Energy and Stack Emission Monitoring In Hybrid Hoffmann Kiln (HHK) Type Universal Kiln

FINAL REPORT

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## Contents

1. Background ........................................................................................................... 1
2. Objectives of the study ...................................................................................... 3
3. Selection of monitoring parameters .................................................................. 4
4. Scope of work ...................................................................................................... 4
5. Terms of reference (ToR) .................................................................................. 4
6. Activities undertaken ......................................................................................... 5
7. Time schedule .................................................................................................... 5
8. Description of the HHK ..................................................................................... 5
  8.1 Manufacturing Process ................................................................................... 6
9. Instrument and monitoring methodology .......................................................... 11
  9.1 Stack emission monitoring ........................................................................... 11
  9.2 Ambient air quality monitoring .................................................................... 13
    9.2.1 PM$_{10}$ and PM$_{2.5}$ ........................................................................... 13
    9.2.2 Carbon monoxide ............................................................................... 15
  9.3 Energy performance monitoring ................................................................. 16
10. Work Schedule .................................................................................................. 18
11. Results and Analysis of Kiln Monitoring ....................................................... 19
  11.1 Stack monitoring results ............................................................................ 20
  11.2 Ambient Air Quality Monitoring Results .................................................. 20
  11.3 Energy performance (Energy Audit) .......................................................... 22
  11.4 Mass Emission load estimation ................................................................... 23
12. Comparison with other kiln Technologies ...................................................... 23
  12.1 Energy .......................................................................................................... 23
  12.2 Stack emission monitoring .......................................................................... 24
  12.3 Calculated mass emission load ..................................................................... 24
  12.4 Summary of Monitoring Results .................................................................. 25
  12.5 Limitations/Assumptions on Monitoring .................................................... 25
13. Conclusions and Recommendations ............................................................... 26
Annexes
Annex- A: Stack and Ambient Air Quality Monitoring data
Annex- B: Universal HHK Production Data from Log Book
Annex- C: Calorific value for coal (Imported)

List of Tables
Table 1: Clay characteristics used for brick production .......................................................9
Table 2: Salient features of the Universal Bricks Ltd. ...........................................................11
Table 3: Tentative work schedule of the Monitoring activities. .........................................19
Table 4: Stack parameters and SPM concentration in flue gas ............................................20
Table 5: Ambient air quality at the kiln gate with kiln in operation ....................................21
Table 6: Ambient background air quality at the kiln gate with ...........................................21
Table 7: Share of fuels ........................................................................................................22
Table 8: Specific Energy Consumption across different technologies ...............................23
Table 9: Comparison of stack emissions from different brick manufacturing processes. ..24
Table 10: Comparison of mass emission load across different technologies......................25

List of Figures
Figure 1: Flowchart of Brick Making Process for HHKs ....................................................8
Figure 2: Project Layout Plan .............................................................................................11
Figure 3: APM 621 portable stack monitor .......................................................................12
Figure 4: APM 550 PM$_{2.5}$ Air Sampler Set-ups ................................................................14
Figure 5: Dragger Pac III CO Portable Gas Monitor .......................................................15
1. **Background**

The ambient air quality in the Dhaka City shows distinct seasonal variations due to the effects of Asian monsoon, and high pollution events observed during dry winter months. In wet summer time relatively cleaner ambient air prevails over the Dhaka City. Emissions from brick kilns located close to the city especially to the north have been identified as one of the important sources of air pollution during dry winter months in the Dhaka City because of the prevailing northerly wind. More than 500 brick kilns are being operated, particularly; in the dry winter months (November to April) in low lying lands surrounding the Dhaka City and producing particulate matters (PM) as well as GHG. The winter operating period of these brick kilns thus coincides with the poor air quality of Dhaka City observed during this period.

A recent modeling study conducted by the Department of Chemical Engineering, Bangladesh University of Engineering and Technology (BUET)\(^1\) has shown that a significant portion of PM\(_{10}\) pollution load in the Dhaka City, ranging from 25 to 100 \(\mu g/m^3\), originates from these brick kilns located in the surrounding areas of the city like a ring.

In Bangladesh, there are over 4,000 brick-making enterprises producing over 12 billion bricks annually. Annual growth rate of the construction sector in Bangladesh has ranged from 8.1% to 8.9% in the last decade and this is expected to continue into the foreseeable future. With Dhaka set to become one of the most populous cities in the world by 2020, the demand for utilization of bricks for building construction is likely to grow manifold, which in turn will drive the growth of local (such as PM\(_{10}\)) and global (greenhouse gases or GHG) emissions, unless efforts are made to control emissions from these sources. Brick production is one of the large sources of greenhouse gas emissions, particularly CO\(_2\) emission, in Bangladesh and it is estimated to be about 3.0 million tones of CO\(_2\) annually. Outmoded, inefficient and poorly constructed kilns and the use of substandard fuels such as high sulfur coal, tires and wood in the kilns have all contributed to these high levels of kiln emissions.

\(^1\) Study on Air Quality of Impacts of the North Dhaka Brickfield Cluster by Modeling of Emissions and Suggestions for Mitigation Measures including Financing Models, Chemical Engineering Department, BUET on contract from DOE (December 2007)
Unless interventions to induce change in design and energy efficiency are implemented, emissions will continue to increase unabated. Besides air pollution, brick making industries have other serious environmental concerns like reduction in horticultural and agricultural production, deforestation, etc.

In response to these aspects of local air pollution effects as well as to global climate change issues related to GHG emissions, brick kilns have come under close scrutiny from citizens groups, environmentalists and as well as the government. In order to resolve this issue, Government of Bangladesh (GoB) with support from donors intends to facilitate the adoption of cleaner technologies and practices in the brick manufacturing sector in Bangladesh. This initiative is focused on the replacement of old technology kilns and retrofitting older kilns for cleaner and more energy efficient operation.

The combination of energy saving and reduction in pollution is a ‘win-win situation’, in which industry benefits because of savings in energy costs and better working conditions. On the other hand, the country and the society gain due to reduction in pollution as well as savings in precious natural energy resources.

With the technical assistance of UNDP-GEF, Hybrid Hoffman Kiln (HHK) is being promoted as an alternative clean brick making technology in order to attain this win-win situation in the brick sector of Bangladesh. A pilot demonstration of the Hybrid Hoffmann Kiln (HHK) has been constructed near Dhaka in the private sector with support from Industrial and Infrastructure Development Finance Company Limited (IIDFCL) which is a consortium of 12 commercial banks and lending institutions in Bangladesh that provide credit support to the private entrepreneurs for adoption of this new technology.

The HHK is a hybrid version of the Hoffman kiln technology that was developed in Germany in the mid-nineteenth century. Since then it has been redesigned to improve heat retention in the kilns and to capture waste heat for recirculation in the drying tunnel. In addition to improving kiln efficiency, the process also reduces CO$_2$ and other emissions since it employs a direct fuel injection technique to create better thermal bonding, reducing fuel usage. It has been claimed that the HHK technology improves energy efficiency through internal combustion of injected fuel through the application of heat optimization techniques in a minimum heat-loss chamber in the combustion zone of the kiln. The design capacity has claimed that one 18-door HHK will enable production of
16.5 million bricks of the size commonly used in Bangladesh whereas the traditional Fixed Chimney Kiln (FCK) produces about 2 million on the average. This means that each new HHK will replace 7.5 of the older energy inefficient kilns in equivalence. It has also been alleged that the fuel, coal, consumed in the HHK is about 10 to 12 tones per hundred thousand bricks compared to 22 to 24 tones in the traditional kilns. It follows, therefore, that the new kilns are about 50% more energy efficient.

At this background, it has been claimed that in overall consideration, the HHK type kilns are more environmental friendly, energy efficient and cost effective than the existing FCK or BTK technology when it is compared in respect of production and quality. However, all claimed advantages in brick manufacturing processes are very much raw materials and technology implementation specific. A more complete knowledge of raw materials and their properties, better control of firing, improved kiln designs, properties of fuel used and more advanced mechanization, all contribute to advancing the brick industry. As HHK is a new technology, no information is available regarding its emission and specific energy consumption under Bangladesh condition. So, it became important to measure the essential environmental parameters of HHK to ascertain whether the adoption of this technology will advance the brick sector of Bangladesh towards the desired ‘win-win situation’.

2. **Objectives of the study**

The objectives of this assignment are to determine the environment performance and energy use of a typical HHK in Bangladesh through detailed monitoring of the first demonstration kiln, designed as Universal Kiln, located at the Dhamrai Upaszilla, about 40 kilometers north of Dhaka city. More specifically, three main objectives of the study are:

(i) To monitor the stack emission of HHK (Universal Kiln)
(ii) To monitor the impact on ambient air quality in the vicinity of HHK
(iii) To examine the performance of HHK in terms of energy saving.
3. **Selection of monitoring parameters**

Emissions from brick manufacturing facilities include SPM, PM$_{10}$, PM$_{2.5}$, SO$_2$, NOx, CO, CO$_2$ and many more hazardous air pollutants. Factors that may affect emissions include raw material composition and moisture content, kiln fuel type, kiln operating parameters, and plant design. However, according to the ToR for this assignment, the parameters that will be monitored in this study are as follows:

- For stack emission monitoring – SPM
- For ambient air quality monitoring – PM$_{10}$, PM$_{2.5}$ and CO
- For energy performance monitoring – Specific Energy Consumption (SEC) in MJ/kg fired brick

4. **Scope of work**

The following was the defined task under the study:

- To perform stack emission measurement for SPM by adopting monitoring methodology suited to HHK
- Carry out ambient air quality monitoring at the factory gate in respect of PM$_{10}$, PM$_{2.5}$ and CO using short term averaging times as defined in the Bangladesh Air Quality standards both during the time when the kiln is in and out of operation.
- To carry out measurements using well defined procedures and perform data analysis
- To perform energy audit of the HHK Universal Kiln using secondary data from the kiln operations.
- To prepare draft report and its finalization in consultation with the World Bank
- To make a presentation of monitoring findings to the DoE/DNA.

5. **Terms of reference (ToR)**

The monitoring will be done according to the following specifications:

- Stack emission concentration measurements for Suspended Particulate Matter (SPM), at least over 4 averaging periods.
- Concentration of Suspended Particulate Matter (SPM), PM$_{2.5}$, PM$_{10}$ and CO in ambient air will be measured at ground level at the Kiln gate. This will be done at least 2 days per week over a period of two weeks.
• All monitoring activities will be performed on dry rain free days.
• Specific energy consumption (SEC) will be determined in MJ/ kg of fired bricks from secondary data of kiln operation and available calorific value of coal used.

6. Activities undertaken

1. Measurement of SPM concentration in the stack emission
2. Measurement of ambient concentration of PM$_{10}$, PM$_{2.5}$ and CO at the gate of the brick kiln.
3. Determination of Specific Energy Consumption (SEC) in MJ/kg of fired bricks using available secondary data.
4. Analyze collected data and prepare a complete energy and environmental monitoring report for HHK.
5. Disseminate the monitoring findings to DoE/DNA.

7. Time schedule

The study was scheduled to be carried out over a period of six weeks from the date of signing of the contract. The work plans of the study were finalized in consultation with World Bank, IIDFC and the entrepreneur. Due to unavoidable delay in starting the kiln operation and later unscheduled shut down of the kiln, the scheduled monitoring work could not be initiated in time.

8. Description of the HHK

The HHK (Hybrid Hoffmann Kiln) approach combines a highly efficient kiln technology with a unique fuel injection technique to produce environment friendly quality bricks. Bricks of any size, shape and pigmentation can be produced at the plant with minor modifications. All bricks are of uniform quality and meet international standards for strength, quality and appearance. The technology is expected to reduce energy use and generate better production economies by reducing production cost compared to the prevailing brick making technologies.

The HHK is a hybrid version of the Hoffman kiln. Structurally, it is built like the Hoffman but, unlike the traditional Hoffman in Bangladesh, the fuel used is coal. The kiln can be
made from firebricks or from green bricks. In the latter event, the green bricks get “cooked” during kiln operation. The inner and outer kiln linings are made with bricks and the space in between them packed with clay to create a solid inner chamber from which heat escape is almost absent. In this version, the firing chamber can be filled manually or automatically with dried green bricks, usually about 8,000 to 9,000 units at one time in line stacks of around 1,000. There are about 8 line stacks in each firing chamber. Each line stack is fired for about half an hour so that total firing time is about six hours. The fuel, granulated coal, is fed into the firing zone in the kiln through stoke holes on the roof. A centrifugal blower forces from behind air required for the combustion process; and, as it reaches the line to be fired, it is already preheated from the previous firing zone thus reducing firing time and energy usage. The temperature in the firing zone is about 900°C.

In the HHK system, green bricks are pre-dried in a “dry tunnel” with waste heat captured from the kiln through elaborate flow mechanisms and pumped into the tunnel by the centrifugal blower which performs two functions simultaneously, blows out hot air from the kiln and feeds it into the dry tunnel.

The technique of fuel injection enables better thermal bonding and reduces fuel usage, and hence CO₂ and other emissions. Clay is premixed with granulated coal and then extruded to produce the green bricks. This is a unique process and is fundamental to the energy efficiency achieved in brick making in China. Almost 80% of the total energy required is injected into the bricks and only about 20% is fed externally into the firing chamber. Most of the fuel mixed into the bricks, over 95%, of which is completely burnt during firing. The technique has been conspicuously absent from the Indian subcontinent and it is only recently that some attempts have been made in India to combine other materials with clay to reduce clay use.

8.1 Manufacturing Process

**Clay Extraction, Transportation and Preparation:** The clay is excavated by hydraulic excavator or by hand from nearby riverbeds or surface clay mined from open pit and transported to plant stacking yard by trucks. The clay is crushed by means of roller mills and then by double shaft mixer where water and granulated coal is added in such a manner as to ensure moisture content of 15%.
Coal Crushing and Pulverizing: Coal is crushed using steel sieve type crushing machine to pulverize the coal.

Brick Shaping: The tempered material is fed into vacuum extruder for continuous column production. The column is then cut by Clay bar cutting machine. The green bricks are set on wood planks that are manually loaded on the drying cars for drying.

Brick Drying: The green brick is then manually loaded on to the drying car, which is then transported into the drying tunnel by means of hydraulic pusher. Hot air for drying is funneled into the tunnel from the annular kiln. The drying cycle is about 24 hours.

Brick Firing: The dried green bricks are unloaded manually into the annular HHK (Hybrid Hoffman kiln). The speed of firing is 1.25 m/h at a sintering temperature of about 950-1050 °C. The fired brick are unloaded and conveyed manually in carts to stacking yard.

Main technical data includes:

| Clay Particle size after roll mill: | < 2mm |
| Brick Moisture content for shaping: | 18%–20% |
| Dry chamber temperature | 120 °C |
| Sintering temperature: | 950 °C –1050 °C |

The schematic diagram for the brick making process using HHK is shown in Figure 1 below.
UNIVERSAL HHK PROJECT

The project design combines a highly efficient kiln technology, the Forced Draft Tunnel Kiln (FDTK) with a unique technique of forming green bricks: granulated coal is injected for internal combustion. This approach results in lower energy usage, higher quality bricks and reduced pollution. Bricks of any size, shape and pigmentation can be produced at the plant with minor modifications. All bricks will be of uniform quality and will meet international standards for strength, quality and appearance.

Product:

The plant has been designed to produce mainly bricks of following measurements:

<table>
<thead>
<tr>
<th>Length</th>
<th>Width</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 mm</td>
<td>120 mm</td>
<td>60 mm</td>
</tr>
<tr>
<td>240 mm</td>
<td>115 mm</td>
<td>53 mm</td>
</tr>
</tbody>
</table>
The plant is able to produce other types and sizes of bricks as well as of different colors. This will require modifications for dies, cutting accessories, pigmentation and the like.

Production Capacity:

Estimated production capacity of the project is 50,000 per day. With 330 working days annual production capacity will be 16.5 million. Actual production might be lower due many practical reasons.

Raw Materials:

The major raw material brick production is clay. However, coal is also a major raw material for bricks. Coal will be partially mixed with clay for internal burning (~70%) and the rest of coal will be externally applied (~30%).

(a) Clay

Initial analysis of the clay available in Bangladesh by Xian Institute indicates that the locally available clay is suitable for brick production in the proposed kiln. The characteristics of clay to be used are as follows:

<table>
<thead>
<tr>
<th>Chemical Properties</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>SO₃</th>
<th>Ignition Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>55~70%</td>
<td>10~20%</td>
<td>3~10%</td>
<td>&lt;5%</td>
<td>&lt;3%</td>
<td>&lt;3%</td>
<td>3~15%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physical Properties</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle size:</td>
<td></td>
</tr>
<tr>
<td>&lt;0.005 mm</td>
<td>~30%</td>
</tr>
<tr>
<td>0.005~0.05 mm</td>
<td>~50%</td>
</tr>
<tr>
<td>0.05~0.25 mm</td>
<td>~20%</td>
</tr>
<tr>
<td>Linear drying shrinkage</td>
<td>~4%</td>
</tr>
<tr>
<td>Sintering Temperature</td>
<td>~950°C</td>
</tr>
</tbody>
</table>

The quantity of clay that would be required to produce the target output of 16.5 million bricks is 3.35 million cu.ft. of clay.
Coal

Yearly estimated requirement of coal for 16,500,000 bricks is 1,750 tons. The actual coal requirement is currently observed to be higher than the estimates.

Utilities:

(a) Power

The total installed power requirement of the equipment is about 300 KVA. REB connection is the primary source of power. A diesel generator is also installed as the secondary source of power.

(b) Water

The plant will require 16 tons of water daily. The project obtains this water from a tube well constructed at site.

(c) Machinery and Equipment

The required machineries and equipment for the project are as follows:

- Box Feeder type XGD800
- Double Shaft Mixer Sj240-42
- Roll Mill Type SGP700x500
- Vacuum Extruder Type ZJN400/YN
- Water Cycling Vacuum Pump: Type 2SH-1/YN
- Cutter for Column Type ZQT300x200
- Cutter for green Type ZQP12
- Push Car for Shifter Type Bdc-5t
- Tunnel Dryer
- FDTK Annular Kiln
- Gas Generator

Technical know-how:

The Plant design and the technical assistance for the project have been provided by the Xian Research and Design Institute of Wall & Roof Materials. The Institute is an agency of the Central Government in China and is both a design institute as well as a regulatory body. It sets standards and codes for brick making process and as its name suggests, it conducts research on wall materials. As the Institute is the technical supervisor of the project, it oversaw the construction work of the project, commissioning of the plant,
supervised the operation of the plant for the first three months of its trial operation and trained the operators to build their capacity for plant operation.

Table 2: Salient features of the Universal Bricks Ltd.

<table>
<thead>
<tr>
<th>Kiln details</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of Chimney*</td>
<td>20 ft</td>
</tr>
<tr>
<td>Length of Chimney</td>
<td>42 ft</td>
</tr>
<tr>
<td>Width of chimney</td>
<td>6 ft</td>
</tr>
<tr>
<td>Firing Temperature</td>
<td>950°C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Production Details</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Production capacity</td>
<td>16.5 million bricks/year</td>
</tr>
<tr>
<td>Drying Capacity</td>
<td>72,000 per day</td>
</tr>
<tr>
<td>Retention time</td>
<td>24 hours</td>
</tr>
<tr>
<td>Fuel used</td>
<td>Barapukutia coal</td>
</tr>
</tbody>
</table>

* In HHK emission chimney (cover picture) is the rectangular stack with the given dimensions.

The project lay out plan is shown in Figure 2.

![Figure 2: Project Layout Plan](image)

9. Instrument and monitoring methodology

9.1 Stack emission monitoring

The mass emission load calculation is a very useful format to measure the overall pollution load that a specific technology may release into the environment. This is the amount of stack emission that a kiln releases into the environment for the production of
each of 1000 fired bricks. In the present study the mass emission load (kg SPM/1000 bricks) is calculated using the following parameters:

- Number of bricks production per day
- Time required for the production of 1,000 bricks, T in hr
- Velocity of gas in stack, V in m/s
- Area of stack, A in m$^2$
- Flue Gas flow per hour, $Q' = V \times A$ in m$^3$/hr
- Flue Gas volume flow for 1,000 bricks in time T hr, $Q$ in m$^3$ = $Q' \times T$
- Concentration of SPM in mg/Nm$^3$
- SPM Emission for 1000 bricks = $Q \times$ Emission concentration of SPM

**Measurement of SPM in the stack**

SPM emission in the stack has been monitored using APM 621 stack monitor manufactured by Envirotech Instruments Pvt. Ltd., India (Figure 3). The instrument is capable of measuring flue gas temperature, flow rate, concentration of SPM and concentration of important gaseous pollutants. The flue gas along with the SPM is passed through a filter medium at a metered flow rate. Change in weight of the filter is used to determine the quantity of dust contained in the flue gas sample. The product of the sampling flow rate and the time is used to determine the sample volume.

![Figure 3: APM 621 portable stack monitor](image)

Since particles in motion have inertia, therefore if the SPM concentration in the sample, drawn from the stack is truly represent SPM concentration in the stack, Iso-kinetic conditions must maintained at the tip of the sampling probe. Non-isokinetic conditions tend to cause a separation of particles and gas molecules so both concentration and size distribution altered by **non-isokinetic sampling**. In the APM 621 sampler the velocity
measured is used to calculate the **isokinetic sampling** flow rate for a nozzle of known aperture.

SPM concentration is determined in the following way:

\[ SPM \ (mg/ \ m^3) = \frac{\text{Weight of dust collected (mg)}}{\text{Volume of air sampled (m}^3)} \]

where, weight of dust collected in mg = (weight of dust collector before measurement – weight of dust collector before measurement) in mg

However, mass emission load can also be calculated as follows by using emission rate i.e., emission in kg per hour:

\[ Emission \ rate \ of \ pollutant \ (kg/hr) = Q_s \times S/106 \]

where, \( Q_s = \) Flue gas flow rate (25º C, 760 Hg mm), Nm\(^3\)/hr

\( Q_s = Velocity \times Area \ of \ stack \)

\( S = Concentration \ of \ pollutant \ (mg/ \ Nm^3) \)

From the emission rate, mass emission load for 1000 bricks is calculated as follows:

\[ Mass \ emission \ load \ (kg/1000 \ bricks) = Pollutant \ emission \ rate \ (kg/h) \times Duration \ of \ production \ for \ 1000 \ bricks \]

**9.2 Ambient air quality monitoring**

The parameters measured for ambient air quality monitoring are: PM\(_{2.5}\), PM\(_{10}\) and CO. PM fractions (PM\(_{10}\) and PM\(_{2.5}\)) were measured using APM 460 and APM 550 Samplers from Envirotech Instruments Pvt. Ltd. India and CO was measured using electrochemical sensor based portable monitors. A short description of the measurement principle and the instrument used for each of the parameter is given in the following sections.

**9.2.1 PM\(_{10}\) and PM\(_{2.5}\)**

The APM 550 (Figure 4) system is a manual method for sampling fine particles (PM\(_{10}\) and PM\(_{2.5}\) fraction) and is based on impactor designs standardized by USEPA for ambient air quality monitoring. Ambient air enters the APM 550 system through an omni-directional inlet designed to provide a clean aerodynamic cut-point for particles greater
than 10 microns. Particles in the air stream finer than 10 microns proceed to a second impactor that has an aerodynamic cut point at 2.5 microns. The air sample and fine particulates exiting from the PM2.5 impactor is passed through a 47mm diameter Teflon filter membrane that retains the FPM.

The Envirotech APM 550 system allows removal of the PM2.5 impactor from the sample stream so that the same system may be optionally used as a PM10 Sampler.

The sampling rate of the system is held constant at 1 m$^3$/hr by a suitable critical orifice. The system uses a continuously rated oil free pump for providing suction pressure. The standard system is supplied with a Dry Gas Meter to provide a direct measure of the total air volume sampled.

For PM concentration measurement, each filter is weighed (after moisture equilibration) before and after use to determine the net weight (mass) gain due to collected PM$_{10}$ or PM$_{2.5}$. The total volume of air sampled, measured at the actual ambient temperature and pressure, and is determined from the measured flow rate and the sampling time. The mass concentration of PM$_{10}$ or PM$_{2.5}$ in the ambient air is computed as the total mass of collected particles in the PM$_{10}$ size range divided by the volume of air sampled, and is expressed in micrograms per actual cubic meter (µg/m$^3$). Sampling and the gravimetric

![Figure 4: APM 550 PM$_{2.5}$ Air Sampler Set-ups](image)

For PM concentration measurement, each filter is weighed (after moisture equilibration) before and after use to determine the net weight (mass) gain due to collected PM$_{10}$ or PM$_{2.5}$. The total volume of air sampled, measured at the actual ambient temperature and pressure, and is determined from the measured flow rate and the sampling time. The mass concentration of PM$_{10}$ or PM$_{2.5}$ in the ambient air is computed as the total mass of collected particles in the PM$_{10}$ size range divided by the volume of air sampled, and is expressed in micrograms per actual cubic meter (µg/m$^3$). Sampling and the gravimetric
analysis of the filters were undertaken using PM sampling facilities of Enviro Consultants Ltd., Dhaka.

9.2.2 Carbon monoxide

The Dragger® Pac III™ Monitor (Figure 5), used in this study, delivers the most of any single gas monitor available and used for the analysis of gases and vapors in ambient or industrial workplace. The instrument uses electrochemical sensors to detect and measure a variety of gases. The basis for all electrochemical sensors is the use of a porous membrane (normally PTFE) or capillary system, which allows the gas to diffuse into the cell containing the liquid or gel electrolyte and the electrodes. When the gas comes into contact with the electrolyte, a change in electrochemical potential between the electrodes is produced. Associated electronic circuitry then will measure, amplify, and control this electronic signal. Because the reaction is proportional to the concentration (partial pressure) of gas present, the signal is easily translated into parts per million, percent, or ppm-hrs, and read on the readout meter or stored in microprocessor circuits for later readout.

Figure 5: Dragger Pac III CO Portable Gas Monitor

Two levels of alarm indicate increasing concentrations. The exact concentration of gas is displayed on the LCD readout. This instrument is operated with only two buttons making it extremely simple and easy to use.
9.3 Energy performance monitoring

Specific fuel consumption, in terms of tones of fuel consumed for firing of one lakh bricks is the popular way of expressing energy performance of any brick kiln technology. The mode of expressing energy performance in this manner may be of interest to brick manufacturers. However, it is difficult to compare performance of brick kilns on this basis, because of:

- Variation in the size and weight of the bricks
- Different characteristics of clays, particularly in terms of heat requirement for firing
- Different calorific values of fuels

The variations in brick weight and the quality of fuels will be taken care when the performance of the kiln is expressed in specific energy consumption. Specific energy consumption is expressed as energy consumed in MJ for firing one kg of fired brick.

The factors that affect energy uses in brick making process are:

- Nature of the clay: Refractoriness – resistance to change by heat; presence of fluxes – substances, which aid vitrification; intrinsic calorific value.
- Moisture content of the “green brick” going into the kiln
- Types of fuel used their calorific values, moisture content, and distribution.
- Design of the kiln.
- Skill of the fireman controlling the burning process.
- Climatic condition: ambient temperature, wind speed and direction.

The exact number of bricks being fired is needed for energy efficiency calculation. This is easier to determine if bricks are stacked in thousands prior to firing. Alternatively, the bricks in each layer can be counted as the kiln is built. Then we need to know the mass of the bricks. A convenient number of green bricks (perhaps 1 per 1,000, but not less than 24) should be selected at random and weighed. Thence an average 'wet mass' can be calculated. Now we need to know the moisture content of the green bricks to calculate the energy needed simply to dry them. The selected bricks can be dried in a conventional oven or a simple field oven. The important thing is to keep bricks between 80 and 100°C and weigh them periodically until no further weight loss is noted. The average 'dry mass' can
then be found. With this data it is possible to calculate the mass of water and the drying
energy:

\[
\text{Moisture Content (Wet Basis)} = \frac{\text{Wet Mass} - \text{Dry Mass}}{\text{Wet Mass}}
\]

\[
\text{Mass of green brick} = \text{Avg. mass of green brick} \times \text{No. of bricks}
\]

\[
\text{Total moisture content} = \text{Moisture content of brick} \times \text{Mass of bricks}
\]

\[
\text{Drying energy} = \text{Specific drying energy} \times \text{Total moisture content}
\]

(\text{where specific drying energy} = 2,591 \text{ kJ/kg of moisture})

All fuels used should be weighed. If a fuel such as saw-dust or pulverized fly ash is mixed
into the body of bricks, its mass must also be determined. A sample of each fuel used
should be taken promptly to test for calorific value and moisture content. If the clay has
natural fuel content, it too should be sent for testing.

If such test facilities are unavailable or unaffordable, then the best that can be done is to
use the most recent local data. If a value is found in this way, it should not be recorded as
the specific calorific value and a note should be made of the source of the information.
From this data the total energy used is calculated:

\[
\text{Total energy} = \text{Mass of fuel} \times \text{Net calorific value}
\]

And the firing energy is obtained by subtracting the energy used for drying:

\[
\text{Firing energy} = \text{Total energy} - \text{Drying energy}
\]

We need to know how well bricks are fired, or rather the heat-work done. Testing brick
properties such as compressive strength will not give useful data to compare kilns because
properties are affected by factors other than firing. The effectiveness of a firing process is
a function of time and temperature, but the relationship is not linear. Bricks fired at
1,000°C for 10 hours would not be the same as bricks fired at 100°C for 100 hours! We
could plot temperature against time for various points in the kiln and present this
graphically to qualify energy use. However, thermometry to measure such high
temperatures is expensive.

Once the kiln is fired and cooled, a representative sample of bricks - the same number as
before - should be weighed, and the average fired mass calculated. From these data one
can calculate the total mass of fired brick and the specific firing energy as:
Mass of fired brick = Mass of a fired brick × No. of fired bricks

\[
\text{Specific firing energy} = \frac{\text{Firing energy}}{\text{Mass of fired brick}}
\]

It is calculated by dividing the energy input to the kiln in a specified time interval by the weight of fired bricks produced during the same time interval. It is the most common way of expressing energy performance of brick kilns. The energy input to the kiln will be calculated by summing the fuel used as internal fuel as well as direct injection of fuel to the kiln. The following secondary data are used to calculate the Specific Energy Consumption (SEC) in MJ/kg fired bricks:

- Total brick production per day
- Average weight of unit brick
- Total weight of brick produced per day
- Fuel consumed for direct injection per day
- Calorific value of fuel used for direct injection
- Fuel used as internal fuel
- Calorific value of internal fuel
- Total fuel (direct injection + internal fuel) consumed per day.

10. Work Schedule

Before performing actual monitoring (SPM emission at the stack and ambient PM10, PM2.5 and CO at the factory gate), the HHK project site was visited on 21 August 2008 to obtain information required to design the stack emission sampling set up. The physical infrastructure necessary for conducting monitoring work was communicated to the relevant authority. During the site visit, the kiln was not operational due the short supply of raw materials. As a result actual monitoring program could only be started during December, 2008. Given the pre-condition of the HHK Universal kiln to be operational and rain free days for conducting the sampling campaign, the following tentative time schedule was worked out to conduct the activities as per the ToR of this study.
Table 3: Tentative work schedule of the Monitoring activities.

<table>
<thead>
<tr>
<th>Sl.</th>
<th>Item</th>
<th>Period</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Stack and Ambient Monitoring</td>
<td>August 25 – 30</td>
<td>Kiln operational and first 3 sampling days were foggy and 1 sampling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>December, 2008</td>
<td>days was sunny.</td>
</tr>
<tr>
<td>2.</td>
<td>Collection of Secondary data for Specific</td>
<td>September -</td>
<td>10 days daily production report and calorific value of the coal used</td>
</tr>
<tr>
<td></td>
<td>Energy consumption monitoring</td>
<td>December 2008</td>
<td>from Petrobangla website</td>
</tr>
<tr>
<td>3.</td>
<td>Data analysis</td>
<td>September –</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>December, 2008</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Report preparation and submission</td>
<td>September –</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>December, 2008</td>
<td></td>
</tr>
</tbody>
</table>

But because of unforeseen delays in kiln operation and stabilization, stack monitoring and ambient air sampling during kiln operation were conducted during December 2008. The Secondary data (Log sheets) for Specific Energy consumption monitoring was also collected from the field when the stack and ambient air quality monitoring samples were collected. Moreover, ambient background sampling was also performed during December 2008 when the kiln was not in operation.

11. Results and Analysis of Kiln Monitoring

The HHK *Universal Bricks Ltd.* was monitored for the following performance parameters:

- Stack emissions
- Ambient air quality
- Energy performance (Energy Audit)

The details of the results and analysis of the data are presented in the following sections. All the field monitoring data were collected after the kiln stabilized in about two weeks of its operation. For ambient air quality, PM$_{10}$, PM$_{2.5}$ and CO concentrations were measured. Baseline data on ambient air quality were collected on 6 December 2008 when the kiln was not in operation.
11.1 Stack monitoring results

In the kiln the stack samples (SPM) were collected for a period of 2 hours each. Kiln operations were not altered and normal practices were followed. It was observed that the kiln was typically sealed and no significant leakage was observed. The results of the stack monitoring data are given in Table 4. Details of the stack monitoring data are given in Annex–A.

Table 4: Stack parameters and SPM concentration in flue gas

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flue gas temperature (ºC)</td>
<td>37 (range was 35-38)</td>
</tr>
<tr>
<td>Velocity (m/s)</td>
<td>3 (range was 2-4)</td>
</tr>
<tr>
<td>SPM (mg/m³)</td>
<td>20.3 (range was 15.8 – 26.9)</td>
</tr>
</tbody>
</table>

Emissions from the kiln were found to be in the range of 15.8 to 26.9 mg/Nm³ while the emission standards for Suspended Particulate Matter (SPM)² are 750 to 1000 mg/Nm³. Recent studies reveal that emissions from brick kilns are generally regarded as one of the important contributors to air quality degradation over urban areas. The poor quality of coal (low calorific value) increases the energy consumption rate because of inefficient combustion and leakages through kiln walls requires higher energy intensity and thereby causing higher levels of air pollution.

11.2 Ambient Air Quality Monitoring Results

The airborne particulate matters are produced through a wide range of processes, both natural and man made activities. Combustion processes are the major sources of fine fraction of particulate matter (PM₂.₅ and PM₁₀) as well as CO. In order to reduce the human exposure of particulate matter and CO, it is assumed that the reduction of emissions from brick kiln obviously will be an effective control strategy that will lead to the improvement of ambient air quality level around the kiln area as well as the neighboring air shed.

The Ambient Air Quality was monitored for PM₁₀, PM₂.₅ and CO concentrations, 12 days after firing of the kiln started and stabilized. The sampling was conducted for 3 days near

² ECR-97, Schedule-11
the entrance gate of the kiln site. PM$_{10}$ and PM$_{2.5}$ samples were taken for 24 hours averaging time whereas CO samples were taken for 8 hours averaging time. The results of the ambient air quality monitoring are given in Table 6. Sampling time was selected based on the averaging time mentioned in the Bangladesh national ambient air quality standard (NAAQS).

To understand the impact of the kiln operation on the neighbouring air quality background PM$_{10}$, PM$_{2.5}$ and CO concentrations was also monitored, when the kiln was not operational. Ambient background air quality data are given in Table 6. Details of the sampling information are given in Annex – A.

Table 5: Ambient air quality at the kiln gate with kiln in operation

<table>
<thead>
<tr>
<th>Date</th>
<th>PM$_{10}$ (µg/m$^3$)</th>
<th>PM$_{2.5}$ (µg/m$^3$)</th>
<th>CO (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25/12/2008</td>
<td>226</td>
<td>137</td>
<td>1.05</td>
</tr>
<tr>
<td>26/12/2008</td>
<td>265</td>
<td>165</td>
<td>1.25</td>
</tr>
<tr>
<td>27/12/2008</td>
<td>263</td>
<td>170</td>
<td>1.50</td>
</tr>
<tr>
<td>03/01/2008</td>
<td>233</td>
<td>151</td>
<td>1.05</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>247</strong></td>
<td><strong>156</strong></td>
<td><strong>1.20</strong></td>
</tr>
</tbody>
</table>

Table 6: Ambient background air quality at the kiln gate with kiln not operational.

<table>
<thead>
<tr>
<th>Date</th>
<th>PM$_{10}$ (µg/cm$^3$)</th>
<th>PM$_{2.5}$ (µg/cm$^3$)</th>
<th>CO (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/12/2008</td>
<td>197</td>
<td>98</td>
<td>1.00</td>
</tr>
</tbody>
</table>

The average ambient PM$_{10}$, PM$_{2.5}$ and CO concentrations near the gate of the kiln site, about 100 m from the stack, are 251 µg/m$^3$, 157 µg/m$^3$ and 1.30 ppm respectively. The 24-hour ambient PM$_{10}$ and PM$_{2.5}$ concentrations exceeded the Bangladesh NAAQS$^3$ but 8-hour CO concentration was found well below the standard. The background monitoring results, when the kiln was operational except firing (Table 6) indicate that the ambient PM$_{10}$ and PM$_{2.5}$ concentrations are higher than the Bangladesh national ambient air quality standards. This may be due to dust generation in the surrounding and green brick production related activities. The ambient PM concentrations at the factory gate during kiln operation increases by about 25% for PM$_{10}$ and about 50% for PM$_{2.5}$. The higher proportional increase in the PM$_{2.5}$ can be understood as these are produced in the high temperature combustion process in the kiln. It should be noted that local meteorological...

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conditions such as wind direction and other local activities also impact the ambient PM concentrations.

11.3 Energy performance (Energy Audit)

Production

Weight of Green brick = 4.00 kg/brick
Weight of dry brick = 3.25 kg/brick
Weight of fired brick = 3.00 kg/brick
Average Brick Production = 39,100 bricks/day
= 1,173,000 kg/day

Energy Input

Coal (Barapukuria) is the main fuel used in the kiln. The average coal consumption data was obtained from the production logbook (Daily production report) kept at site and was used as secondary data. Copies of the 10 days log sheets are given in Annex – B. The gross calorific value for the coal used in the kiln was obtained from Petrobangla website (http://www.petrobangla.org.bd/oper_mining.php). This value was used for further calculation of the energy input for brick manufacturing.

Average coal consumption = 5,511 kg/day
Average internal fuel = 4,094 kg/day
Average fire fuel = 1,417 kg/day
Percentage of moisture = 8.33
Coal consumption = 14.09 tons/100,000 bricks

Details of the share of different fuels and their gross calorific value are shown in Table 7.

Table 7: Share of fuels

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Weight (%)</th>
<th>Energy (%)</th>
<th>Gross Calorific value (BTU/lb)*</th>
<th>MJ/kg*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>25.71</td>
<td>25.71</td>
<td>11,040</td>
<td>25.68</td>
</tr>
<tr>
<td>Internal fuel</td>
<td>74.29</td>
<td>74.29</td>
<td>11,040</td>
<td>25.68</td>
</tr>
</tbody>
</table>

Heat input by coal      = 36,389 MJ/day
Heat input by internal fuel = 1,05,134 MJ/day
Total heat input by the fuels = 1,41,523 MJ/day
Specific energy consumption = 1,41,523/1, 17,300 MJ/kg of fired brick
= 1,207 MJ/kg fired brick
11.4 Mass Emission load estimation

The mass emission load calculation is a very useful parameter to measure the overall pollution load that a specific technology can release into the environment. That is, for the production of each 1,000 bricks, how much pollution/emission a kiln may emit to the environment. This “at source” reduction of SPM emissions through the use of a selected technology is extremely important for improving air quality.

**Brick production = 39,100 per day**

Therefore kiln will produce 1000 bricks in time $T = 0.614$ hrs.

$V =$ Velocity of gas in stack $= 1.03$ m/s

Area of cross-section of the stack $= 19.05 \, \text{m}^2$

**Flue Gas flow per hour $= V \times A = 70,637 \, \text{m}^3/hr$**

Flue Gas flow for 1000 bricks in time $T = 43,358 \, \text{m}^3$

**Concentration of SPM $= 20.3 \, \text{mg/Nm}^3$**

(Taking the normal operation in consideration)

SPM Emission for 1000 bricks $= \text{Flue Gas flow for 1000 bricks in time}$

$T \times \text{Emission concentration of SPM}$

$= 43,358 \, \text{m}^3 \times 20.3 \, \text{mg/m}^3$

$= 8,78,695 \, \text{mg/1000 bricks}$

$= 0.879 \, \text{kg/1000 bricks}$

12. Comparison with other kiln Technologies

12.1 Energy

The Specific Energy consumption of the HHK Universal Kiln was compared with available data for other technologies commonly used in Bangladesh. These are the MC BTKs and the FC BTKs. The comparison of specific energy consumption in these technologies is shown in Table 8 below.

<table>
<thead>
<tr>
<th>Moving Chimney Kiln (7th Cycle)*</th>
<th>Fixed Chimney Kiln (2nd Cycle)*</th>
<th>HHK</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.25 MJ/kg</td>
<td>1.73 MJ/kg</td>
<td>1.207 MJ/kg</td>
</tr>
</tbody>
</table>

* Source: TERI, India, Project Report No. 200CR 45, June 2002

The above data indicate that the energy performance of the HHK is superior to the other prevalent technologies. And thus, for a kg of brick to be manufactured, HHK will consume
less coal than MC BTKs or FC BTKs and this amounts to significant monetary savings for the operators.

In general, FC BTKs will perform better than MC BTKs, however, in the data above, the operational practices of the FC BTK during monitoring by TERI in 2002 was found to be very poor and this is reflected in the results in Table 8. Additionally, the FC BTK was being monitored; it was only in its 2nd round of firing compared to the MC BTK, being in its 7th round of firing.

These findings further indicate that to evaluate the realistic performance of a particular brick manufacturing technology in terms of energy efficiency stabilization time of the firing kiln should be systematically studied.

12.2 Stack emission monitoring

The suspended particulate matter (SPM) concentration in the stack emission from the present study of HHK is compared with the concentration of other types of Kilns, taking the reference of TERI report on monitoring of MC BTKs and FC BTK in 2002. In Table 9, comparisons of SPM emissions from different technologies are given.

Table 9: Comparison of stack emissions from different brick manufacturing processes.

<table>
<thead>
<tr>
<th></th>
<th>Moving Chimney Kiln (7th Cycle)*</th>
<th>Fixed Chimney Kiln (2nd Cycle)*</th>
<th>HHK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>1414 mg/m³</td>
<td>241 mg/m³</td>
<td>26.9 mg/m³</td>
</tr>
<tr>
<td>Min</td>
<td>570 mg/m³</td>
<td>99 mg/m³</td>
<td>15.8 mg/m³</td>
</tr>
<tr>
<td>Average</td>
<td>840 mg/m³</td>
<td>160 mg/m³</td>
<td>20.3 mg/m³</td>
</tr>
</tbody>
</table>

* Source: TERI, India, Project Report No. 200CR 45, June 2002

The emission performance of the HHK was found to be better than that of other technologies used in the country. Apparently, however, one may conclude that SPM emission is significantly lower for this type of kiln. In practice this may not be true because HHK is a forced draft type kiln where total flue gas emission is higher compared to other technology kilns, operated under natural draft condition. Therefore, mass emission load should be compared for assessing the emission characteristics for HHK kilns.

12.3 Calculated mass emission load

The calculated mass emission load for HHK was compared with MC BTKs or FC BTKs obtained from Nepal Valley Report and is given in Table 10.
Table 10: Comparison of mass emission load across different technologies

<table>
<thead>
<tr>
<th></th>
<th>Moving Chimney Kiln (7th Cycle)*</th>
<th>Fixed Chimney Kiln (2nd Cycle)*</th>
<th>HHK</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPM/1000 bricks</td>
<td>8.06 kg</td>
<td>1.71 kg</td>
<td>0.879 kg</td>
</tr>
</tbody>
</table>


As can be seen from Table 10, the mass emission load for HHK is significantly lower than that of MC BTKs and FC BTKs. This feature could be regarded as “at source” reduction of SPM emissions through the use of HHK technology and this is extremely important for the improvement of ambient air quality in the country.

12.4 Summary of Monitoring Results

1. Specific fuel consumption of the Kiln = 1.207 MJ/kg Fired brick compared to 1.25 MJ/kg and 1.73 MJ/kg for moving chimney kiln (MCK) and fixed chimney kiln (FCK) respectively.

2. Observed average stack emission of 20.3 mg/m$^3$ is much lower than the Bangladesh Standard of 1000 mg/Nm$^3$. Although the emission rate appears to be low, the total volume of the flue gas emission is high compared to other technologies, because the technology is based on forced draft.

3. The calculated mass emission load of SPM emission per 1000 brick production is 0.879 kg compared to emission load for MCK and FCK of 8.06 kg/1000 bricks and 1.71 kg/1000 bricks respectively.

4. Ambient PM$_{10}$, PM$_{2.5}$ and CO concentrations near the gate of the Kiln site about 100 m from the stack are 251 µg/m$^3$, 157 µg/m$^3$ and 1.30 ppm respectively. The 24-hour ambient PM$_{10}$ and PM$_{2.5}$ concentrations exceeded the Bangladesh national ambient air quality standards, but 8-hour CO concentration was found well below the Bangladesh standard.

12.5 Limitations/Assumptions on Monitoring

Energy

- Production and Coal consumption data were taken from the kiln logbook.
- Weighing practice may introduce ~10% error in coal consumption.

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• Average calorific value of the coal was taken from Petrobangla website, since the HHK Universal kiln uses coal from Barapukuria Coal Mine Company Ltd. a subsidiary of Petrobangla.
• Coal calorific value for imported coal (Annex-C) has not been used.

Stack Monitoring

• Only one traverse point was considered around the middle section of the rectangular exhaust.
• Sampling hole was at about 3D and not at 8D (D=diameter of stack), since chimney height is only 4D.
• Firing may not be uniformly controlled.

13. Conclusions and Recommendations

Stack Emission

Stack emission level for SPM measured in this study are observed to be about 50 times lower than what is known to date for such emissions from traditional brick kilns that are currently in operation in Bangladesh (i.e., about 20mg/m$^3$ compared to around 1000mg/m$^3$).

One of the reasons for observed low emission is the scrubbing of the flue gases by the wet green bricks in the drying tunnel. In the drying process, the flue gas coming out of the kiln is redirected to the drying tunnel by 8 large fans. A large fraction of the SPM gets deposited on to wet brick surfaces thereby reducing the emission load in the stack gases. Moreover, the huge amount of drawn-in fresh air also dilutes the flue gases and lead to further reduction in the SPM concentration in the gases released through the stack.

The measured stack emission level is well below the present regulatory standards of 1000mg/m$^3$ for brick kilns. In fact, it is so low that it is better than all the known regional standards including India. Thus, HHK technology is one of the cleanest for coal based brick making process.

In view of low stack emissions with consequent observed low impact on ambient air quality at the kiln gate in the case of HHK, higher stack height will not be required to improve the local dispersion. However, if populated areas are located close to the kiln, then it may be necessary to increase stack height for compliance with ambient air quality standards. The stack height of the present HHK (i.e., Universal Kiln in Dhamrai) where the measurement was done is 6m.

Recommendations:

(i) Based on the very low emission observed, the HHK technology should be included as a recommended technology in any future revision of National Brick Kiln Regulations.
(ii) The stack height requirement currently set for FCK should be relaxed for HHK based on observed PM levels at the kiln gate in the present study.
(iii) Stack emission measurements should be done in some more HHKs before emission levels for such kilns are specified in official documents. Some periodic measurements may also be done to see if low emissions are maintained consistently during longer operation of such kilns.

**Ambient air quality**

The ambient air quality data (PM 10 and PM2.5) measured at the gate of the Universal kiln, before the operation of the kiln started are found to be somewhat higher than the current national ambient air quality standard (NAAQS) for these two parameters. The higher values are due to the fact that the measurements were done during dry season when SPMs are normally high. In the dry season there are higher windblown dusts and open biomass burning is also more prevalent. Moreover, in the preparatory work for the operation of the kiln, activities related to green brick making process such as transportation of clays to the site by trucks, coal crushing etc was in progress. These also contributed to higher PM levels.

During the operation of the kiln, the measured ambient PM values went up by less than 50% which is also much lower than expected. Thus, the impact of HHK operation on ambient air quality at the factory gate was moderate. It should be noted that the observed PM levels should not be considered as non-compliance of NAAQS, as occupational exposure standards rather than NAAQS should be applicable at the factory gate. However, occupational standards for air pollution exposure are not available in Bangladesh. It may be noted that US occupation standard\(^5\) for SPM at worksite is 5mg/ m\(^3\).

**Recommendation:** Ambient air quality both at factory gate and nearby population centres should be measured on year round basis to generate data for regulatory purpose i.e., compliance of the ambient air quality standards.

**Energy efficiency**

The average amount of coal required to fire 100,000 bricks is 10-12 tons for HHK universal kiln as per the design. Under the present operational conditions, the coal consumption has been found to be about 14 tons per 100,000 bricks.

The higher consumption of coal may be explained by the fact that the Universal HHK, first of its kind in Bangladesh, is in its early stage of operation. At this stage, it appears that the massive structure of the kiln is still absorbing heat. With longer term operation when heat stabilization is achieved, it is expected that at the steady state of operation, coal consumption would be less and the energy efficiency will further improve. This, however, needs to be confirmed by further studies in more kilns.

**Recommendation:** The current value of energy efficiency as reported in this study is based on secondary data on fuel use from kiln operation for a short period and should only be considered as indicative. This value should not be used for carbon finance purpose. For carbon finance purpose energy efficiency value should be determined from longer term data for several kilns.

Annexes
### Table A1: Stack monitoring data

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Initial Wt (mg)</th>
<th>Final Wt (mg)</th>
<th>Net Wt (mg)</th>
<th>Flow rate (l/min)</th>
<th>Time (min)</th>
<th>Vol Collected (m$^3$)</th>
<th>Conc. (mg/m$^3$)</th>
<th>Average Conc. (mg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>144.437</td>
<td>149.1687</td>
<td>4.732</td>
<td>5</td>
<td>60</td>
<td>0.30</td>
<td>15.77</td>
<td>20.27</td>
</tr>
<tr>
<td>2</td>
<td>140.862</td>
<td>149.0253</td>
<td>8.163</td>
<td>5</td>
<td>90</td>
<td>0.45</td>
<td>18.14</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>143.327</td>
<td>155.4253</td>
<td>12.099</td>
<td>5</td>
<td>90</td>
<td>0.45</td>
<td>26.89</td>
<td></td>
</tr>
</tbody>
</table>

### Table A2: Ambient PM monitoring data

<table>
<thead>
<tr>
<th>Data</th>
<th>PM fraction</th>
<th>Initial Wt (mg)</th>
<th>Final Wt (mg)</th>
<th>Net Wt (mg)</th>
<th>Initial Vol (m$^3$)</th>
<th>Final Vol (m$^3$)</th>
<th>Vol Collected (m$^3$)</th>
<th>Conc. (μg/m$^3$)</th>
<th>Weather condition</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>06/12/08</td>
<td>PM10</td>
<td>137.717</td>
<td>139.232</td>
<td>1.515</td>
<td>46.142</td>
<td>53.841</td>
<td>7.699</td>
<td>196.8</td>
<td>Sunny</td>
<td>Kiln not operational</td>
</tr>
<tr>
<td>06/12/08</td>
<td>PM2.5</td>
<td>140.985</td>
<td>141.751</td>
<td>0.766</td>
<td>97.355</td>
<td>105.171</td>
<td>7.816</td>
<td>98.0</td>
<td>Sunny</td>
<td>Kiln not operational</td>
</tr>
<tr>
<td>12/25/08</td>
<td>PM10</td>
<td>137.712</td>
<td>142.899</td>
<td>5.187</td>
<td>53.841</td>
<td>76.842</td>
<td>23.001</td>
<td>225.5</td>
<td>Foggy</td>
<td>Kiln operational</td>
</tr>
<tr>
<td>12/25/08</td>
<td>PM2.5</td>
<td>141.324</td>
<td>144.413</td>
<td>3.089</td>
<td>82.581</td>
<td>105.171</td>
<td>22.590</td>
<td>136.7</td>
<td>Foggy</td>
<td>Kiln operational</td>
</tr>
<tr>
<td>12/26/08</td>
<td>PM10</td>
<td>136.137</td>
<td>142.051</td>
<td>5.914</td>
<td>76.842</td>
<td>99.135</td>
<td>22.293</td>
<td>265.3</td>
<td>Foggy</td>
<td>Kiln operational</td>
</tr>
<tr>
<td>12/26/08</td>
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## UNIVERSAL BRICKS LTD.
MARUMDAI, DHAMRAI, DHAKA.

### DAILY PRODUCTION REPORT.

<table>
<thead>
<tr>
<th>Date</th>
<th>Green Bricks</th>
<th>Load in</th>
<th>Fire Bricks</th>
<th>MIXER Coal</th>
<th>FIRE Coal</th>
<th>Clay</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>14/12/63</td>
<td>20,000 p</td>
<td>25,500 p</td>
<td>22,100 p</td>
<td>2,400 Kg</td>
<td>884 Kg</td>
<td>2850 p</td>
<td></td>
</tr>
<tr>
<td>15/12/63</td>
<td>28,600 p</td>
<td>25,500 p</td>
<td>15,500 p</td>
<td>3,100 Kg</td>
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</tr>
<tr>
<td>16/12/63</td>
<td>18,800 p</td>
<td>25,500 p</td>
<td>22,100 p</td>
<td>2,200 Kg</td>
<td>933 Kg</td>
<td>2380 p</td>
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<td>17/12/63</td>
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<tr>
<td>18/12/63</td>
<td>25,000 p</td>
<td>33,000 p</td>
<td>33,100 p</td>
<td>2,400 Kg</td>
<td>1362 Kg</td>
<td>9325 p</td>
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</tr>
</tbody>
</table>

PREPARED BY: [Signature]
CHECKED BY: [Signature]
MANAGER: [Signature]

Annex –B
**UNIVERSAL BRICKS LTD.**  
**MARUMDALLI DHAMRAI DHAKA.**

**DAILY PRODUCTION REPORT.**

<table>
<thead>
<tr>
<th>Date</th>
<th>Green Bricks</th>
<th>Load In</th>
<th>Fire Bricks</th>
<th>Mixer Coal</th>
<th>Fire Coal</th>
<th>Clay</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>20/12/08</td>
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<td>34,600 P</td>
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<td>2,840 kg</td>
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<td>34,000 P</td>
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<td>2,920 kg</td>
<td>1156 kg</td>
<td>2875 u</td>
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<tr>
<td>22/12/08</td>
<td>26,000 p</td>
<td>42,500 P</td>
<td>44,200</td>
<td>2,640 kg</td>
<td>1582 kg</td>
<td>3250 u</td>
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<tr>
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<td>2,920 kg</td>
<td>1640 kg</td>
<td>3875 u</td>
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</tr>
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**PREPAIRED BY:**  
29-12-08  

**CHECKED BY:**  
**MANAGER:**
## DAILY PRODUCTION REPORT

<table>
<thead>
<tr>
<th>Date</th>
<th>Green Bricks</th>
<th>Load In</th>
<th>Fire Bricks</th>
<th>Mixer Coal</th>
<th>Fire Coal</th>
<th>Clay</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>25/12/08</td>
<td>33,400 P</td>
<td>30,600</td>
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<td>3225 cft</td>
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<tr>
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<td>1025 cft</td>
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<tr>
<td>28/12/08</td>
<td>44,000 P</td>
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<td>530 cft</td>
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<td>1360 kg</td>
<td>4500 cft</td>
<td>1480 P</td>
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</tr>
</tbody>
</table>

CHECKED BY

MANAGER

PREPARED BY

6/10/08
**The above data on calorific value of coal were provided by the EHJ plant designer and these values are close to what has been used in the study (26.68 MJ/kg)**

Prepared By:  
Ed Hall  
Senior Project Specialist  
Phone: 604 590-7448