INDIAN INSTITUTE OF TECHNOLOGY, BOMBAY
Interdisciplinary Programme in Energy Systems Engineering

SYNOPSIS
of the Ph.D. thesis entitled

ENERGY UTILISATION IN BRICK KILNS

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by
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Introduction

Clay fired bricks are one of the most important building materials in India. Brick firing is an energy intensive process requiring large quantities of coal and biomass fuels. The annual consumption of coal for brick firing is estimated at 24 million tons; making brick industry as one of the largest energy consuming industry in the country.

Bricks are produced in a decentralised manner in cottage and rural enterprises. Traditional technology is used for brick making; bricks are hand-moulded, sun dried and then fired in a kiln. The bricks are fired either in intermittent kilns e.g. clamps; or in continuous kilns e.g. Bull’s Trench Kiln. This thesis deals with the study of energy utilisation in two continuous kilns — Bull’s Trench Kiln (BTK) and Vertical Shaft Brick Kiln (VSBK).

BTK and VSBK are natural draught kilns. VSBK is a moving ware kiln, while BTK is a moving fire kiln. The two kilns differ considerably in size, production capacity, firing process etc (Table 1). BTK has a history of over 100 years in India and it is the principal kiln for firing bricks in the country. It is a large capacity kiln with slow firing process. VSBK has its origin in China. The kiln was introduced in India in 1996. It is a small capacity kiln with fast firing process.

Table 1. Important features of BTK and VSBK

	BTK	VSBK
Type	Moving fire	Moving ware
Direction of movement of air/brick	Horizontal	Vertical
Nature of draught	Natural draught	Natural draught
Production capacity (bricks/day)	15,000 - 60,000	2,000 –5,000*
Kiln length (m)	120-180	3.5-6.0
Firing cycle time (h)	300-350	18-40
Number of kilns in India	>30,000	≈ 20

* capacity per shaft

BTK has a circular or oval kiln circuit (see Fig.1). The bricks to be fired are arranged in column setting. The fire is progressively moved round the kiln through the brick setting at a slow rate (5-8 m per day). Before entering the brick-firing zone, the air is

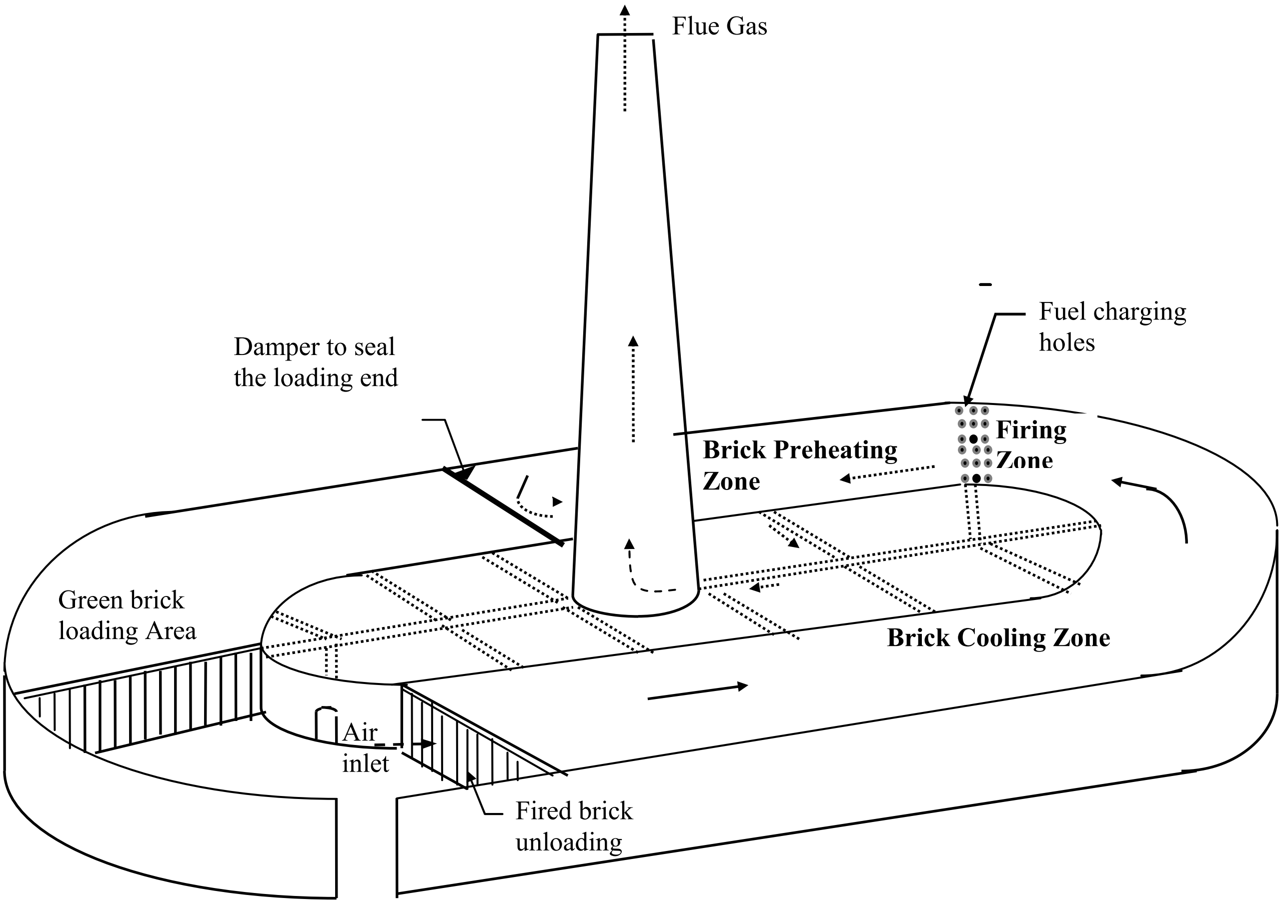

Fig. 1 Bull’s Trench Kiln

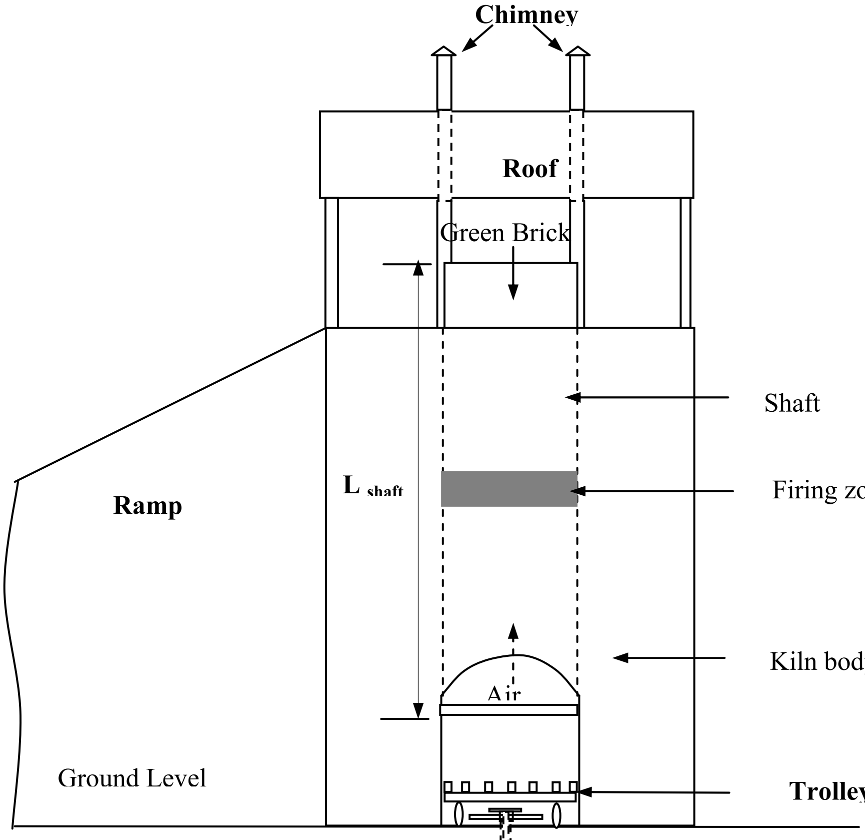

Fig.2 Vertical Shaft Brick Kiln

preheated by exchanging heat with hot-fired bricks in the brick-cooling zone. Brick firing takes place in a narrow brick-firing zone; in which, coal is added manually from the holes provided in the roof of the kiln. The combustion products (hot flue gases) pass over the green bricks resulting in drying and preheating of bricks in the brick-preheating zone. The fire travel takes place in the direction of the airflow. Cooled fired bricks are removed from the brick cooling zone, while fresh green bricks are added in front of the brick preheating zone. A chimney stack provides the necessary draught.

The main element of VSBK is the vertical shaft (of rectangular cross-section) in which firing of bricks is carried out (Fig.2). The green bricks are loaded into the shaft from the top and the fired bricks are unloaded from the bottom. The air enters the shaft from the bottom and flue gases leave the kiln through the chimneys at the top. The kiln works as a counter-current heat exchanger, with heat transfer taking place between the upward moving air (continuous flow) and downward moving bricks (intermittent movement). The maximum temperature is achieved in the middle of the shaft where the fire is maintained. At an interval of 2-3 hours, a batch (4 layers of bricks) is unloaded at the bottom using a screw jack unloading mechanism. The unloading of bricks creates space at the top of the shaft in which a new batch of green bricks is loaded. While loading the bricks, fuel in the form of powdered coal is spread over each layer of bricks. Unlike the BTK, the firing zone of VSBK remains fixed.

Previous Work

There appear to be only three previous field experimental investigations concerned with study of energy utilisation in brick kilns in India. Srinivasan et al. [1] have studied energy utilisation in a clamp kiln; while, Majumdar et al.[2] and TERI [3] have studied the BTK. The VSBK has not been studied earlier under Indian conditions, however, some performance data on VSBKs operating in China are available in NIFES [4]. No analytical investigations have been carried out on any of the brick kilns found in India.

The energy balances presented in the two experimental studies on BTK show little agreement with each other. Majumdar et al. [2] report sensible heat in dry flue gases (Q_{fg}) as the largest heat loss component, accounting for about 60% of the energy supply. TERI [3] ascribes only 7.6 % of the energy supply to Q_{fg}. TERI study identifies convection and radiation heat loss from the kiln surface (Q_{sur}) as the largest heat loss. A large quantity of energy supply (up to 25%) remains unaccounted in the energy balance statements presented in these studies. Foregoing discussion indicates the large gaps that exist in the understanding of energy utilisation in BTK.

Present Experimental Studies

In the present study, a *field experiment* to monitor energy performance in BTK, was conducted on a kiln located near Kolkatta. The main experiment was preceded by one year of planning and preparatory work, which included one pilot experiment also. During the main experiment, the performance of the kiln was continuously monitored for one complete firing cycle of 336 hours. Some of the novel features of the field experiments are:

a) Design of special instrumentation for temperature measurements e.g. multi-sensor thermocouple assemblies for measuring brick and ground temperatures (Fig. 3).
b) Measurement of ground temperatures, leading to evaluation of ground heat loss in BTK, which to the knowledge of the author, is measured for the first time in brick kilns. The measurements were carried out till a depth of 4.25 m using 41 thermocouples.
c) Measurement of brick and gas temperature distribution across kiln cross-section for complete firing cycle.
d) Simultaneous measurements of flue gas composition in the flue gas path to evaluate air infiltration along the flue gas path.

Three field experiments were carried on a VSBK located in Madhya Pradesh. The novel feature of this work are:

a) Use of travelling thermocouple to measure brick temperature (Fig. 4)
b) Evaluation of air to brick mass flow rate ratio (λ) for the kiln.

The specific energy consumption (SEC) for the BTK under investigation is calculated as 1.12 ± 0.03 MJ/kg, which compares well with the value reported in earlier two studies on BTK in India. The SEC for the VSBK under investigation is calculated as 0.84 ± 0.04 MJ/kg. Previously reported ranges of data along with data from the

Fig. 3. A Ground thermocouple assembly

Fig. 4. Brick Temperature Measurement Arrangement in VSBK

present study on SEC of different types of brick kilns are presented in table 2. The table shows that VSBK consumes the least amount of energy.

Table 2. SEC of Brick Kilns

Type of kiln	SEC (MJ/kg)
VSBK	0.76 – 1.14
BTK	1.1 – 1.6
Tunnel	1.2 - 2.5
Clamp	2.0 –8.0

Source: [1,2,3,4,5,6]

The energy balance for the two kilns is presented in table 3. Q_v and Q_r are inevitable items that depend on initial moisture in green bricks and the percentage of clay content in soil. Q_{sur} and Q_{gr} thus emerge as the two predominant energy loss components in BTK; which combined together accounts for 27% of the energy supply in BTK. Large Q_{sur} and Q_{gr} in BTK are attributed to large surface area and continuous requirement of thermal energy for heating cold kiln structure, which comes into contact with the moving fire. Q_{sur} is much smaller in VSBK because of static position of firing zone and smaller thermal mass and surface area. The sensible heat loss (Q_{fbr}+ Q_{fg}) is a relatively larger component in VSBK, which indicates that scope exists for improving heat recovery inside the kiln.

Table3. Energy Balance for BTK and VSBK (kJ/kg)

Energy Balance Component	BTK	VSBK
a) Sensible heat in fired bricks (Q_{fbr})	38	64
b) Sensible heat in dry flue gas (Q_{fg})	42	131
c) Heat loss to ground (Q_{gr})	143	NA
d) Heat loss by convection and radiation (Q_{sur})		
i) from kiln surface (Q_{sur_kiln})	164	55
ii) from hot bricks (Q_{sur_bk})	NA	61
e) Heat required for irreversible chemical reactions (Q_r)	192	174
f) Heat in water vapour leaving the system (Q_v)	521	259
g) Potential heat in CO (Q_{CO})	14	29
h) Misc. and unaccounted	6	67
Total Heat Supplied	1120	840

The brick and gas temperature profile of BTK and brick temperature profile of VSBK are presented in Fig. 5 and Fig.6. The average heating and cooling rates in VSBK are 10-20 times higher compared to that in BTK and for certain temperature ranges exceed 100 ^{o}C/h. These excessive temperature gradients in VSBK, sometime gives rise to firing defects, such as, cooling cracks, bloating, black coring etc.

Present Analytical Studies

For BTK, analytical study of Q_{sur} and Q_{gr} was conducted by considering heat transfer to ground and kiln roof as one-dimensional transient heat conduction problem. Influence of insulating materials and kiln geometric parameters on Q_{gr} and Q_{sur} was studied using this model. Up to 60 % reduction in Q_{gr} and Q_{sur} is predicted with the application of common insulation materials e.g. light weight insulation bricks and mineral wool, in the floor and roof construction. Q_{gr} reduces with reduction in kiln length. A 30% reduction in Q_{gr} is predicted with reduction of 35% in kiln length

A one-dimensional heat transfer and combustion model for VSBK was developed by writing conservation equations for mass, energy, momentum and species concentrations. The model is found to predict the maximum temperature, location of firing zone, flue gas exit temperature, brick exit temperature, O_2 and CO_2 concentration at the flue gas exit, within ± 10% of the measured values. The model was used to study the effect of important operating and design parameters on energy performance of the kiln. The operating parameters studied included, air to brick mass flow rate ratio (λ), specific production rate (SPR) and volumetric void fraction (ϕ). The design parameters studied included, thickness of brick (B_{gbr}) and height of the kiln (L_{kiln}). Based on the analytical investigations, the recommendations for energy conservation in BTK and VSBK are presented in table 4.

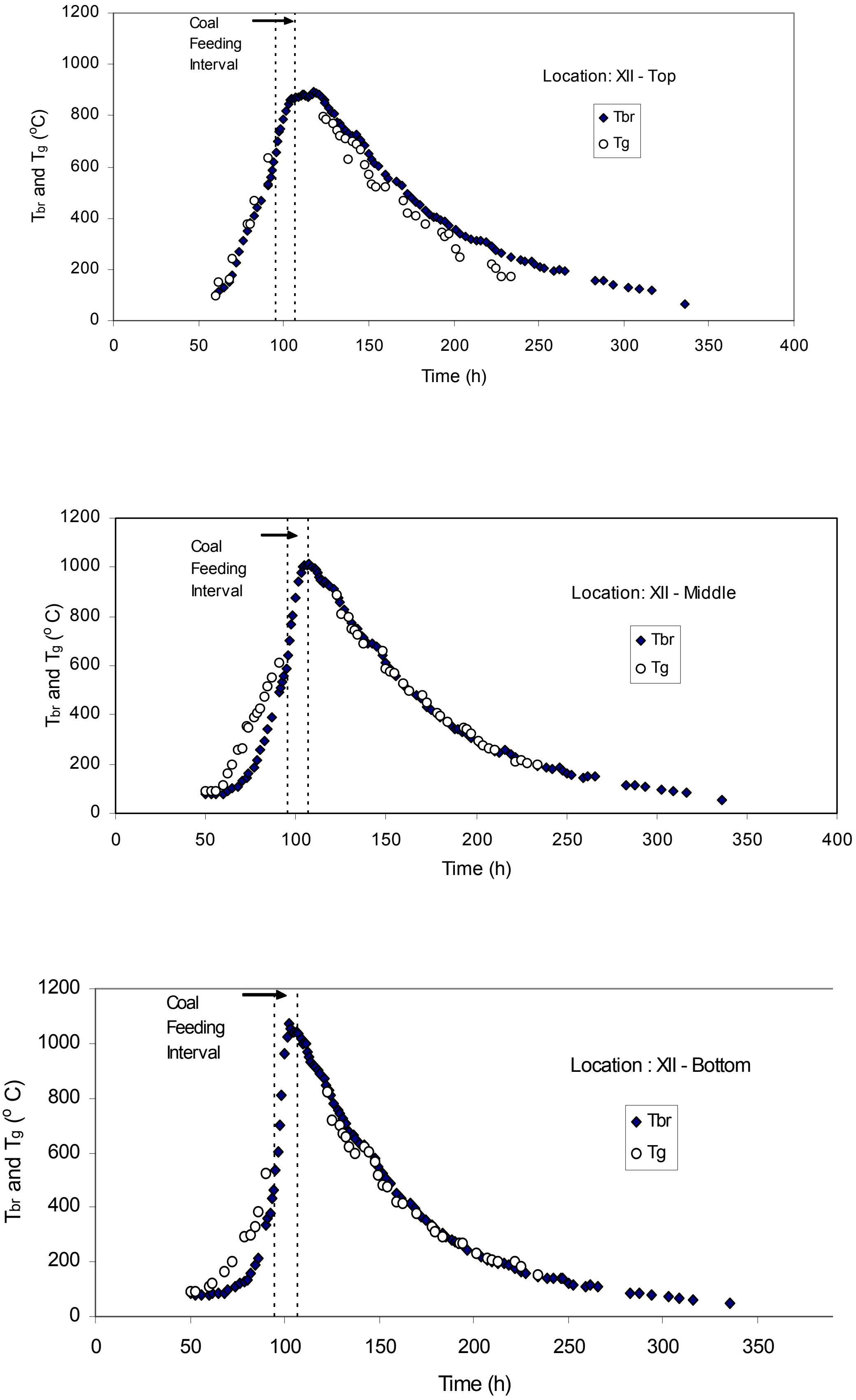

Fig. 5. Brick and Gas Temperature Profile in BTK central brick column (Tbr = brick temperature; Tg: Air/gas temeparture)

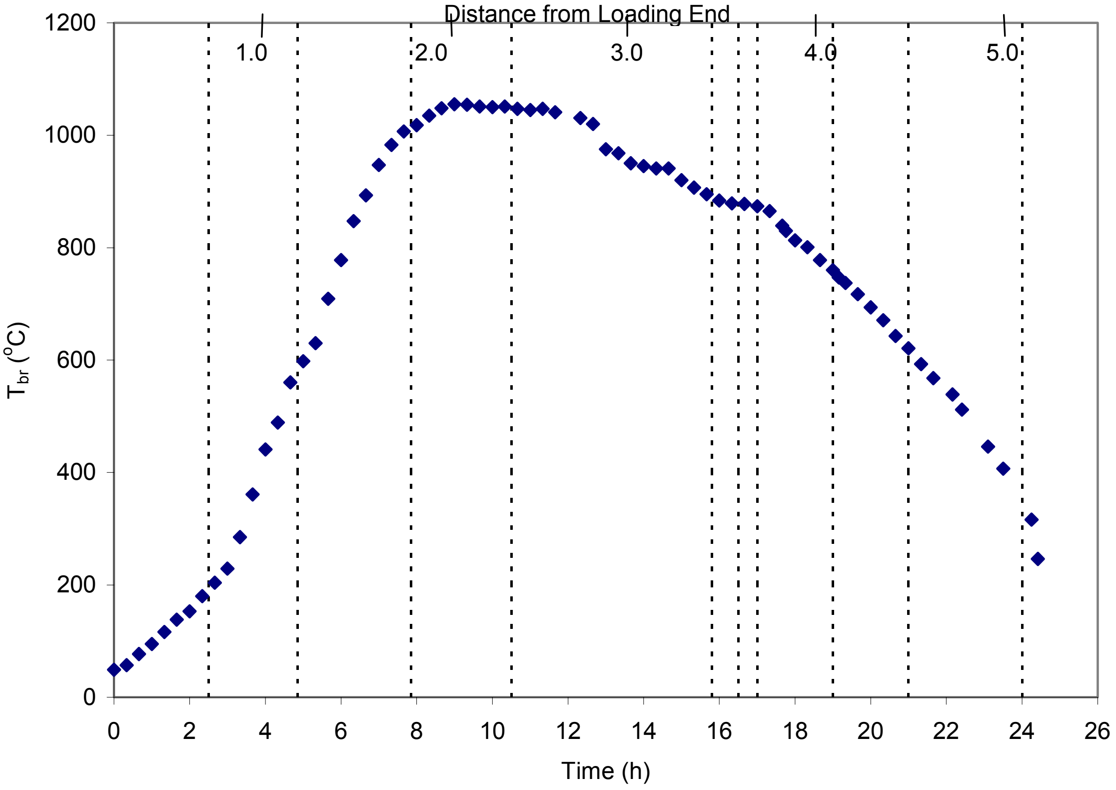

Fig. 6. Brick Temperature Profile in VSBK

Table 4. Recommendations for energy savings based on analytical work

	Parameter/component	Recommendation
BTK	Kiln floor	Use of insulation material e.g. lightweight insulation brick for floor construction.
	Kiln roof	Use of insulation material e.g. lightweight insulation brick, mineral wool insulation along with ash.
	L_{kiln}	Reduction in kiln length; $L_{kiln} \approx 110$ m.
VSBK	λ	Kiln to be operated at optimum $\lambda \approx 0.8$-1.0
	ϕ	Open brick setting; $\phi \approx 0.4$.
	B_{gbr}	Thinner bricks; $B_{gbr} \approx 50$-60 mm
	L_{kiln}	Increasing shaft heights; $L_{kiln} \geq 6.0$ m

Major Contributions

The main contribution of the study are summarised as follows:

1. Development of methodologies for field experiments for studying energy utilisation in BTK and VSBK.

2. Development of special instrumentation for field experiments, e.g.
    a) Travelling thermocouple for measuring brick temperatures in VSBK;
    b) Multi-sensor thermocouple assemblies for measuring brick and ground temperatures in BTK.

3. Measurement of ground temperatures in BTK for evaluation of Q_{gr}.

4. Comprehensive energy balance statements (with uncertainties estimates) are prepared for BTK and VSBK. Q_{gr} and Q_{sur} were identified as the main heat losses in BTK; together, accounting for 27% of the heat input. Sensible heat losses (Q_{fbr} and Q_{fg}) were identified as the main heat losses in VSBK.

5. VSBK was found to have lowest SEC among all types of brick kilns. The main reason for low SEC in VSBK is its natural ability to operate at $\lambda \approx 1.0$.

6. Simultaneous measurements of flue gas composition in the flue gas path resulted in evaluation of air infiltration in BTK. Heavy air leakage (≈ 25%) is detected in

the flue ducts. The excess air level in the kiln is estimated at 179%, which is significantly lower then the estimates of previous studies.

7. Complete profiling of brick temperature distribution in BTK and VSBK is carried out. Large variations in brick temperature (up to 200 ^oC between the top and the bottom) across BTK cross-section are recorded; resulting in significant variation in brick quality across kiln cross-section. Large heating and cooling rates (>100 $^oC/h$) were recorded in VSBK, which can cause firing defects in bricks.

8. A one-dimensional transient heat conduction model was used to study the heat transfer to ground and through kiln roof in BTK. Parametric studies were carried out on the influence of insulating materials and kiln geometric parameters on Q_{gr} and Q_{sur}. This resulted in a set of recommendations for energy conservation in BTK (Table 4)

9. A one-dimensional heat transfer and coal combustion model for VSBK was developed. Parametric studies were carried out on the influence of operating parameters (λ , SPR and ϕ) and design parameters (B_{gbr} and L_{kiln}) on energy performance of the kiln. This resulted in a set of recommendations for energy conservation in VSBK (Table 4)

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