Asian Journal of Water, Environment and Pollution, Vol. 11, No. 2 (2014), pp. 55–65.

Operation of Brick Kilns in Bangladesh—A Comparative Study

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Received July 11, 2013; revised and accepted February 12, 2014

Abstract: This paper presents an investigation on current use of brick kiln technologies in Bangladesh. There are around five thousand established and numerous make-shift brickfields of various capacities all over the country. Most of the kilns in Bangladesh are fixed chimney (FCK) type, which are somewhat old technology and sources of pounding pollutions. Recently the Department of Environment (DoE) of the Bangladesh Government has directed brickfield owners to switch to comparatively better environment friendly technologies like Zigzag, Hybrid Hoffman (HHK) and Vertical Shaft (VSK) kilns. Most of brickfield owners are not familiar with these kilns and thus reluctant to make over due to lack of industrial knowledge and financial support. However few companies have implemented these technologies on pilot-scale and are yet to demonstrate their full financial viability. As such, broad range technical information along with financial analysis of these technologies is presented here.

A set of recommendations are prepared in relation to these technologies suited to their investment opportunity, land accessibility, energy and raw-material supply, labour availability and other requirements. Amongst the three technologies, HHK is the most suitable one for large-scale production whereas FCK if modified and converted into Zigzag kiln will be relatively fuel efficient and less polluting. On the other hand VSK, which are comparatively smaller in capacity, can be made popular in rural Bangladesh. The payback periods of these three kilns are 3.14, 3.27 and 2.62 years respectively, whereas CO_2 emission potentials are 22.20, 15.86 and 28.54 tCO_2e, respectively compared to 38.06 tCO_2e for FCK.

Key words: Hybrid Hoffman kiln, fixed chimney kiln, vertical shaft kiln, zigzag kiln, environmental impact, financial analysis.

Introduction

Dhaka, the capital of Bangladesh, is developing as one of the most populated cities of the world. Population census shows that a population of over 12 million is living in this mega city (BBS, 2011). Huge demand for housing has led to the development of numerous commercial and private housing projects in the city. To support the construction of those housing projects, numerous brickfields have mushroomed near Dhaka city, particularly in the north and north-eastern districts of the city. The total production of bricks in Bangladesh is nearly 17 billion pieces annually, which is contributing about 1% of the GDP of the country (World Bank, 2011). Since the sector is still deeply non-mechanized, a sizable manpower of around one million skilled and unskilled people is working in this sector (CDM, 2007). As most of these brickfields are using age-old Fixed Chimney Kiln (FCK) technology, the working environment remains incredibly disgraceful to the labourers. The kilns are also causing equally disgraceful degradation to the air quality of this mega city. Brickfields are recognized as the second largest polluter after motor vehicles, and the largest stationary

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source of greenhouse gas emitter of the country—emitting close to 10 million tons of carbon-dioxide (tCO_2e) annually (World Bank, 2011). From Table 1, it is evident that the principal pollution of this sector is emitting from the burning of low-grade coal and firewood in those improvised kilns.

A study in 2008 (Guttikunda, 2009) showed that poor air quality in Dhaka city, contributes to around 15,000 premature deaths along with millions of cases of pulmonary, respiratory and neurological illness. In another study (World Bank, 2011) it recognizes that $PM_{2.5}$ (particulate matter of 2.5 μm diameter) pollution from brickfields is responsible for harmful impacts on health, agricultural production and environmental degradations. These circumstances forced the Bangladesh Government to order brickfield owners to shift to three relatively improved technologies, Zigzag, Vertical Shaft and Hybrid Hoffman kilns, within a given timeframe. These improved technologies are relatively cleaner than FCK, consume less energy and emit less pollution to the atmosphere. These technologies are demonstrated in small-scale in various places to educate brickfield owners and to create awareness to the associated people in general. However, the financial viability of these technologies compared to FCK remains mostly vague to the larger community of the brickfield owners.

Because of inadequate gas supply in recent times, the brick industry largely moved towards the use of high emission coal-based kiln technologies. Evidently there exist some major impediments for adopting those cleaner technologies due to lack of proper policy, infrastructure, and financial backup. More than 90% brickfield owners in Bangladesh are small-scale operators. Over the years, government took many initiatives to reduce the environmental impact of this sector. Since 2007, government was trying to persuade the brickfield owners to shift to three improved technologies and was issuing repeated deadlines to obligate (DOE, 2007).

In this paper, those improved technologies are discussed which can in fact potentially replace longstanding FCKs. While setting up a particular brick technology, the factors that are considered by entrepreneurs are like: land availability, initial investment, brick quality in demand, fuel, clay and other raw materials. Comparative analysis of these factors will help the entrepreneurs to decide which technology to implement. Finally, recommendations are drawn about what type of technology will be suitable for the entrepreneurs based on their financial capability and locations.

Brick Kiln Technologies and Emission Status

Brickfields were established near Dhaka city especially in Narayanganj, Aminbazar, Dhamrai, Gazipur, Manikganj and Savar and its surroundings as shown in Figure 1. Most of these brick kilns are fixed chimney type, although Zigzag, Hybrid Hoffman, Hoffman, Vertical Shaft and Tunnel kilns are also visible there in small numbers. From Table 2, it is rather apparent that brick production by FCK outnumbers the total production from other kilns and also the amount of particulate and CO_2 emissions from this technology is quite high compared to others.

Traditional Technology—Fixed Chimney Kiln (FCK) and Its Environmental Impact

The majority of the FCKs that are visible in Narayanganj, Aminbajar and Savar with black smoke emitting are the major sources of pollution in the Dhaka city. FCK is rectangular in shape and measures around 80 m long and 20 m wide as shown in Figure 2. Green bricks are

Table 1: Bangladesh brick sector key characteristics (based on 2011 data)

Parameter	*Value*
Estimated total number of coal-fired kilns	5000
Number of gas-fired kilns	20
Annual brick production and its value	17.2 billion pieces; Tk 83 billion (~US$ 1.2 billion)
Coal consumption and its value	3.5 million tons; Tk 22.6 billion (~US$ 320 million)
Firewood consumption	1.9 million tons; Tk 5.7 billion (~US$ 80 million)
Emission of carbon dioxide (tCO_2e)	9.8 million tons
Clay consumption	45 million tons
Total skilled and unskilled employment (including supply of clay, coal and transport)	~1 million people

US$ 1 = Tk 70 approx. (World Bank, 2011)

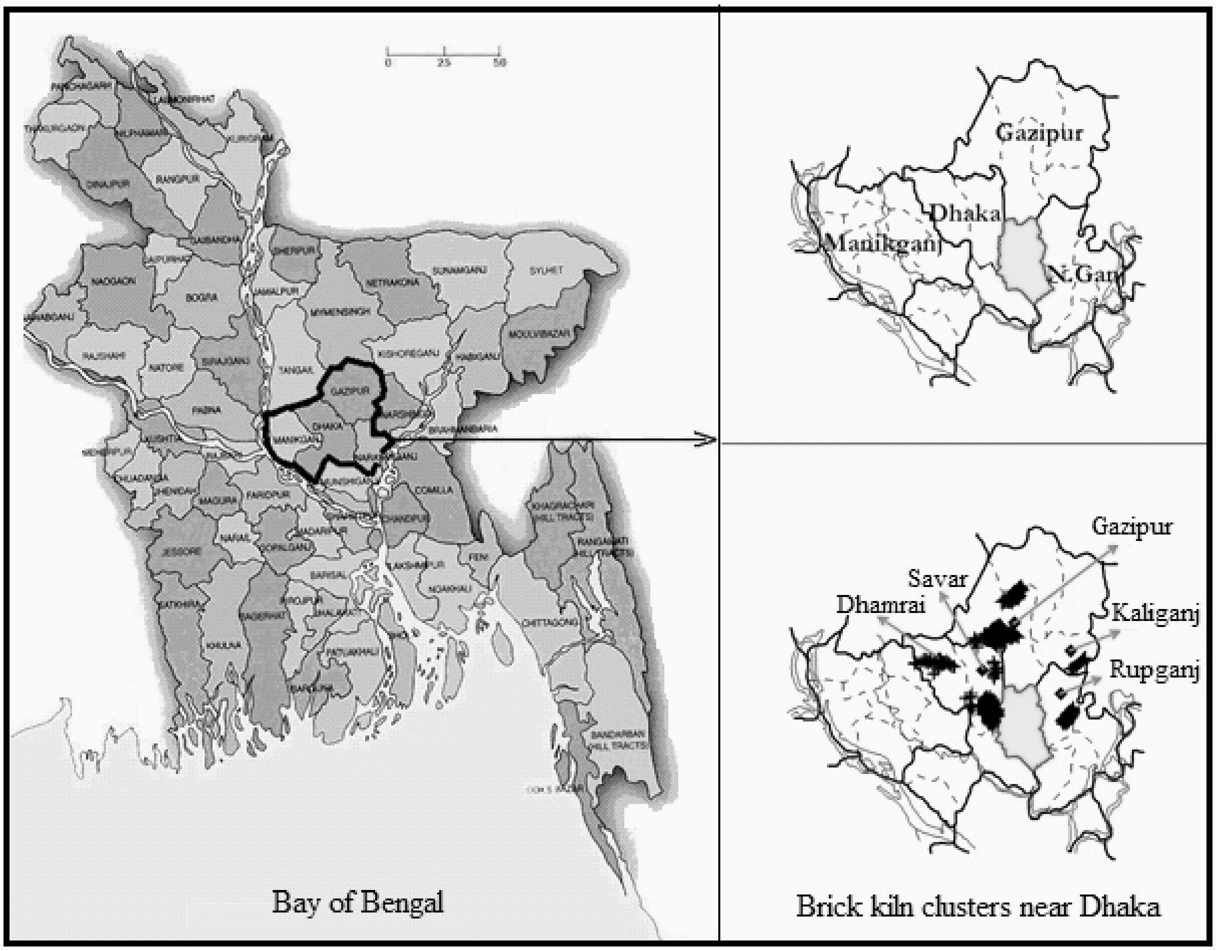

Figure 1: Location of brickfield concentrations in the north, north-west and north-east districts around Dhaka city (Guttikunda, 2009); the clusters account for around 700 brickfields.

Table 2: Brick kiln technologies in Bangladesh

Kiln type	*Number (DOE, 2010)*	*Brick production (in billion) (DOE, 2010)*	*Coal use per 100,000 bricks (ton) (BUET, 2007)*	*Particulate emission (mg/m³) (BUET, 2007)*	*CO_2 emitted per 100,000 bricks (tCO_2e) (BUET, 2007)*
FCK	< 4,500	15.8	20–22[a]	1,000+	50
Zigzag	< 150	0.6	16–20	500–1000+	40–45
Hoffman (gas)	< 20	0.2	16000 m^3	<100	30
Hybrid Hoffman	< 10	0.2	12–14 [CDM, 2009]	20.3[b]	30
Vertical Shaft	-	-	10–12	78–187[c]	25
Others	< 200	0.5			
Total	< 4,880	17.2			

[a] World Bank (2011) uses a coal consumption of 24 ton per 100,000 bricks for the FCK

[b] World Bank (2008) for measurement of an HHK in Bangladesh

[c] Pandit et al. (2004) for Nepal and Maithel et al. (2003) for India

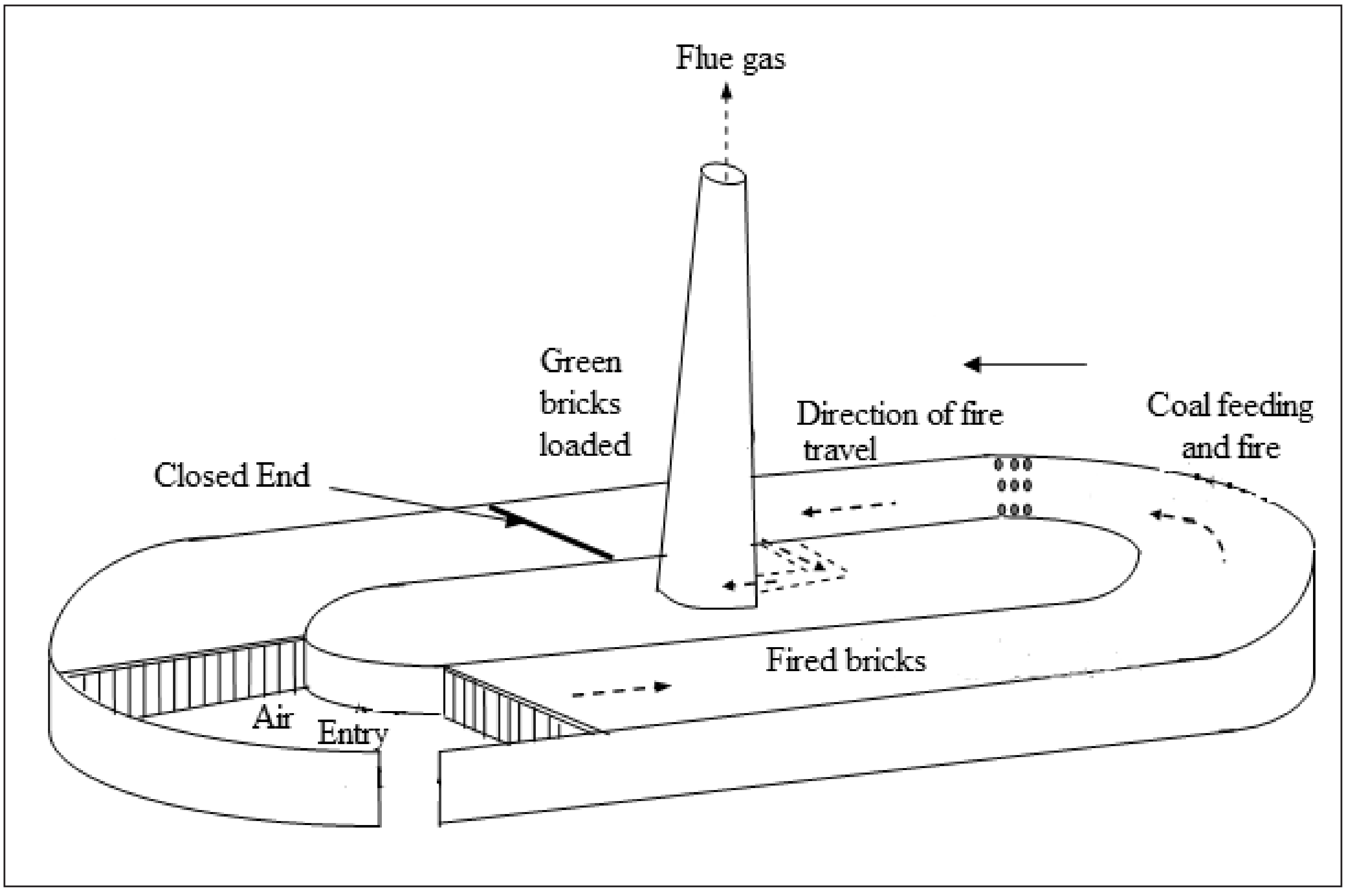

Figure 2: Schematic view of a Fixed Chimney Kiln (FCK) (Maithel, 2003).

stacked at one end which is known as the preheating zone and fired bricks are taken out from the other end which is known as the cooling zone. Fuel (coal) is charged from the top in between these two zones which is known as the firing zone. The burning of coal in FCK is not efficient by any means. The pollutants visible are actually fly ash and un-burnt carbon particles.

Alternative Kilns to Replace Existing FCKs

Zigzag Kiln

Zigzag kiln is rectangular in shape and has an 18 m high fixed chimney (CDM, 2007) located on one side of the kiln as shown in Figure 3. At the bottom of the chimney there is a blower, which draws the flue gas from the kiln and discharges into the atmosphere. This kiln is divided into 20 to 40 chambers by green bricks, which are separated from each other in such a way that the hot gases move in a zigzag path through the kiln (Maithel et al., 1999). In the long travel path of the hot gas, the green bricks absorb much of the waste heat to have better drying and moisture reduction. Based on various studies, Zigzag kiln is considered to be 10-15% more fuel-efficient than the FCK (CEA, 2011). Zigzag kiln is quite similar to FCK and the conversion expenditure is relatively low.

Hybrid Hoffmann Kiln (HHK)

Unlike the gas-based Hoffmann kiln, the Hybrid Hoffmann Kiln (HHK) uses coal as fuel. This kiln has also quite similar construction and operating procedure as that of FCK. The significant difference is that it has a fixed roof whereas FCK has a temporary roof. Due to this fixed roof, bricks can be fired throughout the year. A typical Hoffmann kiln shown in Figure 4 is around 100-130 m by 20 m (CDM, 2007).

Because of the thick wall and effective insulation in HHK, heat loss is minimized to its surrounding. Since the exhaust gas from HHK is forced through preheat chambers to heat green bricks, in fact it reduces the particulate emission considerably into the atmosphere. HHK does not require a tall chimney (IIDFC, 2009).

Vertical Shaft Brick Kiln (VSK)

Vertical Shaft Kiln (VSK) is ideal for rural areas. It showed limited success in China, India and Nepal.

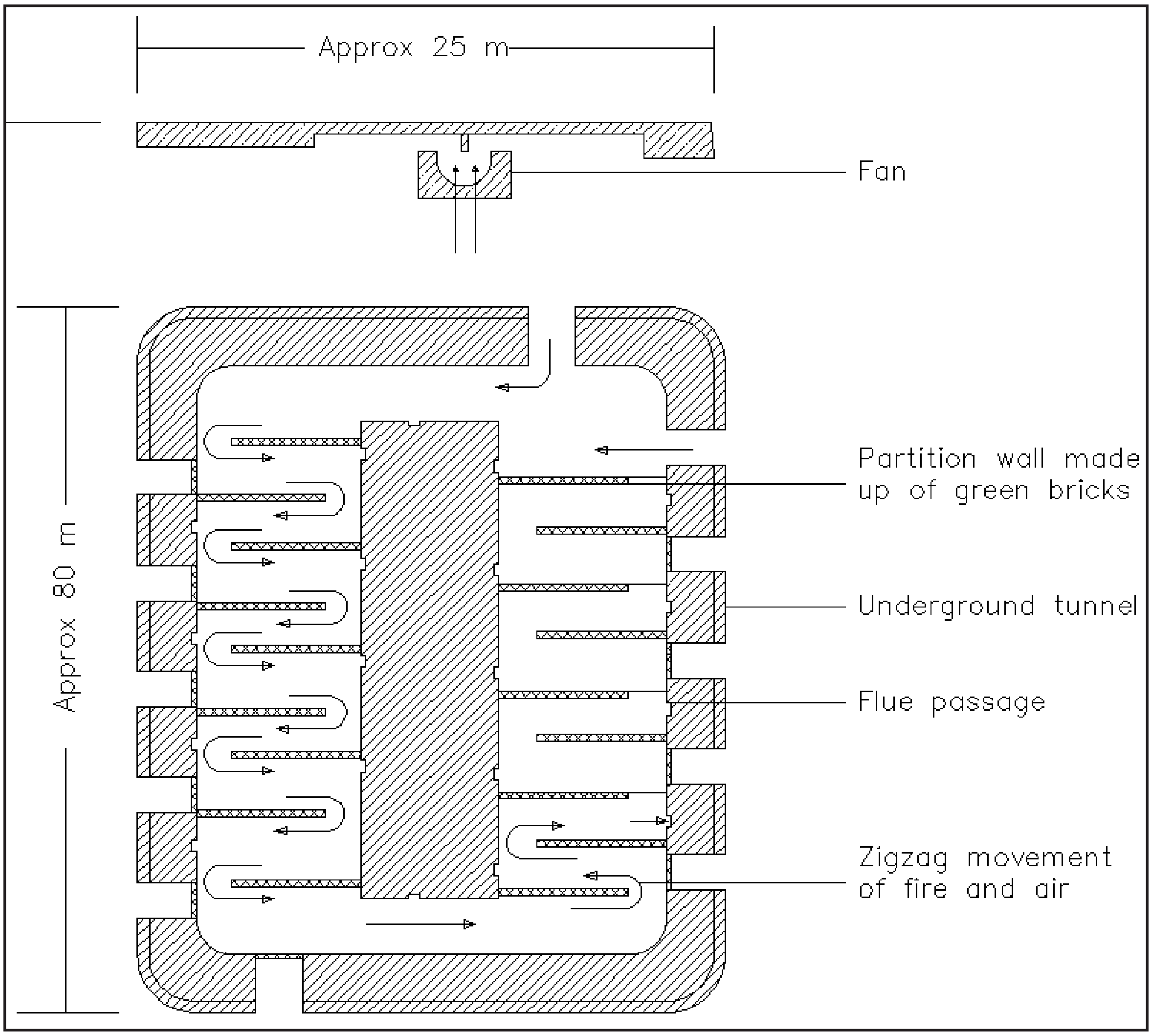

Figure 3: Schematic view of a Zigzag kiln.

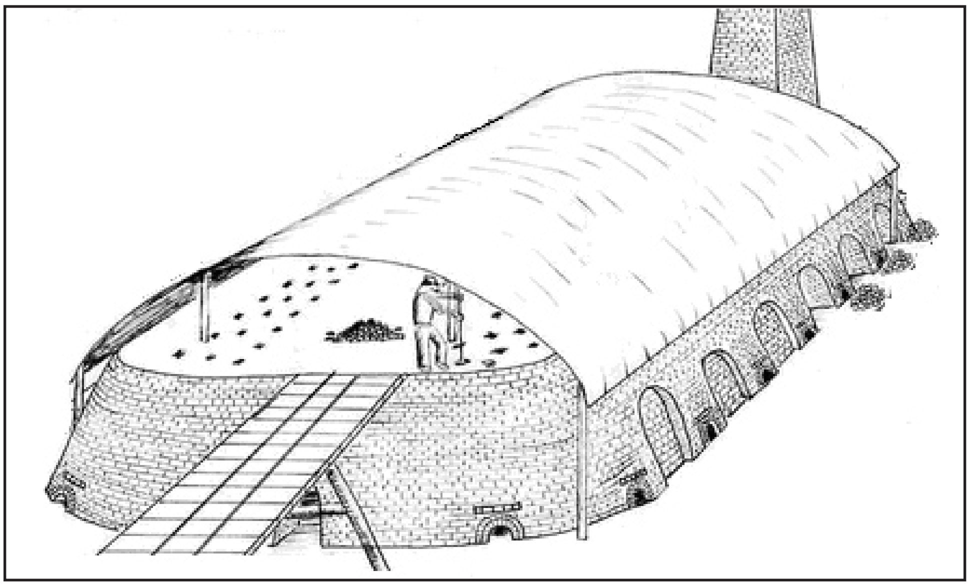

Figure 4: Schematic view of a Hoffman Kiln (Kynaston, 1984).

Compared to FCK, VSK uses less energy and emits less pollution (DA-PA, 2010). However, brick quality of VSK is relatively poor compared to its incremental investment.

In VSK, there is a vertical shaft of rectangular or square cross-section, as shown in Figure 5. Green bricks are loaded from the top on batches. Bricks move down the shaft as it goes through preheating, firing and cooling zone and finally unloaded at the bottom. This kiln has a life of 8 to 10 years with minimum requirement of maintenance (Practical Action, 2010). The greatest benefit of VSK is, as the kiln expands vertically, it is very economical in utilizing space.

Comparative Analysis of Different Brick Kiln Technologies

This section compares Fixed Chimney Kiln (FCK), the most widely used technology with three other alternative technologies that are considered somewhat environment friendly by the Government of Bangladesh. The following characteristics of the three alternative kilns are discussed accordingly.

Land Requirement

Land requirement for a FCK or a Zigzag is about 3-4 acres whereas that for a Hybrid Hoffmann Kiln (HHK)

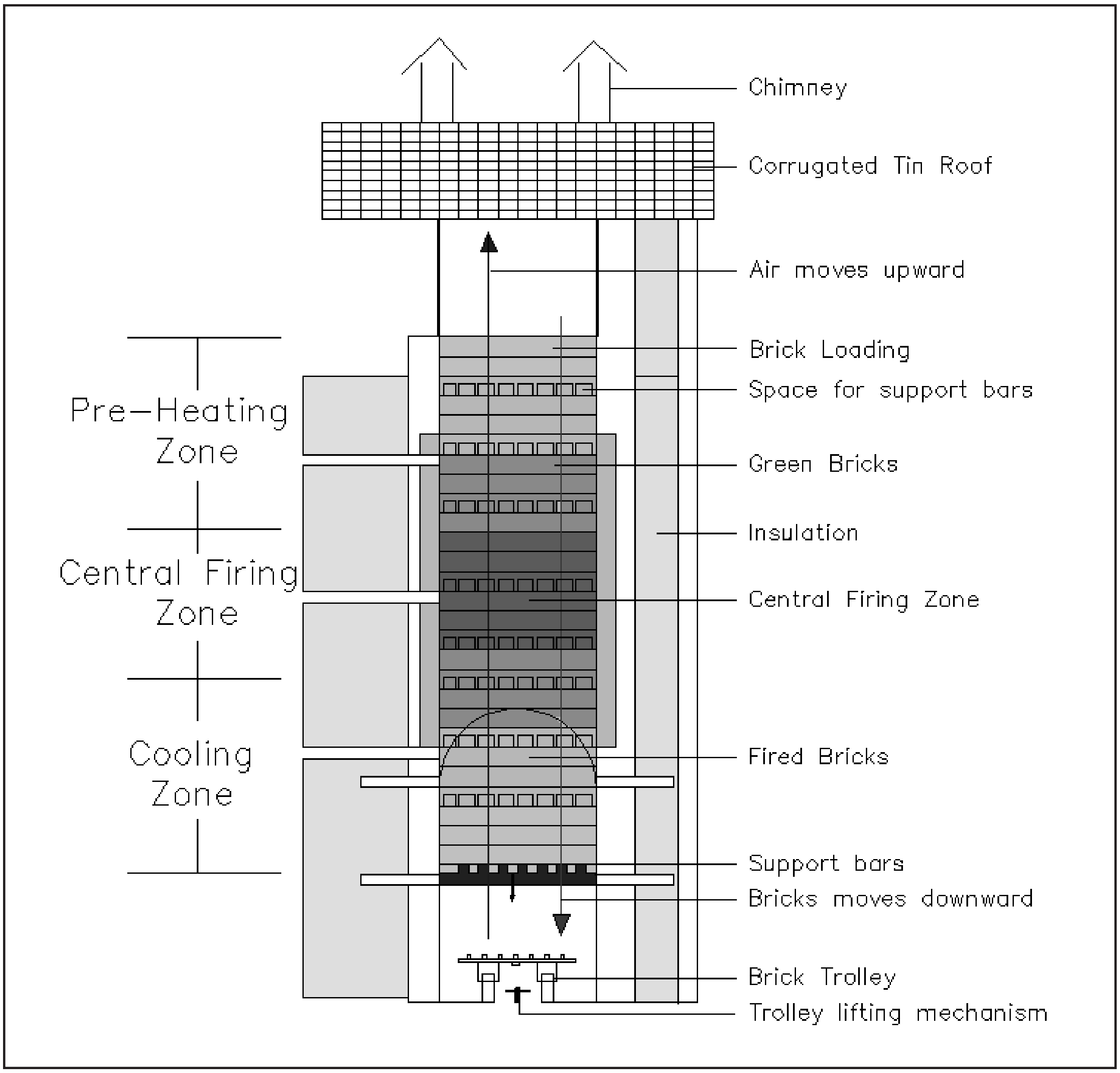

Figure 5: Schematics view of a Vertical Shaft Brick Kiln (VSK).

is about 12 acres (CEA, 2011). Higher land requirement for HHK also ensures greater production capacity. Major part of the land requirement is needed for brick molding, drying and other brick processing operations. If only the kiln portion is compared then the land requirement for HHK is less than half compared to FCK. For VSK, land requirement is less than one-fourth of FCK for same amount of production (Practical Action, 2010). The high variation of cost for different category lands has made this a vital issue for entrepreneurs for selecting the type of kiln.

Fuel Requirement

Because of inadequate supply of gas in Bangladesh, coal has become the only option for brick industries currently. Those previously constructed Hoffman kilns are barely using natural gas as fuel and the consumption rate is 15,000-17,000 m^3 per 100,000 bricks (CEA, 2011). Considering energy consumption requirement, HHK is more efficient than FCKs and Zigzag kilns. The coal requirement for FCK is around 24 ton per 100,000 brick production (DOE, 2011). Zigzag kiln and HHK consume around 18 and 14 ton coal per 100,000 brick production, respectively (CDM, 2007). VSK is the most fuel-efficient, consuming least fuel around 10 ton of coal for 100,000 bricks (Practical Action, 2010).

Brick Quality

Hoffman kilns produce better coloured bricks because of gas burning. Bricks from HHK have also good colour and shape and duly get higher price in the market. VSK cannot produce very good quality bricks as green bricks cannot be fired for long time inside the kiln. Vertical structure of this kiln may cause load variance resulting cracks in bricks if fired for a long time. So, strong bricks which are locally known as “pickets” and used instead of stone for concreting cannot be produced by VSK. Bricks from Zigzag and FCK are of same average quality generally produced in Bangladesh.

Investment Opportunity

In terms of initial investment, FCK, Zigzag or VSK require expenditure in the range of US$ 50,000 to 70,000 (Practical Action, 2010). The conversion of FCK to Zigzag requires only US$ 30,000 and thus not much burden and uncertainty to future business and return.

Hoffmann kiln is quite expensive requiring an initial investment of at least US$ 600,000. HHK also requires an initial investment of about US$ 600,000 to 700,000 (CEA, 2011).

Working capital requirement for FCK and Zigzag kilns is approximately US$ 20,000 to 22,000 but for a Hoffmann/HHK it can go beyond US$ 100,000 because of higher inventory, maintenance and overhead costs (CDM, 2007).

Production Rate

Hoffmann kiln has a production capacity of 7.5 to 9 million bricks per season (CEA, 2011). Coal fueled HHK has a production capacity of around 15 million bricks as preheated and dehydrated green bricks require less time for burning (CDM, 2007). FCK and Zigzag have approximately the same production capacity of around 2.5 million bricks per season as both the kilns are usually built in the low-lying land (CDM, 2007). An ordinary VSK has a production capacity of 2.7 million bricks and can operate all round the year (Practical Action, 2010). The production capacity of VSK can be increased several times simply by increasing the number of kiln shaft.

To visualize the characteristics of the above comparative analysis easily, a number of mentioned factors are shown in Table 3.

Emission

One of the major reasons of pollution from brick kilns is inadequate supply of air during combustion. Blowers are added to Zigzag and HHK to ensure enough air supply to kilns. In VSK, air flows upward through

Table 3: Comparison of various key factors for different brick kilns

Item	*FCK*	*HHK*	*Zigzag*	*VSK*
Land requirement	16,000 m^2	50,000 m^2	16,000 m^2	4,000 m^2
Brick shape and colour quality	Medium	Higher-medium	Medium	Low
Investment requirement (US$)	55,000	700,000	70,000	70,000
Working capital (US$)	22,000	100,000	22,000	22,000
Production rate/day	17,000	50,000	17,000	9,000
Production days/year	150	300	150	300
Coal required per 100,000 bricks	24 ton	14 ton	18 ton	10 ton

natural convection. In Zigzag kiln, as air flows through the zigzag path, the coarse particles are obstructed and settle before it is discharged into the atmosphere. The combustion process improves as artificial draft is created by the addition of blower.

Hoffmann kiln shows better performance than other coal burning technologies in terms of pollution control. For HHK, flue gases are passed through dryer to preheat the green bricks. Hard particles clear up largely from the flue gas since it is obstructed into the stacks of green bricks. VSK requires less fuel per brick basis, so automatically emits less. Carbon dioxide emission from all four types of brick kilns is estimated and shown in Table 4 for comparison.

Financial Analysis

Data has been collected for different technologies and its investment requirement, operation and maintenance, energy supply, production rate and many others. To calculate the profitability and the payback period, detailed calculation is performed based on field data, personal communication and literature review from Bangladesh and neighbouring countries. Information is collected from different non-government organizations (NGOs) like Clean Energy Alternatives, Practical Action, Conforce Limited and field study to various brickfields in Bangladesh. Land cost is excluded from the calculation as in most occasions, land is not purchased instead it is taken as lease. Also land price vary greatly from place to place. Standard rules of business finance are used for estimating economic performances. Calculation was done based on 2011 data. Some of the data are adjusted based on current market trend. Results as shown in Table 5 obtained from the calculation show that all three newer technologies will ensure return of investment in less than four years periods.

In Table 5, brick sale revenue is found from multiplying brick production rate by unit brick price. For HHK unit brick price is Tk. 5.5 and for VSK, FCK and Zigzag kiln unit brick price is Tk. 5. Total cost of raw materials is found by adding the coal and clay cost. Information about fixed cost is found from personal communication with the brick owners. Total cost of production is calculated by adding the raw material cost and fixed cost. Opening and closing stock of raw material and work-in-process inventory is assumed to be 0 to simplify the calculation. It is assumed that, at the beginning and the ending of the year, raw material and work-in-process inventory is same and, thus there is no difference between opening and closing stock of raw materials and work-in-process inventory. As a result, cost of goods sold (COGS) is same as cost of production. Gross profit is found by subtracting the COGS from sales revenue. Net profit is calculated by subtracting selling and administrative expenses from gross profit.

As net profit is calculated at the end of the year, it is converted into present value by using Eq (3) in Appendix with an assumption of inflation rate. On an average inflation rate in Bangladesh is about 6%. For this sector, bank loan in Bangladesh has an interest rate of 12 to 13%; however for calculation purpose a 12% interest rate is assumed for a repayment period of five years. Monthly repayment for bank loan is calculated using Eq (1). This monthly repayment is converted into present value using Eq (2) from the Appendix with an assumption of 6% inflation rate. Total investment is calculated by summing up the present worth of monthly bank loan repayment and initial self investment. Payback period is calculated by dividing present worth of total investment by present worth of net profit. Usually bank lends 50 to 60% of the total investment in this sector. But for HHK as the investment cost is significantly higher than others, bank lends even higher percentage than usual. For FCK as bank does not provide any loan, the total investment requirement needs to come from self finance. From Table 5 it is apparent that payback period of all four technologies are quite close.

Conclusions

The Hybrid Hoffman Kiln (HHK) needs ten times more investment than the other two technologies (e.g., Zigzag and VSK) and also provides higher return. So, the HHK is suitable only for entrepreneurs with high

Table 4: CO_2 emission comparison from different brick kilns

Item	*FCK*	*HHK*	*Zigzag*	*VSK*
Specific fuel consumption (TJ/brick)	4.02×10^{-6}	2.35×10^{-6}	3.02×10^{-6}	1.68×10^{-6}
CO_2 emission per 100,000 bricks (tCO_2e)	38.06	22.20	28.54	15.86

Table 5: Financial analysis for different brick kiln technologies in Bangladesh

Cost components	*FCK*	*HHK*	*Zigzag*	*VSK*
Brick production rate per annum	2,550,000	15,000,000	2,550,000	2,700,000
Brick sale (Tk)	12,750,000	82,500,000	12,750,000	13,500,000
Calculation of cost of goods sold (COGS)				
Total cost of raw material including transport (coal + clay) (Tk)	6,709,600	28,675,000	5,791,600	4,189,500
Fixed cost (Tk)*	3,500,000	20,000,000	4,000,000	4,500,000
Total cost of production (raw material + fixed cost) (Tk)	10,209,600	48,675,000	9,791,600	8,689,500
Cost of goods sold (COGS) (total cost of production ± difference between opening and closing stock of raw material and work-in-process inventory (assuming both opening and closing stocks zero))	10,209,600	48,675,000	9,791,600	8,689,500
Income statement				
Sales revenue†	12,750,000	82,500,000	12,750,000	13,500,000
Cost of goods sold (COGS)	10,209,600	48,675,000	9,791,600	8,689,500
Gross profit (total sale – COGS) (Tk)	2,540,400	33,825,000	2,958,400	4,810,500
Selling and administrative expenses (Tk) ‡	1,200,000	3,500,000	1,200,000	2,600,000
Net profit (gross profit – selling expense) (before interest and tax) (Tk)	1,340,400	30,325,000	1,758,400	2,210,500
Payback period				
Present worth of net income (Tk)	1,264,528	28,608,490	1,658,868	2,085,377
Total investment (bank loan at 12% interest rate for 5 years) (Tk)	4 million self	15 million self and 65 million bank loan	2 million self and 3 million loan	2 million self and 3 million bank loan
Present worth of total investment (Tk)	4,000,000	89,789,425	5,451,820	5,451,820
Payback period (year)	3.16	3.14	3.27	2.62

* Personal communication with brick kiln owners

† Sales Revenue = number of bricks produced at rated capacity per year × brick selling price

‡ Personal communication with brick kiln owners

financial capability. As this brick kiln requires such a big investment, it demands that kiln owners have their own land. With proper maintenance, the HHK kiln lasts longer than 20 years, whereas a land lease may not be that long. Also, HHK can be operated throughout the year. So if the land level is high and is not submerged during the rainy season, it will ensure year round production and an early return of such a hefty investment. So, large scale investors should consider HHK as this will ensure higher profit in the future.

Most of the Fixed Chimney Kilns (FCKs) that are currently operational in Bangladesh can be converted into Zigzag kiln with certain modification by expert technicians. This modification requires only US$ 30,000 and thus quite manageable under the existing setup. For medium scale investors, the Zigzag kiln is also a suitable option.

Although VSK requires less investment and operational costs (less fuel), the aesthetic quality of the bricks is not that good. So, a VSK near city would not ensure higher sales as construction companies tend to buy bricks with better shape and colour to satisfy customers. Ideally the VSK is suitable for rural areas where shape and colour of bricks is not that significant.

Recommendations

Government should continue initiative to disseminate knowledge about these three technologies (i.e., HHK, VSK and Zigzag) by developing more pilot-scale manufacturing. Government can recognize brick sector as a formal industry which will ensure more financial assistance/loan for cleaner technology. Government can invest money for further research on brick burning and how to make the brick burning process more efficient and less polluting. The entrepreneurs can be trained about carbon market and how to access carbon market by adopting cleaner technology. Moreover government agencies can arrange seminar, conference and awareness buildup programme to let people know about green technologies. Also, government can introduce new regulations, policies and incentives to engage and encourage entrepreneurs to adopt green technologies. Furthermore, government can promote automation to improve the working conditions of brickfield labourers.

Appendix

Financial Analysis

For financial evaluation, average size of the bricks is considered as: 250 mm × 120 mm × 75 mm

One truck (3 ton capacity) can carry 3.7-4.25 m^3 of clay to produce 1300-1500 bricks (CEA, 2011)

1 ton coal price including carrying cost = Tk 9000 (CEA, 2011)

Calculation for Payback Period (Ross et al., 2008)

When a loan is taken, which needs to be repaid on a monthly installment, Eq (1) as shown below is used to calculate its monthly installment:

$$C = \frac{L}{\frac{1}{r/12}\left\{1 - \frac{1}{(1+r/12)^{n \times 12}}\right\}} \quad (1)$$

where C = monthly installment for the loan taken, L = total amount of loan taken, r = interest rate and n = number of years for loan repayment (n × 12 = total months).

To get the present value of the monthly installments for five years (n) loan repayment period, affected by general inflation rate (here, r = 6%), the same Eq (1) can be rearranged as follows:

$$PV = C \times \frac{1}{r/12}\left\{1 - \frac{1}{(1+r/12)^{n \times 12}}\right\} \quad (2)$$

In order to convert the future yearly amount/profits into present value, Eq (3) as shown below can also be used:

$$PW = \frac{FV_n}{(1+r)^n} \quad (3)$$

where PW = present worth of the net income, r = inflation rate and FV_n is the net income after n years.

To calculate the payback period, Eq (4) as shown below can be written as:

$$N = \frac{PV}{NP} \quad (4)$$

where N = payback years, PV = total investment in present worth and NP = net profit (before interest and tax in present worth).

At the moment tax is considered negligible as according to Bangladesh Government rule, any of these new technologies investing 30% of their net income will get tax holiday. It is assumed that investors of all three technologies will reinvest 30% of their net income.

Calculation for Emission (CDM, 2007)

$$E = SFC \times Q \times EF \times CF \quad (5)$$

where E = emission of CO_2 in tCO_2e, SFC = specific fuel (energy) consumption in the kiln (TJ/brick), Q = total number of brick production, EF = IPCC default carbon emission factor for coal = 25.80 tC/TJ and CF = carbon to CO_2 conversion factor = 3.67 tCO_2e/tC (CDM, 2007).

The specific fuel (energy) consumption, SFC (TJ/brick) can be calculated as follows:

$$SFC = \frac{Q_{coal} \times CV_{coal}}{Q_{brick}} \quad (6)$$

where Q_{coal} = total coal consumption per 100,000 bricks for the given kiln, CV_{coal} = calorific value of the coal (16,748 kJ/kg coal) (CDM, 2007) and Q_{bricks} = number of bricks produced (say,100,000 bricks).

$$SFC_{FCK} = \frac{24{,}000 \text{ kg} \times 16{,}748 \text{ kJ/kg}}{100{,}000} = 4019.5 \text{ kJ/brick} = 4.02 \times 10^{-6} \text{ TJ/brick}$$

$$SFC_{HHK} = \frac{14{,}000 \text{ kg} \times 16{,}748 \text{ kJ/kg}}{100{,}000} = 2344.7 \text{ kJ/brick} = 2.35 \times 10^{-6} \text{ TJ/brick}$$

$$SFC_{VSBK} = \frac{10{,}000\ \text{kg} \times 16{,}748\ \text{kJ/kg}}{100{,}000}$$
$$= 1674.8\ \text{kJ/brick} = 1.68 \times 10^{-6}\ \text{TJ/brick}$$

$$SFC_{Zigzag} = \frac{18{,}000\ \text{kg} \times 16{,}748\ \text{kJ/kg}}{100{,}000}$$
$$= 3014.6\ \text{kJ/brick} = 3.02 \times 10^{-6}\ \text{TJ/brick}$$

Emission of CO_2 in tCO_2e per 100,000 brick production in each type of kiln

$$E_{FCK} = 4.02 \times 10^{-6}\ \text{TJ/brick} \times 100{,}000\ \text{brick} \times 25.8\ \text{tC/TJ} \times 3.67\ tCO_2e/tC = 38.06\ tCO_2e$$

$$E_{HHK} = 2.35 \times 10^{-6}\ \text{TJ/brick} \times 100{,}000\ \text{brick} \times 25.8\ \text{tC/TJ} \times 3.67\ tCO_2e/tC = 22.20\ tCO_2e$$

$$E_{VSBK} = 1.68 \times 10^{-6}\ \text{TJ/brick} \times 100{,}000\ \text{brick} \times 25.8\ \text{tC/TJ} \times 3.67\ tCO_2e/tC = 15.86\ tCO_2e$$

$$E_{ZigZag} = 3.02 \times 10^{-6}\ \text{TJ/brick} \times 100{,}000\ \text{brick} \times 25.8\ \text{tC/TJ} \times 3.67\ tCO_2e/tC = 28.54\ tCO_2e$$

Acknowledgements

Clean Energy Alternatives, Practical Action, Conforce Limited, Bangladesh Centre for Advanced Studies, British Council Bangladesh.

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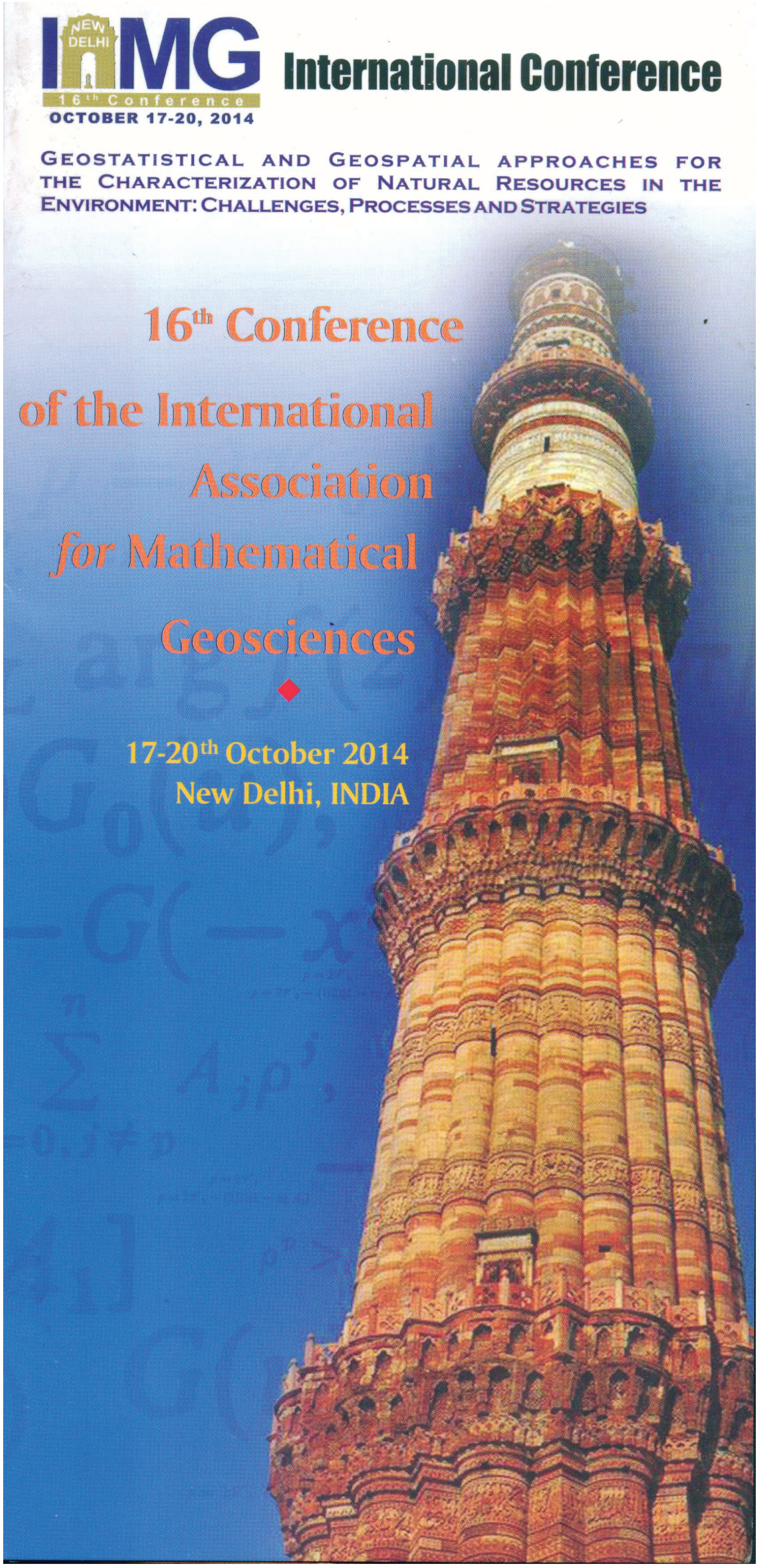

Conference Topics

The interest areas of the conference include but are not limited to the topics related to mathematical geosciences and environmental issues like 3D visualization in geo- and environmental sciences, hydrology and time series analysis, isotope hydrology, environmental geochemistry and pollution, climate and groundwater functioning - the need for correct questions, numerical solutions in hydrogeology, geostatistics in hydrology, engineering geology and geotechnical engineering, trendy geostatistics, mathematical geosciences and planetary geology, multivariate geostatistics, medical geology, classical statistics in the earth sciences, compositional data analysis and its applications, prediction and characterization of natural disasters, fractal modelling, multiple point geostatistics, marine geology and oceanography, advances in mining assessment, petroleum systems, digital rock geophysics, mathematical morphology in geosciences and geoinformatics, remote sensing and geo-informatics for natural resources management, sedimentary basin analysis, modeling aquifer heterogeneities by means of 3D geostatistics, observed changes in Himalayan cryosphere, polar sciences, computer application in earth sciences, spatiotemporal modeling, agriculture, environment & ecosystems, new frontiers of mathematical geology for resources exploration.

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