average CO_2 (%)	8.65
Average CO (ppmv)	4800
Average Excess Air (%)	117
Average temperature of flue gas (^oC)	200

Figure 6-4 shows variations of CO, CO_2 and O_2 for 6 minutes duration, eight hours after the lighting-up of the kiln. It can be observed that the flue gases concentration changes rapidly as fuel is burned in the kiln. After feeding of a fresh charge of fuel, a rapid increase in CO concentration (going up to around 10,000 ppmv) was observed. After some time, the CO concentration came down to 2000-4000 ppmv.

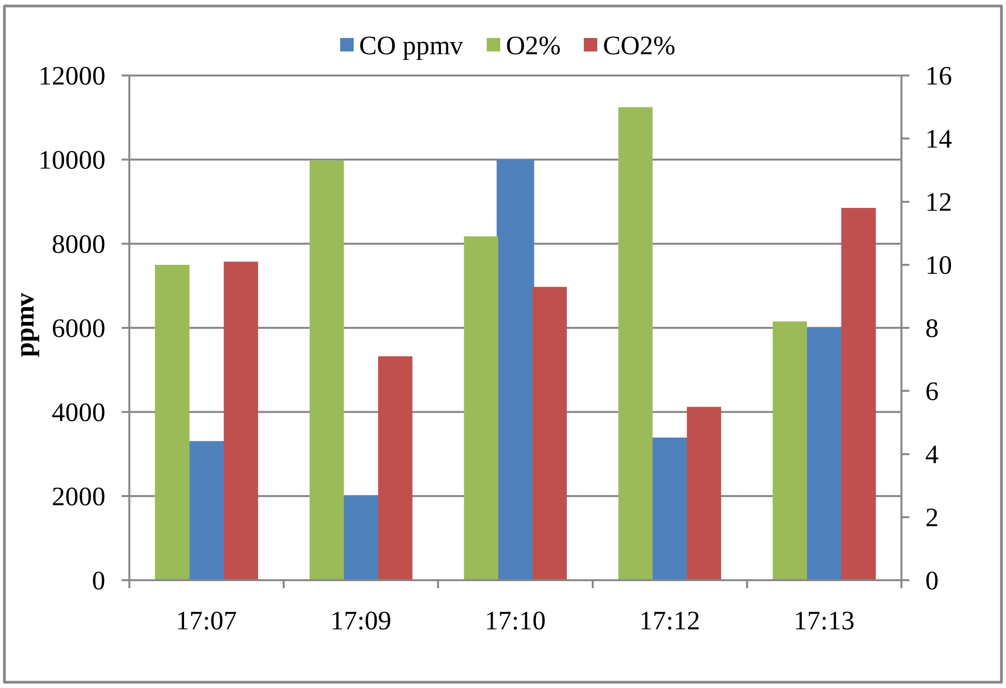


Figure 6-4: Variation in CO, O_2 and CO_2 at kiln 7_down draught

<u>Specific energy consumption and heat balance</u>

Based on the fuel consumption rate and brick production (kg of bricks fired per batch), specific energy consumptions were computed and shown in Table 6-4.

Table 6-4: Specific energy consumption of the monitored down draught kiln

	Fuel Consumption (kg/day)	Production		SpecificEnergy Consumption (SEC) (MJ/kg fired brick)
Kiln 7_Down-draught	*Eucalyptus branches*	*Bricks/day*	*kg/day*	2.91*
	12,000	20,000	64,200	

*Based on GCV and assuming 10% moisture content in *Eucalyptus branches*

The SEC of the down-draught kiln is highest as compared to the other kilns. The main reasons for the high specific energy consumption in a down-draught kiln are:

- The kiln structure must be warmed up for each new batch; this heat is lost when the kiln is cooled for emptying.
- The heat contained in the hot-fired bricks is lost.
- Energy recovery from hot flue gases is partial.
- Incomplete combustion.

Table 6.5 presents the heat balance for the down-draught kiln monitored in the study.

Table 6-5: Heat balance of the monitored down-draught kiln

	Kiln 7_Down-draught
Dry flue gas heat loss	13.87%
Sensible heat loss in unloaded bricks	14.82%
Moisture removal	7.70%
Heat loss due to incomplete combustion	3.46%
Other heat components	60.15%
Total	100 %

6.4. Emissions

Three experiments were carried out to measure the concentration of SPM, SO_2 and NO_X. Samples were collected from the port-hole made in the chimney at a height of 6 m above ground level. Sampling time covered each phase of the firing cycle, and experiments were conducted between 35 minutes to 50 minutes. Prior to sample collection, flue gas temperature and velocity were measured at the sampling port. Flue gas velocity ranged between 1.97 – 5.5 m/s, and temperature varied from 60°C to 300°C. Iso-kinetic sampling was followed for particulate matter sampling.

The following sections present the results of environmental monitoring and emission factor estimation.

Table 6-6: Flue gas characteristics and emission concentrations in the monitored down-draught kiln

	Kiln 7_down-draught
Flue gas temperature (°C)	60°C to 300°C
Flue gas velocity (m/s)	1.97 – 5.5
Concentration of pollutants in the flue gas	
SPM (mg/Nm^3)	531 *(240 - 1088)*
$PM_{2.5}$ (mg/Nm3)	331 *(227-516)*
SO_2 (mg/Nm^3)	0.0047 *(0.0046 – 0.0049)*

The SPM concentration among the three experiments varied from 240 mg/Nm^3 to 1088 mg/Nm^3. The average concentration of SPM in the kiln is calculated as 531 mg/Nm^3. The Indian emission standard is 1200 mg/Nm^3 for small/medium/large categories of down draught kilns[30]. The SO_2 concentrations were very low, mainly because of the low sulphur content in biomass fuel.

Aerosol properties

Aerosol optical properties (scattering and absorption) were measured in real time for 46 to 48 minutes. Three tests were conducted in the down-draught kiln. In addition to real-time measurement of scattering and absorption, particles collected on filter paper were analysed for organic and elemental carbon. Results of scattering and absorption are presented in Table 6-7.

Table 6-7: Scattering and absorption for red λ and elemental & organic carbon for down-draught kiln

	Unit	Kiln 7_down-draught
Scattering	*1/m*	1.2
Absorption	*1/m*	0.39
Elemental carbon	*mg/m³*	98
Organic carbon	*mg/m³*	29

Particle absorption measurements were taken at three wavelengths: blue (467nm), green (530nm), and red (660nm). Results at red wavelength are presented here, and the results from other wavelengths are used to calculate the absorption angstrom exponent. The results are presented in Table 6-8.

Table 6-8: Particle absorption measurement for red wavelength in down-draught kiln

	Kiln 7_down-draught
Single scattering albedo (Red λ)	0.68
Absorption angstrom exponent*	0.76
Elemental carbon % (in total carbon)	75%
Elemental carbon % (in $PM_{2.5}$)	30%

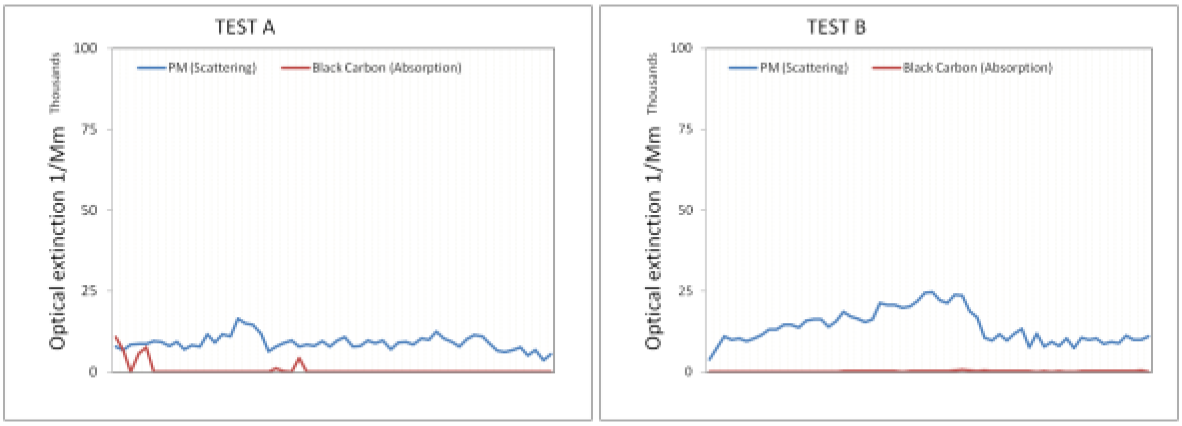
*Between blue and red wavelengths

30 "*G.S.R. 543 (E) MoEF Notification*", Ministry of Environment and Forests, New Delhi, 2009.

In the optical results, the single scattering albedo in the red wavelength can be compared to that of pure black carbon, which has a value of 0.226 at 500nm[31]. The results indicate that these particle emissions are less absorbing than pure black carbon but are still quite dark. The absorption angstrom exponent for this kiln is lower than 1. This indicates that the particles absorb light over the entire visible spectrum, and possibly that the particles are slightly larger than black carbon from other emission sources.

The results of the thermal optical analysis show that elemental carbon was much greater than organic carbon emission. While elemental carbon is sometimes considered a near equivalent to black carbon, non-volatile organic carbon may also contribute to the apparent EC fraction for these emissions.

Figure 6-5 displays the real-time optical data collected at the kiln. All tests are presented on the same scale. Black carbon is often an indicator of flaming combustion, while scattering particles are mostly from smouldering combustion. In this kiln, the traces of absorption and scattering almost always vary at the same time, indicating that mixed combustion is dominant throughout the entire production cycle.



[31] Conant, W. C., J. H. Seinfeld, J. Wang, G. R. Carmichael, Y. Tang, I. Uno, P. J. Flatau, K. M. Markowicz, and P. K. Quinn (2003), A model for the radiative forcing during ACE-Asia derived from CIRPAS Twin Otter and R/V *Ronald H. Brown* data and comparison with observations, *J. Geophys. Res.*,*108*(D23), 8661, doi:10.1029/2002JD003260

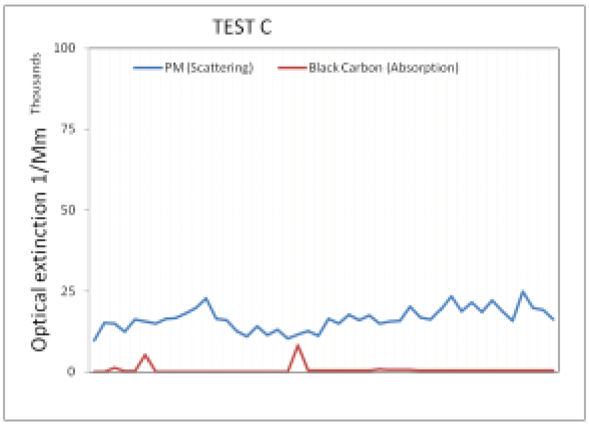


Figure 6-5 Real-time optical data collected at kiln 7_down-draught

In addition to the above measurements, an impactor test with cut sizes at PM_{10} and $PM_{2.5}$ was performed at Kiln 7_down-draught kiln to get the particle size distribution of organic and elemental carbon. These particles were collected on quartz filters in a MOUDI three stage impactor. Figure 6-6 and Table 6-9 summarize the particle size distribution of organic and elemental carbon.

Table 6-9: Particle size distribution of EC & OC in down-draught kiln

	Kiln 7_down-draught	
	Total Carbon fraction (%)	EC in Total Carbon fraction (%)
>PM 10	1.5%	7.9%
PM 10	1.7%	11%
PM $_{2.5}$	4.5%	17%
Fines	92%	69%

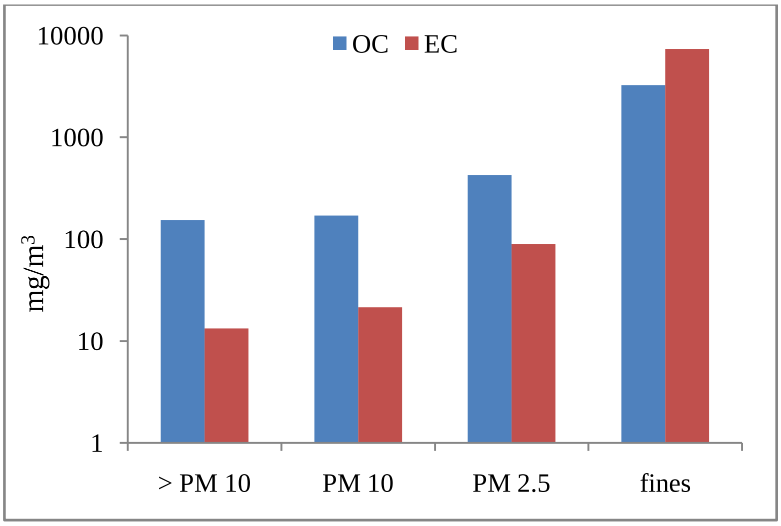


Figure 6-6 Particle size distribution at Kiln 7_down-draught

Submicron aerosols dominated the particulate emissions in the down-draught kiln with 92% of the carbon measured in the fine impact or stage. Black carbon is usually emitted in particles smaller than $PM_{2.5}$, so the high elemental carbon to total carbon ratios in the $PM_{2.5}$ and fines sizes confirms the same.

Emission factors

Pollutant emissions vary according to type of kiln, fuel used and operating conditions. For comparing the emissions across different fuel/operating conditions, it should be normalized either to unit of fuel consumed or to unit of energy consumed, or a comparison based on brick production. Emission factors for PM and SO_2 can be derived from emission rate (ER) fuel consumption rate, energy content of the fuel, and production rate. Another method, namely the carbon balance method (described in Annexure-III), was used to estimate $PM_{2.5}$, CO, CO_2 and black carbon emission factors. A summary of emission factors of pollutants from the down-draught kiln is presented in Table 6-10.

Table 6-10: Emission factors of particulate matter and flue gas pollutants in down-draught kiln

Pollutants			*g/kg fuel*	*g/MJ*	*g/kg fired brick*
Flue Gas Pollutants		CO	34.36	1.99	5.78
		CO_2	1680	97	282
		SO_2	8.33×10^{-5}	4.82×10^{-6}	1.40×10^{-5}
Particulate Matter	SPM	Total SPM	9.30	0.54	1.56
		$PM_{2.5}$	5.75	0.33	0.97
	Aerosol Properties	Elemental carbon	1.71	0.10	0.29
		Organic carbon	0.51	0.029	0.085
			m^2/ kg fuel	*m^2/ MJ*	*m^2/kg fired brick*
		Scattering (Red λ)	21	1.2	3.5
		Absorption (Red λ)	6.7	0.39	1.1

6.5. Summary

A summary of the energy and emission results is shown below.

Energy & Process

- The SEC of 2.91 MJ/kg of fired brick is highest amongst all the kilns monitored, almost 3 times that of VSBK, and more than 2 times that of a FCBTK.
- The main reasons for high SEC are
  - The kiln structure must be warmed up for each new batch; this heat is lost when the kiln is cooled for emptying.
  - The heat contained in the hot-fired bricks is lost.
  - Energy recovery from hot flue gases is partial.
  - Incomplete combustion.

Emissions

- Particulate matter concentrations of monitored DDK ranged from 240 mg/Nm^3 to 1088 mg/Nm^3. The average SPM concentration is calculated as 531 mg/Nm^3.
- As biomass was used as a fuel, SO_2 emissions were lower than other kilns monitored.

Aerosol Properties

- The average emission factor for $PM_{2.5}$ was 5.75g/kg of fuel.
- The average scattering emission factor was 21.02 m^2/kg of fuel, and the average absorption emission factor measured was 6.70 m^2/kg of fuel.
- Filter-based elemental carbon measurements averaged 1.71 g EC/kg of fuel and composed 77% of the total carbon and 30% of the $PM_{2.5}$.
- The optical and chemical analysis of the aerosols indicated higher black carbon emissions in this down-draught kiln than the VSBK kilns, but the emissions were within the range of black carbon measured in the FCBTK and forced draught zig-zag kilns.

Chapter 7. Tunnel Kiln

7.1. Tunnel kiln

In a tunnel kiln, which is a horizontal moving ware kiln, bricks to be fired are passed on cars through a long horizontal tunnel. The firing zone remains stationary near the centre of the tunnel, while the bricks and air move in counter-current paths. Cold air is drawn from the car exit end of the kiln, cooling the fired bricks. The combustion gases travel towards the car entrance, transferring part of their heat to the incoming green bricks. The cars can be pushed either continuously or intermittently at fixed time intervals. The tunnel kilns have provisions for air extraction and supply at several points along the length of the kiln.

Tunnel kilns are the preferred technology for firing bricks in developed countries. The advantages of tunnel kiln technology lie in its ability to fire a variety of products; good control over the firing process; ease of mechanization, thus reducing the labour requirement; and large production volume. Typically the capacity of a single tunnel kiln ranges from 60,000 to 200,000 bricks per day. While there are fewer than 10 tunnel kilns operating in South Asia for brick firing, the technology has become very popular in Vietnam, where roughly 700 tunnel kilns are in operation. Figure 7-1 shows a schematic of typical tunnel kiln.

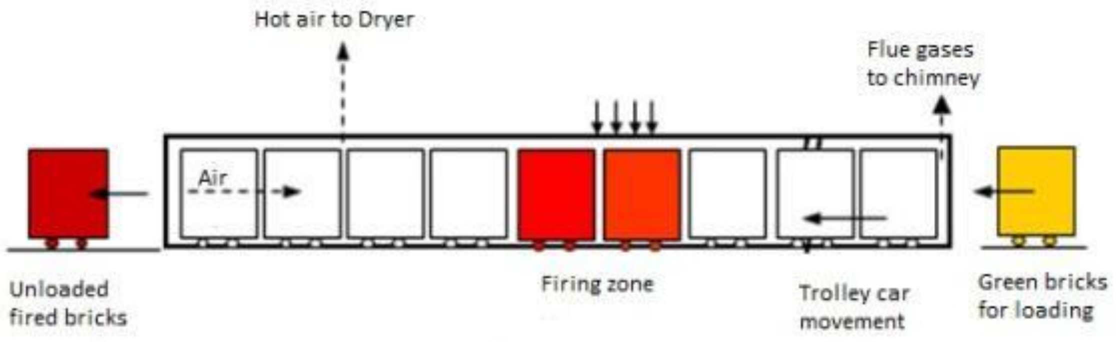


Figure 7-1 Schematic of a Tunnel Kiln

One tunnel kiln was selected for monitoring. The salient feature of this kiln is given in Table 7-1. The location of the kiln is marked on the Vietnamese map (Figure 7-2).

Table 7-1: Salient features of the monitored tunnel kiln

Kiln Identification No	Location	Production Capacity		Fuel	Time of Monitoring
		Bricks/day	Bricks/yr (Million)		
Kiln 8_Tunnel	Nam-Dinh province, Vietnam	68,857	20 - 25	➢ Coal ash ➢ Coal powder	10th to 12th May 2011

Figure 7-2: Location of monitored tunnel kiln

7.2. Salient Features of the Monitored Kiln

Table 7-2: Salient Features of the monitored tunnel kiln

	Kiln 8_Tunnel
Location	Nam-Dinh province, Vietnam
Description of company	➢ The owner is a very experienced brick maker ➢ During last decade, has shifted first from up-draught tradition kiln to VSBK and then to tunnel kilns ➢ Currently the company operates three kilns (all are tunnel)
Annual production	20 – 25 million bricks/ year/ tunnel kiln
Supplying market	➢ In the radius of 60 – 80 km ➢ Nam-Dinh province & near by areas
Operational period	➢ Year round
Kiln description	➢ Tunnel kiln coupled with a tunnel dryer. The hot air extracted from the cooling zone of the tunnel kiln, along with the exhaust gases from the tunnel kiln, are used for drying bricks in the dryer. ➢ Capacity: 30 cars in kiln (8 cars in firing zone, 10 cars in cooling & 12 cars in preheating zone) and 18 cars in the dryer. Some basic instrumentation for measuring temperatures is located in the kiln and dryer. ➢ A lime water scrubber is installed adjacent to the chimney to treat the flue gases. ➢ Use of internal fuel o Accounts for 80% of the total thermal energy

Moulding	➢ Machine moulding – Extruder
	  o Perforated bricks
	  o Around 30% perforation

Drying	➢ All the green bricks are dried under drying shade[a]

Firing fuel	➢ Coal
	  o Coal ash[b] – Used as internal fuel
	  o Coal slurry[c]– Used as external fuel

[a] Drying shade avoids direct exposure to the sun and hence reduce the possibility of drying cracks and protects the green bricks from unseasonal rains.
[b] Coal Ash is the residue obtained from firing of coal in power plants. It has a low volatile content and low calorific value.
[c] Coal powder has medium to high volatile content and medium calorific value.

7.3. Energy Performance of the Monitored Kilns

<u>Fuel feeding practice</u>

Almost 80% of the fuel is added as internal fuel mixed with clay during the moulding process. Finely powdered coal is fed using small spoons through the fire holes on the roof of the kiln in the firing zone (around 8 cars). The frequency of charging is around 30 minutes. The charging is usually done before and after the pushing of cars. The firemen decide on the amount of coal to be fed depending on the firing shrinkage and the temperature. The details of the fuel feeding practice are given in Table 7-3.

Table 7-3: Fuel feeding practice in the monitored tunnel kiln

Kiln Identification No	Fuel feeding Practice
Kiln 8_Tunnel	➢ Fuel fed in 8 cars. ➢ Fuels fed by firemen intermittently. ➢ Coal in finely powdered form. ➢ Very small spoons (140 g) used for feeding the coal. ➢ Temperature in the firing zone ranged from 905 – 930°C.

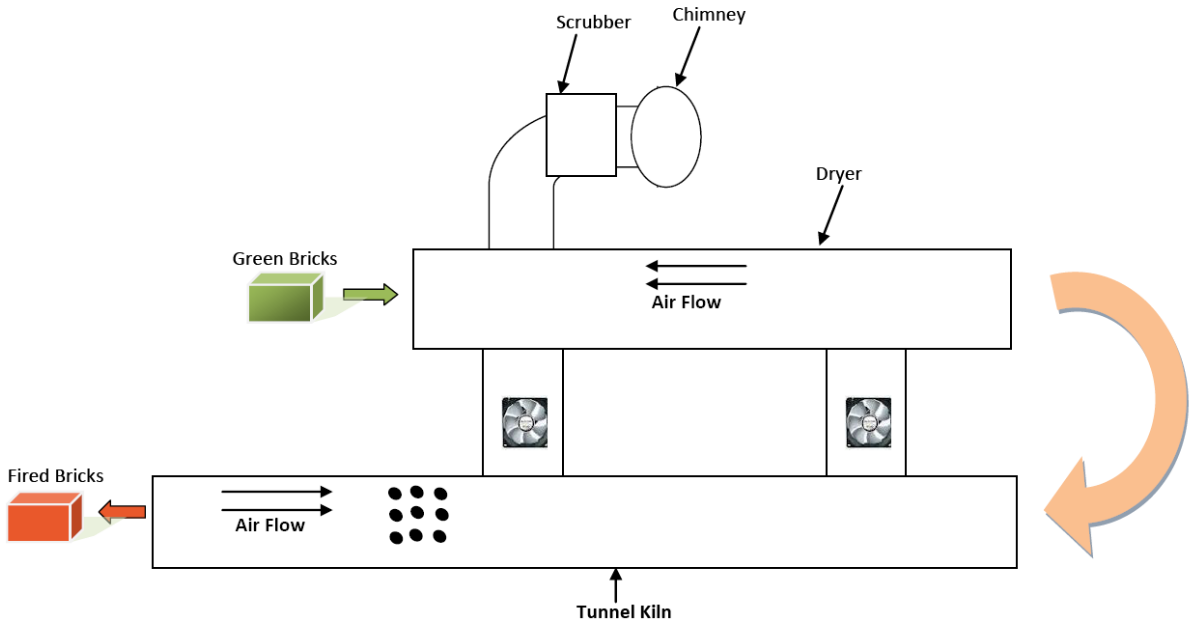


Figure 7-3: Schematic of the monitored tunnel kiln and the dryer

<u>Energy performance</u>

Flue gas measurements were taken at regular interval at a monitoring port in the chimney of the tunnel kiln. The results are presented in Table 7-4.

Table 7-4: Flue gas analysis of tunnel kiln measured at the chimney

	Kiln 8_Tunnel
Average O_2 (%)	19.4
Average CO_2 (%)	1.37
Average CO (ppmv)	533
Average Excess Air (%)	1152
Average temperature of flue gas (^oC)	60.3

Average excess air computed for the monitored kiln is order of 1000%, which is very high. High excess air levels indicate leakages in the kiln.

Specific energy consumption and heat balance

Based on the fuel consumption rate and brick production (numbers and kg of bricks fired per day), specific energy consumption is computed and shown in Table 7-5.

Table 7-5: Specific energy consumption of the monitored tunnel kiln

Kiln Identification No	Fuel consumption (kg/day)		Production		Specificenergy consumption (SEC) (MJ/kg fired brick)
Kiln 8_Tunnel	*Coal Ash*	*Coal Slurry*	*Bricks/day*	*kg/day*	1.46*
	16,181	1894	68857	114303	

*Based on GCV and assuming 4% moisture content in *Coal Ash & Coal Slurry*

The above calculated SEC is only for the thermal energy input to the kiln. In order to create the draft, two fans of 7.5 kW & 15 kW are used. Bricks are moulded from an extruder, which has a load of about 450 kW. As per the kiln owner's estimate, roughly 30 kWh of electricity are used for the production of 1000 bricks. Table 7-6 summarizes the overall energy requirement for the monitored tunnel kiln.

Table 7-6: Overall energy consumption of the monitored tunnel kiln

Kiln identification No	Thermal specific energy consumption (MJ/kg fired brick)	Electrical specific energy consumption (MJ/kg fired brick)*	Total specific energy consumption (MJ/kg fired brick
Kiln 8_Tunnel	1.46	0.26	1.72

*Primary energy considering 25% efficiency of the power generation and transmission

Table 7-7 presents the heat balance for the monitored tunnel kiln in the study.

Table 7-7: Heat balance of the monitored tunnel kiln

	Kiln 8_Tunnel
Dry flue gas heat loss	14.9 %
Sensible heat loss in unloaded bricks	0.57 %
Moisture removal	32.15%
Heat loss due to incomplete combustion	2.68 %
Other heat components	49.71 %
Total	100 %

Energy efficiency improvement measures

Table 7-8: Energy efficiency measures for the monitored tunnel kiln

Kiln Identification No	Energy efficiency measures
Kiln 8_Tunnel	➢ The major opportunity lies in reducing the excess air by reducing the leakage of air in the pre-heating zone of the kiln due to improper sealing between cars. ➢ Reducing the mass of the kiln cars can help in reducing the energy consumption.

7.4. Emissions

Three experiments were conducted to measure the concentration of SPM. Concentration of SO_2 and NO_x was measured using flue gas analyser of CENMA laboratory. Measurement of HF concentration was carried out as per TCVN 7243-2003 method. Samples were collected from the port-hole in the chimney situated at a height of 9 m above ground level. Sampling duration ranged from 42 to 60 minutes. Prior to sample collection, flue gas temperature and velocity were measured at the sampling port. Iso-kinetic sampling was followed for particulate matter sampling. The following sections present the results of monitoring and emission factor estimation.

Table 7-9: Flue gas characteristics and emission concentrations in the tunnel kiln

	Kiln 8_Tunnel
Flue gas temperature (°C)	55 - 65
Flue gas velocity (m/s)	5.0 – 5.9
Concentration of pollutants in the flue gas	
SPM (mg/Nm^3)	45 (39 - 50)
$PM_{2.5}$ (mg/Nm^3)	27 *(9-64)*
SO_2 (mg/Nm^3)	106 *(78– 129)*
NO_x (mg/Nm^3)	18 *(13 – 21)*

The SPM concentration among the three experiments ranged from 39 mg/Nm^3 to 50 mg/Nm^3. The average concentration of SPM in the kiln was 45 mg/Nm^3, which is significantly lower than the Vietnamese emission standard[32] of 400 mg/Nm^3. Concentration of SO_2 was 106 mg/Nm^3, and NO_x concentration was 18 mg/Nm^3. Both SO_2 and NO_x concentrations were found to be significantly below their respective standards. The average HF concentration of the eight experiments carried out at the kiln was 15.8 mg/Nm^3, which is lower than the emission standard of 50 mg/Nm^3.

Aerosol properties

Aerosol optical properties (scattering and absorption) were measured in real time for a period of 46 to 48 minutes. Three tests were conducted in each kiln. In addition to real-time

[32] QCVN, (2009), "*National Technical Regulation on Industrial Emission of Inorganic Substances and Dusts*"

measurement of scattering and absorption, particles collected on filter papers were analysed for organic and elemental carbon. The results of scattering and absorption are presented in Table 7-10.

Table 7-10: Scattering and absorption for red λ and elemental & organic carbon for tunnel kiln

	Unit	Kiln 8_Tunnel
Scattering	*1/m*	0.020
Absorption	*1/m*	Not detected
Elemental carbon	*mg/m*^{3}	0.053
Organic carbon	*mg/m*^{3}	Not detected

In this kiln, elemental carbon and absorption were near or below detection limit, indicating that little absorbing material is emitted. Organic carbon was entirely below detection limit. The mass of the particles must be non-carbonaceous, probably mineral matter. Because elemental carbon and absorption are so low, the ratios presented for other kilns are not meaningful here, and real-time optical charts are not presented.

The ratio between scattering and PM concentration varies with particle size. Particles within a certain size range (about 200-800 nm diameter) scatter more per unit mass than the particles that are larger or smaller than that range. Combustion particles are frequently within the "efficient" size range, but these particles are different and have lower scattering. The evidence is consistent with larger particles that are composed of mineral matter.

Emission factors

Pollutant emissions vary according to type of kiln, fuel used and operating conditions. Comparing emissions across different fuel/operating conditions requires normalizing either to unit of fuel consumed or to unit of energy consumed, or a comparison based on brick production. Emission factors for PM and SO_2 were derived from emission rate (ER), fuel consumption rate, energy content of the fuel and production rate. Another method, namely the carbon balance method (described in Annexure-III), was used to estimate $PM_{2.5}$, CO, CO_2 and black carbon emission factors. A summary of emission factors of various pollutants for the tunnel kiln is presented in Table 7-11.

Table 7-11: Emission factors of particulate matter and flue gas pollutants in tunnel kiln

Pollutants			*g/kg fuel*	*g/MJ*	*g/kg fired brick*
Flue Gas Pollutants		CO	16.19	1.67	2.45
		CO_2	1097	113	166
		SO_2	4.73	0.49	0.72
Particulate Matter	SPM	Total SPM	2.02	0.21	0.31
		$PM_{2.5}$	1.19	0.12	0.18
	Aerosol Properties	Elemental carbon	0	0	0
		Organic carbon	Not detected	Not detected	Not detected
			m^2/ kg fuel	*m^2/ MJ*	*m^2/kg fired brick*
		Scattering (Red λ)	0.86	0.089	0.13
		Absorption (Red λ)	Not detected	Not detected	Not detected

7.5. Summary

A summary of the energy and emission results is shown below.

Energy and process

- The SEC (thermal energy) of the monitored kiln was measured as 1.46 MJ/kg of fired bricks. This also includes energy in the dryer section of the kiln.
- The kiln has a very high excess air level (1172%), and a major opportunity lies in reducing the excess air by reducing the leakage of air in the pre-heating zone of the kiln, caused by improper sealing between cars.

Emissions

- Particulate matter concentration of monitored tunnel kiln ranged from 39 mg/Nm^3 to 50 mg/Nm^3. The average SPM concentration was 45 mg/Nm^3.
- The variation in the concentrations among the three experiments was not significant, which indicates the consistency in the kiln operational practices.

- Concentration of SO_2 varied from 78 to 129 mg/Nm^3 with average at 106 mg/Nm^3. NOx concentration ranged from 13 to 21 mg/Nm^3 with average concentration of 18 mg/Nm^3.
- The average HF concentration was measured at 15.8 mg/m^3.

All pollutant concentrations were significantly lower than their respective emission standards.

Aerosol properties

- Elemental and organic carbon emissions at the kiln were very low, and the particles more likely contain mineral matter.
- Measurements of absorption and elemental carbon suggest that the light absorbing emissions are low compared to the other measured brick kilns.
- Measurements of $PM_{2.5}$ and of scattering indicate that particles are still emitted, but are not generated in the combustion.

Chapter 8. Comparison of Brick Firing Technologies

In chapter 3 to 7, the results of the performance monitoring of various brick kilns were presented. This chapter presents a comparison of the performance of different brick kilns. This comparison covers:

a) *Energy performance*: specific energy consumption (SEC)

b) *Environment performance*: Emission factors for suspended particulate matter (SPM), black carbon, sulphur dioxide (SO_2), oxides of nitrogen (NO_x) and carbon monoxide (CO).

c) *Quality of the product*: Percentage of properly fired bricks; ability to fire a variety of clays; ability to fire a wide variety of fired products.

d) *Financial performance*: Capital investment, pay-back period.

8.1. Energy Performance

Thermal energy

In a brick kiln, fuel is burnt to produce thermal energy which is used for both firing and drying bricks.The details of specific energy consumption (SEC) for various kilns are presented in Table 8-1. A comparison of the average SEC of the kilns is presented in Figure 8-1. The main conclusions are:

Vertical Shaft Brick Kilns

VSBK is the most efficient brick firing technology. The average SEC value is 0.75±0.29 MJ/kg of fired bricks. The Vietnamese kiln has a very low SEC value (0.55 MJ/kg of fired brick). This lower SEC can be attributed to a combination of factors which include higher shaft height, larger kiln cross-section area, almost 100% internal fuel addition and smaller brick size. The predominant effect of these factors is an increase in heat transfer area and time, resulting in better heat recovery.

Zig-zag kilns

The SEC of the two monitored zig-zag kilns was 1.12±0.13 MJ/kg of fired bricks. The zig-zag air path, results in the creation of turbulence, leading to better heat transfer and combustion and hence a superior performance compared to FCBTK.

Fixed chimney bulls trench kiln

The SEC of the three monitored kilns was 1.22 ± 0.22 MJ/kg of fired bricks. The monitored SEC values match well with the earlier reported results for FCBTKs. An analysis of the heat balance for FCBTKs indicates a potential of 10-15% savings in energy consumption through better operating practices.

Down-draught kiln

The downdraft kiln is an intermittent kiln and does not have heat recovery features and as expected has the highest SEC of 2.9 MJ/kg of fired brick.

Tunnel kiln

The SEC of the tunnel kiln monitored in Vietnam was 1.46 MJ/kg of fired brick. The tunnel kiln has a tunnel dryer connected to it. The tunnel dryer does not have a separate heat source; the hot air generated in the tunnel kiln is conveyed to the tunnel dryer. Hence the SEC is a combined SEC for firing and drying operations. The monitored value is comparable to the previous measurements in Vietnam.

Electricity and mechanical power:

Electricity and mechanical power may be used in a kiln for

a) Operating fans to create draft and to convey air from one part of the kiln to the other
b) Material handling systems e.g. tunnel car trolley pusher, lifts, conveyers, etc.
c) Lighting
d) Clay preparation and moulding process.

In all the Indian kilns, there was little use of electricity and mechanical power. It was negligible for FCBTK. In the Indian VSBK, a diesel generator was used to generate electricity to operate the conveyor system to transport green bricks to the kiln top. The zig-zag forced draught kiln had an electricity operated fan for producing a draft. In Vietnam, as most of the moulding and material handling has been semi-mechanized, there is more use of electricity and mechanical power.

Table 8-1: SEC of the monitored kilns

Firing Technology	Process	SEC-Thermal energy (MJ/kg fired brick)*	Electricity/ Mechanical Power used in the production process**
FCBTK	Hand moulding	1.22 ± 0.2	➢ None
Zig-zag	Hand moulding	1.12 ± 0.13	➢ None in case of natural draught ➢ 36 liter diesel/day (SEC: 0.015 MJ/kg of fired brick primary energy) for operating the fan in the forced draught kiln
VSBK	Hand moulding (Indian VSBK) Extruder moulding (Vietnam VSBK)	0.75 ±0.29	➢ Indian VSBK: 10 liter diesel/day (SEC: 0.03 MJ/kg of fired brick) for operating the conveyor (for 1-shaft operation). ➢ Vietnamese VSBK: 15 kWh/1000 bricks (SEC: 0.1 MJ/kg of fired brick) for operating the extruder, lifting of bricks, operation of unloading mechanism
Down draft	Hand	2.9	➢ None
Tunnel Kiln – Vietnam – Internal Fuel	Machine (Extruder)	1.47 ***	➢ 40 kWh/1000 bricks (SEC: 0.3 MJ of primary energy/kg of fired brick) for operating the extruder, tunnel dryer, tunnel kiln etc

*The values presented are average ± SD. In case of FCBTK the data is from 3 kilns; for zig-zag – from 2 kilns; VSBK- 2 kilns; while for downdraft and tunnel it is for one kiln only.
**Energy/fuel not used for producing heat for firing or drying process.
*** The kiln and the dryer are interconnected. The specific thermal energy also includes the energy required in the tunnel dryer

The contribution of electricity and mechanical power (in terms of primary energy) ranged from 0 to 0.3 MJ/kg of fired brick for the monitored kilns, representing only 0 - 20% of the thermal energy component.

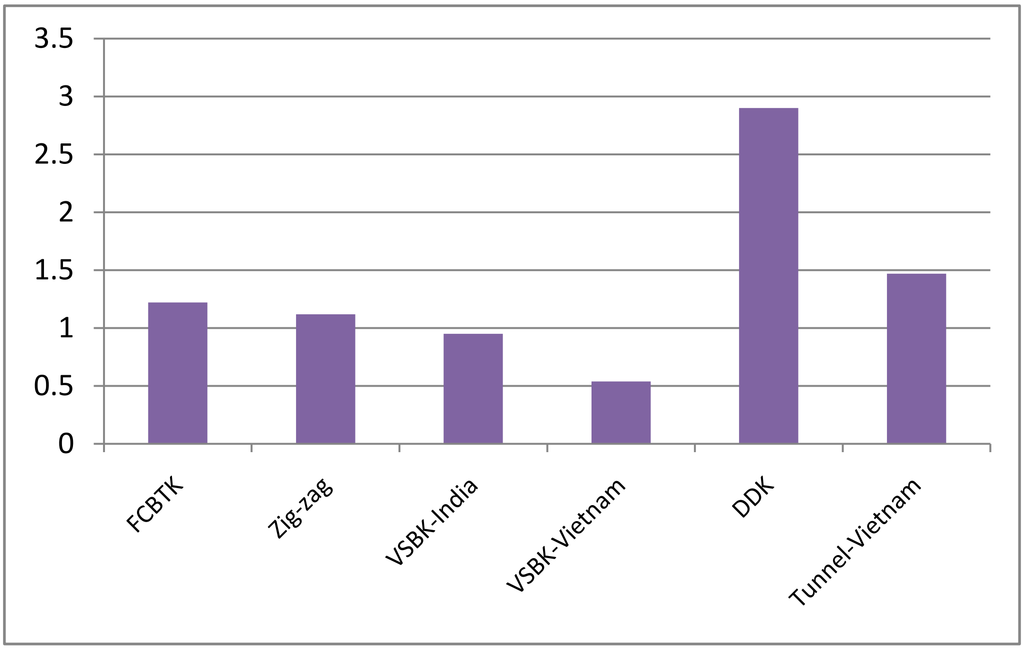


Figure 8-1 Comparison of Average SEC (MJ/ kg of fired brick) for various kilns

8.2. Environment Performance

Environmental performance with respect to particulate matter and other gaseous pollutants was assessed for all selected kilns.

Suspended Particulate Matter (SPM)

SPM are particles with a diameter less than 100 µm that tend to be airborne. The emission factor for SPM is presented in Table 8-2. Zig-zag natural draught kiln at Varanasi which followed excellent fuel preparation and feeding practices[33] has the lowest SPM emissions. The improved VSBK in Vietnam, the Indian VSBK and the tunnel kiln in Vietnam also have low SPM emissions. Both the Vietnamese kilns (VSBK and Tunnel kiln) internally mix the fuel. In this practice, powdered fuel is mixed with clay prior to the moulding of bricks. The Indian VSBK also practices internal fuel additions, though the percentage of fuel is lower (around 40%) compared to the Vietnamese kilns (90-95%).The combustion process for

[33] The excellent fuel preparation and feeding practices refer to use of sawdust as fuel in front rows (where there are low temperatures), use of powdered coal, continuous feeding of fuel in small quantities, measurement of process parameters – temperature of flue gases and inside the kiln and using these parameters for controlling the firing process, etc.

internal fuel differs substantially from external fuels. Thus apart from the type of kiln, the mode of fueling and operating practice seems to have a significant impact on the SPM emissions.

Most of the SPM measurements were lower than the Indian standards. However, the current mission standards are not normalized for excess air. In practice, pollutants in the stack emissions are diluted due to leakage and variation in operation practice. This factor needs to be recognized. Emission standards for SPM would offer better guidance if normalised on the basis of O_2 or CO_2 content.

Significant variation in the SO_2 concentration was observed in the kilns monitored. Variations in SO_2 emissions are due to fuel sulphur content. The lowest SO_2 concentration was observed in the down draft kiln, where biomass was used as fuel. In addition to fuel sulphur content, moisture content of the flue gas also reduces concentration of SO_2, where it act as a scrubber and reduces SO_2 emissions. NO_x emissions were generally low.

Emissions of carbon monoxide (CO) are an indication of incomplete combustion of fuel. The zig-zag natural draft kiln shows the lowest CO emissions, and the downdraft kiln has the highest CO emissions among the kilns monitored. CO emissions in the Vietnamese VSBK are lower than those in the Indian VSBK.

Accurate comparison requires normalizing the emissions on the basis of energy content (per MJ) or brick production (per kg of fired brick). Table 8-2 provides the average emission factors for various pollutants monitored in the study, normalized to g/kg of emissions. Figure 8-2 provides a comparison of average SPM and $PM_{2.5}$ emission factors for various kiln types.

Table 8-2: Emission factors for the monitored kilns

Technology	Emission Factors (g/kg of fired brick)				
	SPM	$PM_{2.5}$	SO_2	CO	CO_2
FCBTK	0.86 ± 0.74	0.19 ± 0.07	0.65 ± 0.55	2.25	115
Zig-zag	0.26 ± 0.26	0.13 ± 0.07	0.36 ± 0.28	1.47	103
Down draft kiln	1.56 ± 1.41	0.09 ± 0.06	Nil	5.78	282
VSBK	0.1 ± 0.02	0.97 ± 0.47	0.54 ± 0.47	1.84	70
Tunnel Kiln	0.31 ± 0.04	0.18 ± 0.21	0.72 ± 0.1	2.45	166

In comparison with FCBTK, SPM and CO emission factors (g/kg of fired bricks) for zig-zag kilns are significantly lower. This indicates better combustion conditions in zig-zag kilns. CO_2 emission factors are also lower by 10%.VSBK has lower emission factor in terms of CO_2 and SPM. SO_2 emission factors depend on fuel sulphur content.

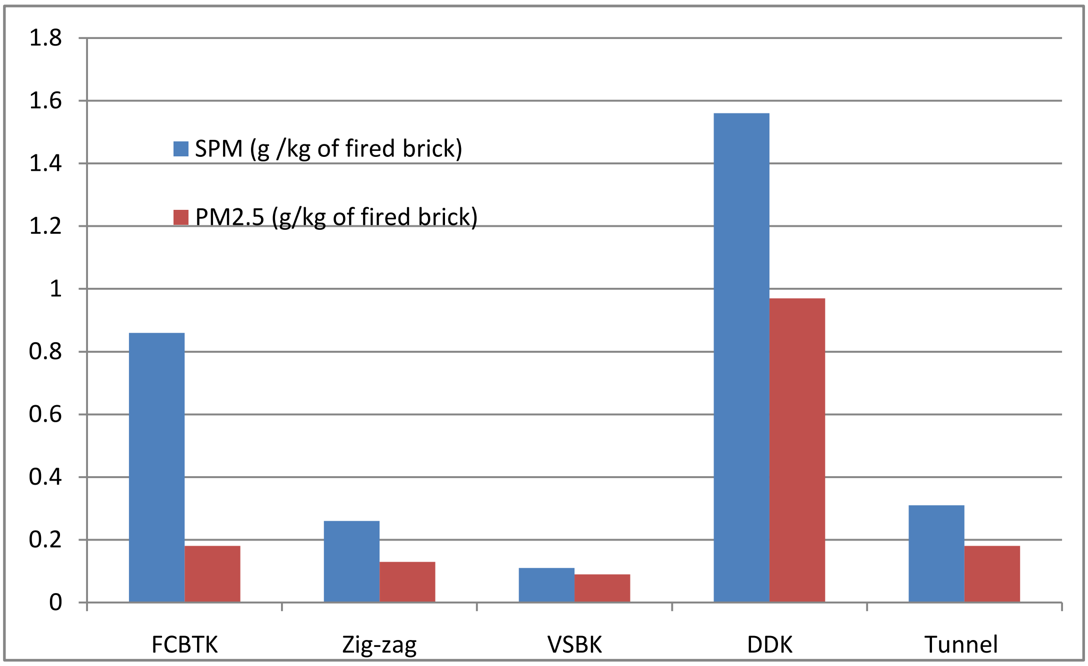


Figure 8-2 Comparison of average SPM and PM2.5 emissions factors

Particulate matter ($PM_{2.5}$)

Emission norms in India do not address $PM_{2.5}$ specifically, but it is frequently monitored because of its environmental and health effects. Fine particulate matter (diameters less than 2.5 micrometers) can penetrate more deeply into lungs than larger particles. It also has a longer atmospheric lifetime and a disproportionately greater effect on visibility and climate than do larger particles. Unlike SPM, which might contain large ash particles, $PM_{2.5}$ from coal combustion contains some mineral matter but also large quantities of carbonaceous aerosol. VSBK and tunnel kilns had the lowest $PM_{2.5}$ of monitored kilns, and down draught kiln had the highest emissions.

Black and organic carbon (optical measurements)

Black carbon is a combustion product predominantly composed of strongly bonded graphitic-like carbon rings. This composition causes black carbon to be thermally stable at high temperatures, and to strongly absorb visible light. Organic carbon comprises all carbon species that are neither black nor carbonate carbon. Two methods were used in this study to measure light-absorbing carbon. Thermo-optical analysis measured "elemental carbon," which is stable at high temperatures, similar to BC. This analysis also measured organic carbon. Results of black and organic carbon measurements, and single scattering albedo, are shown in Table 8-3.

Table 8-3: Results of composition and optical measurements

Technology	Elemental Carbon (g/kg fired brick)	Organic Carbon (g/kg fired brick)	Absorption (m^2/kg fired brick) *	Single Scattering Albedo *
FCBTK	0.16 ± 0.04	0.02 ± 0.04	0.22 ± 0.18	0.70 ± 0.07
Zig-zag	0.04 ± 0.03	0.02 ± 0.04	0.16 ± 0.11	0.64 ± 0.01 **
VSBK	0.002 ± 0.002	0.03 ± 0.04	0.06 ± 0.04	0.84 ± 0.13
Down draught kiln	0.34 ± 0.02	0.09 ± 0.02	1.13 ± 0.36	0.74 ± 0.09
Tunnel kiln	n.d.	n.d.	0.01 ± 0.004	0.96 ± 0.03

n.d. = not detectable (measurement below detection limit)
* At red wavelength (660 nm)
** Excludes zig-zag natural draught where scattering measurements were questionable.

The results indicate that better combustion in zig-zag kiln lowers BC emissions compared to FCBTKs and down draft kiln. Further, the black carbon emissions can be almost totally eliminated by internally adding fuel and firing in kilns like VSBK and tunnel kiln, presently done in Vietnam. As with the particulate matter results, the down draught kiln has the highest emissions, followed by FCBTK. In all kilns the emission factors of organic carbon are quite low. This material is easier to oxidize than black carbon or mineral matter and may be consumed at elevated stack temperatures.

A second measure of BC-like carbon is particle light absorption, measured in units of square meters (m^2). Together with scattering measurements, this can be used to calculate how particles affect visibility and radiative transfer. The single scattering albedo is a measure of particle lightness, with pure black carbon having a value of about 0.22, polluted urban air about 0.7, and pure white particles 1.0. Emissions at the forced zig-zag kiln are the darkest and most consistent as shown by the single scattering albedo.

The brick kiln emission factors can be compared with those from studies of other sources. For this comparison, grams pollutant per MJ of fuel (rather than per kg fired brick) is used. Figure 8-3 compares $PM_{2.5}$ and BC emission factors from this study with emissions from other types of coal combustion and from mobile sources.

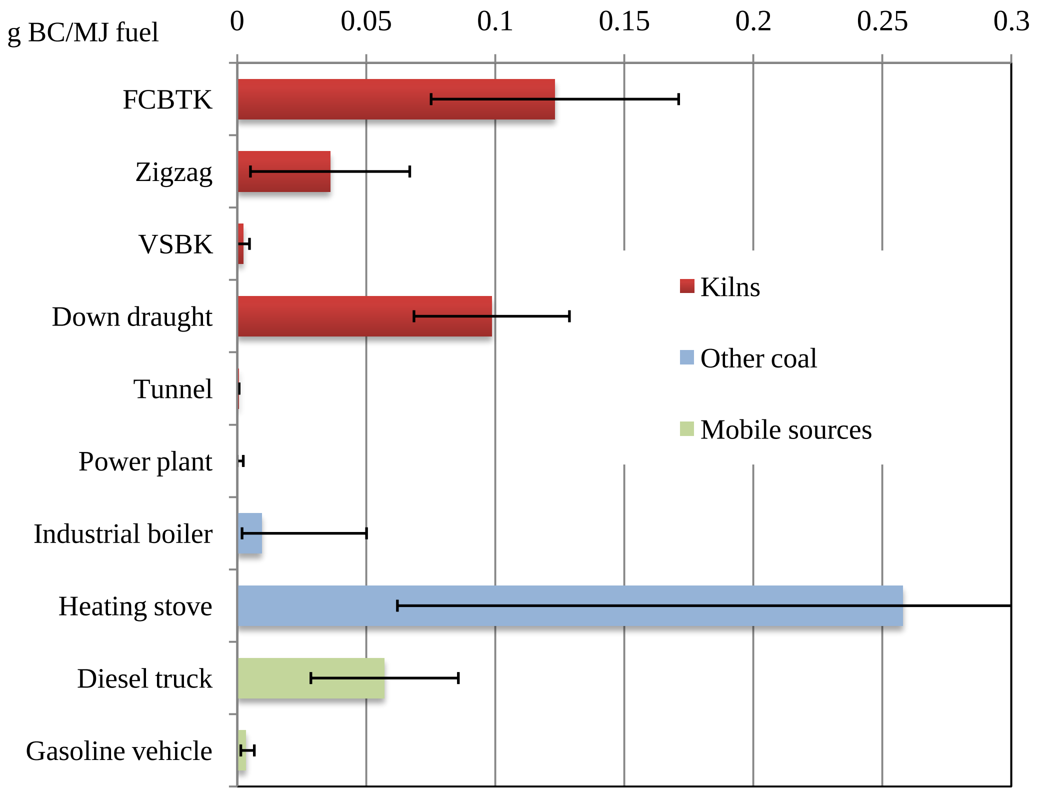


Figure 8-3 Comparison of $PM_{2.5}$ and BC emitted from kilns in this study to other coal sources, and mobile sources.

*Values presented for mobile sources are approximate emission rates for unregulated vehicles.

Emissions from coal combustion can vary widely depending on the quality of the combustion. The figure shows that well-operating power plants with emission controls have very low emissions of both PM and BC, industrial stoker boilers have detectable emissions, and heating stoves – which have no control of emissions or airflow within the stove – have quite high emissions. (Heating stoves are not used in India.) The difference in emissions is not caused by the fuel, but rather is attributable to the management of the fuel-air mixing and proper handling of the exhaust products. Emissions of the kilns measured in this project fall between those of industrial boilers and heating stoves, as could be expected based on the combustion management. On an emission per fuel basis, kilns are similar to diesel engines.

8.3. Quality of Fired Products

Apart from considerations of energy efficiency and pollution control, a brick entrepreneur's decision to invest in a particular firing technology is also influenced by factors, such as:

- The ability of the kiln to handle different types of clay. That is, a kiln that is not very sensitive to the type of clay provides freedom to the brick maker to use a variety of raw materials.
- The ability of the kiln to minimize wastage and to maximize the number of properly fired bricks.
- The ability of the kiln to fire a variety of products including hollow products.

A comparison of kiln technologies presented in Table 8-4 illustrates that

- Tunnel kiln is the best kiln for quality brick production, followed by the zig-zag kiln.
- FCBTK produces the lowest percentage of quality bricks.
- VSBK is limited in the clays that can be used.

Table 8-4 Comparison of kiln technologies (fired brick quality and fired products)

Technology	Ability to fire a wide-variety of clays	% of properly fired bricks	Ability to fire hollow products
FCBTK	Can fire a wide variety of clays because of the slow firing process.	50-80%	Limits on percentage of bricks that can be hollow.
Zig-zag	Can fire a wide variety of clays because of the slow firing process and long firing zone.	80-90%	Limits on percentage of bricks that can be hollow.
VSBK	Not suitable for all types of clays. The fast rate of heating and cooling can results in the formation of firing cracks.	50-90%	Not suitable to fire hollow products or thin products like roofing tiles.
Down draught kiln	Can fire a wide variety of clays because of the slow firing process.	Can vary from firing to firing	Limits on percentage of bricks that can be hollow.
Tunnel	Can fire a wide variety of clays because of the excellent mechanism to regulate the firing process.	90-95%	Most suitable for firing a wide-variety of products, including hollow products.

8.4. Financial Performance

A comparison of the financial performance of various technologies is presented in Table 8-5. It can be observed that both FCBTK and zig-zag kilns have lower investments and shorter pay-back periods. The tunnel kiln technology is suitable for large-scale production and requires 10-20 times the initial investment compared to other kiln types. VSBK, being modular in nature, can be used for small as well as medium scale production, but has a longer pay-back period compared to FCBTK and zig-zag kilns.

Table 8-5: Comparison of kiln technologies (financial performance)

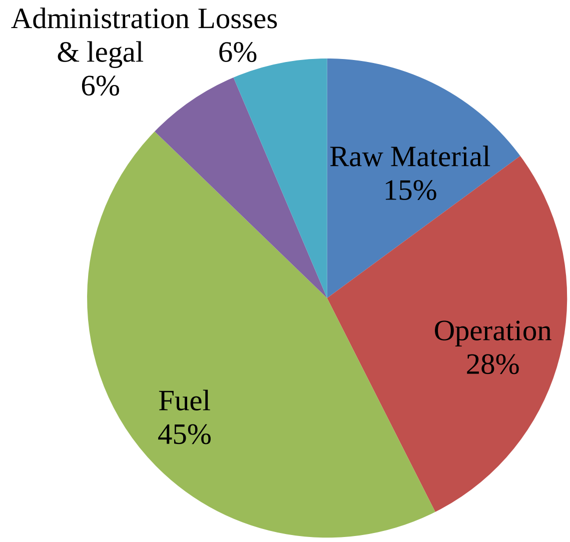
Technology	Capital Cost (US $)	Production Capacity (million bricks/year)	Typical pay-back period
FCBTK	60,000 - 80,000	5-8	< 2 years
Zig-zag	80,000 - 200,000	5-8	< 2 years
VSBK	60,000 - 400,000	1.5 -10	2-4 years
Tunnel	1-2 million	15-20	> 3 years

Data was collected on production cost and revenue. Typical production and selling price of bricks for different regions in the country are shown in Table 8-6. The profitability of brick enterprises is higher in southern and western India, due to the higher selling price of bricks.

Table 8-6: Typical Production and Selling Price Data

Indo Gangetic Plains (Punjab, Haryana, UP, Bihar)	Production cost: Rs 2.00- 2.50 / brick	Selling Price: Rs 3.00 – 4.00/ brick
Southern and western India	Production cost: Rs 2.50 -3.50/ brick	Selling Price: Rs 4.50 – 8.00/ brick

Figure 8-4 shows the typical break-up of production costs for a FCBTK in the Indo-Gangetic plains and illustrates that fuel is the largest cost component followed by operations (mainly manpower). The production cost of the natural draught zig-zag kiln is 15% lower than that of FCBTK.



Total Production Cost:- Rs. 2.35/Brick

Figure 8-4: Average Production Cost Break-down Data for Monitored FCBTKs in Indo-Gangetic Plains Region

8.5. Conclusions

The main conclusions that can be drawn from the comparison are as follows:

Fixed Chimney Bull's Trench Kiln

FCBTK fares poorly in emissions. In terms of its energy performance and quality, its performance is moderate. Its geatest advantage is the lowest capital cost requirement.

Zig-Zag Kilns

The performance of zig-zag firing technology is superior to FCBTK using most criteria:

- Reduction in energy consumption and CO_2 emissions by at least 10% as compared to FCBTK
- Significant reduction in SPM emissions
- Significant reduction in black carbon emissions as compared to FCBTK
- Substantial increase in the quality of class I bricks, from typically 60-70% for FCBTK to 80-90%.

The capital cost of a new zig-zag is equal to or marginally higher than a FCBTK. The pay-back period is attractive.

- Payback period of around 1 year in case of retrofitting an existing FCBTK to zig-zag firing and

- Payback period of around 2 years in case of a new zig-zag kiln.

The production capacity of zig-zag kilns is similar to that of FCBTK[34].

Vertical Shaft Brick Kilns

VSBK performance is mixed. It has the best performance in terms of energy and emissions, but the poorer performance in terms of brick quality and economics.

- VSBK has the best performance in terms of energy among all kilns. The improved VSBK in Vietnam has a very low SEC. The savings in energy, compared to the FCBTK, is between 20-50%.
- Emissions are the lowest amongst all kilns. The reduction in SPM and black carbon compared to a FCBTK is about 75%.
- Both the VSBKs monitored had problems with brick quality. The problem was more severe in the Indian VSBK.

Issues related to brick quality in VSBK

The problems in brick quality in a VSBK are due to a combination of factors.

- The high static and dynamic load on the bottom bricks damages bricks.
- Hand moulded bricks, which are common in India, have lower density and lower compressive strength, resulting in greater damage to the bricks. This problem is lower with better quality machine-moulded bricks.
- The fast heating up and cooling down can induce cracks in bricks.
- Some damage is also caused by excessive handling of green bricks during the lifting and loading process.

- VSBK is also limited in terms of the variety of clay products that can be fired; it is suitable for firing of solid bricks only. It may be used to fire bricks with perforations, but is not suitable for firing hollow bricks or thinner products like roofing tiles.
- The economics of VSBK in India does not seem to be as attractive as a zig-zag kiln, when considered as a replacement for FCBTK. The primary reason is the low production volume of a VSBK, which results in a longer pay-back period. A comparison of the

[34] However, there are no significant improvements in working conditions in the present version of the zig-zag kilns.

production cost of an FCBTK and a VSBK indicates that, though the energy costs in a VSBK are lower, the savings in energy costs are offset by the higher cost of kiln operation and the additional costs of equipment and power needed to lift the bricks. As a result the production cost of bricks in a VSBK is almost the same as that of an FCBTK.

Tunnel kiln

The tunnel kiln has a good environmental performance; it also ranks best in terms of its ability to fire a variety of clay products[35]. On the other hand, it uses more energy than other kilns; it has higher SEC (20-30% higher compared to FCBTK and hence higher CO_2 emissions). This is partly due to additional energy required for the tunnel dryer, residual heat losses in the kiln cars, as well as additional electrical energy requirements. It requires a significantly higher capital investment (15-20 times more than an FCBTK).

[35] Working conditions in a Tunnel kiln are far superior to an FCBTK.

Chapter 9. The Way Forward

9.1. Brick Sector Dynamics

During the monitoring, prominent brick makers from the clusters where monitoring was undertaken were interviewed. The responses to key issues are presented in Table 9-1.

Some of the key issues are as follows:

- The brick industry is facing a severe labour shortage, which has resulted in higher payroll expenses and a decrease in brick production (up to 30%) in several important brick making clusters during 2011. The labour shortage was first noticed in 2007 with the first phase implementation of MNERGA[36]. Most of the brick kiln owners want to semi-mechanize the process to reduce the dependence on labour.
- The fuel prices have gone up 100-175% during the last five years. Management of fuel costs is an important consideration for brick makers.
- The majority of brick kilns in the Indo-Gangetic plains are on leased land, which is a disincentive to invest in modernisation (semi-mechanization). To modernize, owners have to buy land. Given the high cost of land around cities, this may move kilns to remote locations. Transportation distances (of clay and fired bricks) have been increasing steadily and commonly range from 100-400km.

[36] MNREGA: The Mahatma Gandhi National Rural Employment Guarantee Act aims at enhancing the livelihood security of people in rural areas by guaranteeing a hundred days of wage-employment in a financial year to a rural household whose adult members volunteer to do unskilled manual work.

Table 9-1 Response on key issues in different brick making clusters

	Ludhiana Cluster (Punjab)	Garh Mukteshwar Cluster (UP)	Varanasi Cluster (UP)	Arah Cluster(Bihar)	Malur Cluster (Karnataka)
Labour shortage during 2011	➢ Severe labour shortage ➢ 25-30% loss in production	➢ Severe labour shortage ➢ 10-15% loss in production	➢ Severe labour shortage ➢ Loss of production	➢ Labour problem not severe; limited to shortage of kiln unloading labour	➢ Severe labour shortage. ➢ Labour coming from as far as Orissa and Bihar
Growth in brick production (2006-2011)	➢ No new kiln added ➢ No significant addition in demand	➢ No new kiln added	➢ No net increase ➢ Around 25% of the demand is being met from neighbouring districts	➢ The number of kilns has almost doubled ➢ 80-85 kilns (2005) to 180 kilns (2011)	➢ Production decreasing since 2007 ➢ The Bangalore market of bricks has been taken over by concrete blocks ➢ The main brick market now is Chennai (350 km away)
Increase in fuel prices 2006-2011	➢ 100-120% increase ➢ The cost of Assam coal in 2011 is Rs 10,000/ton	➢ 150% increase in fuel cost ➢ The current cost is Rs 850-900/ 1000 bricks.	➢ 175% increase ➢ Rs 2000/ton (2006) for Jharia coal to Rs 5500/ton (2011)	➢ 100% increase ➢ The price of coal is Rs 5100/ton (2011)	NA
Increase in selling price of bricks	➢ The selling price of class-I bricks is Rs 3.5/ brick in 2011.	➢ The selling price of class-I bricks is Rs 2.8/brick in 2011	➢ 94% increase in class-I brick prices ➢ Rs 1.8 (2006) to Rs 3.5/ brick (2011)	➢ 100% increase. ➢ Rs 2.0 (2006) to Rs 4.0/ brick (2011)	NA
Land ownership by kiln owners	➢ 95% of the 300 kilns are on leased land	➢ Majority of the kilns are on leased land	➢ 95% of the 225 kilns are on leased land	➢ 90% of the kilns are on leased land are in partnership	➢ Most of the kilns are on owned land ➢ Several of the kiln owners have plans to sell land and exit brick making

9.2. Strategy for Cleaner Brick Production in India

India's brick sector is characterized by traditional firing technologies, with high emissions; reliance on manual labour and low mechanization rate; dominance of small-scale brick kilns with limited financial, technical and managerial capacity; and dominance of single raw material (clay) and product (solid clay brick).

This report suggests that development of a cleaner brick production industry in India over the next ten years should aim at:

Adoption of cleaner kiln technologies: The FCBTKs and DDKs should be replaced by zig-zag, VSBK or other cleaner kiln technologies by 2020.

- Zig-zag kilns are the logical replacement for FCBTKs, because of low capital investment, easy integration into the existing production process, and possibility of retrofitting FCBTKs into zig-zag firing. The zig-zag kiln performance strongly depends on the kiln operation practices; also, zig-zag natural draught kilns appear to perform better than zig-zag forced draught kilns. These aspects need further study before finalizing recommendations and formulating a large-scale dissemination programme for zig-zag kilns.

- VSBK appears to have a limited market, mainly because of its inability to produce good quality bricks from all types of clays and its low productivity under Indian conditions. Incorporation of features of Vietnamese VSBKs into Indian VSBKs may help in improving the VSBK technology package. VSBK dissemination needs to be properly targeted.

- The tunnel kiln technology is capital intensive, and the current technological know-how and experience is limited in India. Adoption of the tunnel kiln also requires extensive modifications in brick moulding, drying and material handling. Widespread adoption of tunnel kiln technology is not foreseen in the immediate future.

Promotion of internal fuel in brick making by mechanizing the brick making process; Internal fuel addition significantly reduces SPM and BC emissions. Cheaper fuels, such as coal slurry, coal dust, charcoal dust, and sawdust, can be used as internal fuels and can help reduce fuel cost. Management of internal fuel addition is extremely difficult in the manual molding process. Semi-mechanization of moulding needs to be promoted to support use of internal fuels. Semi-mechanization of the brick moulding process would have other benefits, including an ability to use inferior clay resources and wastes, reduction in drudgery and better working conditions for workers, and the potential to produce hollow and perforated bricks.

Promotion of mechanized coal stoking systems: High PM and BC emissions in FCBTKs occur during the period of fuel feeding. Continuous feeding of properly sized fuel, using a coal stoker in an FCBTK or a zig-zag kiln, can reduce the emissions significantly.

Diversifying products (e.g. hollow and perforated bricks): Hollow and perforated bricks require less clay and fuel as well as provide better thermal insulation of walls and hence need to be promoted.

Promotion of modern renewable energy technologies in brick making: Apart from the CO_2 emissions caused by the firing of coal in brick kilns, the current brick making practice has a very low carbon footprint. Any mechanization of the brick making process, as proposed above, would require the use of electricity. Captive power generation using diesel fuel is expensive and has a high carbon footprint. Renewable electricity generation options using biomass gasifiers and solar PV need to be promoted. Semi-mechanization of the brick moulding process also requires artificial drying, which may increase the coal consumption in brick making. There is a need to develop more efficient drying systems based on use of modern solar thermal and biomass energy technologies.

To achieve these goals, recommendations to the government of India, include:

Modification in environmental regulations to phase-out FCBTKs:

Environmental regulations can be amended to phase-out FCBTKs and replace them with cleaner brick firing technologies. Any action on environmental regulations needs to be supported by complementary supporting actions, which may include:

- Preparation of standard zig-zag and other cleaner kiln technology knowledge packages (containing design, construction and operation guidelines).
- Training and certifying a cadre of technology providers in cleaner brick firing technologies.
- Educating/training brick kiln owners, supervisors and workers in cleaner brick firing technologies

- Supporting a modest R&D programme to consider improvements in zig-zag firing package, e.g. mechanical stoking of fuel; replacement of ash layer on the top of the kiln.
- Conducting environment monitoring of kilns to gain further understanding and guide the policy action.

Launching an Indian brick development programme

There is a strong case for a national programme for the development of the brick sector. The programme should address issues related to:

- *Planned relocation of brick industry clusters*: Identify sites for relocation of brick industry, based on factors such as clay resource mapping, mapping of waste sources appropriate for brick making, access to electricity and distance from demand centers.
- *Technology transfer and dissemination*: Support for technology transfer/demonstration/field testing of semi-mechanized and cleaner firing technology packages.
- *Skill development*: Develop a cadre of local technology providers, who can also provide service and train supervisors and the workforce.
- *Financing*: Provide access to financing.
- *Advocate for policy change.* Work with appropriate partners to enact environmental policies to transform the industry.

Implementation of these measures can result in annual coal savings of the order of 2.5 to 5.0 million tons/year; significant reduction in air pollution; improvement in profitability of brick enterprises; and improvement of working conditions for millions of workers employed in brick kilns.

Annexure I. Brick Making Process

The production of common burnt clay bricks consists mainly of five operations.

i) Soil winning
ii) Soil-mix preparation
iii) Moulding
iv) Drying
v) Firing

A brief description of the operations (as practiced in India) is provided in the following sub-sections.

I-1 Soil Winning

The brick making process starts with the mining of soil or soil winning. In India, mostly surface soils from agriculture fields are used for brick making, though in some cases silt from water bodies, such as rivers and ponds, is also used. In case of agriculture soils, the soil winning operation is carried out by manual excavation of the soil. The excavation depth is shallow and is generally kept around 1 m. The typical human energy requirement for winning 3 m^3 of soil, which is generally sufficient for making 1000 bricks, is observed to range from 2 to 4 person-hours.

I-2 Soil-Mix Preparation

During soil-mix preparation, water is added to the soil; after water addition, the typical moisture content of the mix is about 25-35% w/w. At this stage, fuels such as rice husks, saw dust, powdered coal, fly ash etc. can also be added to the soil. The fuels added to the soil during soil preparation are referred as *internal fuels*. The soil, water, and fuel are mixed into a homogenous mass. All operations during soil-mix preparation are carried out manually. The typical human energy requirement for preparation of soil-mix sufficient for making 1000 bricks is estimated at 2-4 person-hours.

I-3 Moulding

During moulding, the clay mass is transformed into the shape of the brick. In the manual method or *hand moulding*, a clot of the prepared soil-mix is thrown to fill a wooden or metallic mould, excess soil is scraped off, and the brick is demoulded. The typical human energy requirement for hand moulding is estimated at 15-25 person-hours for moulding 1000 bricks.

I-4 Drying

Freshly moulded green bricks (the unbaked bricks are referred to as *green bricks*) contain about 25% w/w moisture. The bricks are left in the open (initially spread on the ground and later stacked in layers) for drying. The combined action of the sun and wind removes the moisture in the bricks. The moisture content in green bricks at the end of drying can range from 3 - 15% w/w. The typical quantity of moisture removed during the drying process range from 400 to 800 kg per 1000 bricks. The final moisture content and the time taken for drying depend on the local weather conditions. As the open drying cannot be practiced during the rainy season, brick making is a seasonal activity in most regions of the country.

In the case of artificial drying, fuel is burnt to supply energy required for the drying process. Drying 1000 bricks (with each brick containing 700 g of water) in a dryer – by burning fuel – requires 2,900 - 8,200 MJ of energy.

I-5 Firing

The brick firing process consists essentially of increasing the temperature of the bricks progressively over a period of time, holding it at a peak temperature (of about 1000^oC), and then cooling back to the ambient temperature. The important reactions and changes from the point of view of energy are:

i) Removal of mechanical moisture or drying of bricks ($T < 200^oC$):
During heating of bricks, the residual mechanical moisture present in bricks is driven off. Thermal energy is required for heating and evaporating the water.

ii) Combustion of inherent carbonaceous matter ($350<T<700^oC$):
The combustion of inherent carbonaceous matter present in the soil results in release of thermal energy.

iii) Decomposition of the clay molecules and evaporation of chemically combined water ($400<T<600^oC$): The brick soil consists of clay minerals (e.g. kaolinite, illite), quartz and a large number of other minerals (e.g. iron oxides, carbonates etc.). The clay minerals are essentially silicates, which decompose during the heating process, resulting in the release of chemically combined water. For example, kaolinite decomposes into alumina, silica and water at a temperature of about 600°C.

$Al_2O_3.2SiO_2.2H_2O = Al_2O_3 + 2SiO_2 + 2H_2O$,

ΔH_{clay} = -501.6 kJ/kg of kaolinite

The decomposition of clay mineral is an endothermic process.

iv) Decomposition of calcium carbonate: A common impurity in soil is calcium carbonate. The calcium carbonate decomposes into calcium oxide and carbon dioxide at temperatures ranging from 600-800°C during heating. The decomposition of calcium carbonate is an endothermic process.

$CaCO_3 \rightleftarrows CaO + CO_2$ ΔH_{CaCO_3} = -7302.5 kJ/kg of $CaCO_3$ [17]

v) Vitrification: During vitrification, new mineral phases are formed including liquid phases, which on cooling set as glass phases and provide strength to the fired brick. Vitrification is generally an exothermic process.

The amount of thermal energy required for reactions occurring during firing varies from one brick soil to another, primarily depending on the type of clay minerals present in the soil.

Annexure II. Types of Brick Kilns

A large variety of kilns are used for firing bricks. These can be classified in several ways, e.g. on the basis of the method of production of draught (natural draught and forced draught kilns); or based on the direction of airflow in the kiln (up-draught, down-draught and cross-draught kilns). From energy utilization viewpoint, it is best to classify brick kilns into:

a) Intermittent kilns
b) Continuous kilns

II-1 Intermittent Kilns

In intermittent kilns, bricks are fired in batches; fire is allowed to die out and the bricks allowed to cool after they have been fired. The kiln must be emptied, refilled and a new fire started for each load of bricks. In intermittent kilns, most of the heat contained in the hot flue gases, fired bricks, and the kiln structure is thus lost. Clamp, scove, scotch, and downdraught kilns are examples of intermittent kilns. Such kilns are still widely used in several countries of Asia, Africa, and South and Central America.

II-2 Continuous Kilns

In a continuous kiln, on the other hand, fire is always burning and bricks are being warmed, fired, and cooled simultaneously in different parts of the kiln. Heat in the flue gas is utilised for heating and drying green bricks and the heat in the fired bricks is used for preheating air for combustion. Due to the incorporation of heat recovery features, continuous kilns are more energy efficient. Such kilns can be further sub-divided into two categories: moving fire kilns and moving ware kilns.

- In a moving-fire kiln, the fire progressively moves round a closed kiln circuit while the bricks remain stationary. The kiln circuit can have oval, rectangular or circular shapes. FCBTK and zig-zag kilns are types of moving-fire kilns.
- In a moving ware kiln, the fire remains stationary, while the bricks and air move in counter-current paths. In a tunnel kiln, which is a horizontal moving ware kiln, goods to be fired are passed on cars through a long horizontal tunnel. A vertical shaft brick kiln is another example of a moving ware kiln. In this kiln the movement of bricks is in a vertical downward direction, and upward air movement is brought about by natural convection.

Annexure III. Emission factor estimation methodology & carbon balance method

III-1 Emission factor estimation

Pollutant emissions vary according to type of kiln, fuel used and operating conditions. For comparing the emissions across different fuel/operating conditions, it should be normalized either to unit of fuel consumed or to unit of energy consumed or production based. Emission factors can be derived from emission rate (ER) and fuel consumption rate, energy content of the fuel and production rate. Details are as follows:

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

Where Qs 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 (EFm) in g/kg could be calculated as follows.

$$EF_m = \frac{ER}{F}$$

Where F is the fuel burn rate (kg/h)

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

$$EF_e = \frac{ER}{EC}$$

Where EC is energy input in MJ

Similarly production based emission factor i.e emissions per Kg of fired brick can be estimated as

$$EFp = EFe \times Specific\ energy\ consumption\ \text{(MJ/Kg of fired brick)}$$

III-2 Carbon balance model

The carbon balance model is based on the mass balance of carbon in fuel combustion process described as follows:

$$FC = CO_2 + CO + HC + PM$$

FC is fraction of carbon in the quantity of fuel consumed.

The equation above can be arranged as:

$$CO_2 = FC - (CO + HC + PM)$$

Dividing by CO_2

$$1 = \frac{FC}{CO_2}\left\{\left(\frac{CO}{CO_2}\right) + \left(\frac{HC}{CO_2}\right) + \left(\frac{PM}{CO_2}\right)\right.$$

or

$$1 = \left(\frac{FC}{CO_2}\right) - K$$

Where $K = \Sigma \frac{CO}{CO_2} + \frac{HC}{CO_2} + \frac{PM}{CO_2}$

The carbon content in CO_2 (C_{CO2}) can be calculated as

$$C_{CO2} = \frac{FC}{1+K}$$

Carbon content on other pollutants namely CO, HC and PM can b calculated as

$$C_{CO} = \left(\frac{CO}{CO_2}\right) x\ C_{CO2}$$

The fuel mass based emission factor (EF_m) in g/kg can be calculated as

$$EF_m\ CO_2 = \frac{C_{CO2}\ x\ \left(\frac{44}{12}\right)}{QF}$$

Where QF is quantity of fuel consumed in kg

$$EF_m\ CO = \frac{C_{CO}\ x\ \left(\frac{28}{12}\right)}{QF}$$

From mass based emission factors (EF_m), emission per unit of energy content in the fuel (EF_e) in MJ/kg could be calculated as follows:

$$EF_e = EF_m / EC$$

Annexure IV. Fuel & Clay Analysis from all the monitored kilns

Table III-1: Fuel analysis results collected at all 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 1_FCBTK	Coal	19.47	0.86	60.1	2.7	4.7	24.3	2.72	19.47	35.32	42.34	5926
Kiln 2_zigzag_ND	Coal (Assam)	19.3	0.9	58.3	2.8	4.8	13.8	3.60	19.33	34.73	42.34	5855
	Coal (Jharia)	30.7	1.3	55.7	1.0	4.0	7.3	0.86	30.67	24.88	43.60	5584
	Sawdust	4.7	0.4	45.6	0.5	6.2	42.7	7.30	4.68	68.42	19.59	4300
Kiln 3_zigzag_FD	Coal	21.06	0.92	58.36	2.49	4.51	12.66	3.2	21.06	31.33	44.41	6209
Kiln 4_FCBTK	Coal	10.41	0.95	73.18	3.82	5.52	6.13	0.35	10.41	40.32	48.92	7288
Kiln 5_VSBK	Coal Slurry	37.63	1.16	49.00	1.11	3.42	7.69	0.52	37.63	20.79	41.06	4909
	Steam Coal	28.61	1.25	59.86	0.66	4.07	5.55	0.50	28.61	22.14	48.76	5967

Kiln identification No	Fuel	Ultimate analysis						Proximate analysis				GCV (kcal/kg)
		Ash (%)	Nitrogen (%)	Carbon (%)	Sulphur (%)	Hydrogen (%)	Oxygen (%)	Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	
Kiln 6_FCBTK	Coal Slurry	37.63	1.16	49.00	1.11	3.42	7.69	0.52	37.63	20.79	41.06	4841
	Steam Coal	28.61	1.25	59.86	0.66	4.07	5.55	0.50	28.61	22.14	48.76	5967
Kiln 7_Down draught	Eucalyptus branches	2.75	0.79	47.39	0.16	6.41	42.51	9.87	2.75	69.20	18.18	4132
Kiln 8_Tunnel	Coal (internal)	67.90	0.15	28.59	0.09	0.46	2.82	2.28	67.90	2.25	27.58	2057
	Coal (External)	43.61	0.68	47.71	0.31	2.19	5.51	1.05	43.61	7.80	47.54	4471
Kiln 9_VSBK	Coal Powder	48.38	0.58	42.25	0.26	1.94	6.60	1.86	48.38	6.60	43.16	3825
	Coal Ash	78.26	0.11	21.16	0.11	0.21	0.15	1.16	78.26	78.26	1.36	1542

Table III-2: Clay analysis collected at all the monitored kilns

Kiln identification No	Clay Analysis															
	SiO_2 %	Al_2O_3 %	CaO %	Fe_2O_3 %	Na_2O %	K_2O %	MgO %	LOI %	TiO_2 %	MnO_2 %	BaO %	Cr_2O_3 %	NiO %	P_2O_5 %	SO_3 %	Cl %
Kiln 1_FCBTK	66.193	11.909	1.742	3.615	1.035	3.362	1.567	5.723	0.561	0.078	0.054	0.014	0.014	0.063	3.153	0.009
Kiln 2_zigzag_ND	67.992	12.298	1.439	3.756	0.979	3.506	1.252	6.547	0.536	0.082	0.058	0.013	0.089	0.104	1.071	0.019
Kiln 3_zigzag_FD	67.248	11.664	1.337	3.677	1.020	3.610	1.218	7.288	0.574	0.085	0.062	0.009	0.008	0.127	1.227	0.013
Kiln 4_FCBTK	69.915	10.492	2.059	2.735	1.417	2.957	1.678	5.839	0.371	0.068	0.042	0.007	0.004	0.072	1.455	0.018
Kiln 5_VSBK	70.069	9.141	1.746	3.619	0.900	2.440	1.289	6.541	1.006	0.098	0.052	0.019	0.027	0.116	2.467	0.009
Kiln 6_FCBTK	75.065	9.123	1.266	2.772	0.932	2.293	0.902	5.419	0.681	0.059	0.045	0.013	0.043	0.042	0.922	0.020
Kiln 7_Down draught	67.842	10.198	1.111	3.809	1.045	2.690	0.550	8.441	0.564	0.049	0.037	0.030	0.005	0.074	3.340	0.011
Kiln 8_Tunnel	63.584	15.051	1.404	5.241	0.182	0.909	1.888	6.231	1.184	0.108	0.056	0.028	0.013	0.180	3.599	0.012
Kiln 9_VSBK	61.486	14.287	1.343	5.512	0.670	2.638	1.913	5.168	1.245	0.092	0.053	0.026	0.011	0.168	5.025	0.015

Annexure V. Operation cost & revenue data of brick kiln technologies in India

Table V-1: Basic details of operation and revenue data collected at the monitored kilns

Type of Kiln	BTK	Zig-zag Natural Draft	Zig-zag forced draft	Tunnel	VSBK-India
Type of moulding	Hand	Hand	Hand	Machine	Hand
Type of brick	Solid	Solid	Solid	Perforated	Solid
Annual Capacity (Million brick/yr)	6	6	6	13	1.5
Total Land (Acres)	8	8	8	8	2
Operation Cost (Rs per 1000 bricks)					
Raw Material	350	350	350	400	400
Operation	650	650	800	1200	1100
Fuel	1050	700	800	850	600
Administration & legal	150	175	175	175	150
Losses	150	150	150	75	75
Total cost	2350	2025	2275	2700	2325
Total operation cost/yr	1,41,00,000	1,21,50,000	1,36,50,000	3,51,00,000	34,87,500
Revenue Generated					
Class -I (%)	63.33%	80%	80%	95%	55%
Class -II (%)	15.00%	10%	10%	2%	40%
Class -III (%)	21.67%	10%	10%	3%	5%
Class - I (Rs/brick)	3.300	3.300	3.300	3.800	3.600
Class - II (Rs/brick)	2.900	2.900	2.900	3.200	3.300
Class - III (Rs/brick)	2.200	2.200	2.200	3.000	2.500
Average Selling Price (Rs/brick)	3.002	3.150	3.150	3.764	3.425

Annexure VI. Photo Gallery

Kiln 1_FCBTK






Kiln 2_zigzag_ND

Kiln 3_zigzag_FD

Kiln 4_FCBTK


04 09 2011 23 08


04 09 2011 23 32


04 10 2011 06 04


04 09 2011 23 32


04 10 2011 06 01


04 10 2011 00 58

Kiln 5_VSBK





Kiln 6_BTK

Kiln 7_Down draught






Kiln 8_Tunnel

Kiln 9_VSBK