SOURCES OF AIR POLLUTION IN BANGLADESH

(BRICK KILN & VEHICLE EMISSION SCENARIO)




CLEAN AIR AND SUSTAINABLE ENVIRONMENT PROJECT

Department of Environment
Ministry of Environment, Forest and Climate Change
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Minister
Ministry of Environment, Forest and Climate Change
Government of the People's Republic of Bangladesh

MESSAGE

The Ministry of Environment, Forest and Climate Change has been working hard to control the environmental pollution in the country. As part of its continuous efforts to keep the environment clean, several measures have recently been taken to upgrade the air quality, especially in dry season in the country.

The Ministry has been implementing Clean Air and Sustainable Environment (CASE) Project with a view to identify the major air polluting sectors, to design and demonstrate cleaner technologies for brick manufacturing, and to study the emissions from other important sources like vehicles, industries, etc. Countrywide network of continuous air quality monitoring has been established to inspect the status of the air quality in the cities. In addition, the government has adopted Brick Manufacturing and Kiln Establishment (Control) Act – 2013 (revised in 2018) to limit the emissions from the brick kiln sector, and is currently making a Clean Air Act to address the air quality in the country in a systemic way.

This report has been prepared with the field-based activities done under the CASE project on the brick kiln and vehicle inventory and emission monitoring. This is an important task which would certainly contribute greatly to devise a source-based air quality management plan in the country in general, and in the cities in particular.

I thank the team involved in preparing the report, and hope utmost utilization of this report.

Md. Shahab Uddin, MP

Deputy Minister
Ministry of Environment, Forest and Climate Change
Government of the People's Republic of Bangladesh

MESSAGE

The Ministry of Environment, Forest and Climate Change is very active to ensure quality environment for the people of Bangladesh. The Ministry is listing the sources of air pollution in the country, facilitating environment-friendly technologies, and is revising Acts and Rules to control pollutions in the country.

The report "Sources of Air Pollution in Bangladesh" is the outcome of the activities under the Clean Air and Sustainable Environment (CASE) Project on the two major sources of air pollution, brick kilns and vehicles. These two sources jointly contribute about 70% of the air pollution in Dhaka. The GIS-based countrywide inventory of brick kilns and estimation of emission profile of different technologies are great accomplishments done under the CASE project. These works will undoubtedly help take necessary measures on controlling emissions from these source sectors.

I expect rapid adoption of environment friendly technologies in brick kilns, and also finding alternatives to bricks for construction materials. This report would serve as an important document to formulate and implement plans and programs in order to manage the air quality in Bangladesh.

I appreciate the work and thank to the CASE project team for generating the report.

Habibun Nahar, MP

Secretary
Ministry of Environment, Forest and Climate Change
Government of the People's Republic of Bangladesh

MESSAGE

The Ministry of the Environment, Forest and Climate Change has been implementing the Clean Air and Sustainable Environment (CASE) Project in Bangladesh with the financial assistance from the World Bank. The project has conducted several studies on the identification of sources of air pollution, GIS-based inventory of prime sources (brick kilns as one of this), and the emission measurement of the sources, all of which are highly important for planning for an effective air quality management in this country. Considering the dynamic characteristics of the sources, the databases produced from these studies should be updated each time any changes occur in source number, emissions or positions.

I am really happy that the CASE project has compiled and prepared this report based on the studies on the emission monitoring and improved design of brick kiln technology. I hope this report will facilitate bringing reform in the brick kiln and vehicle sectors, and thus improving air quality in Bangladesh.

I appreciate this worthy work done by the CASE project and expect continuation of the work.

Abdullah Al Mohsin Chowdhury

Additional Secretary
Ministry of Environment, Forest and Climate Change
Government of the People's Republic of Bangladesh
And
Project Director
Clean Air and Sustainable Environment Project
Department of Environment

MESSAGE

The Ministry of Environment, Forest and Climate Change is responsible for sustainable environmental management in Bangladesh. The ministry has taken many initiatives towards environmental issues including environmental pollution control.

Air is an important component of the environment. It is so essential that the human being cannot survive more than a minute without it. Alarmingly, this crucial component of the environment is getting severely polluted by some anthropogenic activities. The medical science has found air pollution causing many fatal and harmful human diseases. The World Health Organization (WHO) reveals about 7.0 million people die worldwide due to the inhalation of polluted air. It is thus an imperative task to take useful measures to control air pollution.

The Clean Air and Sustainable Environment (CASE) Project of the Department of Environment (DoE) has been implementing numbers of activities on the air quality management in Bangladesh with the financial assistance from the World Bank. In addition to the continuous air quality monitoring in major cities of the country, the project has completed several studies on the source apportionment, emission inventory, and dispersion modeling. Conversions of high polluting Fixed Chimney Brick Kilns to Improved Zigzag Brick Kilns have been done with demonstrations in 08 cities. More than 50% emission reduction is achieved at the converted Improved Zigzag Kilns. In addition, the project has drafted a Clean Air Act in which stringent emission standards will be set for the industries including brick kilns, and vehicles. Besides the brick sector, the project conducts regular emission testing on the on-road vehicles and has assisted in revising the vehicle emission standards in Bangladesh.

This report has discussed in details on the brick kiln scenario in Bangladesh and on the technological improvement designed and demonstrated under the CASE Project. The vehicular emission scenario in Dhaka city is also illustrated exhaustively.

This report is expected to be highly beneficial in bringing reforms in the two major sources of air pollution namely brick kilns and vehicles, which will finally improve the environmental quality of the country.

Dr. S.M. Munjurul Hannan Khan

CONTENTS

ABBREVIATIONS

2–S	2 stroke
4–S	4 stroke
AQMP	Air Quality Management Plan/Program
BAPMAN	Bangladesh Air Pollution Management
BARC	Bangladesh Agricultural Research Council
BBS	Bangladesh Bureau of Statistics
BCL	Bangladesh Consultants Limited
BCSIR	Bangladesh Council of Scientific and Industrial Research
BMKEA	Brick Manufacturing & Kiln Establishment Act
BRTA	Bangladesh Road Transport Authority
BTK	Bull Trench Kiln
BUET	Bangladesh University of Engineering & Technology
CAA	Clean Air Act
CMAQ	Community Multi-scale Air Quality
CNG	Compressed Natural Gas
E&E	Energy and Environment
EF	Emission Factor
ER	Emission Rate
FCK	Fixed Chimney Kiln
GCV	Gross Calorific Value
GDP	Gross Domestic Product
GIS	Geographical Information System
GPS	Geographical Positioning System
HHK	Hybrid Hoffman Kiln
HSU	Hartridge Smoke Unit
IHERE	Institute of Heat Engineering and Refrigeration
IZK	Improved Zigzag Kiln
LDV	Light Duty Vehicle
LULC	Land Use and Land Cover
MDL	Minimum Detection Limit
MHK	Mini Hoffman kiln
NDIR	Non-Dispersive Infra Red
NILU	Norwegian Institute for Air Research

RPM	Rotation per Minute
NIST	National Institute of Standards and Technology
SAE	Society of Automotive Engineers, USA
SEC	Specific Energy Consumption
SPM	Suspended Particulate Matters
SRO	Statutory Regulatory Order
TK	Tunnel Kiln
TZK	Traditional Zigzag Kiln
UNDP	United Nations Development Program
USEPA	United States Environment Protection Agency
VEIP	Vehicle Emission Inspection Program
VSBK	Vertical Shaft Brick Kiln

SYMBOLS

CO	Carbon monoxide
CO_2	Carbon dioxide
HC	Hydrocarbons
HF	Hydrogen fluoride
NO_x	Nitrogen oxides
O_3	Ozone
PM	Particulate matters
$PM_{2.5}$	Particulate matters with less than 2.5 micron aerodynamic diameter
PM_{10}	Particulate matters with less than 10 micron aerodynamic diameter

UNITS

%	percent
%(v)	percent by volume
$\mu g/m^3$	microgram per cubic meter
ft.	feet
g/h	gram per hour
g/s	gram per second
kg/h	kilogram per hour
kg/lac_b	kilogram per one lac brick
m^{-1}	per meter
m/s	meter per second
mg/kg_f	milligram per kilogram (fuel)
mg/Nm^3	milligram per cubic meter (at normal condition)
MJ/kg	megajoule per kilogram
Nm^3/kg_f	cubic meter (at normal condition) per kilogram (fuel)
Nm^3/s	cubic meter (at normal condition) per second
ppb	parts per billion
ppm	parts per million

ACKNOWLEDGEMENT

The Part – A of this report has been prepared from the works and data produced by the consulting firms performed under the CASE project: IHERE of the Hanoi University designed of an Improved Zigzag Kiln and demonstrated in 8 districts of Bangladesh, the BCSIR monitored the energy and environment performances of the traditional and demonstrated IZKs. Geography and Environment Department of Jahangirnagar University prepared the countrywide GIS-based inventory of the brick kilns. However, the vehicular emission data that have been analyzed in Part – B of this report were generated by the CASE project staff with active cooperation and participation of the DoE.

The CASE project would like to offer special thanks to the Ministry of Environment, Forest and Climate Change of the Government of Bangladesh for its continued support, encouragement and guidance. The Department of Environment (DoE) also contributed greatly to the activities of the project; especially, the Air Quality Management (AQM) Wing of the DoE actively took part in the activities of emission monitoring of the brick kilns and vehicles. The cooperation of the Traffic Police Department of the Bangladesh Police during the vehicle emission testing is highly appreciated. In addition, the project deeply acknowledges the financial assistances from the World Bank vide its credit facility (id # 4581 BD and 5924 BD). The encouragement, assistances and guidance of the team members of the CASE project of the World Bank office helped to manage the tasks of the project in a timely manner.

PREFACE

The Clean Air and Sustainable Environment (CASE) Project has been implementing several tasks relating to the management of air pollution in the urban areas of Bangladesh. Identification of sources, preparation of a GIS-based source inventory, finding the source emission characteristics, and designing for environment-friendly technologies in brick kiln sector are some of the important works the project has done during its period from 2010 to 2019. The outcomes of the studies and works on the sources of air pollution have been described with illustrations in two parts of this report; the Part – A contains activities and results of the tasks performed in the brick kiln sector while the Part – B shows results of the tailpipe emission monitoring of vehicles in Dhaka city. A complete GIS-based inventory of the brick kilns throughout the country has been done; the inventory lists not only the geographical positions but the physical, technological and ownership information of the brick kilns are also recorded. A 1.0 km Land Use and Land Cover (LULC) map around each brick kiln has also been created to evaluate the settlements being affected around the kilns. As part of the technological improvement, a design of the environment friendly Improved Zigzag Kiln (IZK) has been prepared; the IZK is converted from the Fixed Chimney Kiln (FCK) keeping the original 120 feet chimney at place. This report presents the design of the conversion, and the energy and environment performance of the IZK with respect to the traditional Zigzag kilns and the FCKs. Estimates of the reductions in energy use, and emissions of PM and CO_2 are also shown for the hypothetical scenario of conversions of all the FCKs throughout the country to the IZKs.

Roadside vehicular emission tests were conducted regularly in major hotspots of Dhaka city. Idle Carbon Monoxide (CO) and Hydrocarbons (HC) from the gasoline/CNG vehicles and free acceleration smoke opacity of diesel vehicles were measured. Overall 1317 vehicles were tested at 08 hotspots in the city, out of which 815 were CNG/gasoline and 502 were diesel vehicles. The Part – B of this report shows detailed analysis of the emission data generated from the on-road vehicle emission testing. Comparative studies of different types of vehicles, and fuel use have been shown.

This report presents deliberations on the emission potentials of two major sources of air pollution in Bangladesh, and it is expected to be helpful in the policy formulation on the air quality management in the country.

Md. Masud Rana
Consultant, CASE Project

1 EXECUTIVE SUMMARY

The Government of Bangladesh with the financial assistance from the World Bank has been implementing the Clean Air and Sustainable Environment (CASE) project with a view to improve the air quality in the urban areas of the country. The Ministry of Environment, Forest and Climate Change (MOEFCC) of the government has been functioning as the sponsoring agency while the Department of Environment (DoE), Dhaka City Corporation (DCC) and the Dhaka Transport Coordination Authority (DTCA) are executing their respective parts of the project. The DoE component of the project (from now only the CASE Project) is assigned with the tasks of studying and working on different components of the air quality management program (AQMP) – the components are (a) air quality screening in major cities, (b) continuous monitoring of air quality, (c) emission inventory, (d) source apportionment, (e) dispersion modeling, etc. The project has worked on all of the components during its period from 2010 to 2019. Air quality screening in two big cities (Dhaka & Chattogram) has been done, and a countrywide air quality monitoring network has been established. Source apportionment studies have been performed in major cities, as well as emission inventories and dispersion modeling works have been carried out in Dhaka and Chattogram cities. The project has also drafted rules under the Brick Manufacturing and Kiln Establishment (Control) Act – 2013 (revised in 2018), revisions to vehicular emission standards, and a Clean Air Act; the drafts are at present under the process of government ratification.

The source apportionment studies carried out in the divisional cities have identified brick kilns as a major source of air pollution in the cities. Vehicles are also good sources, although the introduction of cleaner fuel CNG to vehicle sector and the drive out of 2-stroke 3-wheelers from the Dhaka city helped lessen the contributions from this sector to air pollution. The latest apportionment study has attributed about 58, 10.4 and 15.3 % of fine particles in Dhaka city to brick kilns, vehicles and dusts respectively.

This report is divided into two parts; the Part – A presents the energy and environment monitoring of the mostly used technologies for brick manufacturing in the country, the performances of the Improved Zigzag Kiln (IZK) technology designed and demonstrated under the CASE project, and the countrywide GIS based inventory of the brick kilns, and the Part – B demonstrates with illustrations the results of the tailpipe emission testing of the on-road vehicles in Dhaka city.

PART – A (BRICK KILN EMISSION)

The increase in construction activities in recent years in the country has created high demand on the construction materials. As the country lacks alternatives to bricks for the construction activities, the number of brick kilns has been increasing with the annual growth rate assumed to be 5-6%. The Bangladesh Bureau of Statistics (BBS) had reported about 4959 brick kilns in the country in 2013 whereas the inventory conducted in 2018 under the CASE project reported about 8000 kilns. More than 90% of these kilns before 2010 were Fixed Chimney Kiln (FCK) type, a primitive and energy extensive technology. The Zigzag technology having share of about 5% before 2010 was the next choice to the entrepreneurs. Adopted from the Indian experience, the Zigzag technology at that time was very new in the country. The constructions and maintenance of the Zigzag kilns at that time were not carried out in proper way. A bad maintained Zigzag kiln could be as inefficient as an FCK in terms of the energy and environment performances. The entrepreneurs were also highly reluctant to go for the expensive technologies like HHK and TK. In this scenario, The CASE project with the help of the Institute of Heat Engineering and Refrigeration (IHERE) of the Hanoi University devised a design for converting the existing FCK to an Improved Zigzag Kiln (IZK), keeping the original 120 feet chimney at place. The major modifications in the new design were as follows,

a. The thicknesses of the top and side-wall insulations were increased to prevent heat losses.

b. Good sticky and plasticity clay was layered firmly at the bottom with at least 1.0 feet thickness to reduce penetration of water in the rainy season.

c. A gravity settling chamber filled with water by two-third was constructed underground. The water of the tunnel acted as a scrubber partly for the SPM.

d. A water scrubber was installed at a suitable height in the chimney.

e. A cyclone system was installed at the bottom inside the chimney to force flue gases to follow a cyclonic upward path. This system helped coarse particles settle down and fine particles get attached with the wall first and then settle down.

The IZKs were demonstrated in 08 districts of the country. The energy and environment performances of the demonstrated IZKs were monitored firstly during its establishment by the consulting firm IHERE, and then again in the next year by the Bangladesh Council of Scientific and Industrial Research (BCSIR). The summary of the results on the E&E performances of IZKs with respect to the FCKs and artisan Zigzag kilns are as follows,

1. Coal consumptions in the IZKs were found about 30 and 40 % lower than the artisan Zigzag kilns and FCKs respectively.
2. The specific energy consumptions of the FCK, artisan Zigzag kiln and IZK were found as 1.35, 1.28 and 1.0 MJ/kg brick respectively
3. PM emissions from the IZKs were found about 67 and 89 % lower than the artisan Zigzag kilns and FCKs respectively.
4. More than 95% of the SO_2 gas could be reduced in the IZKs compared to the artisan Zigzag kilns and FCKs.

Furthermore, following estimates could be made on the basis of the energy and environment monitoring results,

Brick kiln number at present in the country is about 8000; if the technology proportion were not changed from the 2010 scenario (FCK>90%), about 7200 kilns must have been of FCK technology by today. Now,

(a) If all the 7200 FCKs were replaced by the traditional Zigzag Kilns (TZK), about 810 thousand tons of coal or about 10.12 billion taka would be saved every year – meaning that each kiln would save about 1,406,250 taka every year (5 months operation time). Environmentally, about 2579 tons of PM_{10}, 927 tons of SO_2, and 5970.2 tons of CO_2 would be reduced countrywide in one day;

(b) If all the 7200 FCKs were replaced by the IZKs, about 2.55 million tons of coal that would cost about 31.9 billion taka would be saved every year – meaning that each kiln would save 4,443,750 taka every year (5 months operation time). Environmentally, about 3443 tons of PM_{10}, 1874.4 tons of SO_2 and 7093.4 tons of CO_2 would be reduced countrywide in each day if all the FCKs were replaced by the IZK designed by the CASE project of the DoE.

In addition to the energy and environment monitoring of the brick kilns, the CASE project with the help of Geography and Environment Department of the Jahangirnagar University has prepared a GIS-based inventory of the brick kilns throughout the country. Brick kilns were first identified from the image interpretation of the Google Earth. Overall 7326 brick kilns were spotted from this desk work of the image interpretation. However, the field visits of the team members throughout the country found about 7902 kilns, of those 2487 kilns were in Dhaka division (including Mymensingh). Every site was visited to explore the Land Use and Land Cover (LULC) Pattern of 1.0 km buffer area around the brick kiln. Eleven natural/infrastructural property/establishments were shown in the LULC maps, which were brick kilns, area of the kilns, settlement with homestead vegetation, road network, river, standing natural water body, pond, agricultural land, forest, hilly area and features like school/hospital/mosque, etc. During the field visits, information like the lat/lon positions, owner information, kiln structure, capacity and type, etc. were recorded. Finally, a database software was prepared to demonstrate all the information of the kilns on the GIS platform. The inventory found mixed results in the district-wise proportion of FCK and Zigzag kilns; in general, it may be assumed that about 70% of the kilns countrywide are now Zigzag type.

PART – B (VEHICLE EMISSION)

Vehicle emission is one of the major sources of air pollution in the country, especially in Dhaka city where about 40% of the vehicles imported in the country are registered. Old fleet, improper traffic and parking management, overloading, lack of maintenance, adulterated fuel, etc., have driven the vehicle sector contributing to air pollution in Dhaka city. Although the government took several measures to lessen the emissions from this sector, it is still an important source of air pollution since it pollutes not only through tailpipe emissions but also through the dust emissions generated from the frictions with the roads. The number of vehicles in recent years in Dhaka city has grown drastically due to the increased commercial activities. The latest source apportionment study by the Norwegian Institute for Air Research (NILU) under the CASE project attributed about 10.4% of fine particles in Dhaka city to vehicular emission and 7.7% to road dusts. The government of Bangladesh revised in 2005 the emission standards for both new (equivalent to EURO – II standards) and in-use vehicles (equivalent to EURO – I standards). In this scenario, the CASE project conducted roadside vehicle emission testing program with a view to assess the vehicle compliance and to raise public awareness about the danger of vehicle emission. Other objectives of this program were (a) to formulate and suggest a revision to the existing Vehicle Emission

Standards, (b) to assess the emission characteristics of the in-use vehicles in Dhaka city and (c) to identify the high polluting vehicles in Dhaka city. Overall 1317 vehicles of all types were tested, out of which 815 were CNG/gasoline and 502 were diesel fueled vehicles. Idle Carbon Monoxide (CO) and Hydrocarbons (HC) from the gasoline/CNG vehicles and free acceleration smoke opacity of diesel vehicles were measured. The data analyses revealed that more than 75% of the gasoline/CNG vehicles emitted CO within the limit value of 1 %(v), and 85% of all types of CNG vehicles complied with the HC emission standard of 1200ppm. Motorcycles and all types of diesel vehicles were identified from this emission testing program as the worst polluters in the vehicle sector in Dhaka city. It was found that 78% of motorcycles and 77% of diesel vehicles failed to satisfy their respective limit values set by the government.

2 INTRODUCTION

The city of Dhaka is afflicted with heightened level of particulate matter (PM) in dry season (November – April) every year. Favorable meteorology and seasonal sources like brick kilns, open burning, etc. exacerbate the pollution situation during this season. The air monitoring results published by the Clean Air and Sustainable Environment (CASE) Project of the Department of Environment (DoE) have reported PM_{10} concentrations above the Bangladesh standard in about 75% days of the dry season (CASE[1]). On the other hand, the PM level in the air of Dhaka city during wet season (May – October) is very compatible with the standard. Thus, the air pollution in Dhaka city is actually a phenomenon of about one third days of a year.

The Government of Bangladesh is very sincere in addressing the air pollution in the country. It has implemented several controlling measures at different times, which abruptly improved the air quality, especially of Dhaka city. For example, the drive-out of 2-stroke 3-wheeled baby taxies from Dhaka city in 2001 instantly cut off the PM_{10} concentrations in the city by about 40% (Begum et al. 2006[2]). Not only this, several other measures were also implemented on the vehicle sector, one of the major of which was the introduction of cleaner fuel compressed natural gas (CNG) to the transport sector in early 90s. Such reforms on the vehicle sector helped reduce great amount of emissions from this sector. However, the continuous growth of population, vehicles, brick kilns and industries in the following years cancelled out the benefits gained from the control-measures on the vehicle sector, resulting almost similar pollution level during the last 7 – 8 years. Only the apportionment of the sources to air pollution has been changed. Latest source apportionment study has attributed about 58, 10.4 and 15.3 % of the fine particle concentration in Dhaka city to the brick kiln industry, vehicles and dusts respectively (CASE project, 2014[3]), whereas the previous apportionment study calculated about 22.0, 36.0 and 24.5 % contributions from these prime sources respectively (Begum et al. 2013[4]). The Government is now very determined to reform the brick manufacturing sector with the primary objective to reduce emissions from

1 CASE Project (2018) Ambient Air Quality in Bangladesh, Department of Environment, Dhaka.

2 Begum et al. (2006) Impact of banning of two-stroke engines on Airborne Particulate Matter Concentration in Dhaka, Bangladesh. Journal of the Air and Waste Management Association, 56, 85-89

3 Identification and apportionment of sources from air particulate matters at urban environments in Bangladesh http://case.doe.gov.bd/

4 Air pollution by fine particulate matter in Bangladesh. Atmospheric Pollution Research, 2013

this big source. "Brick Manufacturing and Kiln Establishment (control) Act – 2013 (revised in 2018)" (BMKEA) has been adopted for this purpose. Using improved technologies for brick manufacturing has been encouraged in the new Act. In addition, a Clean Air Act (CAA), and a set of rules under the BMKEA have been drafted. Stringent emission standards for the brick kilns, vehicles and other sources have been proposed in those drafts.

The Ministry of Environment, Forest and Climate Change of the Government of Bangladesh has been implementing Clean Air and Sustainable Environment (CASE) project with the financial assistance from the World Bank. Started in 2010, the project is set to end in June 2019. Three agencies, Department of Environment (DoE), Dhaka City Corporation (DCC) and Dhaka Transport Coordination Authority (DTCA) are executing their respective part of the project. While the DoE component is building up the infrastructures for continuously monitoring the air quality, tracking sources and finding ways of reducing industrial emissions, the DCC and DTCA components are finding solutions to lessen the vehicular emissions by modernizing traffic systems, building up facilities for pedestrians' movement, and by facilitating smooth traffic flow and mass transit.

The CASE Project of the DoE component has been implementing several studies on both the brick kiln and vehicle sectors. In brick sector, the project has been working on (i) preparing a countrywide GIS-based inventory of the brick kilns, (ii) demonstrating energy efficient technologies for brick production, (iii) designing and demonstrating conversion of existing Fixed Chimney Kiln (FCK) technology to improved Zigzag kiln technology, (iv) monitoring emissions from different brick kiln technologies, etc. At the same time, the project has been conducting regular vehicle emission testing to identify high polluting vehicles, to understand existing vehicle emission scenario and to assess the feasibility of revising the vehicle emission standards which were last adopted in 2005.

This report has two parts; the studies on the brick kiln sector implemented under this project have been discussed in PART – A and the results of the roadside vehicle emission testing have been demonstrated in PART – B. However, before starting the discussions on the major two sources of air pollution, a glimpse on the latest status of the ambient air quality of especially Dhaka city in the following section would be much worthy.

2.1 Ambient PM concentrations in Dhaka city

The CASE project has been monitoring ambient air quality at three sites in Dhaka city; the sites are (1) Parliament premises, (2) Bangladesh Agricultural Research Council (BARC) premises, Farmgate, and (3) Darussalam, Mirpur. Five (05) criteria air pollutants (PM, SO_2, NO_x, O_3, and CO) and useful meteorology parameters are being monitored every minute in the CAMS. The trends in PM concentrations (both PM_{10} and $PM_{2.5}$) at the Darus Salam station are shown in Figure 1.

PM is the main responsible pollutant for bad air quality in dry season in Dhaka city. Table 1 shows an overview of the PM concentrations in different years in Dhaka city. The concentrations are daily averaged, calculated when minimum 80% hourly concentration data was present in a day.

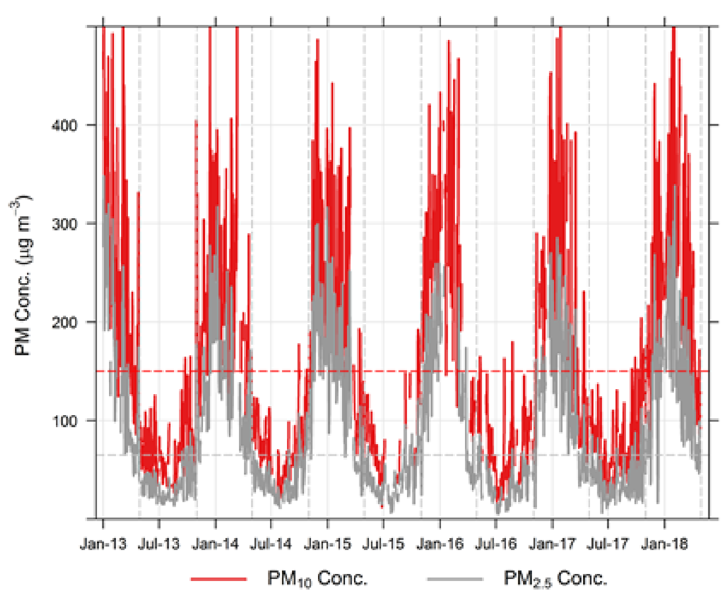
Table 1 primarily reveals a declining trend in yearly PM concentrations in Dhaka; both the PM_{10} and $PM_{2.5}$ concentrations have declined from 2016. Compared to 2013-14, Dhaka experienced about 12% lower PM concentration (annual) in 2017. This reduction in yearly PM concentrations in air may be attributed to the ongoing reforms in the brick kiln sector. A large number of FCK has been replaced with Zigzag technologies in the last 4-5 years as a result of the adoption of the Brick Manufacturing and Kiln Establishment Act – 2013 (revised in 2018).

Year	PM_{10} Conc. ($\mu g\ m^{-3}$)						$PM_{2.5}$ Conc. ($\mu g\ m^{-3}$)					
	Data capture rate %	percentile				mean	Data capture rate %	percentile				mean
		25	50	75	95			25	50	75	95	
2013	90.7	66	122	221	394	161.4	87.6	32	57	127	259	92.0
2014	82.2	66	120	237	393	159.4	86.5	34	70	145	236	95.0
2015	62.7	80	160	254	349	172.8	90.0	35	62	143	222	90.0
2016	69.3	58	98	214	395	145.1	64.0	28	44	92	211	68.0
2017	85.7	65	103	207	362	142.6	85.5	34	53	118	200	80.5

Table 1 Overview of daily PM concentrations in Dhaka in recent years; daily concentrations are determined when minimum 80% valid hourly data is available in a day

Temporal trends (Figure 1) in PM concentrations demonstrate seasonal variations sharply; PM_{10} and $PM_{2.5}$ concentrations in air remain higher than the standards of Bangladesh during November to April, and during the time from May to October the PM levels satisfy the limit values. The month of January is found to be the most polluted month, followed by December and February. Winter season (December – January) is also characterized with higher fraction of fine particles to PM_{10} mass concentrations and the summer time (February – April) is typified with coarse particles in air. It is important to note that hundreds of brick kilns around the city operate during the dry season only.

Figure 1 Trends in daily-averaged PM concentration (data threshold 80%) in Dhaka. The red and grey horizontal lines are standards for PM_{10} and $PM_{2.5}$ respectively



PART – A

BRICK KILNS

1 BACKGROUND

Brick making industry with the contribution of about 1% to the national GDP is one of the significant energy consuming sectors in Bangladesh. BUET (2007[5]) reported about 2.2 million tons of coals being burned annually in about ~5000 brick kilns all over the country, producing about 15 billion bricks. Of this, Dhaka along with the neighboring districts (Gazipur, Narayanganj, Narsindhi) possessed about 1000~1200 kilns. The growth of the brick kilns was substantial (about 5.6%) in the previous decades as a need from the high construction spree in the country. According to the 2005-06 records, most of these kilns (~95%) were Fixed Chimney Kiln (FCK) type including the Bulls Trench Kilns (BTK), the rests were mostly Zigzag type (~4.5%) and Hoffman Kiln (0.5%). The Government of Bangladesh undertook several measures at times to control the use of firewoods in kilns and to increase the chimney height for proper plume dispersion. The major control measures from the Government were, (i) The Brick Burning (Regulation) Act 1989 that prohibited use of firewoods in the brick kilns, (ii) The Environmental Conservation Rules – 1997 which set the SPM emission limit at 1000 mg/Nm^3 from brick kilns, (iii) Revision of the Brick Burning (Regulation) Act, and (iv) the Brick Burning Rules – 2002 which established FCKs in place of BTKs, heightening the chimney height at minimum 120 feet.

Addition to the high emitting characteristics of the FCKs, the clustering of those kilns in several close vicinity of Dhaka city rather deteriorates the situation. BUET (2007) reported more than 500 brick kilns operating in clusters in the north periphery of Dhaka city. The north cluster kilns are important for its upwind position in the winter season (December – January), the most polluted season of Dhaka city. The south clusters, containing ~500 kilns too, are crucial during March – April time period as the wind blows from that direction during that time. In Bangladesh, the production of bricks from FCK and Zigzag technologies is not a year-round process; it operates only for 5 months (December – April) of dry season. Great amount of particulate matter (PM), sulfur dioxide (SO_2), carbon monoxide (CO), carbon dioxide (CO_2), and toxic organic substances like dioxins and furans (Ahmed and Hossain 2008[6]) are emitted from burning low quality coals in those kilns.

5 Small study on air quality of impacts of the North Dhaka brickfield cluster by modeling of emissions and suggestions for mitigation measures including financing models. Prepared by the Chemical Engineering Department, BUET, Dhaka.

6 Applicability of air pollution modeling in a cluster of brickfields in Bangladesh. Chemical Engineering Research Bulletin, 12 (2008)

Several studies (both dispersion and receptor approaches) had been conducted to evaluate the contributions of brick kilns to the air pollution in Dhaka city during dry season. BUET (2007) calculated the dispersion of emissions from the brick kilns using ISC3 dispersion model and found that approximately 25 to 100 $\mu g/m^3$ of PM pollution in the Dhaka city on a four months dry seasonal average were contributed from the northern kiln clusters. Begum et al. (2013[7]) estimated through receptor modeling an average contribution of 22% of fine particles originating from brick kilns and 36% from motor vehicles. An approach on Community Multi-scale Air Quality (CMAQ) chemical transport dispersion modeling over Dhaka, Bangladesh estimated at least 35% of PM_{10} and 15% of $PM_{2.5}$ in Dhaka Metropolitan Area associated with brick kiln emissions (IBN Azkar et al. 2012[8]). Investigations performed as part of the Bangladesh Air Pollution Management (BAPMAN) project also indicated that a major part of the PM emissions in Dhaka city were related to brick kiln industry (Randall et al. 2014[9]). However, the continuous growth of brick kilns in clusters, and effective control measures on the vehicle sector upsurge the brick kiln contribution to the air pollution in the city. Latest apportionment study by the Norwegian Institute for Air Research (NILU) revealed about 58% of the fine particles in Dhaka city coming from the brick kiln sector (CASE 2014[10]). To control the emissions from this sector, the Government has adopted a new act namely "The brick manufacturing and kiln establishment (control) act – 2013 (revised in 2018)". A set of rules under this act has been prepared and are currently under the process of government ratification. As a result of these act/rules all of the FCKs will be removed, replaced by/converted to the environment friendly technologies. A large portion of the FCKs have already been replaced by/converted to the Zigzag technologies by artisan arrangement, which is deemed creating another problem as artisan conversion of FCK to Zigzag technology, in many times, result no improvement in emission.

In these circumstances, the CASE project conducted studies on the scientifically viable conversion of FCK to Zigzag kiln technology, keeping the original stack at place. Demonstration kilns of such improved Zigzag technology were established and operated in different districts of the country, The emission concentrations of different kiln technologies were measured. Furthermore, the project, in association with the Jahangirnagar University performed a countrywide GIS-based inventory of the brick kilns. In this report, the outcomes of these works and studies will be discussed and illustrated.

1.1 Objectives

The brick kiln sector being identified as a major source of air pollution in the country, many developments/reforms in this sector is expected in the coming days. At this time, field based kiln inventory, and realistic information on fuel use and emissions would be highly crucial for policy formulation. The entrepreneurs should also be guided with energy-efficient, environment-friendly and easy-to-use alternative technologies to ensure supply of construction materials. To address these issues, the CASE project conducted several studies to learn the existing scenarios of the brick kiln sector, to prepare a field based brick kiln inventory and to find an alternative user-friendly technology for brick production.

The main objectives of the studies are,

a. To assess the contributions of brick kiln sector to air pollution;
b. To evaluate by demonstration the viability of improved technologies in local environment;
c. To design and demonstrate environment friendly technologies that would be cost effective, user friendly and acceptable to the entrepreneurs;
d. To build up an appropriate field based inventory of the brick kiln technologies throughout the country;

7 Air pollution by fine particulate matter in Bangladesh. Atmos Pollut Res 4(1)

8 Simulation of urban and regional air pollution in Bangladesh. J Geophys Res 117: D07303

9 Contribution of brick kilns to air quality in Dhaka City. BAPMAN project deliverable 1.3: Bottom-up-emission inventory and dispersion modelling. Kjeller, Norway. (NILU OR, 12/2014)

10 Identification and apportionment of sources from air particulate matters at urban environments in Bangladesh http://case.doe.gov.bd/

2 EXISTING BRICK KILN TECHNOLOGIES

2.1 Fixed Chimney Kiln

Although the FCK technology will be disqualified for brick manufacturing according to the new government Act, and the entrepreneurs are already switching to the alternative qualified technologies, the characteristics of FCK technology, considering as baseline status, are described in this report. Before the recent restructuring in the brick making industry, more than 90% of the bricks produced in the country were burnt in FCKs.

The Fixed Chimney Kiln (FCK) is a next version of the traditional Bull's Trench Kiln (BTK), which is essentially an elliptical shaped dug out area in an open field. The standard FCK is about 250 ft long and 57 ft wide. The bottom and the sidewalls of the kiln are lined with bricks with the top kept open. Figure 1 & 2 show the structure and operation of a typical FCK. The chimney in an FCK is fixed and is approximately 125 feet high. This tall chimney creates a strong draft, improving the combustion process, and releases the flue gas at a height of 125 feet above the ground. In the central portion of the elliptical kiln, there is a chamber and underground piping to divert the flue gases from anywhere of the kiln to the chimney. The air/flue gas is managed by opening and closing dampers to guide the air to the desired path, i.e., past fired bricks for preheating the combustion air (and cooling fired bricks), and past green bricks for heat recovery (also aiding the drying process of the green bricks), and out through the central fixed chimney.

Sun dried bricks are stacked in the kiln in an orderly fashion leaving enough room for fuel stoking and air circulation. After arranging the green bricks in the kiln, the top of the kiln is covered with fired bricks, dusts and pebbles. The bricks are fired from the top and the fire moves forward. The bricks are fired all around the kiln, which means that the connections to the chimney and the air hole must progressively move forward, until all bricks in the trench are fired.

Figure 1 Structure of a typical Fixed Chimney Kiln (FCK)

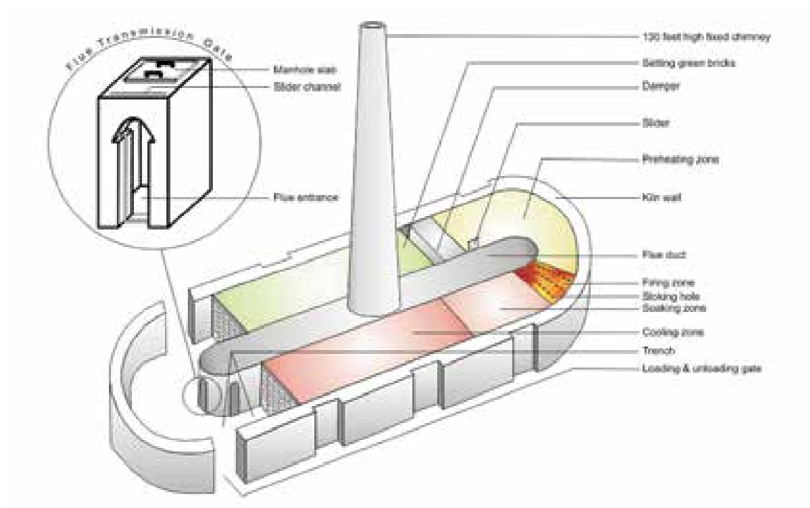
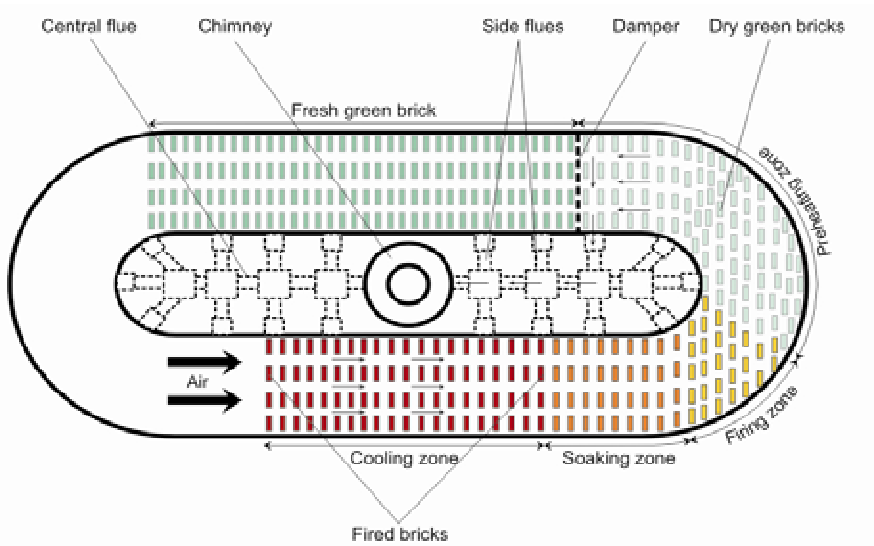


Figure 2 Structure and operation of a typical FCK



2.2 Zigzag Kiln

Similar to FCK, Zigzag kilns work in continuous mode where the brick stacking inside the kiln could be divided into several zones, such as cooling zone, soaking zone, pre-heating zone, firing and drying zone.

The Zigzag Kiln is rectangular in shape and measures about 250 ft by 80 ft. It has a 55 ft high fixed chimney located on one side of the kiln (Figure 3). At the bottom of the chimney there is an induced draft (ID) fan, which draws the flue gas from the kiln and discharges it to the atmosphere. The ID fan ensures a better and more controlled air flow through the kiln, ensuring higher efficiency than the FCK. The kiln is divided into 44 to 52 chambers, which are separated from each other using green bricks in such a way that the hot gases move in a zigzag path through the kiln. The fact that the flue gas changes directions several times in addition to impinging on the walls and stacked bricks implies that significant amount of particulates are deposited. The better heat transfer of the Zigzag kiln ensures less carbon particles in the flue gases. This is the reason the emissions from this type of kilns appear to be more brownish as opposed to the grey-black emissions of the FCK.

Addition to the zigzag pathway of plume gases, the Zigzag kiln incorporates a very interesting feature of pollution reduction – half to two-third of the connecting duct between the center of the kiln and the inlet of the ID fan is filled with water. The flue gas laden with dust particles impinges on the water, thus losing some of its particulate load. The water is periodically cleaned to ensure good scrubbing.

Figure 3 Structure of a typical zigzag kiln

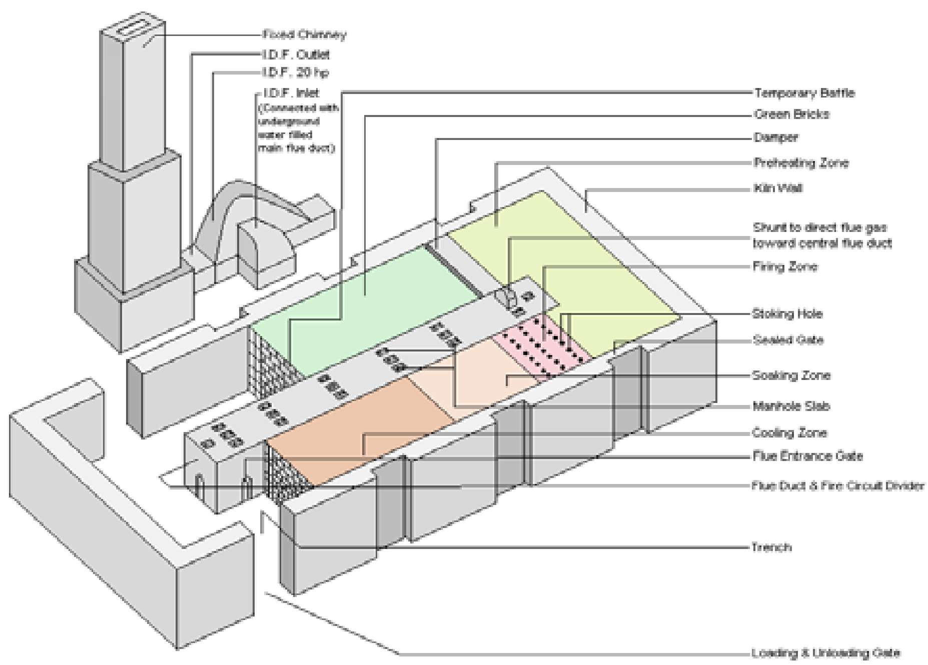
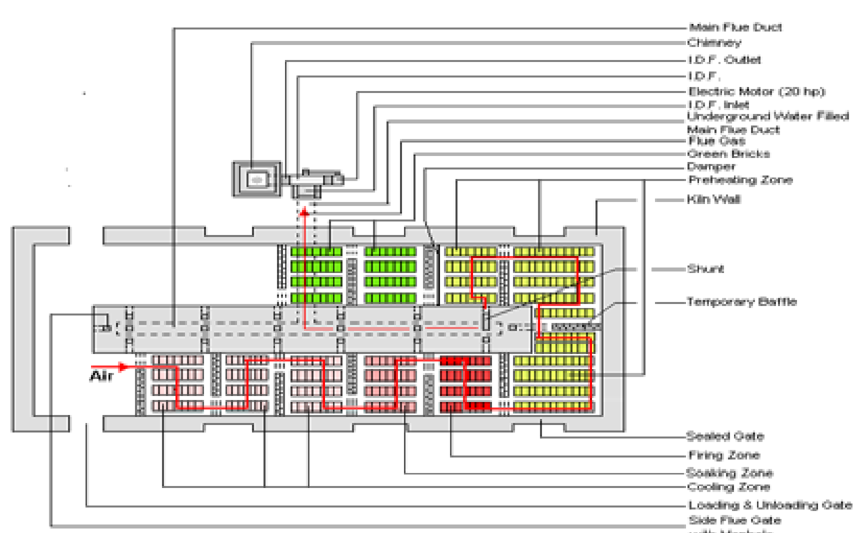


Figure 4 Structure and operation of a typical zigzag kiln



2.2.1 Limitations of existing Zigzag kilns in Bangladesh

- The construction technology of the Zigzag kiln is not easily available, and the expertise has to be procured from the neighboring states of India;
- Scrubbing water in the kiln is not changed regularly;
- Operation procedure of Zigzag kiln is more sophisticated than FCK – a badly operated Zigzag kiln could be similar to an FCK regarding to energy consumption and emissions.
- Zigzag kiln requires electricity and standby diesel generator;

2.2.2 Firing Practices in FCK and Zigzag kilns

The top of both the FCK and Zigzag kiln are covered by rubbish made from the mixture of burned or dried clay, coal ash, sand, brick powder etc. Depending on the operation of the kiln, the top rubbish layer may have thickness from 5 – 10 inches. This top insulation of rubbish protects the heat losses and also prevents air penetration in the kiln through the cooling zone.

Fuel is fed from the top of the firing zone of the kiln through the feeding holes made of steel tube and is covered by a cap; the coal is fed by an interval of 15 – 20 minutes to keep the fire stable. When the temperature in the firing zone reaches to the required level, the firing zone is closed and covered with the rubbish again. This portion of the kiln now belongs to the cooling zone. The feeding holes in the next chamber of the kiln are now opened and are fed with the coals to start a new firing zone, the progression of firing bricks in the kiln goes on in this way. The way of arranging holes in the firing zone is different between FCK and Zigzag kiln due to the difference in firing principles. Figure 5 shows the existing coal feeding system in a Zigzag kiln.

Figure 5 Fuel stoking from the top of a Zigzag kiln

2.2.2.1 Characteristics of Firing Practices

i. First round of brick firing in a brick season usually consumes more fuel for burning the bricks; production capacity is also low at the beginning of the season. Each round of kiln operation normally takes 25 – 30 days to burn a batch of bricks.

ii. Insulation at the top of the kilns is not done properly due to the lack of knowledge and awareness. As a result, heat loss through the top of the kiln is high.

iii. Coal fed from the top directly goes down of the kiln and settles at the bottom of the brick stack. Consequently, the bricks at the bottom of the kiln usually get over-burnt compared to the bricks at the top layer of the kiln.

iv. In some kilns, coals are grinded in smaller sizes before being poured into the kiln. The grinded coal seems to be more effective for it may be well burnt at higher amount before falling to the bottom of the kiln, creating uniform heat energy. The uniform heat helps brick quality to be more uniform.

v. Coal dusts feeding from the top are easy to be dragged with the flue gases and emitted as black carbon through the chimney. This type of black emission is comparatively low in Zigzag kiln because the particles have greater chance to settle down during changing directions in zigzag arrangement of the bricks, and also in the gravity settling chamber.

2.3 Energy and environment monitoring of existing FCK and Zigzag kilns

The engineers of the consulting group (IHERE from Vietnam and BCL as local) visited 20 existing brick kilns (both FCK and Zigzag kilns), and did the following activities to collect background information,

- Visiting and making questionnaire for 20 brick kilns including 05 FCKs, 11 Zigzag kilns and 04 locally converted Zigzag kilns to research on the existing structures of the kilns, clay, brick making process, management in the kiln site, etc. The following activities have been done in the kilns,
  - Measuring dimensions of the kilns;
  - Measuring dimensions of bricks, and weighing the bricks after molded, dried and fired;
  - Asking and filling questionnaire about coal consumption, production, brick quality, advantages and disadvantages of the kilns;
  - Writing observation report;
- Doing detail Energy and Environment audit in 10 brick kilns including 05 FCKs and 05 Zigzag kilns. The following activities were performed for the audit,
  - Measuring flue gas component emissions including CO, CO_2, O_2, NO_x, SO_2, C_xH_y, HF,
  - Taking sample of coal and clay for analyses;
  - Measuring SPM emission from the chimney;
  - Measuring temperature at different locations of the kiln, temperature of the flue gas, and temperature of the unloaded bricks;
  - Measuring dimensions and weight of the bricks after molded, dried and fired;
  - Gathering information, calculating energy losses and noting environment pollution;

2.3.1 Results of Energy and Environment monitoring of the existing technology

After the thorough energy and environment audit of the existing FCKs and Zigzag kilns, following observations were noticed,

1. The energy balance of the brick kilns showed that the heat losses by convection and radiation through the top cover of the kilns were higher than the heat losses by other means. Improvement in the insulation of the covers of the kilns could possibly reduce the heat losses.

2. Calculation of energy balance also showed that the excess air was very high in the brick kiln even during combustion time. It was found that firing efficiency in FCKs was lower than the Zigzag kilns, and so low quality bricks were expected from the FCKs.

3. On an average, FCK consumed 19 – 20 tons of coal for the production of 100 thousand bricks, in contrast to 17 – 18 tons consumed by the Zigzag kiln for the production of same quantity bricks (Figure 6).

4. Producing bricks by hand was very laborious job under the exposure of direct sun light. This practice might form low quality bricks because of high water content (up to 50%) in the green bricks; high porosity of the bricks was expected after water evaporation during baking. Consequently, the compressive strength of the bricks could be reduced, or the bricks could get bad shapes, and could be highly absorptive.

5. Changing technology from the FCK to the Zigzag kiln could help reduce emissions from brick firing, especially the SPM emission. Flue gas control using draft Fan was also more stable compared to the natural draft by chimney in FCK, giving better combustion in Zigzag kilns.

6. Serious SPM emissions from the FCKs was not just for the technology itself but also due to the structure of the kiln that encouraged flue gas carrying small particles without any obstacle. This problem could be solved by introducing different types of SPM scrubbing systems within the chimney.

Results of clay and coal analysis, and environment monitoring at the existing brick kilns are shown in table 1 to table 3.

Table 1 Chemical Analysis of Clay at different brick kilns (types of the kilns are shown in Table 3)

Parameter	Atiq brick	S. Rahman brick	Imran Brick	Titas brick	Rose Brick
Chemical Analysis					
SiO_2 (%)	66.59	62.69	67.87	63.39	62.24
Al_2O_3 (%)	14.02	15.8	14.17	15.85	16.31
Fe_2O_3 (%)	5.44	5.83	5.13	4.99	5.81
TiO_2 (%)	1.56	1.68	1.32	1.41	2.04
MgO (%)	2.17	2.32	1.3	1.82	2.29
CaO (%)	1.79	1.87	0.76	1.36	1.59
K_2O (%)	2.8	2.89	2.67	2.8	3.02
Na_2O (%)	1.68	1.7	0.98	1.28	1.36
Loss in Ignition (%)	3.73	4.82	5.47	6.94	5.15

Particles size analysis					
>63 µm (%)	14.417	11.086	14.784	5.961	4.53
>20 µm (%)	55.92	52.075	41.781	36.51	35.39
20 - 2 µm (%)	43.04	45.394	55.463	60.87	60.02
<2 µm (%)	1.04	2.531	2.756	2.62	4.59
Shrinkage analysis					
Linear Drying shrinkage at 105°C (%)	5.31	6.62	5.99	6.16	5.24
Linear Firing shrinkage at 1050°C (%)	2.58	4.37	3.46	4.1	2.08
Total shrinkage of the clay (%)	7.61	10.95	9.12	9.9	7.08

Note: SiO_2 = Silicon-di-oxide, Al_2O_3 = Aluminum oxide, Fe_2O_3 = Iron oxide, TiO_2 = Titanium oxide, MgO = Magnesium oxide, CaO = Calcium oxide, K_2O = Potassium oxide, Na_2O = Sodium oxide.

Table 2 Chemical Analysis of Coal collected at different brick kilns

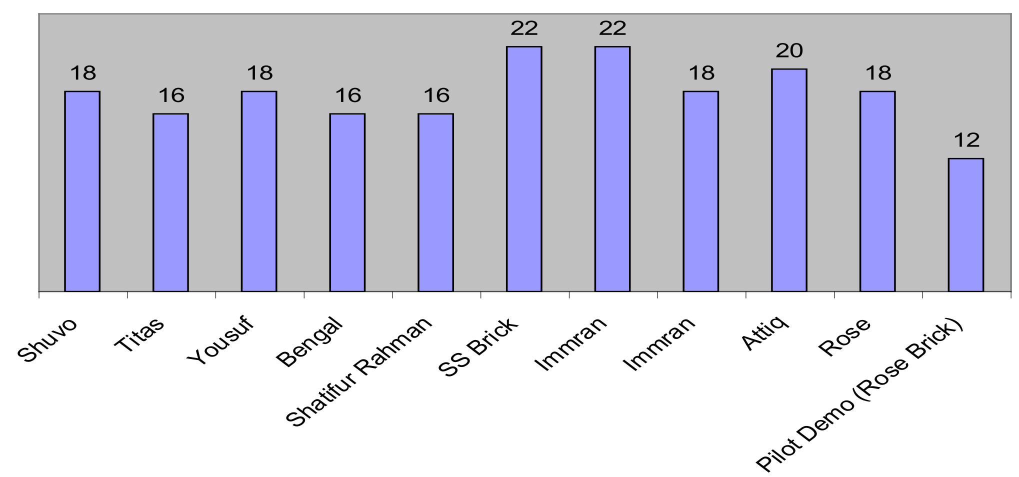
Parameter	Unit	Atiq brick	S. Rahman brick	Imran Brick	Titas brick	Rose Brick
Proximate analysis						
Ash (dry)	%	30.29	11.36	30.06	19.46	34.92
Volatile Matter (dry)	%	34.3	41.28	34.07	37.8	32.66
Fixed Carbon (dry)	%	35.41	47.36	35.87	42.74	32.42
Gross Calorific value (dry)	kCal/kg	4650	6030	4690	5630	4410
Total Moisture (dry)	%	4.28	7.75	3.3	6.39	5.11
Ultimate analysis						
Carbon (C) (dry)	%	52.72	68.63	54.03	58.15	56.35
Hydrogen (H) (dry)	%	4.88	5.54	4.74	6.82	2.13
Nitrogen (N) (dry)	%	1.31	1.46	1.51	1.59	1.19
Sulfur (S) (dry)	%	2.91	1.74	1.68	3.73	2.71
Oxygen (O) (dry)	%	7.88	11.27	7.98	10.21	2.54

Table 3 Flue gas analyses of existing FCKs and Zigzag kilns (mg/m³)

Parameter	Suvo Brick	Titas brick	Yousuf Brick	Bengal brick	S. Rahman brick	SS Brick	Imran brick	Imran brick	Attiq brick	Rose brick
Type of kiln	**Zigzag**	**FCK**	**FCK**	**Zigzag**	**Zigzag**	**FCK**	**FCK**	**Zigzag**	**FCK**	**Zigzag**
Location	Savar	Savar	Savar	Gazipur	Gazipur	Comilla	Comilla	Comilla	Chadpur	Narayanganj
NO_x	26	34	30	38	82	9	16	21	5	7
SO_2	404	738	3213	330	2014	4788	1984	780	966	389
CO	4613	1362	4838	1440	1293	3560	2080	1125	1452	1050
HF	11.7	11.7	7.6	22.9	20.7	10.8	20	8.8	12.5	14.1
VOC	0.67	1.21	0.97	0.87	1.15	3.06	1.3	0.93	0.41	0.35
CO_2	2	2.7	2.6	2.3	2.7	2.3	1668	2.4	2.8	2.3
O_2	14.3	19.5	17.8	16.1	16.8	17.8	18	16.1	18.3	18
SPM1	98	155	41	138	106	1529	2422	686	2270	324
SPM2	95	326	1958	121	160	407	491	744	129	275
SPM3	99	523	803	77	123	2341	1650	466	1472	221
SPM average	97.33	334	934	112	129	1425	1521	632	1290	273

* The SPM samples were taken at different coal stoking conditions: before stoking, just after coal stoking and between two stoking.

Figure 6 Fuel Consumption rate at the existing brick kilns (ton coal/lac brick)



3 IMPROVED ZIGZAG KILN DEMONSTRATED UNDER THE CASE PROJECT

3.1 Improved Zigzag kiln (IZK) converted from the FCK

For the past several years, research and studies have been going on in search of suitable brick making technologies in Bangladesh and in the region. Many studies have suggested adopting capital intensive modern technologies such as VSBK, HHK and even Automatic Tunnel Kiln (TK). But none of them seemed to be real substitute of the FCK in terms of low capital investment and simplicity in operation, main requirements of the entrepreneurs. The study on Zigzag kiln, however, suggested that should it be properly designed and built, it might be the perfect alternative to the FCK. A campaign was lodged to popularize the Zigzag technology but till 2010 the share was only 5-7% of the total brick production and had been suffering from lack of proper scientific design and innovation. The entrepreneurs were in dilemma whether they should demolish all the FCKs recently constructed, or convert into suitable forms of Zigzag, etc. Initiative-campaign under UNDP for popularizing Hybrid Hoffman Kiln (HHK) was launched but the responses were slow for HHK being the most capital intensive and expensive technology. The Vertical Shaft Brick Kiln (VSBK) was in experimental stage and no successful outcome was proven till date. Replacing FCKs without providing any suitable alternative would simply cause chaos in the manufacturing industry.

Under this backdrop, the CASE project contracted with the Institute of Heat Engineering and Refrigeration (IHERE) of Hanoi University, Vietnam to accomplish pilot demonstrations on converting FCK to Zigzag technology with modern and improved engineering design, innovative construction method, improved kiln operation practices and interventions to make it more environment friendly and energy efficient. Under the contract, overall 08 demonstration plants were set up in different regions of the country. The purposes of the demonstrations were to encourage the entrepreneurs showcasing the method of converting the FCKs, improved construction and kiln management as well as to present the results and successes of the piloting.

3.1.1 Design and Construction

Based on the observations from the field visits, energy and environment survey, monitoring of energy and emissions of the FCKs and Zigzag kilns, and consultations with the clients and stakeholders, some changes in construction (particularly in insulation) and improvement in design (especially in scrubbing) were suggested for an Improved Zigzag Kiln (IZK). The IZKs were constructed by demolishing the original FCKs, keeping the original chimneys (120 ft) at place. The improvement criteria considered for the design were as follows,

a. The thicknesses of the top and side-wall insulations were increased to prevent heat losses.
b. Good sticky and plasticity clay was layered firmly at the bottom with at least 1.0 feet thickness to reduce penetration of water in the rainy season.
c. A gravity settling chamber filled with water by two-third was constructed underground. The water of the tunnel acted as a scrubber partly for the SPM.
d. A water scrubber was installed at a suitable height in the chimney.
e. A cyclone system was installed at the bottom inside the chimney to force flue gases to follow a cyclonic upward path. This system helped coarse particles settle down and fine particles get attached with the wall first and then settle down.

3.1.1.1 Design of the converted Zigzag kiln

Kiln dimensions

The kiln was designed with 52 chambers, having dimensions as,

Length: 225′ -0″ Wide: 68′ -4″ Height: 10′ -5″ Wall thickness: 3′ -10″

The kiln island had the dimensions of 205′ -6″ (L) X 14′ -0″ (W)

Draft Fan

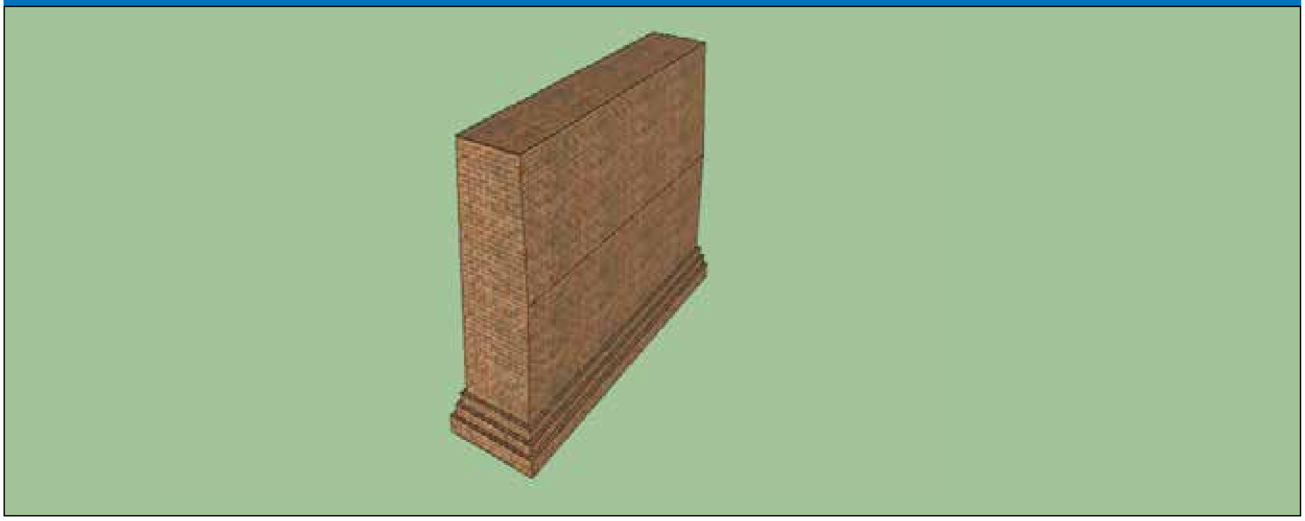
Draft Fan was used to withdraw flue gases from the kiln to the chimney through the flue gas tunnel system and gravity settling chamber. Because of the long distance and obstacles of zigzag pathway, the draft fan needed high suction force and volume flow capacity. Some specifications of the draft fan were as follows,

Suction force: >300mm Hg, Motor capacity: 25 hP, Volume Flow: 3.5m^3/sec

Outside wall Insulation

Outside wall of the kiln have functions of holding the brick stacking inside and also working as insulation layer to prevent heat losses through the sides of the kiln. Thickness of 50″ of the outside wall may be sufficient to avoid heat losses and also be firm enough to counter forces from inside or outside. Measurement of actual outside temperature from the existing Zigzag kilns having the same outside wall thickness was found the value not more than 55^{o}C in the hottest places just before firing chamber. Figure 7 shows kiln outside wall in 3D model.

Figure 7 Structure of the outside (boundary) wall of the demonstrated Zigzag kiln



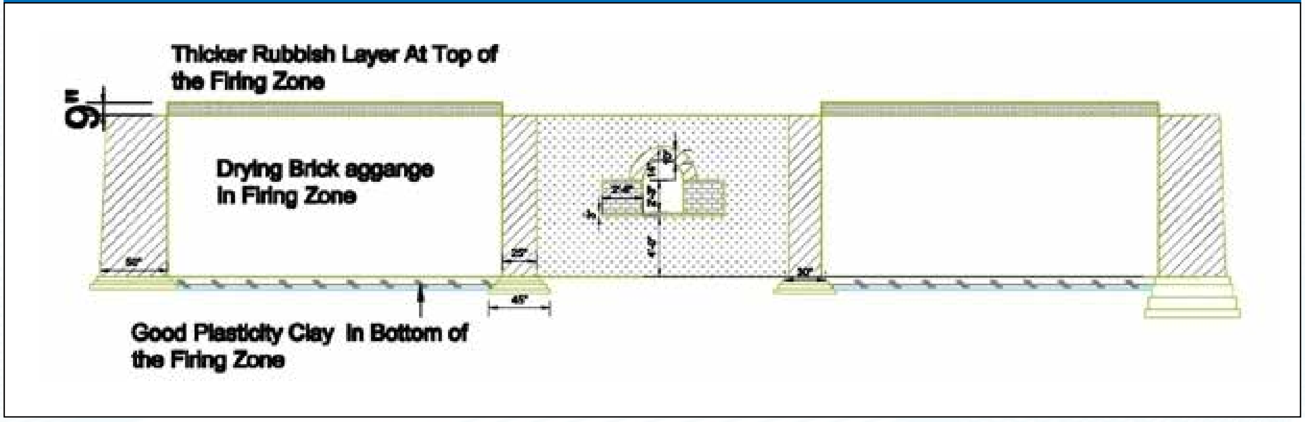
Top and bottom Insulation at the Firing Zone

In order to prevent heat losses through the top of the kiln, rubbish that included coal-ash, burned clay, and sand was used for top insulation. The thickness of the top insulation was such that the temperature at the top of the kiln was not over 70ºC.

Bottom of the kiln in Bangladesh normally suffered from the flooding or water absorption in the rainy season. Evaporation of water from the bottom at the beginning of the brick season consumes a significant amount of heat energy. In order to get rid of these troubles, following activities were done,

- Good sticky and plasticity clay was layered firmly at the bottom with at least 1.0 feet thickness to reduce penetration of water in the rainy season.
- Before stacking of the bricks in the kiln, rubbish was sprayed over the clay bed of the kiln and one layer of fired brick was arranged over the bed to increase insulation.

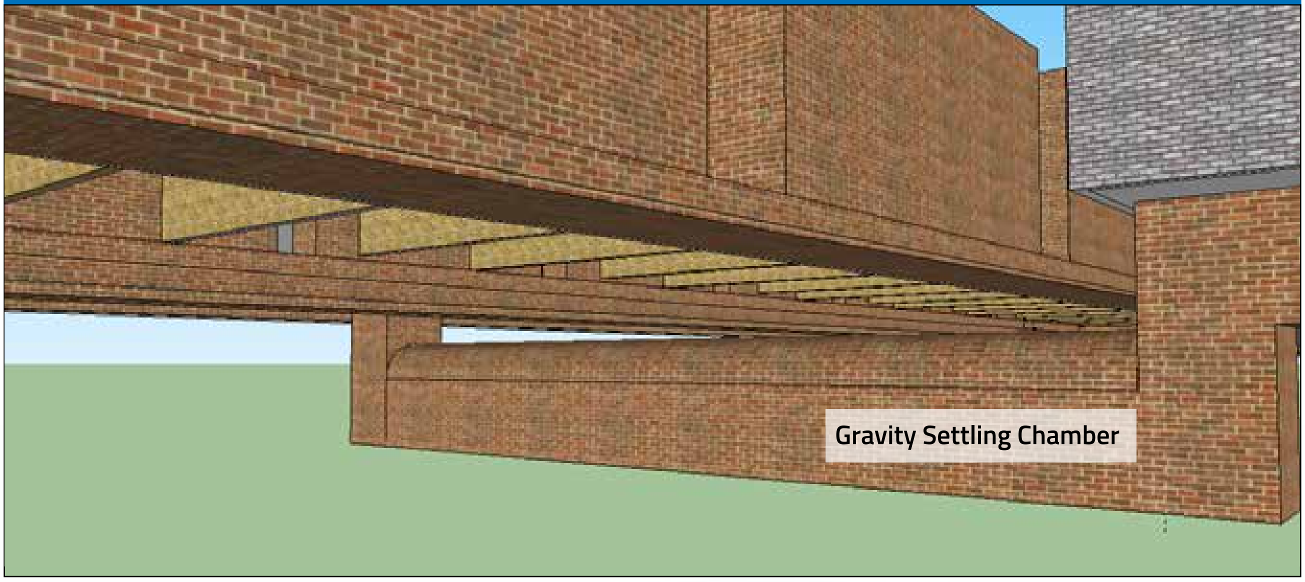
Figure 8 Top and bottom insulation at the firing zone



Gravity Settling Chamber

Gravity settling chamber is an underground tunnel which is filled with water by its 2/3 parts by volume and is located between the kiln and chimney. Since it is placed at the lowest level of the kiln, the condensates are drained to this tunnel. The water of the tunnel acts as a scrubber partly for the SPM. The Gravity Settling Chamber was constructed int the IZK with thick concrete work to prevent water penetration through it to the ground level. Flue gas temperature in this part of the kiln was low.

Figure 9 Gravity settling chamber at the bottom of the kiln

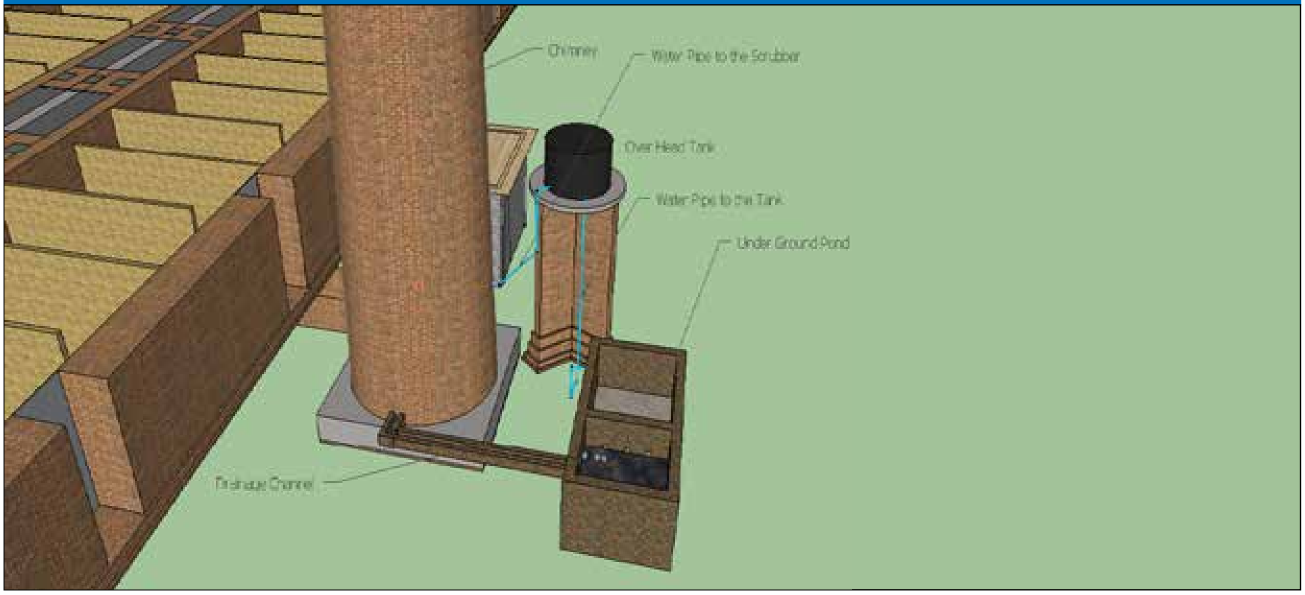


Water Circulation Sprayer Unit

In order to scrub SPM and SO_2, a water scrubber system was installed inside the chimney. The design of the water spraying unit is shown in the Figure 10. The working principle of the water circulation sprayer unit was as the following:

- One water tank was placed at the level higher than the spraying unit;
- One suction pump was working to take water from the well to the overhead tank;
- Sprayed water was collected to a two parts container which was constructed by high concrete work.
- The container had two parts; the first part received water enriched with high amount of SPM which, after sometimes, settled at the bottom of this part. Clear water from the top of the first part was drained to the second part of the container. The water received in the second part was used again to scrub the SPM in the chimney.

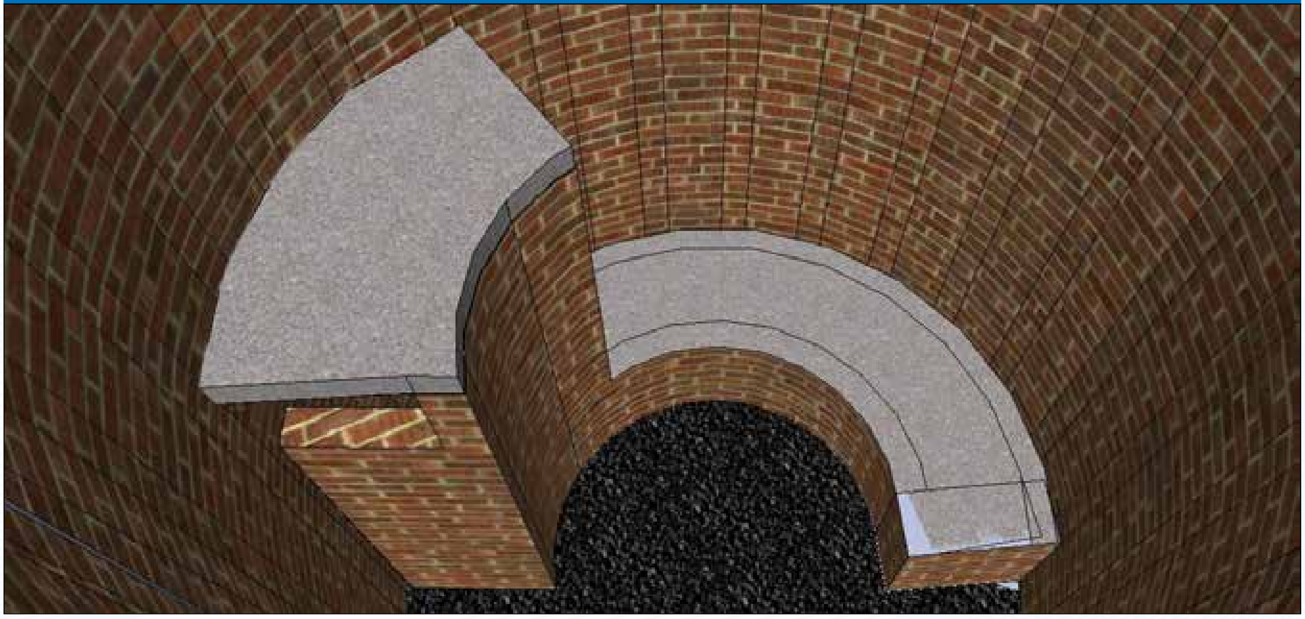
Figure 10 Water scrubbing system to be placed inside the chimney



SPM Scrubber System

Since the original chimney of the kiln was big and had enough spaces inside, a cyclonic scrubber was constructed at the bottom inside the chimney to force flue gases to follow a cyclonic upward path inside the chimney before finally leaving out. This system helped coarse particles settle down and fine particles get attached with the wall first and then settle down, thus lessening a remarkable amount of SPM from the flue gases before leaving out. Figure 11 shows 3-D view of a SPM cyclonic scrubber.

Figure 11 3-D view of SPM scrubber placed at the bottom inside the chimney



3.1.1.2 Green Brick Production Process

Brick Extruding Machines were introduced in the pilot demonstrations to produce green bricks as a measure to proceed towards mechanization of back process in the brick industry. Finely powdered coal was homogeneously mixed with the clay before forming green bricks.

3.1.1.3 Improving the Firing Practices

With the disadvantages of supplying fuel from the top of the kiln, the pilot demonstration offered the methodology of supplying fuel within the kiln during stacking bricks inside the kiln i.e. use of coal briquettes. This way of adding fuel is now being practiced successfully in Vietnam. In order to adopt good firing practices, coal fuel could be introduced inside the kiln on the following estimates,

i. Calculate the necessary coal required to fire certain quantities of bricks.
ii. Produce coal briquette to arrange with bricks during stacking (should be at least 50% of necessary coal for firing the bricks).
iii. Produce internal fuel mixed green bricks (should be about 30 – 40% of necessary coal).
iv. Add coal feeding from outside (10 – 20%).
v. Following advantages could be achieved from the above practices:
a. Combustion process inside the kiln would be absolutely continuous;
b. Would reduce labor cost for saving numbers of fireman;
c. Brick quality would be better and more uniform because of the uniform temperature while firing the bricks. The combustion reaction would happen uniformly in the brick stacking because of the uniform arrangement of coal briquette; and
d. Would reduce SPM creation significantly.

3.2 Energy and environment monitoring of the improved Zigzag kilns

Energy and environment monitoring of the improved Zigzag technology were performed by the IHERE of Vietnam, the consulting firm of the conversion study, and also by the Bangladesh Council of Scientific and Industrial Research (BCSIR) as a third party organization. In both cases specific energy consumption (energy requirement to produce one kg brick) was determined from the calculation of coal consumption and the coal calorific value which was got from laboratory analyses. The stack gases (NO_x, SO_2, CO, CO_2) and SPM concentrations were monitored by recognized monitors following internationally accepted methods.

3.2.1 Monitoring done by the IHERE, Vietnam

Following tasks were done to measure and analyze the energy consumption and flue gas emissions of the kilns,

- Measuring dimensions and weight of the dried green bricks and fired bricks using measuring tape and electronic balance.
- Calculating fuel consumption of each kiln as per the following steps,
  a. Measuring weight of buckets filled with coal
  b. Measuring the amount of coal in each bucket upon subtracting the bucket weight

c. Maintaining records of the number of buckets filled with coals being consumed in 24 hours.

d. Maintaining records of estimated number of bricks fired in 24 hours.

e. Assessing specific coal consumption and calculating specific energy consumption.

- Measuring temperature at different sections of the kiln when it was in operation using thermo couple.
- Analyzing flue gas components (NO_x, SO_2, CO, etc.) in the chimney using stack emission monitoring equipment (TESTO Stack Monitor)
- Analyzing oxygen content by Hand Held Multiwarn II – Drager.
- Collecting the Suspended Particulate Matter (SPM) following the USEPA method-17 with the PolTech SPM Stack Sampler.
- Monitoring ambient particulate matters (SPM, PM_{10}, $PM_{2.5}$) using Low volume Air Matrics PM Sampler, and gaseous components (CO, NO_x, SO_2, etc.) with appropriate hand held equipments.
- Collecting sample of coal for Ultimate and Proximate analysis (Calorific value, fixed carbon, volatile matter, ash, moisture content)
- Collecting clay samples for chemical analysis (SiO_2, Al_2O_3, Fe_2O_3, TiO_2, MgO, CaO, K_2O and Na_2O), loss on Ignition, particle size analysis and Shrinkage analysis.

The main components of the flue gas at the chimney as well as at the connecting tube between the brick loading area and flue gas tunnel system were CO_2, NO_x, SO_x, CO_2, O_2, and SPM. To assess the emission rates from the demonstrated IZKs, emission measurements were done for three consecutive days at different firing conditions, such as before stoking coal, after stoking coal and during the time of stoking coal in the kilns. The energy and environment monitoring at the kilns was performed at least one month after the beginning of firing, when the kiln platforms were no more water-soaked. The averages of the measurements were taken as the representatives of the emissions. Flue gases were monitored for about 25-75 minutes, and PM was collected for about 10-20 minutes in each measurement cycle to cover all the different states of firing. SPM sampling period was sometimes restricted due to high moisture content of the flue gas, which tends to clog the sample thimbles. Results of the measurements are given in Table 4 to Table 7. The following is the salient finding of the emission measurements at the kilns.

- Compared to FCK and artisan Zigzag kilns monitored earlier (Table 3), the IZKs emitted much lower flue gases, especially CO_2 and SO_2. With the use of water scrubber, most of the SO_2 in the flue gases seemed absorbed.

SPMs (suspended particles matters) consist of very small solid particles that remain suspended in the flue gas or air. SPMs are generated from unburned coal powder, fly ash, fine clay particles, fine sand, etc. Those fine particles are swirled by the flue gases and emitted in to the atmosphere. Thus, SPMs are directly not a product of combustion process, but depend more on the combustion organization of the kiln. With the drafting in the zigzag path and different types of SPM trapping systems introduced in the pathway of flue gas emission system, the IZKs were found to emit quite low SPMs compared to other technologies.

SPM emission mostly depends on the coal feeding practices in the kiln. Coal is usually fed into the kiln in an intermittent way. When coal is fed, fire increases suddenly in the kiln and consequently flue gas volume increases, which easily blows fine particles to create higher SPM emission. By changing the fuel feeding practices such as using internal fuel or coal briquette can make firing process continuous and reduce the SPM emission. The coal feeding practices by the fireman may also affect the SPM emission. Practice of feeding smaller amount of coal each time and repeating the process frequently could give lower SPM emissions. Higher amount of coal feeding for longer time would result in higher SPM emission, as well as produce inferior brick quality. Fuel quality and size may also contribute to the SPM emission. If the fuel does not burn completely before being drafted out of the kiln, SPM emission will increase.

3.2.2 Results of E&E monitoring by the IHERE

The results of the coal and E&E analyses of the demonstrated improved Zigzag kilns are shown in the Table 4 to Table 7. The next chapter will present the results of the coal and E&E analyses of the same improved kilns along with other technology kilns monitored by BCSIR. The addresses of these kilns have been given in Table 8.

Table 4 Results of Clay Analyses in the demonstrated zigzag kilns

Parameter	Unit	Ashraf	Harinpala	Setu	SS	N. Fulmala	BLL	Hazera
SiO_2	(%)	61.46	61.7	59.34	65.85	66.64	67.21	68.81
Al_2O_3	(%)	16.06	14.97	15.28	15.41	14.21	15.32	13.98
Fe_2O_3	(%)	6.25	6.03	6.1	6.31	6.48	5.85	5.1
TiO_2	(%)	0.9	0.98	1.05	0.91	0.86	0.83	0.71
MgO	(%)	2.65	2.56	2.85	1.1	1.38	1.28	1.93
CaO	(%)	1.8	2.62	2.72	0.39	0.79	0.47	1.02
K_2O	(%)	3.56	3.54	3.56	2.79	2.72	2.9	3.29
Na_2O	(%)	1.61	1.53	1.6	0.91	1.13	0.9	1.35
Loss in ignition	(%)	5.24	5.56	7.1	6.15	5.52	5.05	3.58
Particles size analysis								
>63 µm	(%)	3.67	10.47	8.16	17.27	20.54	23.92	43.37
>20 µm	(%)	28.25	41.64	28.68	27.05	48.78	44.56	64.41
20 - 2 µm	(%)	68.57	56.48	67.1	71.32	50.65	54.87	35.38
<2 µm	(%)	3.18	1.88	4.22	1.63	0.58	0.57	0.22
Shrinkage analysis								
Linear Drying shrinkage at 150°C (%)								
		3.41	3.71	4.99	5	4	5.67	3.33
Linear firing shrinkage at 105°C (%)								
		1.55	0.81	1.12	1.94	1.39	0.88	1.03
Total shrinkage of the clay (%)								
		4.92	4.5	6.04	6.84	5.34	6.5	4.34

Table 5 Results of the flue gas components measured at Stacks

Parameter	Unit	Ashraf	Harinpala	Setu	SS	N. Fulmala	BLL	Hazera
NO_x	mg/m^3	7.98	11.9	10.5	13.5	60	1.3	6.7
SO_2	mg/m^3	0	0	0	0	0	0	0
CO	mg/m^3	858	745	1899	1107	2226	752	750
CO_2	%	4	4.23	5	3	3.5	2.5	2.5
O_2	%	16.6	15.7	13.9	17	16	18	18
SPM1	mg/m^3	19.2	47.8	125	82	75	40.1	29
SPM2	mg/m^3	37	47	164	71	75	37.5	28.4
SPM3	mg/m^3	71.5	89.3	113	129	96	89	

Table 6 Summary Result of Coal and Specific Energy Consumption

Parameter	Ashraf	Harinpala	Setu	SS	N. Fulmala	BLL	Hazera
Total no. of brick produced ($x10^3$)	2251.3	2082.0	1968.0	3778.2	4044.1	4637.9	5536.3
Total amount of coal consumed (kg) $x10^3$	271.1	262.4	246.3	400.9	427.1	484.34	536.1
Total amount of coal required/lac bricks (kg)	12042	12603	12515	10610	10561	10443	9683
Average mass of bricks (kg)	2.77	3.25	3.35	3.113	3.312	3.286	3.233
Gross calorific value of coal (Kcal/kg)	6525	6545	6670	6865	5995	6780	6595
Gross calorific value of coal (MJ/kg)	27.32	27.4	27.93	28.74	25.1	28.39	27.61
Specific energy consumption (MJ/kg brick)	1.19	1.06	1.04	0.98	0.8	0.9	0.83

Table 7 Emissions of PM and gases from the demonstrated kilns, calculated in different units

Parameter	Unit	Ashraf	Harinpala	Setu	SS	N. Fulmala	BLL	Hazera
SPM average	mg/m^3	42.6	61.4	134	99.5	157	39.3	28.7
flue gas volume	Nm^3/kg_f	34	28.9	20.3	37.9	25.7	50.3	50.9
Flue gas volume	Nm^3/brick	3.97	3.35	3.07	4.42	2.97	7.59	7.68
Flue gas volume flow	Nm^3/s	1.38	1.2	0.82	1.54	1.06	2.02	2.05
gas velocity in tunnel	m/s	2.7	1.93	1.32	3.01	1.71	3.27	3.31
Emission based on mg/kg fuel (mg/kg_f)								
NO_x	mg/kg_f	271	342	214	404	1247	32	243
SO_2	mg/kg_f	0	0	0	0	0	0	0
CO	mg/kg_f	29185	21530	38611	36625	49894	33069	33354
SPM average	mg/kg_f	1448	1772	2722	3770	4017	1975	1461

Emission based on mg/kg brick (mg/kg_b)								
NO_x	mg/kg_b	31.68	39.66	32.27	47.15	144.46	4.85	36.63
SO_2	mg/kg_b	0	0	0	0	0	0	0
CO	mg/kg_b	3406	2495	5827	4275	5782	4991	5035
SPM average	mg/kg_b	169	205	411	440	465	298	221
Emission based on kg/lac brick (kg/lac_b)								
NO_x	kg/lac_b	8.79	12.9	10.8	14.7	47.9	1.6	11.8
SO_2	kg/lac_b	0	0	0	0	0	0	0
CO	kg/lac_b	945	812	1954	1331	1915	1640	1628
SPM average	kg/lac_b	46.9	66.9	138	137	154	98	71.3

Figure 12 Energy and Environment monitoring by IHERE

3.3 Monitoring done by the Council of Scientific and Industrial Research, Bangladesh

With the success on the reduction of pollutants in the flue gases of the improved Zigzag kilns demonstrated by the consulting firm IHERE, Vietnam, a third party energy and environment monitoring of those kilns was arranged to cross verify the results. Bangladesh Council of Scientific and Industrial Research (BCSIR) was contracted to monitor the energy and environment performances of the existing Zigzag kilns and the demonstrated improved Zigzag kilns. The objectives of the assignment to the BCSIR were (i) To establish a baseline of energy and environment parameters of the traditional kilns, (ii) To independently verify the environmental and energy performance of the pilot demonstrations under the CASE projects, and (iii) To also monitor the energy and environmental performance of the Hybrid Hoffman Kiln (HHK) and Tunnel Kilns (TK) built by the private entrepreneurs.

A total of 17 kilns of 4 different technologies as shown in table 8 were selected for this study.

Table 8 List of brick kilns with technology and addresses monitored by BCSIR

Type	Type ID	Name	Address
Traditional Zigzag (TZK)	TZK-1	M/S United Bricks	Mirzaganj, Patuakhali
	TZK-2	M/S Fatema Bricks	Muradnagar, Comilla
	TZK-3	M/S NBM Bricks Ltd	Aminbazar, Savar
	TZK-4	M/S Fahad Bricks Ltd	Baliarpur, Savar
	TZK-5	Eshak Bricks Factory	Ghior, Manikganj
Improved Zigzag Kiln (IZK)*	IZK-1	New Fulmala Bricks Ltd	Muradnagar, Comilla
	IZK-2	M/S Ashraf Brick Fields	Mirzaganj, Patuakhali
	IZK-3	M/S Harinpala Bricks Ltd	Vandaria, Pirojpur
	IZK-4	M/S Setu Bricks & Ind. Ltd	Dumuria, Khulna
	IZK-5	M/S Hazera Brick Fields	Manda, Naoga
	IZK-6	M/S Brick Link Ltd	Saidpur, Nilphamari
	IZK-7	M/S Shaon Sujan Bricks Ltd	Chunarughat, Hobiganj
Mini- Hybrid Hoffmann (MHK)**	MHK-1	M/S Jamuna Auto Bricks	Kaliganj, Satkhira
	MHK-2	M/S HNB Bricks Ltd	Chailgazi, Dinajpur
Hybrid Hoffmann (HHF) Kiln	HHK-1	Metrocem Auto Bricks Ltd	Kolma, Savar
	HHK-2	Kapita Auto Bricks Ltd	Kalampur, Savar
Tunnel Kiln (TK)	TK-1	MHCL Auto Bricks Ltd	Genda, Ulail, Dhaka
	TK-2	Stone Bricks Ltd	Ghior, Manikganj

These kilns were designed and demonstrated under the CASE Project and the E&E of these kilns were also monitored by the IHERE presented in the previous chapter.

*** This technology was another type of demonstration done under the CASE project with technical assistance from Xi'an Research and Design Institute of Wall and Roof Materials. As the number of demonstrations of MHK (only one in operation during the time of this report preparation) is not remarkable, it is not provided in details in separate chapter.*

3.3.1 Methods of energy and environment monitoring

3.3.1.A. Methods of energy monitoring

(i) Specific Energy Consumption

Specific Energy Consumption (SEC) is defined as the energy in MJ ($1X10^6$ Joules) consumed for producing 1kg of fired brick. SEC is usually used as a parameter to compare energy performance of brick kilns.

The SEC of the kiln is given by:

$$SEC = \frac{H_{in}}{M_{fbr}}$$

Where,

H_{in} = Total energy input to the kiln for the duration of one firing cycle/batch

= (Energy input from external fuels fed in the kiln)

+ (Energy input from internal fuels added during molding the bricks)

+ (Energy input from the organic matter present in the brick soil[11*]).

$$= \sum_{i=1}^{n1} W_{f-exti} * GCV_{f-exti} + \sum_{i=1}^{n2} W_{f-inti} * GCV_{f-inti}$$

Where, n1 and n2 are the types/ lots of external and internal fuel used.

M_{fbr}= Mass of fired bricks produced during one firing cycle/batch

= Average mass of fired brick X number of bricks fired in one firing cycle/batch= m X n

(ii) Measurement of energy input (external and internal fuel)

The energy for firing bricks was added in two ways – externally or mixed internally with the clay during green brick preparation, or both. Both internal (if added) and external fuel were considered for calculating the total input of energy in the kiln.

Regardless of the internal fuel usage, external fuel was poured from the top of the furnace through the holes, namely the 'pot' or 'burner'. The coal charging rate was very much dominated by the foreman in charge of firing of the kiln, also known as 'Agun -mistri'. The coal was grinded to a preferred mesh size in the brick field and stored in bulk in the vicinity. From this bulk, pulverized coal was transported to the kiln top for using stock in drums via buckets or sacks. The number of buckets full of coal transported to the kiln-top over the measured time was noted, and from the average weight of coal per bucket the amount of external fuel was estimated.

In order to calculate total energy input in one batch of bricks, following equation was followed

$$H_{in} = \sum_{i=1}^{n1} W_{f-exti} * GCV_{f-exti} + \sum_{i=1}^{n2} W_{f-inti} * GCV_{f-inti}$$

11 *The energy from carbonaceous content in green bricks is often small and difficult to measure and is neglected in these calculations.

External Fuel

= Weights of each of the external fuels added in one batch/cycle of green bricks ($W_{f\text{-}ext}$) X Type and Gross Calorific Values (GCV) of each of the external fuels ($GCV_{f\text{-}ext}$)

Internal fuel

= Weight of each of the internal fuels added in one batch/cycle of green bricks ($W_{f\text{-}int}$) X Type and Gross Calorific Values (GCV) of each of the internal fuels ($GCV_{f\text{-}int}$)

Notes:

a) Coal measurements were verified with the secondary data (tons of coal per 1,00,000 fired brick) as much as possible,

b) The studied kilns were all of continuous type. The measurements were taken for a firing cycle of 48 hours.

c) GCV is the gross calorific value of the fuel. Samples of coals for the measurement of GCV in laboratory, were collected from wherever seemed to be more resembling to the actual firing conditions regardless of the size and condition (moisture %, etc.). This was in most cases, from the top of kiln just before charging.

Figure 13 Coal charging from the top (Top), grinding and bulk storing area of a brick field (Bottom-Left), transported by bucket to kiln top (Bottom-Right)

(iii) Measurement of weight of fired bricks

The total weight of the fired bricks in a batch/cycle was obtained by determining the average weight of a fired brick and then multiplying it by number of bricks fired in the batch/cycle. The average mass of fired brick was determined by randomly selecting 24 fired bricks, weighing them and calculating a simple average. In reality fired bricks were collected from the kiln and stacked depending on the popular type, namely: Picket, grade-1, 2 and 3. In such cases equal number of bricks from each type was selected randomly to meet 24 bricks. Finally, calculation of the weight of the fired batch was as:

Weight of fired batch = average weight of fired brick x number of bricks in batch

$$M_{fbr} = m \text{ X } n$$

(iv) Stack height and diameter

The height, diameter and cross-sectional area of the stack were determined by standard methods. Height of the Stack was measured by survey equipment, Total Station (GTS-230N, Topcon, Japan)

3.3.1.B. Methods of environment monitoring

The environment monitoring in each kiln was carried out in three consecutive days. Following activities were done in the kilns to perform the monitoring,

(i) Sampling point selections

The sampling point on the stack/chimney was selected at a height where laminar flow of the flue gases was assumed. To ensure the laminar flow, the sampling port was prepared at a height, about 8 times of the chimney diameter (Figure 14).

Figure 14 Stack emissions monitoring by BCSIR

(ii) SPM: sample collection determination

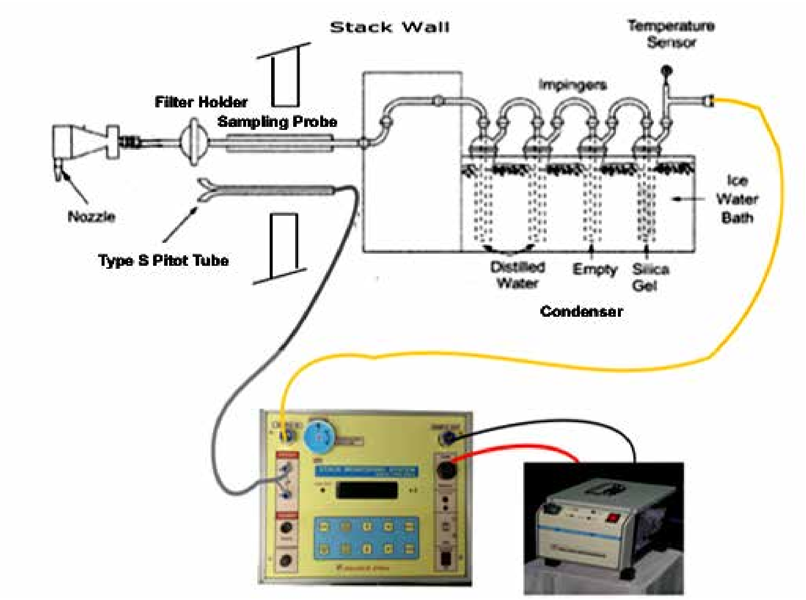
Static gas pressure and stack gas velocity were determined by using S-type pitot tube. Moisture content of the flue gas was measured by condensation method. The measured velocity was used to calculate the Isokinetic sampling rate.

SPM was collected on a thimble filter that was set in a fully automatic microprocessor-based Stack Monitoring System (model Polltech PEM–SMS4), following the USEPA method 17 (Figure 15). Minimum 1m^3 of dry emission gas was withdrawn in each sampling. The sampling was carried out under iso-kinetic conditions.

The thimble filter was properly dried in an oven (about 2 hours at 120°C) before and after the expose. The weight of the SPM was determined from the weights taken before and after its expose to the flue gases. The SPM concentration was determined from the following equation,

$$\text{SPM (mg/Nm}^3) = \frac{\text{Weight of dust Collected (mg)}}{\text{Volume of air sampled (m}^3\text{)}}$$

Figure 15 Automatic iso-kinetic air sampler for capturing particulate matter (PEM–SMS4, Polltech)



Flue gas temperature, Stack Gas Velocity, Moisture content, volumetric flow rate was measured in accordance with the USEPA requirements using both pollutech PEM–SMS4 and E Instrument (E 8500).

(iii) Stack gas determination

Concentration of SO_2, NO_x, O_2, CO_2 and CO in the flue gases at the sampling point of the stack was measured by Industrial Flue, Combustion Gas and Emissions Analyzer (E8500 plus E-Instruments, USA) according to the USEPA CTM-030 and CTM-034 test methods.

Figure 16 Industrial Flue gas, Combustion Gas and Emissions Analyzer (E 8500, E-Instrument, USA)

(iv) Emission rate and emission factor estimation

Pollutant emissions were found to vary with the type of the kiln, fuel used and kiln operating conditions. The emission rates of the pollutants in different units were deduced by the following equations,

Emission rate of pollutant ER (g/s) = $\frac{Qs \times S}{1000}$

Emission rate of pollutant ER (g/h) = $\mathrm{ER\ (g/s)} \times 3600$

Where, Qs = Flue gas flow rate, Nm^3/s

= velocity x inner area of the stack (at the height of the measurement)

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

From the emission rate (ER), fuel unit mass-based emission factor (EF_m) in g/kg coal was calculated as follows:

$$\mathrm{EF_m} = \frac{\mathrm{ER\ (g/h)}}{\mathrm{F}}$$

Where, F is the fuel consumption rate (kg of coal burned per hour).

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

$$\mathrm{EF_p} = \frac{\mathrm{ER\ (g/h)}}{\mathrm{P}}$$

Where, P is the total amount of weight of bricks produced per hour (kg/h).

3.3.2 Results of the E&E monitoring by the BCSIR

3.3.2.1 Measurement of energy requirement

Table 9 Origin, gross calorific value and sulfur content of the coal used in the kilns

Type	ID	Coal Origin	Gross Calorific Value (MJ/kg)	Sulfur Content (%)
TZK	TZK-1	Indonesia	21.08	2.89
	TZK-2	India	21.02	4.32
	TZK-3	India/ Indonesia	18.49	1.82
	TZK-4	India/ Indonesia	19.25	0.79
	TZK-5	India	23.30	3.99
		Saw dust (local)	10.42	-
IZK	IZK-1	India	20.82	4.47
	IZK-2	South Africa	19.13	0.81
	IZK-3	South Africa	17.38	0.97
	IZK-4	Indonesia	19.00	0.76
	IZK-5	Bangladesh	21.32	0.67
	IZK-6	India/Bangladesh	19.65	3.87
	IZK-7	Russia	20.02	2.16
Mini-HHK	MHK-1	Indonesia	17.84	2.18
HHK	HHK-1	Indonesia	18.13	2.07
	HHK-2	Indonesia	21.26	1.62
TK	TK-1	Indonesia	21.73	0.61
	TK-2	India	15.64	1.38

TZK = Traditional Zigzag; IZK = Improved Converted Zigzag; Mini-HHK = Mini Hybrid Hoffman Kiln (Demonstrated by the CASE project through another contract); HHK = Hybrid Hoffman Kiln; TK = Tunnel Kiln

Specific Energy Consumption (SEC) was calculated from both primary and projected secondary data. The secondary data was collected from the manager and workers in the kilns. The secondary data was projected to the daily production of bricks as in nos./day, to compare with the primary data on the same basis. In most cases, the secondary SEC was reasonably close to the primary data. But in some cases, the variations were noticeably high. Depending on the field observations, background and comparison with the similar type, only one SEC value is reported in Table 11.

Table 10 Specific energy consumption of the brick kilns under study

Type	ID	Coal Consumption (kg)			Cum C.V. (MJ) consumed per day	Brick Production			SEC MJ/kg	SEC MJ/kg
		Secondary Data (T/lac$_b$)	**Secondary Data Projected (kg/day)**	**Primary Data (kg/day)**		**No/Day**	**Avg. Wt. kg/pcs**	**Kg/ Day**	**(1°)**	**(2°)**
Traditional Zigzag Kiln	TZK- 1	14.5	4754	5684	119860.6	32785	2.77	90814.45	**1.32**	1.10
	TZK- 2	18	3600	4500	94573.04	20000	3.07	61400	**1.54**	1.23
	TZK- 3	14.7	6395	4875	90134.34	43500	2.71	117885	**0.76**	1.00
	TZK- 4	14	3360	2900	55838.83	24000	2.75	66000	**0.85**	0.98
	TZK- 5	25	9900	5400	127513.3	39600	3.58	141768	**0.90**	1.64
		0.5 (Sawdust)	198	160						
	Avg. ± std.	**17.24 ±4.62**	**5601.8 ±2685.86**	**4672 ±1091**	**97584 ±28280**	**31977 ±9982**	**2.976 ±0.37**	**95573 ±34267**	**1.07 ±0.34**	**1.19 ±0.27**
Improved Zigzag Kiln	IZK- 1	14.75	5753	5100	106179.9	39000	3.21	125190	**0.85**	**0.96**
	IZK- 2	14	5663	5400	103275.3	40450	2.74	110833	**0.93**	**0.98**
	IZK- 3	14	4340	7200	136826.8	31000	2.745	85095	**1.61**	**0.97**
	IZK- 4	20	4200	8000	139042.7	30000	3.39	101700	**1.37**	**1.03**
	IZK- 5	11	5214	2025	43167.9	47400	2.94	139356	**0.31**	**0.80**
	IZK- 6	13.3	4362	4200	82521.87	32800	3.22	105616	**0.78**	**0.81**
	IZK- 7	12.5	4419	3800	76061.77	35350	3.075	108701.25	**0.70**	**0.81**
	Avg. ± std.	**14.21 ±2.87**	**4850 ±672**	**5103 ±2035**	**91853 ±34190**	**36571 ±6166**	**3.05 ±0.25**	**110927.3 ±17307**	**0.94 ±0.43**	**0.90 ±0.1**
Mini Hofmann Kiln	MHK-1	10.5	2678	2700	48180.85	25500	3.1	79050	**0.61**	**0.60**
Hybrid Hoffmann	HHK-1	18.5	5550	7000	126904.9	30000	3.39	101700	**1.25**	**0.99**
	HHK-2	11	6985	6750	143497.6	63500	3.1	196850	**0.73**	**0.75**
	Avg. ± std.	**14.75 ±5.3**	**6267 ±1014**	**6875 ±177**	**135201± 11732**	**46750± 23688**	**3.25 ±0.21**	**149275 ±67281**	**0.99 ±0.37**	**0.87 ±0.17**
Tunnel Kiln	TK- 1	18	5400	5650	122760.4	30000	3.02	90600	**1.35**	**1.30**
	TK- 2	25	62500	62500	977748.5	250000	3.37	842500	**1.16**	**1.16**
	Avg. ± std.	**21.5 ± 4.95**	**33950 ±40375**	**34075 ±40199**	**550254 ±604567**	**140000 ±155563**	**3.195 ±0.25**	**466550 ±531674**	**1.255 ±0.13**	**1.23 ±0.10**

Cum. C.V= Cumulative Calorific Value

Where the secondary SEC was reasonably close to the primary data, it was deemed authentic and reported as it is. In case of discrepancy, the higher value among the two was reported.

Table 11 Reported SEC for different types of kiln and remarks

Type	ID	SEC MJ/ kg (1°)	SEC MJ/ kg (2°)	Reported SEC	Remarks
TZK	TZK- 1	1.32	1.10	1.32	Difference is greater, hence 1°
	TZK- 2	1.54	1.23	1.54	Difference is greater, hence 1°
	TZK- 3	0.76	1.00	1.00	Verified 2°
	TZK- 4	0.85	0.98	0.98	Verified 2°
	TZK- 5	0.90	1.64	1.64	Verified 2°
	Avg. ± std.			**1.29±0.31**	
IZK	IZK- 1	0.85	0.96	0.96	Verified 2°
	IZK- 2	0.93	0.98	0.98	Verified 2°
	IZK- 3	1.61	0.97	1.61	Difference is greater, hence 1°
	IZK- 4	1.37	1.03	1.37	Difference is greater, hence 1°
	IZK- 5	0.31	0.80	0.80	Verified 2°
	IZK- 6	0.78	0.81	0.81	Verified 2°
	IZK- 7	0.70	0.81	0.81	Verified 2°
	Avg. ± std			**1.05±0.31**	
MHK	MHK- 1	0.61	0.60	0.60	Verified 2°
HHK	HHK- 1	1.25	0.99	1.25	Difference is greater, hence 1°
	HHK- 2	0.73	0.75	0.75	Verified 2°
	Avg. ± std.			**1.00±0.35**	
TK	TK- 1	1.35	1.30	1.30	Verified 2°
	TK- 2	1.16	1.16	1.16	Verified 2°
	Avg. ± std.			**1.23±0.05**	

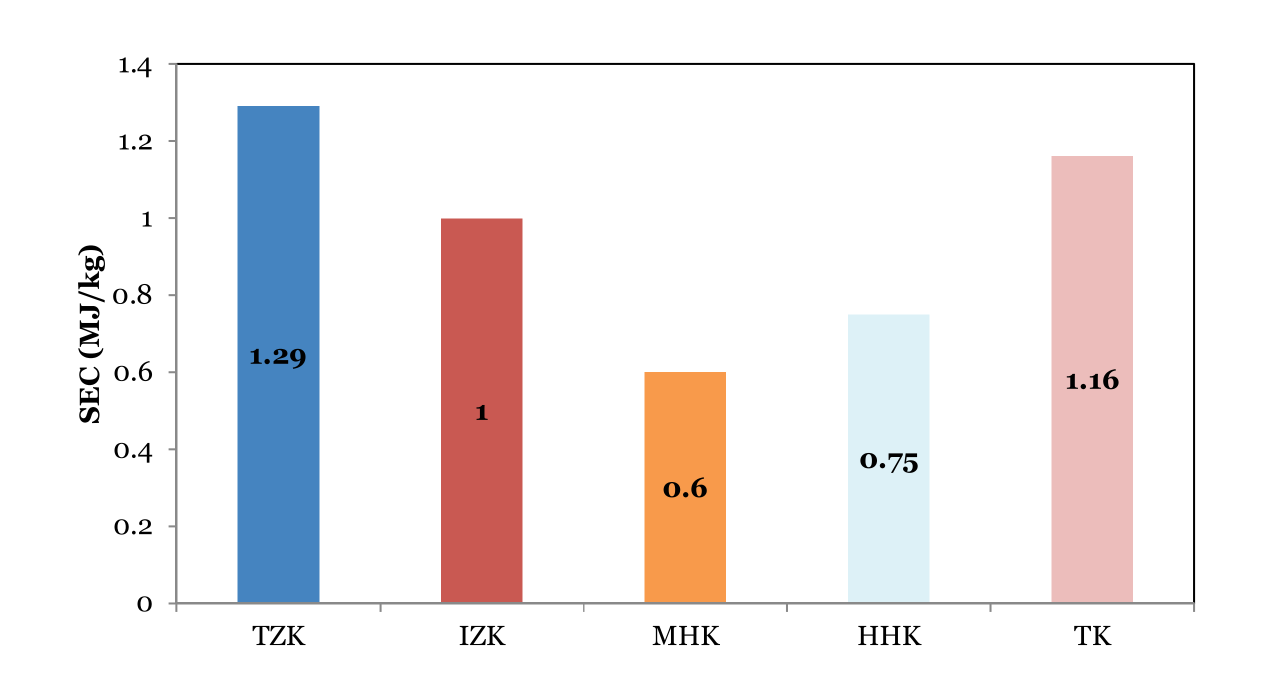
Table 11 shows that the SEC value was the highest at the TZK-5 (1.64 MJ/ kg) which was a traditional Zigzag kiln. The IZK-4 was not maintaining the features initially set out by the consulting firm under the CASE project. HHK-1 was rather old, converted from gas fired to coal fired system and 50% chimney was not working. TK-1 was 30 years old, had leakage in the exhaust path at the top of the dryer. So, these kilns were not taken into comparing the energy performances of the different types of Kiln, shown in Figure 17.

Figure 17 shows average value of SEC. The average value of SEC for TZKs (1.296±0.302 MJ/ kg) was higher than that of IZK (0.995±0.472 MJ/ kg). The value for the improved MHK (0.60 MJ/ kg) was the lowest among the technologies under the study. The SEC value of the TK was 1.16 MJ/ kg and of the HHK was 0.75 MJ/ kg. Based on the energy performances, the technologies could be arranged as follows, with notifications that the sample sizes of MHK, HHK and TK were very low,

MHK(0.60*) – HHK(0.75) – IZK(0.995) – TK(1.16) – TZK(1.29)

*in the unit of MJ/kg

Figure 17 Comparison of average SEC value of different kilns



3.3.2.2 Measurement of environmental performances

TZK-2 and TZK-5 emitted relatively higher amount of CO, SO_2 gases and SPM. For example, TZK-5 emitted with CO concentrations of 2733.83±573.59 mg/Nm^3, SO_2 concentrations of 917.11±76.94 mg/Nm^3 and SPM of 906.13±55.46 mg/Nm^3. These high emission values were obtained due to improper design, lack of maintenance and use of high sulfur containing coal. TZK-2 and TZK-5 used coal containing 4.32 and 3.99% of sulfur, respectively (Table 9). Among the traditional zigzag kilns, the TZK-1, TZK-2 and TZK-4 emitted comparatively lower amount of gases and SPM; however, the average emission of TZK was much higher than the IZKs as shown in the table 12.

Table 12 Emission parameters measured by BCSIR at different types of brick kilns

Kiln ID		Temp. (°C)	Oxygen (%)	CO_2 (%)	Velocity (ft/s)	CO (mg/ Nm^3)	NOx (mg/ Nm^3)	SO_2 (mg/ Nm^3)	SPM (mg/ Nm^3)	Flow Rate (m^3/s)
TZK-1	mean	50.92	16.61	3.7	3.29	2134.6	62.56	269.2	272.4	2.633
	sd.	2.47	0.46	0.4	0.1	285.8	4.64	17.7	16.7	0.06
TZK-2	mean	53.51	16.24	3.9	2.76	2536.4	63.10	872.2	601.0	1.799
	sd.	2.3	0.13	0.1	0.11	100.8	2.24	26.4	21.4	0.07
TZK-3	mean	45.03	15.37	5.3	3.15	2048.7	75.07	348.2	365.4	2.811
	sd.	0.5	0.22	0.2	0.32	52.6	0.52	34.7	6.4	0.30
TZK-4	mean	45.6	15.4	5.3	2.19	2014.1	73.92	341.4	375.0	1.949
	sd.	0.9	0.17	0.1	0.1	111.9	1.44	18.05	21.3	0.10
TZK-5	mean	50.05	17.32	3.0	2.51	2733.8	72.64	917.1	906.1	4.536
	sd.	1.06	0.43	0.4	0.1	573.6	2.57	77.0	55.5	0.2
IZK-1	mean	42.74	16.62	3.6	2.07	1557.6	48.39	383.9	190.2	1.354
	sd.	0.71	0.2	0.2	0.1	227.0	3.85	20.2	12.84	0.07
IZK-2	mean	42.15	17.77	2.8	1.58	938.6	33.63	77.82	117.4	4.237
	sd.	1.24	0.04	.02	0.03	29.0	0.73	8.63	16.35	0.08
IZK-3	mean	39.96	15.75	5.0	3.67	1618.3	37.66	86.45	113.8	2.397
	sd.	1.0	0.35	0.4	0.26	373.5	2.2	3.26	12.6	0.2
IZK-4	mean	47.28	15.57	5.4	3.82	2300.3	49.60	315.9	254.3	2.494
	sd.	1.16	0.4	0.4	0.3	86.8	3.81	44.8	17.1	0.2
IZK-5	mean	46.13	18.79	1.9	1.79	325.2	24.74	47.22	71.93	3.233
	sd.	1.0	0.14	0.1	0.13	63.8	2.13	3.22	5.3	0.23
IZK-6	mean	45.45	18.80	1.9	1.88	323.2	39.98	82.59	126.7	3.387
	sd.	1.7	0.08	0.0	0.1	34.0	4.15	5.5	9.63	0.16
IZK-7	mean	46.88	15.73	4.4	1.75	929.9	45.38	87.06	123.8	3.646
	sd.	1.3	0.33	0.3	0.08	97.7	2.5	9.8	18.0	0.2
MHK-1	mean	48.75	19.39	1.4	4.53	670.5	22.36	45.90	131.1	2.052
	sd.	1.9	0.5	0.5	0.56	113.2	1.9	5.4	19.0	0.25
HHK-1	mean	52.98	20.08	0.7	2.62	344.9	25.42	99.87	97.80	11.435
	sd.	0.94	0.2	0.2	0.2	31.7	6.4	34.7	14.3	0.9
HHK-2	mean	44.34	20.34	0.6	2.72	121.5	20.30	13.18	53.78	14.536
	sd.	1.32	0.03	0.1	0.16	51.7	3.9	1.4	7.01	0.9
TK-1	mean	57.74	20.42	0.5	15.5*	186.5	12.86	14.51	66.25	15.32
	sd.	0.9	0.11	.07	1.9	39.3	0.8	1.34	5.54	1.85
TK-2	mean	64.42	17.21	3.5	3.37	1233.0	31.44	37.33	123.3	2.401
	sd.	0.73	0.25	0.5	0.26	160.3	6.05	0.35	25.0	0.2

4 COMPARISON OF E&E PERFORMANCE OF THE BRICK MAKING TECHNOLOGIES

Table 13 Comparison of energy and environment performances of TZK and IZK with the baseline technology FCK

Parameter	FCK	TZK		IZK	
monitored by	**IHERE (5*)**	**IHERE (5)**	**BCSIR (5)**	**IHERE (7)**	**BCSIR (7)**
Coal consumption (Tons/100k brick)	20.1±0.6	17.9±0.9	17.1±4.7	11.2±1.7	13.25±1.7
Sp. energy consumption (MJ/kg brick)	1.35±0.21	1.27±0.10	1.29±0.31	1.0±0.14	1.0±0.31
PM (mg/Nm^3)	1103±95	243±260	504±237	71.2±35	123±37
CO (mg/Nm^3)	2658±1502	2118±1668	2332±925	1191±616	1034±610
SO_2 (mg/Nm^3)	2658±1503	2118±1668	582±51	<MDL	127±8
CO_2 (%)	2.5±0.3	2.4±0.3	4.2±1.4	3.5±0.9	3.4±1.6

MDL = Minimum Detection Limit; *kiln number tested

The performance of the Mini-Hoffmann Kiln (MHK) demonstrated under the CASE project was found the superior in all respect of energy and environment monitoring. However, as the number (only 01) of MHK tested was very poor, the result of MHK was not shown in comparison in Table 13. Similarly, the results of HHK and TK were not shown in the table for the small kiln number although the test results were primarily shown in Table 12.

5 ENERGY SAVINGS FOR REPLACEMENT OF FCKS TO ZIGZAG KILNS

The latest inventory done by the Jahangirnagar University under the CASE project (discussed in chapter 7) in 2018 found about 8000 brick kilns (FCK and Zigzag) throughout the country. Before 2010 more than 90% of the kilns were FCK. If there were no interventions/directions from the government, this proportion would have sustained – meaning that total number of FCK would have been 7200 by today. If on an average, an FCK produces 30000 bricks a day and the brick production takes place in 150 days in a dry season (December - April), an FCK would produce 4.5 million bricks in a season.

So, 7200 FCKs would produce (4.5 x 7200) million = 32.4 billion bricks in a season. Now,

(a) if all the 7200 FCKs are replaced by Traditional Zigzag Kiln (TZK):

Production of 100k bricks would save 2.5 tons of coal (considering 20.0 tons/100k brick for FCK and 17.5 tons/100k bricks for TZK (Figure 6, Table 10, Table 13).

Production of 32.4 billion bricks by TZK would save 810 thousand tons of coal.

Considering coal price 12500 taka per ton, total 10.12 billion taka would be saved every year. Or, every brick kiln would save 1,406,250 taka every year.

(b) if all the 7200 FCK replaced by Improved Zigzag Kiln (IZK),

Let IZK consumes (11.2 + 13.0)/2 tons coal/100k bricks (Table 13) = 12.1 tons coal/100k bricks

Therefore, production of 32.4 billion bricks by IZK would save 2.55 million tons of coal which cost about 31.9 billion taka. Thus, every kiln would save about 4,443,750 taka every year if fitted with IZK technology in place of FCK.

6 REDUCTIONS IN PM, SO_2 AND CO_2 EMISSIONS FOR REPLACEMENT OF FCKS TO ZIGZAG KILNS

Table 14 Emission factors of the parameters emitted from brick kilns

Technology	EF unit	*PM_{10}	SO_2	CO_2	Source
FCK	g/kg_f	[2]86.0	[3]50.0	[1]242	[1]Haque et al. 2018[1]
TZK	g/kg_f	[4]26.30	[4]28.54	[4]103.8	[2]EF_{PM10} = 6.8 g/s from Randall et al. 2013[2]
IZK	g/kg_f	[4]6.30	[4]6.61	[4]77.8	[3]from sulphur content (2.5%) of Coal
	g/kg_f	[5]2.5	[5]0.0	–	[4]EF calculated by BCSIR [5]EF calculated by IHERE

*Considering PM_{10} to SPM 0.96 and $PM_{2.5}$ to PM_{10} 0.33 (Le & Kim 2009[12])

Each FCK burns about 6000 kg coal a day, emitting about 516 kg PM_{10}, 300 kg SO_2 and 1452 kg CO_2 in the atmosphere every day, according to Table 14. CO_2 is not an air pollutant; however, this work is taking opportunity to calculate the emissions and reductions of CO_2, a strong greenhouse gas from brick kiln sector in the country.

(c) Countrywide about 2579 tons of PM_{10}, 927 tons of SO_2, and 5970.2 tons of CO_2 would be reduced in one day if all the 7200 FCKs are replaced by TZK;

(d) Similarly, countrywide about 3443 tons of PM_{10}, 1874.4 tons of SO_2 and 7093.4 tons of CO_2 would be reduced each day if all the FCKs are replaced by the IZK designed under the CASE project of the DoE.

(**Note:** EFs of PM_{10}, SO_2 and CO_2 for the IZK calculated by the BCSIR were considered in these calculations. BCSIR monitored the energy and environment of the IZKs after 1-2 years of the establishment of the kilns, when the operations of those kilns were in real native conditions, whereas in contrast, the monitoring by the IHERE was done at once after the establishment of the IZKs, when all the operations of the kilns were in ideal conditions under the direct supervision of the consulting firm).

12 Integrated assessment of brick kiln emission impacts on air quality. Environ. Monit. Assess. (2009), 171, 381–394.

7 COUNTRYWIDE INVENTORY OF BRICK KILNS

GIS-based source and emission inventory is an important tool for air quality management. Grid-based information on source, emissions and meteorology facilitate the atmospheric modelers in estimating overall grid-based pollution levels accrued from all/individual type of sources, as well as virtually calculating different scenario-based dispersions of pollutants to find a best suited scenario for the environmental, economical and social benefit. In view of this, the CASE project hired Geography and Environmental Science Department of the Jahangirnagar University to prepare a countrywide GIS-based inventory of the brick kilns and steel mills. Along with the measurement of emission factors and energy consumptions discussed in the previous chapters, this inventory will create a base for estimating contributions of brick kilns to air pollution throughout the country.

The work was divided into two phases; in the first phase, the brick kilns in Dhaka (including Mymensign division) and Chattogram divisions were located during the brick season of 2017-2018, and in the second phase conducted in the season of 2018-2019, the kilns in the rest of the country were identified and recorded. This work not only located the brick kilns but also a 1.0 km Land Use and Land Cover (LULC) map around each brick kiln was created to observe the settlements being affected around the kilns. Major objectives of this work could be summarized as follows,

a. To prepare database software capable of visualizing brick kilns and re-rolling steel mills on different administrative level maps of Bangladesh, as well as showing 1.0 km LULC buffer zone around each brick kiln. Furthermore, the database software will contain and show information like technology type, chimney height, address and owner details, etc.

b. To identify absolute Lat/Lon and relative (up to mouza scale) location of the brick kilns and steel mills;

c. To prepare a detail 1.0 km LULC for each of the brick kiln and steel mill;

d. To prepare an atlas of brick kilns and re-rolling mills in the country.

The methodology of this study was mainly based on GPS, GIS and Remote Sensing based research work. The first task however, was to develop a background database of the brick kilns in the country. At the first stage, Google Earth satellite imagery was exhaustively surveyed; 7326 brick kilns were primarily located, by this process, throughout the country. Google kml files with the locations of the brick kilns were then created and connected with the google map server. With smart phone facility the survey team visited each of the sites by locating it on the google map and collected the GPS coordinates in the field, recorded it in the smart phone and instantly sent the records to the server computer to verify the accuracy of the satellite images. During the field visit the team also collected fundamental information about the brick kilns according to an approved questionnaire. Furthermore, any new kilns which could not be identified during Google imagery survey were also recorded during field survey. In total, 7902 brick kilns were spotted throughout the country during the inventory survey.

The verified image locations of the brick kilns were geo-referenced with the Bangladesh Universal Mercator Projection (standard projection parameters by the Government of Bangladesh). Geo-processing of other relevant data sources from Local Government Engineering Department (LGED), BBS and Bangladesh Water Development Board had been compiled and verified. The brick kiln points were then converted in to the GIS shape files and 1.0 kilometer buffer area of each of the sites was drawn with the help of buffer analysis in ArcMap. This buffer area was then digitized in to twelve classes – location of the Kiln, area of the kiln, settlement area with homestead vegetation, road network, river network, other water bodies, area of the agricultural land, forest area, hilly area, salt bed area, runway/airport, and other major institutional features.

After the preparation of GIS based land use and land classification, the shape files were further verified upon overlaying on the Google images; individual shape files were also created for each of the brick kilns. At the final stage of the GIS analyses, maps were prepared with standard mapping parameters. A total of 3341 maps were generated to represent the study sites. These maps were combined together with designated legends to prepare a comprehensive LULC atlas. In addition, a customized GIS database tool was developed to visually interpret the brick kilns through simple query building. Advanced level of analysis and interpretation is also possible in any GIS software with this developed geodatabase. The software and maps are stored in the laboratory of the DoE.

In this report the latest number of district-wise brick kilns is provided in Table 15. Geo-positions of the brick kilns in Dhaka and its vicinity, division-wise proportion of brick kiln technology, examples of creation of 1.0 km buffer zone around brick kilns, and a sample of creation of LULC maps are provided and shown respectively in Appendix-A, Appendix-B, Appendix-C and Appendix-D. The brick kiln density around Dhaka city, and in the country are provided respectively in Figure 18 and Figure 19.

Figure 18 Brick kilns around Dhaka city

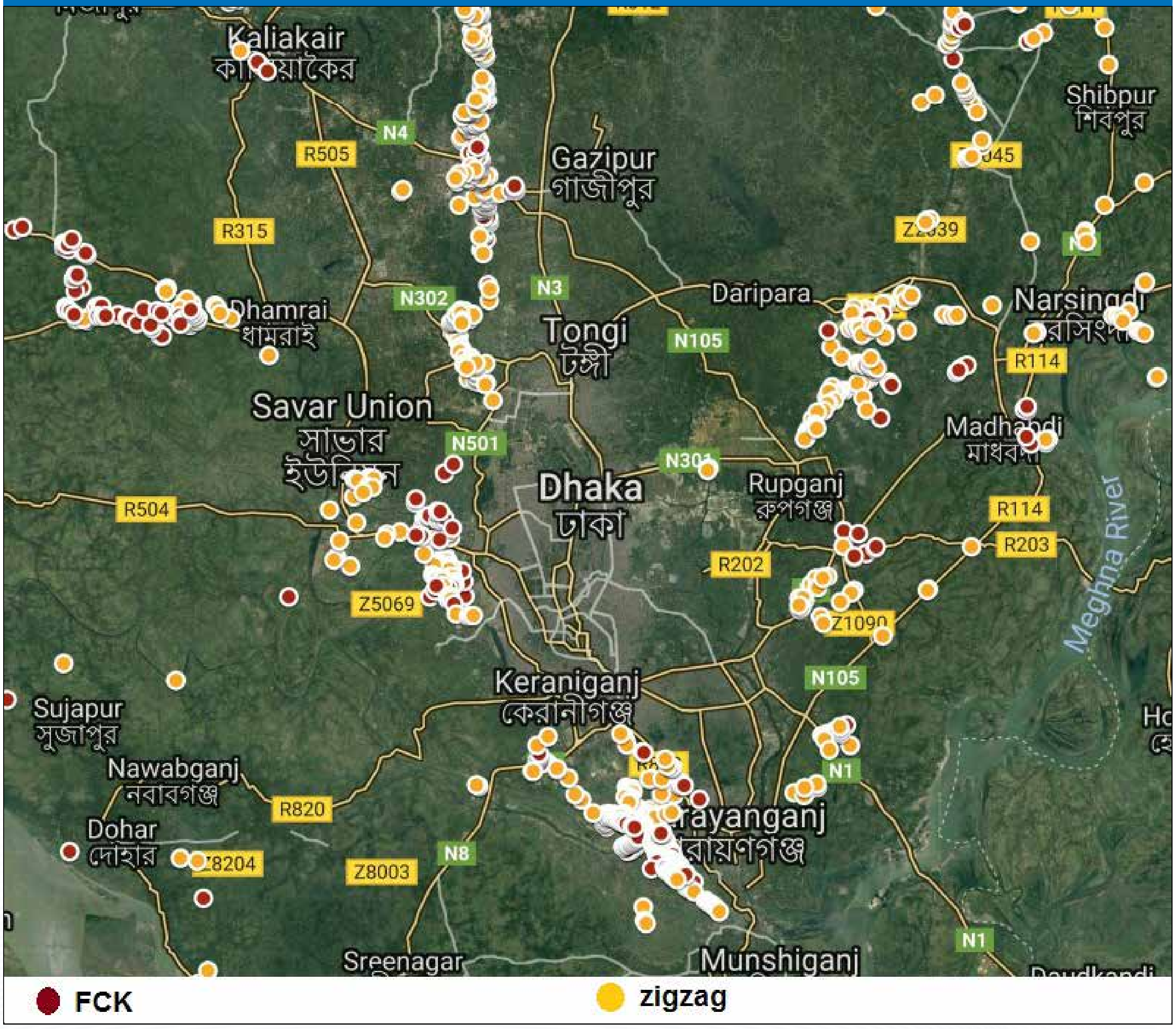


Figure 19 Brick kiln locations throughout the country

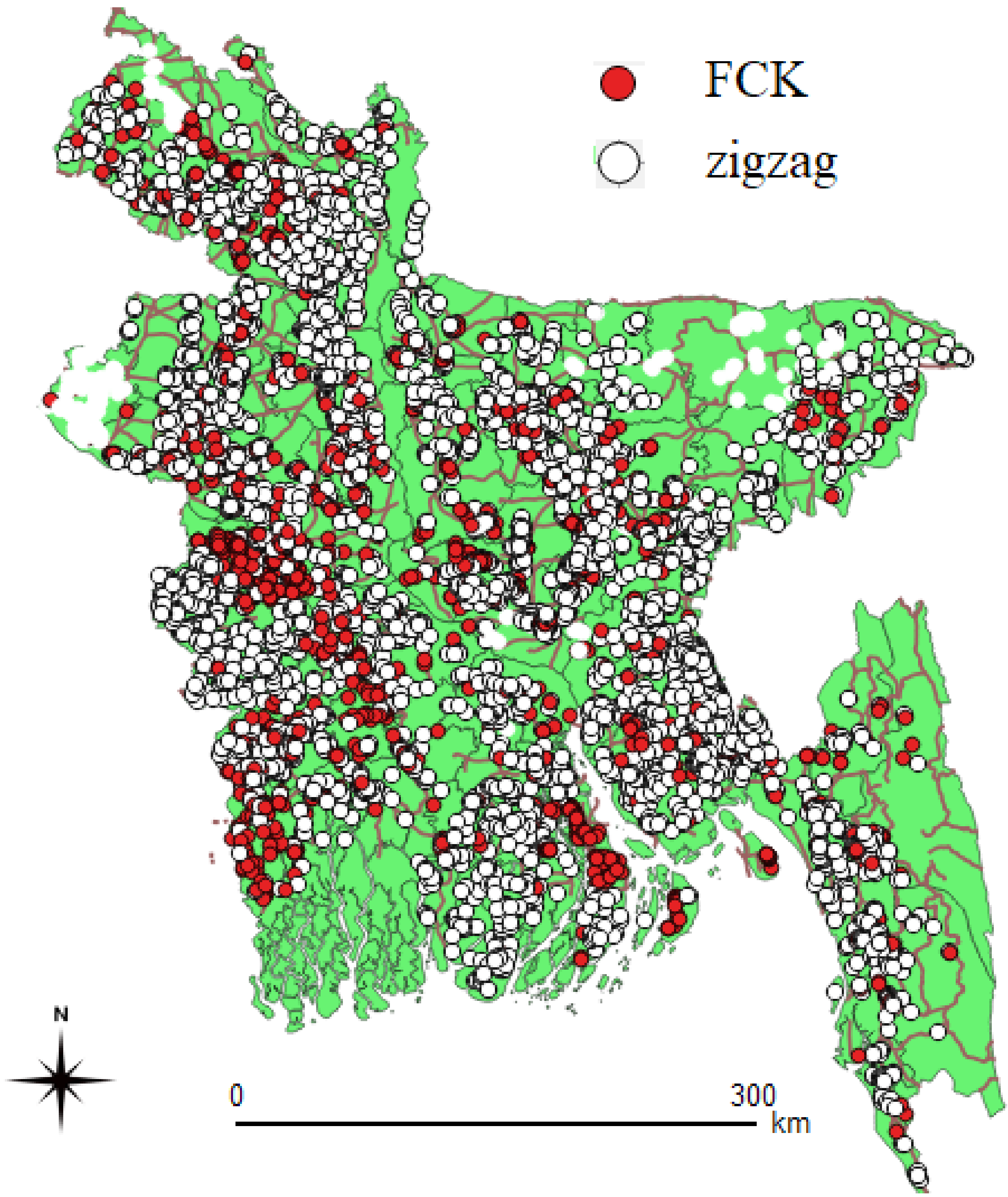


Table 15 District-wise brick kiln numbers

District Name	Brick Kiln Number According to this inventory			District Name	Brick Kiln Number According to this inventory		
Dhaka Division (incl. Mymensingh)	**Active**	**Inactive**	**Total**	**Rajshahi Division** (Incl. Rangpur)	**Active**	**Inactive**	**Total**
Dhaka	371	116	487	Bogura	221	0	221
Faridpur	100	4	104	C. Nababganj	142	9	151
Gazipur	298	44	342	Joypurhat	42	5	47
Gopalganj	22	1	23	Pabna	174	0	174
Jamalpur	79	4	83	Naogaon	169	8	177
Kishoreganj	89	12	101	Natore	135	0	135
Madaripur	64	1	65	Rajshahi	155	7	162
Manikganj	93	32	125	Sirajganj	110	3	113
Munshiganj	79	8	87	Dinajpur	200	11	211
Mymensingh	256	8	264	Gaibandha	123	25	148
Narayanganj	236	25	261	Kurigram	80	1	81
Narsingdi	137	26	163	Lalmonirhat	33	1	34
Netrakona	43	4	47	Nilphamari	45	3	48
Rajbari	68	8	76	Panchagarh	34	1	35
Shariatpur	44	0	44	Rangpur	171	45	216
Sherpur	33	8	41	Thakurgaon	70	8	78
Tangail	127	47	174				
Sub-Total	**2139**	**348**	**2487**	**Sub-Total**	**1904**	**127**	**2031**
Chittagong Division				**Khulna Division**			
Bandarban	31	15	46	Bagerhat	35	3	38
Brahmanbaria	134	20	154	Chuadanga	91	5	96
Chandpur	112	5	117	Jessore	171	12	183
Chattagram	417	14	431	Jhenaidah	100	5	105
Cumilla	253	18	271	Khulna	133	1	134
Cox's Bazar	72	13	85	Kushtia	182	10	192
Feni	99	3	102	Magura	73	2	75
Khagrachhari	32	0	32	Meherpur	86	1	87
Lakshmipur	110	0	110	Narail	50	3	53
Noakhali	138	0	138	Satkhira	114	4	118

Table 15 District-wise brick kiln numbers

District Name	Brick Kiln Number According to this inventory			District Name	Brick Kiln Number According to this inventory		
Rangamati	10	12	22				
Sub-Total	**1408**	**100**	**1508**		**1035**	**46**	**1081**
District Name	Brick Kiln Number According to this inventory			**District Name**	Brick Kiln Number According to this inventory		
Barisal Division	**Active**	**Inactive**	**Total**	**Sylhet Division**	**Active**	**Inactive**	**Total**
Barguna	56	0	56	Habiganj	92	1	93
Barishal	193	5	198	Maulvibazar	78	0	78
Bhola	89	2	91	Sunamganj	21	0	21
Jhalokati	44	0	44	Sylhet	93	1	94
Patuakhali	77	1	78				
Pirojpur	42	0	42				
Sub-Total	**501**	**8**	**509**	**Sub-Total**	**284**	**2**	**286**
Grand Total					**7271**	**631**	**7902**

8 RECOMMENDATIONS

The CASE Project has gained a lot of knowledge on the ongoing practices in the brick manufacturing sectors. It has also produced scores of data and information on the same. On the basis of these, following recommendations are made to reduce the emissions from the brick kilns in the country,

a. The existing emission standards of brick kilns should be revised. Currently, the PM emission standard of brick kiln is 1000 mg/Nm^3. Addition to the SPM, SO_2 emission standard should also be set for the brick kilns.

b. Regular inspection and enforcement programs should be conducted to audit the emission compliance of the brick kilns.

c. Clustering of brick kilns creates great problem – the sum of the emissions from all the kilns in a cluster could impact greatly on the nearby town/ settlements even if individual kiln within the cluster complies with the emission standard. To overcome this problem, dispersion of emissions from the kilns (including new one which has applied for permission) situated within an area should be modeled to calculate combined effect on the nearby airsheds before granting permission to the new kiln. Or, possible addition of pollutant concentrations due to the establishment of a new brick kiln around a place/area should be determined using dispersion modeling approach before granting permissions to the new kiln.

d. Operation and maintenance of the sophisticated technologies (IZK, HHK, and TK) should be done properly. This is to note that the emitting pattern of the FCK and Zigzag kilns are different from HHK and TK. While the first ones are point sources releasing gases through narrow outlets at 125 feet high from the ground, the later ones are volume sources releasing gases through a vast area which dilutes the emitting gases to some extent. Thus, the concentration of SPM or SO_2 from HHK or TK could be low at first view, but the overall emissions per second from badly operated HHK or TK could be substantial to affect nearby settlements. As the brick production capacity of TK is high, total emissions produced per second from this type of kiln could also be high. A well managed HHK or TK utilizes a major portion of this hot emission internally for drying the green bricks, allowing a little of the emission gases to the atmosphere.

APPENDIX – A

THANA WISE BRICK KILNS IN DHAKA AND ITS VICINITY

District	Thana	Kiln Id	Lon	Lat	Thana	Kiln Id	Lon	Lat
Dahaka	Dhamrai	Kiln 001	90.05	23.97	Dhamrai	Kiln 047	90.09	23.92
		Kiln 002	90.06	23.97		Kiln 048	90.09	23.92
		Kiln 003	90.05	23.97		Kiln 049	90.09	23.92
		Kiln 004	90.06	23.97		Kiln 050	90.21	23.90
		Kiln 005	90.06	23.97		Kiln 051	90.19	23.92
		Kiln 006	90.06	23.97		Kiln 052	90.16	23.98
		Kiln 007	90.08	23.99		Kiln 053	90.10	23.95
		Kiln 008	90.08	23.99		Kiln 054	90.10	23.95
		Kiln 009	90.08	23.99		Kiln 055	90.10	23.95
		Kiln 010	90.08	23.98		Kiln 056	90.10	23.96
		Kiln 011	90.08	24.00		Kiln 057	90.08	23.97
		Kiln 012	90.08	24.00		Kiln 058	90.09	23.96
		Kiln 013	90.08	24.00		Kiln 059	90.14	23.91
		Kiln 014	90.08	23.98		Kiln 060	90.14	23.91
		Kiln 015	90.08	23.98		Kiln 061	90.15	23.91
		Kiln 016	90.19	23.97		Kiln 062	90.14	23.89
		Kiln 017	90.20	23.95		Kiln 063	90.14	23.90
		Kiln 018	90.20	23.96		Kiln 064	90.14	23.90
		Kiln 019	90.20	23.96		Kiln 065	90.14	23.90
		Kiln 020	90.20	23.96		Kiln 066	90.14	23.90
		Kiln 021	90.18	23.98		Kiln 067	90.15	23.90
		Kiln 022	90.21	23.94		Kiln 068	90.14	23.90
		Kiln 023	90.09	23.94		Kiln 069	90.16	23.89
		Kiln 024	90.09	23.94		Kiln 070	90.16	23.88
		Kiln 025	90.09	23.94		Kiln 071	90.15	23.93
		Kiln 026	90.09	23.94		Kiln 072	90.15	23.93
		Kiln 027	90.10	23.93		Kiln 073	90.15	23.95
		Kiln 028	90.09	23.93		Kiln 074	90.15	23.95
		Kiln 029	90.09	23.94		Kiln 075	90.15	23.95
		Kiln 030	90.09	23.94		Kiln 076	90.15	23.95
		Kiln 031	90.09	23.96		Kiln 077	90.15	23.94
		Kiln 032	90.08	23.96		Kiln 078	90.15	23.95
		Kiln 033	90.09	23.96		Kiln 079	90.15	23.95
		Kiln 034	90.09	23.96		Kiln 080	90.17	23.92
		Kiln 035	90.09	23.94		Kiln 081	90.16	23.92
		Kiln 036	90.09	23.94		Kiln 082	90.16	23.92
		Kiln 037	90.09	23.96		Kiln 083	90.16	23.92
		Kiln 038	90.09	23.96		Kiln 084	90.16	23.91
		Kiln 039	90.09	23.95		Kiln 085	90.16	23.91
		Kiln 040	90.08	23.96		Kiln 086	90.16	23.92
		Kiln 041	90.08	23.96		Kiln 087	90.17	23.92
		Kiln 042	90.08	23.96		Kiln 088	90.17	23.92
		Kiln 043	90.09	23.96		Kiln 089	90.17	23.92
		Kiln 044	90.09	23.96		Kiln 090	90.16	23.92
		Kiln 045	90.08	23.91		Kiln 091	90.17	23.92
		Kiln 046	90.09	23.92		Kiln 092	90.16	23.92

Dhaka	Dhamrai	Kiln 093	90.16	23.92	Dhamrai	Kiln 140	90.10	23.91
		Kiln 094	90.16	23.93		Kiln 141	90.15	23.92
		Kiln 095	90.16	23.93		Kiln 142	90.15	23.92
		Kiln 096	90.16	23.92		Kiln 143	90.15	23.92
		Kiln 097	90.16	23.95		Kiln 144	90.16	23.92
		Kiln 098	90.18	23.92		Kiln 145	90.16	23.92
		Kiln 099	90.18	23.92		Kiln 146	90.10	23.91
		Kiln 100	90.18	23.92		Kiln 147	90.11	23.90
		Kiln 101	90.12	23.91		Kiln 148	90.11	23.92
		Kiln 102	90.12	23.91		Kiln 149	90.11	23.92
		Kiln 103	90.13	23.90		Kiln 150	90.11	23.92
		Kiln 104	90.12	23.90		Kiln 151	90.16	23.92
		Kiln 105	90.12	23.90		Kiln 152	90.16	23.91
		Kiln 106	90.12	23.90		Kiln 153	90.16	23.91
		Kiln 107	90.12	23.90		Kiln 154	90.16	23.92
		Kiln 108	90.12	23.89		Kiln 155	90.16	23.92
		Kiln 109	90.12	23.89		Kiln 156	90.13	23.91
		Kiln 110	90.13	23.89		Kiln 157	90.13	23.92
		Kiln 111	90.13	23.89		Kiln 158	90.14	23.91
		Kiln 112	90.13	23.89		Kiln 159	90.13	23.91
		Kiln 113	90.15	23.88		Kiln 160	90.14	23.92
		Kiln 114	90.15	23.88		Kiln 161	90.14	23.92
		Kiln 115	90.15	23.88	Dohar	Kiln 162	90.09	23.61
		Kiln 116	90.10	23.92		Kiln 163	90.17	23.54
		Kiln 117	90.10	23.92		Kiln 164	90.17	23.54
		Kiln 118	90.10	23.92		Kiln 165	90.17	23.59
		Kiln 119	90.10	23.92		Kiln 166	90.16	23.61
		Kiln 120	90.10	23.92		Kiln 167	90.17	23.61
		Kiln 121	90.15	23.93		Kiln 168	90.14	23.64
		Kiln 122	90.12	23.92		Kiln 169	90.15	23.63
		Kiln 123	90.12	23.92		Kiln 170	90.15	23.63
		Kiln 124	90.12	23.92		Kiln 171	90.15	23.63
		Kiln 125	90.14	23.91	Kadamtali	Kiln 172	90.43	23.68
		Kiln 126	90.13	23.91		Kiln 173	90.43	23.68
		Kiln 127	90.13	23.91	Keraniganj	Kiln 174	90.34	23.65
		Kiln 128	90.13	23.91		Kiln 175	90.34	23.65
		Kiln 129	90.13	23.91		Kiln 176	90.25	23.76
		Kiln 130	90.13	23.91		Kiln 177	90.22	23.76
		Kiln 131	90.13	23.91		Kiln 178	90.43	23.67
		Kiln 132	90.09	23.92		Kiln 179	90.44	23.64
		Kiln 133	90.09	23.92		Kiln 180	90.44	23.64
		Kiln 134	90.10	23.92		Kiln 181	90.44	23.63
		Kiln 135	90.09	23.92		Kiln 182	90.41	23.64
		Kiln 136	90.10	23.92		Kiln 183	90.44	23.63
		Kiln 137	90.11	23.92		Kiln 184	90.44	23.63
		Kiln 138	90.11	23.92		Kiln 185	90.43	23.65
		Kiln 139	90.09	23.92		Kiln 186	90.44	23.65

		Kiln 187	90.44	23.65		Kiln 234	90.42	23.63
		Kiln 188	90.44	23.65		Kiln 235	90.42	23.63
		Kiln 189	90.44	23.65		Kiln 236	90.42	23.63
		Kiln 190	90.44	23.65		Kiln 237	90.42	23.63
		Kiln 191	90.44	23.65		Kiln 238	90.42	23.63
		Kiln 192	90.44	23.64		Kiln 239	90.43	23.63
		Kiln 193	90.44	23.64		Kiln 240	90.43	23.63
		Kiln 194	90.43	23.64		Kiln 241	90.43	23.63
		Kiln 195	90.44	23.64		Kiln 242	90.43	23.63
		Kiln 196	90.46	23.64		Kiln 243	90.43	23.63
		Kiln 197	90.44	23.63		Kiln 244	90.43	23.63
		Kiln 198	90.44	23.63		Kiln 245	90.43	23.63
		Kiln 199	90.44	23.63		Kiln 246	90.43	23.63
		Kiln 200	90.45	23.63		Kiln 247	90.43	23.63
		Kiln 201	90.44	23.63		Kiln 248	90.43	23.63
		Kiln 202	90.42	23.63		Kiln 249	90.43	23.63
		Kiln 203	90.42	23.63		Kiln 250	90.44	23.63
		Kiln 204	90.42	23.63		Kiln 251	90.41	23.63
		Kiln 205	90.42	23.63		Kiln 252	90.46	23.65
		Kiln 206	90.42	23.63		Kiln 253	90.46	23.65
		Kiln 207	90.45	23.64		Kiln 254	90.46	23.65
		Kiln 208	90.45	23.63		Kiln 255	90.46	23.65
		Kiln 209	90.45	23.63		Kiln 256	90.46	23.65
Dhaka	**Keraniganj**	Kiln 210	90.45	23.63	**Keraniganj**	Kiln 257	90.46	23.63
		Kiln 211	90.45	23.63		Kiln 258	90.46	23.63
		Kiln 212	90.45	23.63		Kiln 259	90.46	23.63
		Kiln 213	90.45	23.63		Kiln 260	90.47	23.65
		Kiln 214	90.45	23.63		Kiln 261	90.45	23.65
		Kiln 215	90.45	23.63		Kiln 262	90.45	23.65
		Kiln 216	90.46	23.63		Kiln 263	90.46	23.65
		Kiln 217	90.46	23.63		Kiln 264	90.43	23.68
		Kiln 218	90.43	23.63		Kiln 265	90.31	23.76
		Kiln 219	90.44	23.63		Kiln 266	90.39	23.66
		Kiln 220	90.44	23.64		Kiln 267	90.38	23.66
		Kiln 221	90.44	23.67		Kiln 268	90.38	23.67
		Kiln 222	90.45	23.67		Kiln 269	90.38	23.66
		Kiln 223	90.43	23.63		Kiln 270	90.38	23.66
		Kiln 224	90.43	23.63		Kiln 271	90.38	23.67
		Kiln 225	90.43	23.63		Kiln 272	90.38	23.67
		Kiln 226	90.43	23.63		Kiln 273	90.38	23.67
		Kiln 227	90.43	23.63		Kiln 274	90.38	23.67
		Kiln 228	90.43	23.63		Kiln 275	90.38	23.67
		Kiln 229	90.43	23.63		Kiln 276	90.39	23.68
		Kiln 230	90.44	23.63		Kiln 277	90.38	23.66
		Kiln 231	90.44	23.63		Kiln 278	90.40	23.65
		Kiln 232	90.44	23.63		Kiln 279	90.40	23.65
		Kiln 233	90.44	23.63		Kiln 280	90.39	23.66

Dhaka	Keraniganj	Kiln 281	90.39	23.66	Savar	Kiln 328	90.32	23.76
		Kiln 282	90.38	23.66		Kiln 329	90.33	23.77
	Khilkhet	Kiln 283	90.49	23.83		Kiln 330	90.32	23.79
		Kiln 284	90.49	23.83		Kiln 331	90.32	23.79
	Md. Pur	Kiln 285	90.33	23.75		Kiln 332	90.33	23.79
		Kiln 286	90.33	23.76		Kiln 333	90.31	23.79
	Nawabganj	Kiln 287	90.22	23.66		Kiln 334	90.31	23.79
		Kiln 288	90.22	23.67		Kiln 335	90.33	23.91
		Kiln 289	90.23	23.67		Kiln 336	90.33	23.91
		Kiln 290	90.23	23.67		Kiln 337	90.33	23.91
		Kiln 291	90.15	23.63		Kiln 338	90.33	23.90
		Kiln 292	90.12	23.65		Kiln 339	90.33	23.90
		Kiln 293	90.14	23.66		Kiln 340	90.33	23.90
		Kiln 294	90.12	23.65		Kiln 341	90.33	23.90
		Kiln 295	90.13	23.65		Kiln 342	90.33	23.90
		Kiln 296	90.17	23.68		Kiln 343	90.33	23.89
		Kiln 297	90.05	23.70		Kiln 344	90.33	23.89
		Kiln 298	90.28	23.68		Kiln 345	90.33	23.89
		Kiln 299	90.15	23.64		Kiln 346	90.34	23.89
		Kiln 300	90.15	23.63		Kiln 347	90.34	23.88
		Kiln 301	90.08	23.72		Kiln 348	90.34	23.88
		Kiln 302	90.09	23.71		Kiln 349	90.34	23.88
		Kiln 303	90.08	23.71		Kiln 350	90.34	23.88
		Kiln 304	90.15	23.71		Kiln 351	90.35	23.88
	Savar	Kiln 305	90.32	23.78		Kiln 352	90.34	23.88
		Kiln 306	90.32	23.78		Kiln 353	90.34	23.88
		Kiln 307	90.32	23.78		Kiln 354	90.34	23.88
		Kiln 308	90.32	23.78		Kiln 355	90.34	23.88
		Kiln 309	90.32	23.78		Kiln 356	90.34	23.89
		Kiln 310	90.32	23.77		Kiln 357	90.35	23.89
		Kiln 311	90.32	23.77		Kiln 358	90.35	23.89
		Kiln 312	90.32	23.78		Kiln 359	90.34	23.89
		Kiln 313	90.32	23.78		Kiln 360	90.34	23.89
		Kiln 314	90.32	23.78		Kiln 361	90.34	23.89
		Kiln 315	90.32	23.78		Kiln 362	90.34	23.89
		Kiln 316	90.33	23.77		Kiln 363	90.34	23.89
		Kiln 317	90.33	23.77		Kiln 364	90.34	23.89
		Kiln 318	90.33	23.77		Kiln 365	90.34	23.89
		Kiln 319	90.33	23.77		Kiln 366	90.35	23.88
		Kiln 320	90.32	23.77		Kiln 367	90.34	23.89
		Kiln 321	90.32	23.77		Kiln 368	90.29	23.80
		Kiln 322	90.32	23.77		Kiln 369	90.31	23.81
		Kiln 323	90.33	23.77		Kiln 370	90.27	23.82
		Kiln 324	90.33	23.77		Kiln 371	90.27	23.83
		Kiln 325	90.33	23.77		Kiln 372	90.28	23.83
		Kiln 326	90.33	23.77		Kiln 373	90.28	23.83
		Kiln 327	90.33	23.76		Kiln 374	90.30	23.81

Dhaka	Savar	Kiln 375	90.30	23.81	Savar	Kiln 422	90.31	23.80
		Kiln 376	90.26	23.78		Kiln 423	90.31	23.80
		Kiln 377	90.32	23.78		Kiln 424	90.31	23.80
		Kiln 378	90.31	23.78		Kiln 425	90.32	23.80
		Kiln 379	90.31	23.77		Kiln 426	90.32	23.80
		Kiln 380	90.32	23.77		Kiln 427	90.31	23.80
		Kiln 381	90.32	23.77		Kiln 428	90.31	23.80
		Kiln 382	90.32	23.77		Kiln 429	90.32	23.80
		Kiln 383	90.32	23.77		Kiln 430	90.32	23.80
		Kiln 384	90.32	23.77		Kiln 431	90.32	23.80
		Kiln 385	90.32	23.76		Kiln 432	90.32	23.81
		Kiln 386	90.32	23.76		Kiln 433	90.32	23.81
		Kiln 387	90.32	23.76		Kiln 434	90.33	23.80
		Kiln 388	90.32	23.76		Kiln 435	90.24	23.92
		Kiln 389	90.32	23.76		Kiln 436	90.22	24.01
		Kiln 390	90.32	23.76		Kiln 437	90.22	23.99
		Kiln 391	90.32	23.76		Kiln 438	90.21	23.98
		Kiln 392	90.32	23.76		Kiln 439	90.21	23.98
		Kiln 393	90.33	23.76		Kiln 440	90.21	23.98
		Kiln 394	90.33	23.75		Kiln 441	90.20	23.98
		Kiln 395	90.33	23.75		Kiln 442	90.19	23.99
		Kiln 396	90.34	23.75		Kiln 443	90.22	24.01
		Kiln 397	90.34	23.75		Kiln 444	90.23	23.99
		Kiln 398	90.34	23.75		Kiln 445	90.23	23.99
		Kiln 399	90.32	23.83		Kiln 446	90.20	24.01
		Kiln 400	90.35	23.87		Kiln 447	90.19	24.01
		Kiln 401	90.33	23.83		Kiln 448	90.25	23.81
		Kiln 402	90.24	23.94		Kiln 449	90.31	23.78
		Kiln 403	90.32	23.80		Kiln 450	90.31	23.79
		Kiln 404	90.32	23.80		Kiln 451	90.30	23.79
		Kiln 405	90.32	23.80		Kiln 452	90.29	23.79
		Kiln 406	90.32	23.80		Kiln 453	90.28	23.79
		Kiln 407	90.32	23.80		Kiln 454	90.30	23.79
		Kiln 408	90.32	23.80		Kiln 455	90.25	23.78
		Kiln 409	90.32	23.80		Kiln 456	90.25	23.78
		Kiln 410	90.31	23.80		Kiln 457	90.27	23.80
		Kiln 411	90.31	23.80		Kiln 458	90.26	23.79
		Kiln 412	90.32	23.80		Kiln 459	90.26	23.82
		Kiln 413	90.31	23.80		Kiln 460	90.27	23.83
		Kiln 414	90.31	23.80		Kiln 461	90.27	23.82
		Kiln 415	90.31	23.80		Kiln 462	90.27	23.82
		Kiln 416	90.31	23.79		Kiln 463	90.28	23.82
		Kiln 417	90.31	23.79		Kiln 464	90.28	23.82
		Kiln 418	90.31	23.79		Kiln 465	90.27	23.82
		Kiln 419	90.32	23.79		Kiln 466	90.33	23.92
		Kiln 420	90.32	23.79		Kiln 467	90.33	23.92
		Kiln 421	90.31	23.80		Kiln 468	90.33	23.92

Dhaka	Savar	Kiln 469	90.34	23.92	Gazipur Sadar	Kiln 516	90.35	23.99
		Kiln 470	90.34	23.92		Kiln 517	90.34	24.00
		Kiln 471	90.35	23.94		Kiln 518	90.34	24.00
		Kiln 472	90.34	23.96		Kiln 519	90.34	24.00
		Kiln 473	90.33	23.92		Kiln 520	90.35	24.00
		Kiln 474	90.34	23.92		Kiln 521	90.34	24.00
		Kiln 475	90.34	23.92		Kiln 522	90.34	24.00
		Kiln 476	90.34	23.92		Kiln 523	90.35	24.00
		Kiln 477	90.34	23.92		Kiln 524	90.35	24.00
		Kiln 478	90.33	23.92		Kiln 525	90.35	24.00
		Kiln 479	90.33	23.92		Kiln 526	90.34	24.00
		Kiln 480	90.33	23.92		Kiln 527	90.34	24.00
		Kiln 481	90.33	23.92		Kiln 528	90.34	24.00
		Kiln 482	90.33	23.92		Kiln 529	90.34	24.00
		Kiln 483	90.33	23.92		Kiln 530	90.36	23.99
		Kiln 484	90.33	23.92		Kiln 531	90.37	23.99
		Kiln 485	90.33	23.92		Kiln 532	90.37	23.99
		Kiln 486	90.33	23.91		Kiln 533	90.37	23.99
Gazipur	Sadar	Kiln 487	90.35	23.96		Kiln 534	90.35	23.95
		Kiln 488	90.35	23.96		Kiln 535	90.35	23.93
		Kiln 489	90.35	23.97		Kiln 536	90.35	23.93
		Kiln 490	90.35	23.97		Kiln 537	90.35	23.96
		Kiln 491	90.35	23.97		Kiln 538	90.29	23.99
		Kiln 492	90.35	23.97		Kiln 539	90.30	23.99
		Kiln 493	90.35	23.98		Kiln 540	90.33	23.98
		Kiln 494	90.34	23.98		Kiln 541	90.35	24.04
		Kiln 495	90.35	23.98		Kiln 542	90.35	24.05
		Kiln 496	90.34	23.96		Kiln 543	90.35	24.05
		Kiln 497	90.35	23.97		Kiln 544	90.35	24.05
		Kiln 498	90.35	23.98		Kiln 545	90.35	24.05
		Kiln 499	90.34	23.98		Kiln 546	90.35	24.05
		Kiln 500	90.35	23.98		Kiln 547	90.35	24.07
		Kiln 501	90.35	23.98		Kiln 548	90.35	24.07
		Kiln 502	90.35	23.98		Kiln 549	90.35	24.07
		Kiln 503	90.34	23.98		Kiln 550	90.34	24.07
		Kiln 504	90.35	23.98		Kiln 551	90.35	24.07
		Kiln 505	90.35	23.98		Kiln 552	90.34	24.07
		Kiln 506	90.35	23.99		Kiln 553	90.34	24.07
		Kiln 507	90.35	23.99		Kiln 554	90.34	24.08
		Kiln 508	90.35	23.99		Kiln 555	90.34	24.08
		Kiln 509	90.34	23.99		Kiln 556	90.35	24.04
		Kiln 510	90.35	23.99		Kiln 557	90.35	24.05
		Kiln 511	90.33	24.00		Kiln 558	90.34	24.05
		Kiln 512	90.35	23.99		Kiln 559	90.34	24.05
		Kiln 513	90.35	23.99		Kiln 560	90.34	24.05
		Kiln 514	90.36	23.99		Kiln 561	90.34	24.05
		Kiln 515	90.34	23.99		Kiln 562	90.34	24.04

Gazipur	**Sadar**	Kiln 563	90.34	24.04	**Gazipur Sadar**	Kiln 610	90.34	24.01
		Kiln 564	90.34	24.05		Kiln 611	90.34	24.01
		Kiln 565	90.34	24.01		Kiln 612	90.34	24.01
		Kiln 566	90.34	24.01		Kiln 613	90.34	24.01
		Kiln 567	90.34	24.01		Kiln 614	90.34	24.01
		Kiln 568	90.34	24.01		Kiln 615	90.34	24.01
		Kiln 569	90.34	24.02		Kiln 616	90.34	24.01
		Kiln 570	90.34	24.02		Kiln 617	90.34	24.01
		Kiln 571	90.34	24.02		Kiln 618	90.34	24.01
		Kiln 572	90.34	24.02		Kiln 619	90.34	24.01
		Kiln 573	90.34	24.02		Kiln 620	90.34	24.01
		Kiln 574	90.34	24.02		Kiln 621	90.34	24.01
		Kiln 575	90.34	24.02		Kiln 622	90.34	24.01
		Kiln 576	90.34	24.02		Kiln 623	90.34	24.00
		Kiln 577	90.34	24.02		Kiln 624	90.34	24.00
		Kiln 578	90.34	24.02		Kiln 625	90.34	24.00
		Kiln 579	90.34	24.02		Kiln 626	90.34	24.01
		Kiln 580	90.34	24.02		Kiln 627	90.33	24.03
		Kiln 581	90.34	24.02		Kiln 628	90.34	24.03
		Kiln 582	90.34	24.02		Kiln 629	90.34	24.04
		Kiln 583	90.34	24.02		Kiln 630	90.34	24.04
		Kiln 584	90.34	24.02		Kiln 631	90.34	24.04
		Kiln 585	90.34	24.02		Kiln 632	90.34	24.04
		Kiln 586	90.34	24.02		Kiln 633	90.33	24.04
		Kiln 587	90.33	24.02		Kiln 634	90.33	24.04
		Kiln 588	90.33	24.02		Kiln 635	90.34	24.04
		Kiln 589	90.33	24.02		Kiln 636	90.34	24.04
		Kiln 590	90.34	24.02		Kiln 637	90.34	24.04
		Kiln 591	90.34	24.02		Kiln 638	90.34	24.04
		Kiln 592	90.34	24.03		Kiln 639	90.33	24.00
		Kiln 593	90.34	24.03		Kiln 640	90.33	24.00
		Kiln 594	90.34	24.03		Kiln 641	90.33	24.00
		Kiln 595	90.33	24.03		Kiln 642	90.33	24.00
		Kiln 596	90.34	24.03		Kiln 643	90.31	24.01
		Kiln 597	90.34	24.03		Kiln 644	90.35	24.10
		Kiln 598	90.34	24.03		Kiln 645	90.35	24.11
		Kiln 599	90.34	24.03		Kiln 646	90.35	24.11
		Kiln 600	90.34	24.03		Kiln 647	90.35	24.11
		Kiln 601	90.34	24.03		Kiln 648	90.36	24.11
		Kiln 602	90.34	24.02		Kiln 649	90.34	24.08
		Kiln 603	90.34	24.03		Kiln 650	90.34	24.08
		Kiln 604	90.32	24.03		Kiln 651	90.34	24.08
		Kiln 605	90.34	24.00		Kiln 652	90.34	24.08
		Kiln 606	90.34	24.00		Kiln 653	90.34	24.08
		Kiln 607	90.34	24.00		Kiln 654	90.34	24.08
		Kiln 608	90.34	24.00		Kiln 655	90.34	24.08
		Kiln 609	90.34	24.00		Kiln 656	90.34	24.08

Gazipur	Sadar	Kiln 657	90.34	24.08	Kaliakoir	Kiln 704	90.21	24.01
		Kiln 658	90.34	24.08		Kiln 705	90.21	24.01
		Kiln 659	90.34	24.09		Kiln 706	90.19	24.02
		Kiln 660	90.34	24.09		Kiln 707	90.18	24.04
		Kiln 661	90.34	24.09		Kiln 708	90.18	24.04
		Kiln 662	90.34	24.09		Kiln 709	90.19	24.04
		Kiln 663	90.34	24.09		Kiln 710	90.19	24.05
		Kiln 664	90.34	24.09		Kiln 711	90.34	24.11
		Kiln 665	90.34	24.09		Kiln 712	90.34	24.12
		Kiln 666	90.34	24.09		Kiln 713	90.35	24.13
		Kiln 667	90.34	24.09		Kiln 714	90.35	24.13
		Kiln 668	90.34	24.09		Kiln 715	90.35	24.14
		Kiln 669	90.34	24.09		Kiln 716	90.35	24.14
		Kiln 670	90.34	24.10		Kiln 717	90.22	24.10
		Kiln 671	90.34	24.09		Kiln 718	90.24	24.10
		Kiln 672	90.34	24.10		Kiln 719	90.34	24.09
		Kiln 673	90.34	24.10		Kiln 720	90.34	24.09
		Kiln 674	90.34	24.10		Kiln 721	90.33	24.09
		Kiln 675	90.33	24.10		Kiln 722	90.33	24.09
		Kiln 676	90.34	24.10		Kiln 723	90.34	24.08
		Kiln 677	90.34	24.10		Kiln 724	90.34	24.08
		Kiln 678	90.34	24.10		Kiln 725	90.34	24.08
		Kiln 679	90.34	24.10		Kiln 726	90.26	24.10
		Kiln 680	90.34	24.10		Kiln 727	90.21	24.06
		Kiln 681	90.34	24.10		Kiln 728	90.20	24.06
		Kiln 682	90.34	24.10		Kiln 729	90.20	24.08
		Kiln 683	90.34	24.10		Kiln 730	90.19	24.07
		Kiln 684	90.34	24.10		Kiln 731	90.19	24.10
		Kiln 685	90.34	24.10		Kiln 732	90.19	24.10
		Kiln 686	90.34	24.10		Kiln 733	90.18	24.11
		Kiln 687	90.34	24.10		Kiln 734	90.18	24.11
		Kiln 688	90.34	24.10		Kiln 735	90.18	24.11
		Kiln 689	90.34	24.10		Kiln 736	90.18	24.11
		Kiln 690	90.35	24.10		Kiln 737	90.18	24.11
		Kiln 691	90.34	24.11		Kiln 738	90.18	24.11
		Kiln 692	90.34	24.10		Kiln 739	90.18	24.10
		Kiln 693	90.34	24.11		Kiln 740	90.19	24.10
		Kiln 694	90.34	24.11		Kiln 741	90.18	24.11
		Kiln 695	90.34	24.11		Kiln 742	90.18	24.11
		Kiln 696	90.34	24.11		Kiln 743	90.18	24.11
		Kiln 697	90.34	24.11		Kiln 744	90.19	24.10
	Kaliakoir	Kiln 698	90.20	24.01		Kiln 745	90.19	24.10
		Kiln 699	90.19	24.02		Kiln 746	90.19	24.10
		Kiln 700	90.19	24.04		Kiln 747	90.19	24.10
		Kiln 701	90.19	24.04		Kiln 748	90.20	24.08
		Kiln 702	90.22	24.02		Kiln 749	90.21	24.06
		Kiln 703	90.21	24.01	Kaliganj	Kiln 750	90.66	24.02

		Kiln 751	90.66	24.02		Kiln 798	90.56	24.26
		Kiln 752	90.62	24.04		Kiln 799	90.54	24.27
		Kiln 753	90.56	23.90		Kiln 800	90.53	24.26
		Kiln 754	90.56	23.91		Kiln 801	90.54	24.26
		Kiln 755	90.58	23.92		Kiln 802	90.56	24.25
		Kiln 756	90.58	23.92		Kiln 803	90.56	24.25
	Kaliganj	Kiln 757	90.58	23.92		Kiln 804	90.59	24.26
		Kiln 758	90.61	23.93		Kiln 805	90.59	24.25
		Kiln 759	90.61	23.93	Kapasia	Kiln 806	90.59	24.25
		Kiln 760	90.60	23.93		Kiln 807	90.54	24.15
		Kiln 761	90.60	23.93		Kiln 808	90.54	24.15
		Kiln 762	90.60	23.93		Kiln 809	90.55	24.15
		Kiln 763	90.59	23.93		Kiln 810	90.55	24.15
		Kiln 764	90.62	23.94		Kiln 811	90.55	24.15
		Kiln 765	90.60	24.10		Kiln 812	90.54	24.15
		Kiln 766	90.60	24.10		Kiln 813	90.59	24.11
		Kiln 767	90.60	24.10		Kiln 814	90.58	24.11
		Kiln 768	90.65	24.04		Kiln 815	90.58	24.11
		Kiln 769	90.65	24.05		Kiln 816	90.54	24.24
		Kiln 770	90.65	24.05		Kiln 817	90.54	24.24
		Kiln 771	90.63	24.05		Kiln 818	90.54	24.24
		Kiln 772	90.65	24.05		Kiln 819	90.53	24.24
		Kiln 773	90.64	24.05		Kiln 820	90.51	24.27
Gazipur		Kiln 774	90.64	24.07		Kiln 821	90.52	24.27
		Kiln 775	90.59	24.11	Sripur	Kiln 822	90.48	24.27
		Kiln 776	90.59	24.11		Kiln 823	90.54	24.19
		Kiln 777	90.59	24.10		Kiln 824	90.54	24.28
		Kiln 778	90.68	24.17		Kiln 825	90.49	24.32
		Kiln 779	90.67	24.17		Kiln 826	90.48	24.31
		Kiln 780	90.55	24.11		Kiln 827	90.49	24.31
	Kapasia	Kiln 781	90.55	24.14		Kiln 828	90.49	24.32
		Kiln 782	90.58	24.11				
		Kiln 783	90.62	24.11				
		Kiln 784	90.55	24.22				
		Kiln 785	90.64	24.11				
		Kiln 786	90.64	24.11				
		Kiln 787	90.68	24.11				
		Kiln 788	90.63	24.07				
		Kiln 789	90.63	24.07				
		Kiln 790	90.64	24.08				
		Kiln 791	90.64	24.08				
		Kiln 792	90.64	24.09				
		Kiln 793	90.64	24.09				
		Kiln 794	90.64	24.09				
		Kiln 795	90.64	24.09				
		Kiln 796	90.56	24.25				
		Kiln 797	90.56	24.26				

Narayanganj	Araihazar	Kiln 829	90.65	23.79	Sadar	Kiln 876	90.49	23.58
		Kiln 830	90.62	23.76		Kiln 877	90.49	23.58
		Kiln 831	90.62	23.76		Kiln 878	90.49	23.58
	Bandar	Kiln 832	90.54	23.65		Kiln 879	90.49	23.58
		Kiln 833	90.56	23.68		Kiln 880	90.49	23.58
		Kiln 834	90.56	23.68		Kiln 881	90.49	23.58
		Kiln 835	90.56	23.68		Kiln 882	90.49	23.58
		Kiln 836	90.55	23.69		Kiln 883	90.45	23.62
		Kiln 837	90.55	23.68		Kiln 884	90.45	23.62
		Kiln 838	90.57	23.67		Kiln 885	90.45	23.62
		Kiln 839	90.56	23.68		Kiln 886	90.45	23.62
		Kiln 840	90.56	23.68		Kiln 887	90.45	23.62
		Kiln 841	90.57	23.69		Kiln 888	90.44	23.62
		Kiln 842	90.56	23.68		Kiln 889	90.44	23.62
		Kiln 843	90.57	23.68		Kiln 890	90.44	23.62
		Kiln 844	90.57	23.68		Kiln 891	90.44	23.62
		Kiln 845	90.57	23.68		Kiln 892	90.44	23.62
		Kiln 846	90.57	23.68		Kiln 893	90.44	23.61
		Kiln 847	90.57	23.68		Kiln 894	90.44	23.61
		Kiln 848	90.57	23.68		Kiln 895	90.44	23.61
		Kiln 849	90.56	23.70		Kiln 896	90.44	23.61
		Kiln 850	90.56	23.70		Kiln 897	90.44	23.61
		Kiln 851	90.56	23.70		Kiln 898	90.45	23.62
		Kiln 852	90.56	23.71		Kiln 899	90.45	23.63
		Kiln 853	90.55	23.65		Kiln 900	90.45	23.63
		Kiln 854	90.55	23.65		Kiln 901	90.44	23.63
		Kiln 855	90.55	23.65		Kiln 902	90.44	23.63
		Kiln 856	90.55	23.65		Kiln 903	90.44	23.63
		Kiln 857	90.55	23.65		Kiln 904	90.45	23.63
		Kiln 858	90.55	23.65		Kiln 905	90.45	23.63
		Kiln 859	90.55	23.64		Kiln 906	90.45	23.63
		Kiln 860	90.55	23.65		Kiln 907	90.45	23.63
		Kiln 861	90.54	23.65		Kiln 908	90.44	23.63
		Kiln 862	90.55	23.65		Kiln 909	90.44	23.63
		Kiln 863	90.54	23.65		Kiln 910	90.44	23.63
		Kiln 864	90.56	23.68		Kiln 911	90.44	23.63
		Kiln 865	90.56	23.67		Kiln 912	90.44	23.63
		Kiln 866	90.56	23.67		Kiln 913	90.44	23.62
		Kiln 867	90.53	23.65		Kiln 914	90.44	23.62
	Sadar	Kiln 868	90.47	23.59		Kiln 915	90.44	23.62
		Kiln 869	90.47	23.59		Kiln 916	90.44	23.62
		Kiln 870	90.47	23.60		Kiln 917	90.45	23.62
		Kiln 871	90.47	23.60		Kiln 918	90.43	23.62
		Kiln 872	90.48	23.60		Kiln 919	90.43	23.62
		Kiln 873	90.48	23.59		Kiln 920	90.44	23.62
		Kiln 874	90.48	23.59		Kiln 921	90.44	23.62
		Kiln 875	90.48	23.58		Kiln 922	90.44	23.62

Narayanganj	**Sadar**	Kiln 923	90.44	23.62	**Sadar**	Kiln 970	90.45	23.61
		Kiln 924	90.44	23.62		Kiln 971	90.45	23.60
		Kiln 925	90.44	23.62		Kiln 972	90.46	23.60
		Kiln 926	90.44	23.62		Kiln 973	90.46	23.60
		Kiln 927	90.44	23.63		Kiln 974	90.46	23.60
		Kiln 928	90.46	23.62		Kiln 975	90.46	23.60
		Kiln 929	90.46	23.62		Kiln 976	90.46	23.60
		Kiln 930	90.46	23.62		Kiln 977	90.46	23.60
		Kiln 931	90.46	23.62		Kiln 978	90.47	23.60
		Kiln 932	90.46	23.62		Kiln 979	90.47	23.60
		Kiln 933	90.46	23.62		Kiln 980	90.45	23.58
		Kiln 934	90.46	23.62		Kiln 981	90.45	23.57
		Kiln 935	90.46	23.61		Kiln 982	90.45	23.57
		Kiln 936	90.46	23.61		Kiln 983	90.46	23.63
		Kiln 937	90.46	23.61		Kiln 984	90.46	23.64
		Kiln 938	90.46	23.61		Kiln 985	90.46	23.62
		Kiln 939	90.46	23.61		Kiln 986	90.46	23.62
		Kiln 940	90.46	23.61		Kiln 987	90.46	23.62
		Kiln 941	90.46	23.61		Kiln 988	90.46	23.62
		Kiln 942	90.46	23.61		Kiln 989	90.47	23.65
		Kiln 943	90.46	23.61		Kiln 990	90.47	23.65
		Kiln 944	90.46	23.61		Kiln 991	90.47	23.65
		Kiln 945	90.47	23.61		Kiln 992	90.47	23.65
		Kiln 946	90.46	23.61		Kiln 993	90.48	23.64
		Kiln 947	90.46	23.60		Kiln 994	90.46	23.66
		Kiln 948	90.47	23.60		Kiln 995	90.46	23.66
		Kiln 949	90.47	23.60		Kiln 996	90.46	23.66
		Kiln 950	90.47	23.60		Kiln 997	90.46	23.67
		Kiln 951	90.47	23.60		Kiln 998	90.46	23.67
		Kiln 952	90.47	23.60	**Rupganj**	Kiln 999	90.59	23.87
		Kiln 953	90.47	23.60		Kiln 1000	90.59	23.87
		Kiln 954	90.47	23.60		Kiln 1001	90.59	23.87
		Kiln 955	90.47	23.60		Kiln 1002	90.59	23.89
		Kiln 956	90.45	23.62		Kiln 1003	90.59	23.88
		Kiln 957	90.45	23.62		Kiln 1004	90.59	23.88
		Kiln 958	90.45	23.62		Kiln 1005	90.59	23.88
		Kiln 959	90.45	23.62		Kiln 1006	90.58	23.88
		Kiln 960	90.45	23.62		Kiln 1007	90.58	23.88
		Kiln 961	90.45	23.62		Kiln 1008	90.58	23.88
		Kiln 962	90.45	23.61		Kiln 1009	90.59	23.89
		Kiln 963	90.45	23.61		Kiln 1010	90.59	23.89
		Kiln 964	90.45	23.61		Kiln 1011	90.57	23.88
		Kiln 965	90.45	23.61		Kiln 1012	90.57	23.88
		Kiln 966	90.45	23.61		Kiln 1013	90.60	23.88
		Kiln 967	90.45	23.61		Kiln 1014	90.60	23.88
		Kiln 968	90.46	23.61		Kiln 1015	90.58	23.88
		Kiln 969	90.46	23.61		Kiln 1016	90.58	23.88

Narayanganj	Rupganj	Kiln 1017	90.58	23.87	Rupganj	Kiln 1064	90.54	23.76
		Kiln 1018	90.59	23.86		Kiln 1065	90.55	23.77
		Kiln 1019	90.58	23.87		Kiln 1066	90.55	23.77
		Kiln 1020	90.59	23.86		Kiln 1067	90.55	23.85
		Kiln 1021	90.59	23.86		Kiln 1068	90.55	23.85
		Kiln 1022	90.57	23.88		Kiln 1069	90.55	23.85
		Kiln 1023	90.56	23.88		Kiln 1070	90.55	23.85
		Kiln 1024	90.56	23.88		Kiln 1071	90.55	23.86
		Kiln 1025	90.57	23.90		Kiln 1072	90.55	23.85
		Kiln 1026	90.55	23.86		Kiln 1073	90.56	23.75
		Kiln 1027	90.58	23.89		Kiln 1074	90.55	23.76
		Kiln 1028	90.58	23.89		Kiln 1075	90.55	23.76
		Kiln 1029	90.58	23.89		Kiln 1076	90.56	23.77
		Kiln 1030	90.58	23.89		Kiln 1077	90.54	23.75
		Kiln 1031	90.59	23.89		Kiln 1078	90.55	23.76
		Kiln 1032	90.59	23.89		Kiln 1079	90.55	23.76
		Kiln 1033	90.59	23.89		Kiln 1080	90.54	23.76
		Kiln 1034	90.59	23.89		Kiln 1081	90.54	23.75
		Kiln 1035	90.59	23.89		Kiln 1082	90.54	23.75
		Kiln 1036	90.59	23.89		Kiln 1083	90.54	23.75
		Kiln 1037	90.55	23.85		Kiln 1084	90.54	23.75
		Kiln 1038	90.55	23.86	Sonargaon	Kiln 1085	90.59	23.74
		Kiln 1039	90.55	23.86		Kiln 1086	90.58	23.76
		Kiln 1040	90.57	23.80		Kiln 1087	90.57	23.76
		Kiln 1041	90.58	23.78		Kiln 1088	90.57	23.76
		Kiln 1042	90.59	23.79		Kiln 1089	90.56	23.74
		Kiln 1043	90.59	23.79				
		Kiln 1044	90.56	23.77				
		Kiln 1045	90.56	23.77				
		Kiln 1046	90.57	23.79				
		Kiln 1047	90.58	23.78				
		Kiln 1048	90.58	23.78				
		Kiln 1049	90.58	23.79				
		Kiln 1050	90.57	23.87				
		Kiln 1051	90.56	23.87				
		Kiln 1052	90.56	23.87				
		Kiln 1053	90.56	23.87				
		Kiln 1054	90.56	23.87				
		Kiln 1055	90.56	23.88				
		Kiln 1056	90.56	23.87				
		Kiln 1057	90.56	23.87				
		Kiln 1058	90.56	23.87				
		Kiln 1059	90.56	23.87				
		Kiln 1060	90.56	23.87				
		Kiln 1061	90.56	23.86				
		Kiln 1062	90.55	23.86				
		Kiln 1063	90.55	23.86				

Narsingdi	Belabo	Kiln 1090	90.85	24.09	Monohordi	Kiln 1137	90.64	24.09
		Kiln 1091	90.84	24.10		Kiln 1138	90.65	24.09
		Kiln 1092	90.85	24.11		Kiln 1139	90.68	24.10
		Kiln 1093	90.86	24.10		Kiln 1140	90.68	24.10
		Kiln 1094	90.86	24.10		Kiln 1141	90.70	24.10
		Kiln 1095	90.85	24.09		Kiln 1142	90.73	24.11
		Kiln 1096	90.88	24.10		Kiln 1143	90.71	24.11
		Kiln 1097	90.85	24.14		Kiln 1144	90.71	24.10
		Kiln 1098	90.91	24.07		Kiln 1145	90.71	24.10
		Kiln 1099	90.91	24.07		Kiln 1146	90.76	24.11
		Kiln 1100	90.92	24.06		Kiln 1147	90.75	24.13
		Kiln 1101	90.82	24.14		Kiln 1148	90.74	24.19
		Kiln 1102	90.82	24.14		Kiln 1149	90.75	24.16
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		Kiln 1118	90.92	24.08		Kiln 1165	90.74	23.92
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	Monohordi	Kiln 1120	90.77	24.19		Kiln 1167	90.77	23.88
		Kiln 1121	90.78	24.19		Kiln 1168	90.68	23.86
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		Kiln 1134	90.69	24.08		Kiln 1181	90.71	23.84
		Kiln 1135	90.67	24.09		Kiln 1182	90.64	23.89
		Kiln 1136	90.64	24.08		Kiln 1183	90.64	23.89

Narsingdi	Sadar	Kiln 1184	90.66	23.92
		Kiln 1185	90.66	23.93
		Kiln 1186	90.64	23.92
		Kiln 1187	90.64	23.92
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		Kiln 1196	90.60	23.91
		Kiln 1197	90.59	23.91
		Kiln 1198	90.59	23.92
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		Kiln 1203	90.58	23.91
		Kiln 1204	90.58	23.91
		Kiln 1205	90.58	23.91
		Kiln 1206	90.59	23.91
		Kiln 1207	90.58	23.91
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		Kiln 1209	90.59	23.91
		Kiln 1210	90.59	23.91
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		Kiln 1216	90.62	23.97
		Kiln 1217	90.62	23.97
		Kiln 1218	90.61	23.93
	Roypura	Kiln 1219	90.86	24.01
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		Kiln 1222	90.76	23.94
		Kiln 1223	90.76	23.94
		Kiln 1224	90.92	23.91
		Kiln 1225	90.94	23.98
		Kiln 1226	90.74	23.92
		Kiln 1227	90.74	23.92
		Kiln 1228	90.75	23.91
		Kiln 1229	90.76	23.91
		Kiln 1230	90.76	23.91
	Roypura	Kiln 1231	90.75	23.90
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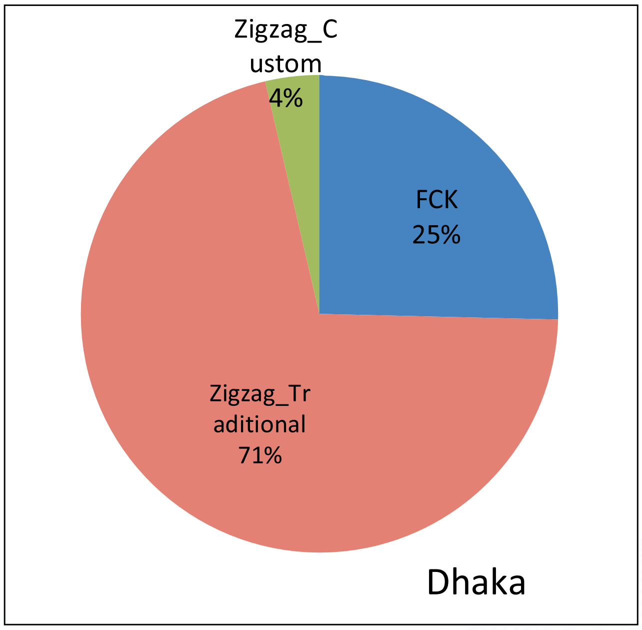
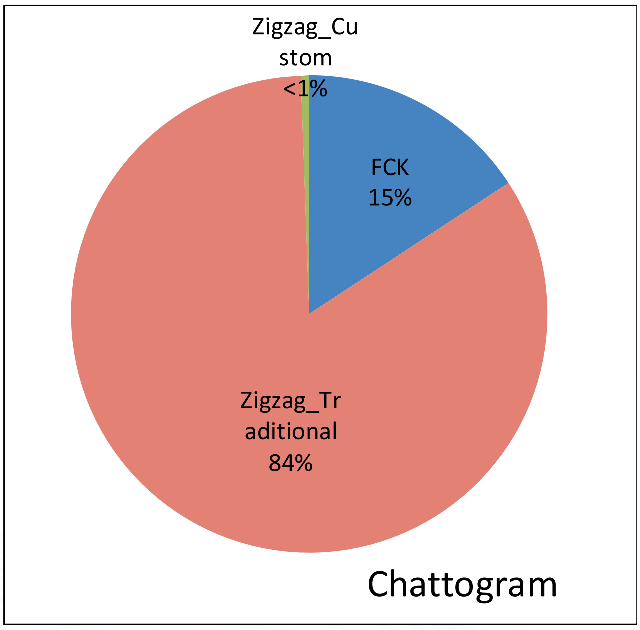
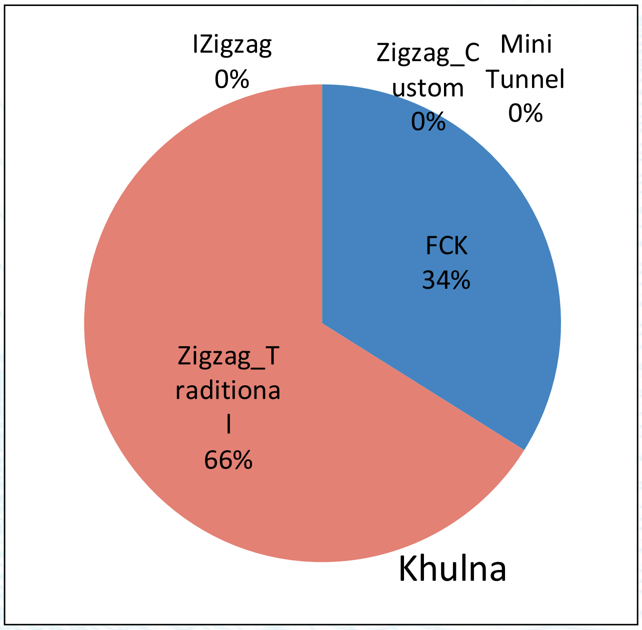
		Kiln 1234	90.80	23.92
		Kiln 1235	90.84	24.04
		Kiln 1236	90.95	24.06
		Kiln 1237	90.97	24.03
		Kiln 1238	90.96	24.01
		Kiln 1239	90.96	24.02
		Kiln 1240	90.96	24.01
		Kiln 1241	90.83	23.99
		Kiln 1242	90.82	24.00
	Shibpur	Kiln 1243	90.76	23.99
		Kiln 1244	90.74	24.06
		Kiln 1245	90.69	24.08
		Kiln 1246	90.69	24.08
		Kiln 1247	90.82	24.00
		Kiln 1248	90.81	24.10
		Kiln 1249	90.72	23.97
		Kiln 1250	90.72	23.97
		Kiln 1251	90.72	23.96
		Kiln 1252	90.73	23.98

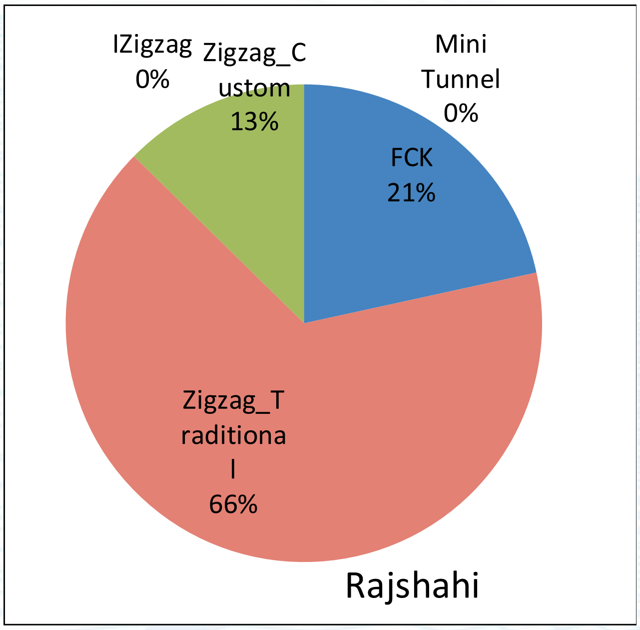
APPENDIX – B

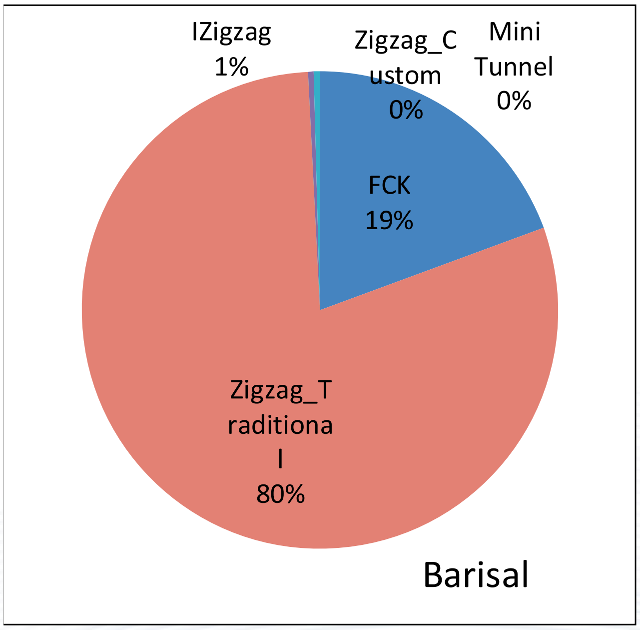
DIVISION-WISE PROPORTION OF BRICK TECHNOLOGY (as per inventory'18)







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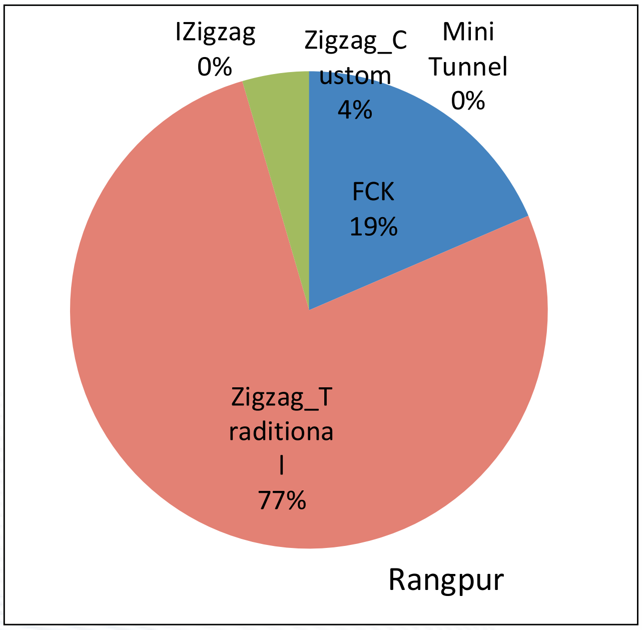
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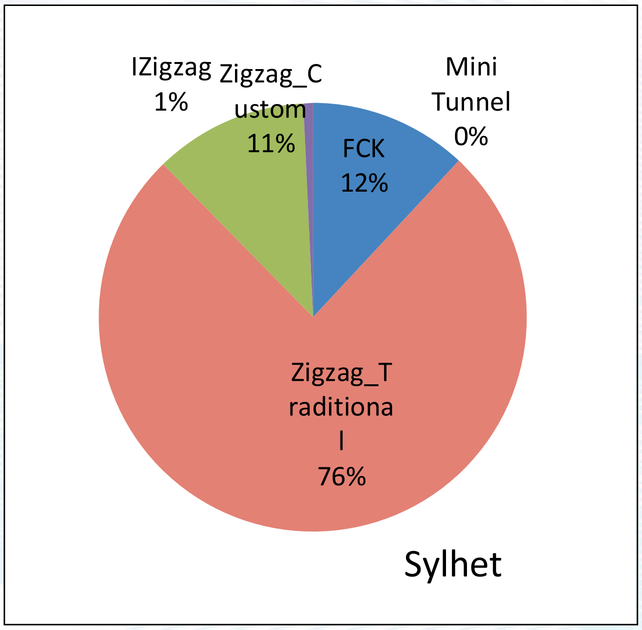
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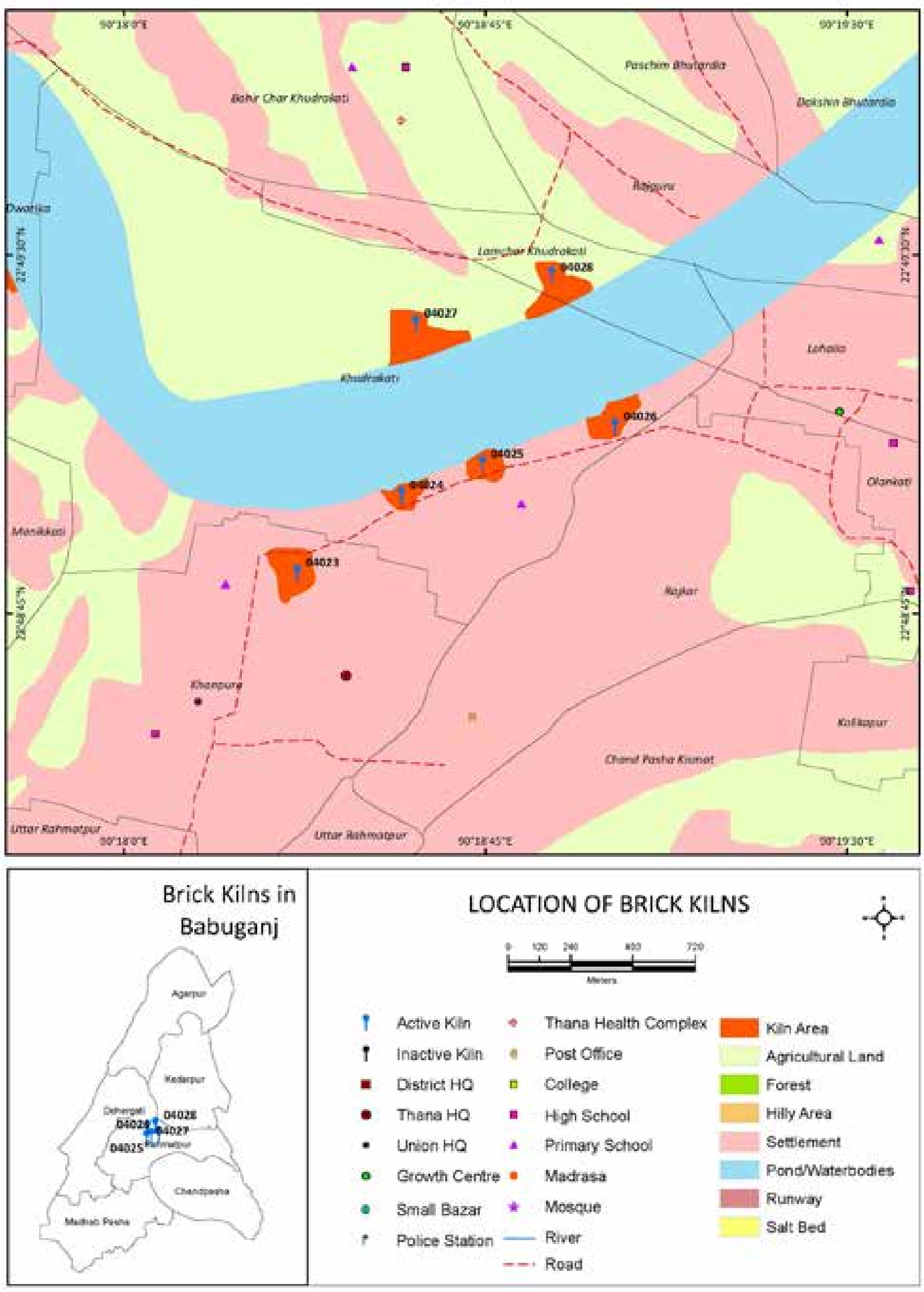
APPENDIX – C

SAMPLES OF LAND USE BUFFER ZONE AROUND BRICK KILN

APPENDIX – D

SAMPLE OF CREATION OF LULC MAPS



PART – B

VEHICLE EMISSION

1 BACKGROUND

Vehicle emission is a proven source of air pollution in many urban areas of the world. Big cities like Los Angel's, London, Paris, Beijing, etc. are found to suffer from severe photochemical smog resulted from the vehicular emissions. In Dhaka, although the number of vehicles is not as large as the big cities of the world, poorly managed vehicles and unbearable traffic congestions load the city atmosphere with a great amount of polluting gases and PM. The city of Dhaka was once called a "gas chamber" for the huge emissions of PM and hydrocarbons from the 2-stroke 3-wheeled baby taxis. The complete phase-out of those taxis from Dhaka city in 1st January 2003 improved the air pollution situation in the city; Begum et al. (2012[1]) reported about 41% decrease in the $PM_{2.5}$ concentrations in Dhaka city as a result of the phase-out of those taxis. Addition to that, the widespread use of cleaner fuel CNG to vehicle sector, especially in Dhaka city helped reduce PM drastically from this sector. The government revised in 2005 the vehicle emission standards equivalent to EURO – II for new vehicles and EURO – I for on-road vehicles. It is believed that had these steps not taken at proper time, air quality in Dhaka city would have been unlivable by today because the city has been experiencing massive increase in vehicle number as well as other sources like brick kilns and constructions from the last two/three decades. Latest source apportionment study has attributed about 58% of the fine particle concentration in Dhaka to the brick kiln industry, 10.4% to vehicles and 15.3% to dusts (CASE project, 2014), whereas in the previous apportionment result the contributions from these prime sources were 22.0, 36.0 and 24.5 % respectively (Begum et al. 2013[2]).

The CASE project conducted regular vehicle emission testing program to assess the existing emission scenario of the in-use vehicles in Dhaka city, and to aware public on the consequences of high vehicle emission. Idle Carbon Monoxide (CO) and Hydrocarbons (HC) from gasoline/CNG vehicles and free acceleration smoke opacity of diesel vehicles were measured. Overall 1317 vehicles were tested at 08 hotspots in the city, out of which 815 were CNG/gasoline vehicles and 502 were diesel vehicles. In this report, the analyses of the emission data have been illustrated and discussed in details.

[1] Impact of Banning of Two-Stroke Engines on Airborne Particulate Matter Concentrations in Dhaka, Bangladesh. Journal of the Air & Waste Management Association, vol. 56

[2] "Air pollution by fine particulate matter in Bangladesh" Atmospheric Pollution Research, 2013

1.1 Vehicle emission limit values

The emission standards for different types of vehicles were revised and notified in the gazette (SRO# 220-Law/2005) by the Government of Bangladesh in 2005. Emission standards of different category in-use vehicles are provided in Table 01 and table 02.

Table 01 Emission Standards for Petrol and CNG Driven Vehicles Registered before September 1, 2004

Vehicle Type	Test	CO (% v)	HC (ppm)
4-wheeled petrol	Idle Speed	4.5	1,200
All CNG vehicles	Idle Speed	3.0	-
Petrol driven 2-Stroke engine 2 and 3-wheelers	Idle Speed	7.0	12,000
Petrol driven 4-Stroke 2 and 3-wheelers	Idle Speed	7.0	3,000

Note: Idle Speed RPM to be specified by the manufacturer.

Table 02 Emission Standards for Vehicles Registered after September 1, 2004

Vehicle Type	Test	CO (% v)	HC (ppm)	Lambda (λ)	Smoke Opacity
4-wheeled petrol and CNG vehicles.	Idle Speed	1.0	1200	-	-
	No load, 2500-3000 RPM	0.5	300	1.0 ± 0.03	-
Petrol driven 4-Stroke 2 and 3-wheelers	Idle Speed	4.5	1200	-	-
CNG driven 3-wheelers	Idle Speed	3.0	-	-	-
Naturally aspirated diesel vehicles	Free acceleration	-	-	-	65 HSU or 2.5 m^{-1}
Turbo-charged diesel vehicles	Free acceleration	-	-	-	72 HSU or 3.0 m^{-1}

Note: Idle speed RPM to be specified by the vehicle manufacturer.

1.2 Vehicle number and growth

Steady economic growth and ongoing urbanization in recent years in the county instigate vehicle numbers to grow fast in the urban areas. It is estimated that the number of vehicles registered in Dhaka alone up to June 2018 is 1.67 times greater than the numbers in 2010. Table 03 shows the number of vehicles registered in Dhaka up to June 2018 (BRTA 2018[3]).

3 http://www.brta.gov.bd/

Table 03 Number and increase of different category vehicles registered in Dhaka from 2010 to 2018			
Vehicle category	Registered up to 2010	Registered up to June 2018	% increase
Auto Rickshaw	7664	11467	50.0
Bus	26273	39375	50.0
Car	268829	399808	49.0
LDV	39989	112220	183.0
Truck	26922	56784	111.0
Total	369677	619654	67.6

The statistics reveal that the Light Duty Vehicles (LDV) have increased greatly (183%) within the period from 2010 to 2018; human hauler, jeep, leguna, mini truck, maxi, microbus, mini-van, pick up, rider, etc. are within the category of LDV. The increase in Auto Rickshaws, buses and cars were moderate, all of these categories have increased by about 50%. Trucks have grown to double in the last 7 years; a good portion of new heavy duty trucks runs on CNG.

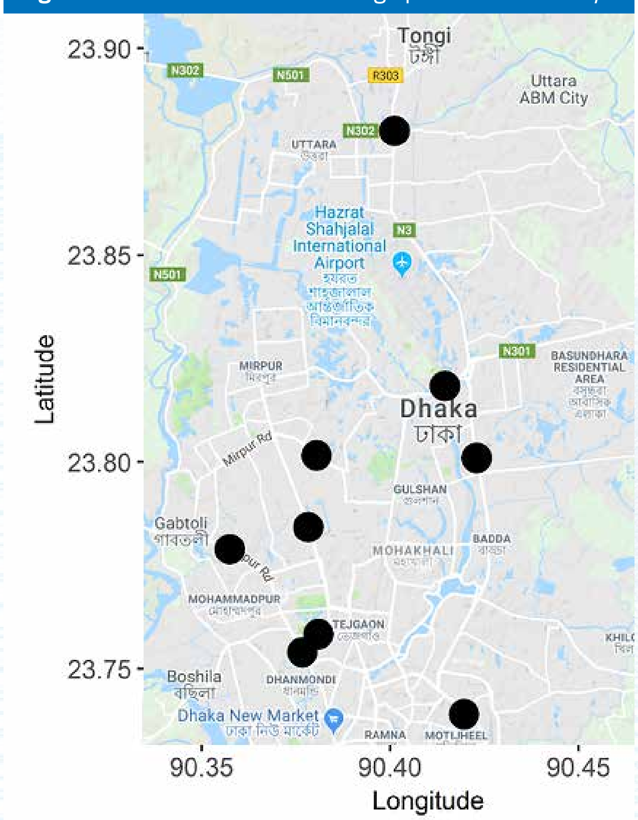
2 VEHICLE EMISSION INSPECTION PROGRAM (VEIP)

CASE Project conducted in-use vehicle emission inspection in major hotspots of Dhaka city. The city has adequate infrastructure for CNG fuelling to the vehicles, and most of the light to medium duty vehicles within the city run on CNG. Heavy duty trucks and buses, which are mostly diesel fueled, are allowed entering the city after 10.00pm till 8:00am next morning. Daytime vehicle fleet thus comprises mainly of CNG vehicles.

The inspection program in Dhaka City was carried out in 08 different hot-spots; the spots were chosen in different routes of the city so that vehicles plying to all directions could be tested. The hot-spots were Abdullahpur (Uttara), Joar Shara (Badda), Police Shriti College (Mirpur – 14), Taltala (Agargaon), Darussalam (Mirpur), Sobhanbagh (Dhanmondi), Manik Mia Avenue (Tejgaon), and Notun Bazar (Badda) (Figure 1).

A microvan fitted with the testing equipment and other facilities was used in the testing activities. Idle CO and HC concentrations of the gasoline/CNG vehicles were measured while free acceleration tests were carried out to measure the smoke opacity of the diesel vehicles. Overall 1317 vehicles were tested at the aforesaid spots, out of which 815 were CNG/gasoline vehicles and 502 were diesel vehicles.

Figure 1 Vehicle emission testing spots in Dhaka city



2.1 Objectives of the program

Overall objective of the roadside emission testing program was to assess vehicle compliance scenario and to raise public awareness about the danger of vehicle emission.

Specific Objectives could be summarized as,

- To formulate and suggest a revision to the existing Vehicle Emission Standards;
- To assess emission characteristics of in-use vehicles in Dhaka city;
- To raise awareness for regular Inspection & Maintenance of the vehicles;
- To identify gross polluting vehicles in Dhaka city;
- To provide city officials and national policymakers with results and policy implications;

2.2 Classification of Vehicles

Vehicles with great varieties in their fuel-use, capacity, size & weight, manufacturing years, etc. ply on the roads. Because of heavy traffic movement and absence of legal documents (in many cases) with the drivers, it was fairly impossible to collect all the information for a proper vehicle classification. With this drawback, the vehicles were primarily classified by their fuel use, (1) CNG/gasoline vehicles and (2) Diesel vehicles. Most of the vehicles (>95%) tested under category 1 were CNG driven and hence, a separate category for the gasoline driven vehicles was not considered. Table-04 shows detailed classification and name/type of the vehicles under each class.

Table 04 Category of Vehicles tested under the VEIP

Category	Local Names of Vehicles
CNG/Octane	
Auto Ricksaw	Auto Ricksaw
Bus	Bus, Minibus
Car	Private car, human hauler, jeep, laguna, mircobus, taxi
Light Duty Vehicle	Pickup, minivan, mini truck, mini covered van, delivery van, mini delivery van
Motor Cycle	Motor Cycle
Diesel	
Bus	Bus, Minibus
Truck	Covered Van (heavy duty), Concrete Mixtures, Lorries, Trucks
Light Duty Vehicle	Delivery van, human hauler, jeep, leguna, mini truck, maxi, microbus, mini covered/ delivery van, pick up, rider

Table 05 Number of vehicles tested

Vehicle Type	CNG/Octane	Diesel
Car	243	–
Bus	67	158
Light Duty Vehicle	118	203
Auto-rickshaw	144	–
Motorcycle	243	–
Truck	–	141
Total	**815**	**502**

2.3 Instruments and Methods of Testing

HORIBA made Automotive Gas Analyzer (model –MEXA 554 JA) was used to measure idle HC and CO emissions from the gasoline/CNG vehicles. The instrument analyzes gases (CO, HC) based on the Non Dispersive Infra Red (NDIR) method. During the testing, CO_2 was also measured to check dilution of the exhaust gases by air in the exhaust system or during sampling. The analyzers had been calibrated using NIST traceable gases at least once every day before the measurements started. If felt necessary, the analyzers were re-calibrated on the spot during the progress of the emission measurements. Leak checks and HC hang-up tests were performed as per the manufacturer's instructions. Idle tests were carried out in all cases. Annex-III–A provides full description of guidelines for operation of Gas Analyzer.

WAGER 6500 full flow smoke opacity meter was used to estimate smoke opacity of the emission from diesel vehicles. Smoke opacity measurement under free acceleration test by a full flow smoke opacity meter was performed according to the method SAE J1667. The diameter of the vehicle exhaust pipe or of the extension pipe, if used, was also recorded to convert the smoke density in terms of m^{-1} units to % opacity for a common optical path length of 430 mm, as applicable for Hartridge Smoke Unit (HSU). Annex-III–B provides full description of opacity measurement using an opacity meter.

Officers from all divisions of the DoE and from the CASE project were trained several times on the operation and maintenance of the testing equipment including the calibration processes. A team comprised of trained officers from the CASE project and from the Air Quality Management Wing of the DoE carried out the vehicle emission testing in Dhaka city. Training pictures are shown in Annex-II.

Figure 2 Instrument for vehicle emission testing

2.4 Data Correction

For a 4-stroke petrol engine sum of CO% and CO_2% should be 15 or higher and for CNG engine it should be 12 or higher. When the sum of these two gases for an individual test was less, exhaust gas dilution was suspected and the observed CO and HC concentrations were corrected. Similarly, for a 2-stroke petrol engine CO% + CO_2% should be 10 or higher and the concentration of CO and HC were corrected when the sum was less than 10. In all cases corrections were done as per the following equations (AQMP 2007),

(a) ***For 4-S Petrol Engine:***

$CO_{corr} = CO_{meas}(\%) \text{ x } \%$

$HC_{corr} = HC_{meas}(ppm) \text{ x } ppm$

(b) ***For 2-S Petrol Engines:***

$CO_{corr} = CO_{meas}(\%) \text{ x } \%$

$HC_{corr} = HC_{meas}(ppm) \text{ x } ppm$

(c) ***For 4-S CNG Engines:***

$CO_{corr} = CO_{meas}(\%) \text{ x } \%$

$HC_{corr} = HC_{meas}(ppm) \text{ x } ppm$

3 RESULT AND DISCUSSION

3.1 Overview of Vehicle Performance

The VEIP was mainly Dhaka centric for 40% of vehicles of the country are registered in Dhaka alone, and also for a great portion of populations in the city lives under a threat of increased level of air pollution, to which vehicle sector is a big contributor. The emission testing results were compared with the corresponding limit values – the vehicles were tagged with "Passed" when the emission results satisfied the respective limit values and with "Failed" when the results were over the limit values. Table-06 gives an overview of the performance of different category vehicles. The result shows the Auto Rickshaws and cars performed very well in respect to the standards set by the Government, 92.3% of the Auto Rickshaws and 87.8% of the cars could meet the national standards. However, bus and light duty vehicles with success rates of 74.5 and 76.7 % respectively should have done further better in consideration of using cleaner fuel CNG. The performances of motor cycles were very pale; its performance rate was only 22.2%.

On the other hand, diesel vehicles irrespective of the category performed very poorly. About 84% of the diesel buses and minibuses were found emitting smokes with opacity more than the limit value, 69% trucks and 58.6% LDVs were also unsuccessful in meeting the national limit values (Table 06).

Table 06 Overview of the performances of different category vehicles

CNG/Octane Vehicles			Diesel Vehicles		
Category	Total vehicles tested	% of vehicles passed	Category	Total vehicles tested	% of vehicles passed
Auto Rickshaw	144	92.3	Bus	158	16.0
Bus	67	74.5	LDV	203	41.4
Car	243	87.8	Truck	141	31.0
LDV	118	76.7	–	–	–
Motor Cycle	243	22.2	–	–	–

3.2 Analyses of Vehicle Emission Data

3.2.1 Idle CO emissions from CNG/Octane Vehicles

I. Among the CNG/Octane vehicles auto rickshaws were the most promising in emitting CO. About 83% and 86.0% of them exited emissions with CO concentrations less than 0.3 and 0.6 %(v) respectively (Figure-3), and about 95.0% of the Auto Rickshaws emitted CO concentrations less than 2.0 %(v). The existing limit value of CO concentrations for this category vehicle is 3.0 %v.

II. About 70% of the cars emitted CO concentrations less than 0.3 %(v); 77% of them passed the standard of 1 %(v) (Figure 3).

III. Buses performed little better than LDVs in respect to CO emissions – while 77% of the buses emitted CO concentration less than 1%(v), only 63% of LDVs did the same. 82% of the buses contrasted to only 70% LDVs exited CO within 2%v (Figure 3).

Figure 3 cumulative distributions of CNG vehicles for CO emissions

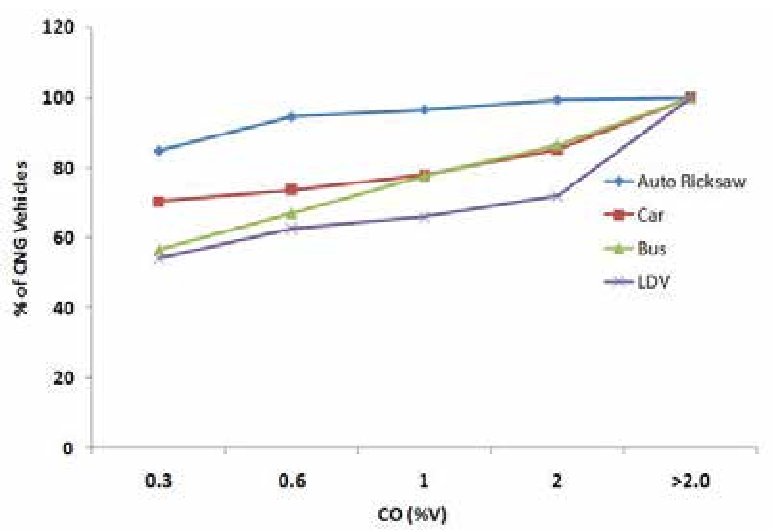


Table 07 shows a comparative position of the CNG/Octane vehicles in terms of their CO emission.

Table 07 Ranking of CNG/Octane driven vehicles in respect to CO emissions

Vehicle Category	% of vehicle with CO emission (%v)			Rank
	≤0.6	≤1.0	≤2.0	
Auto rickshaw	94.5	96.5	99.3	1st
Car	73.7	77.8	85.2	2nd
Bus	67.2	77.6	86.5	3rd
LDV	62.7	66.1	72.0	4th

3.2.2 Idle HC emissions from CNG/Octane Vehicles

I. There is no national limit value for HC emissions from the on-road CNG three wheeled auto rickshaws; nevertheless, HC concentrations from this type of vehicles were recorded and analyzed to assess their performances. Figure 4 shows the HC emitting potentials of different category CNG vehicles. It is found that 50.6% of auto rickshaws exited HC concentration ≤ 500ppm and 72% of these vehicles emitted HC ≤1500ppm. The result (Figure 4) shows the CNG Auto Rickshaws were not so promising in HC emissions although those were very miser in CO emissions (Figure 3).

II. About 43.2% of buses exited HC concentrations ≤500ppm and 87.0% of them emitted HC ≤1500ppm. All of the CNG driven buses emitted HC within 3000ppm (Figure 4).

III. Cars and LDVs showed comparatively good results in HC emissions. About 74.3% of cars and 70.5% of LDVs emitted HC concentrations less than 500ppm, and about 97.5% of these vehicles emitted HC ≤1500ppm.

Figure 4 Cumulative distributions of CNG vehicles for HC emissions

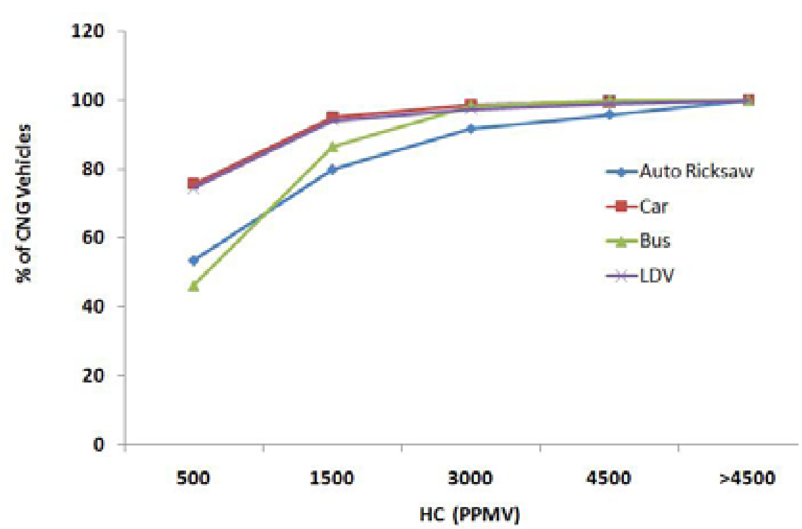


Table 08 Comparative positions of CNG/Octane vehicles in respect to HC emissions

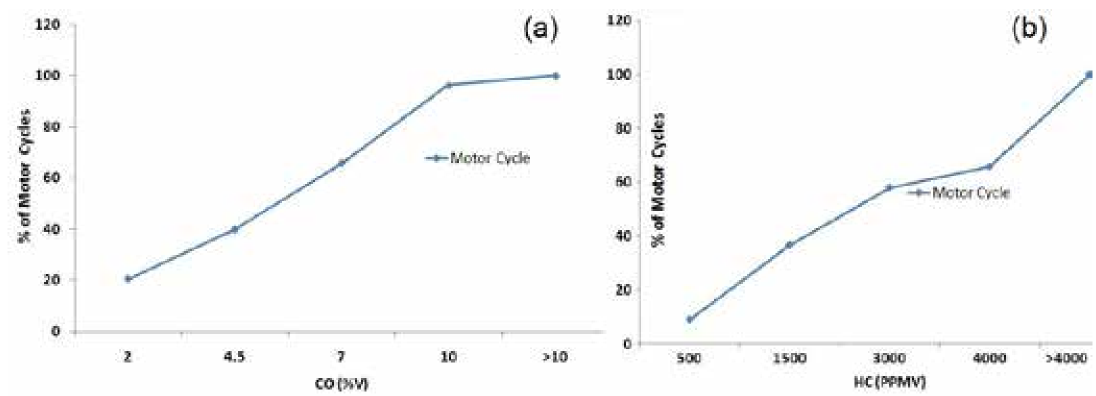
Vehicle Category	% of vehicle with HC emission (ppmv)				Rank
	≤500	≤1200	≤3000	≤4500	
Auto rickshaw	53.5	71.3	91.7	95.8	4th
Car	75.7	90.5	98.8	99.6	1st
Bus	46.3	80.6	98.5	100	3rd
LDV	74.6	88.6	97.5	99.2	2nd

3.2.3 Idle CO and HC emissions from motor cycles

I. Motorcycles were found as the worst polluters in the CNG/Octane vehicle category. Figure 5a shows that only 40% of the motorcycles exited emissions with CO concentrations ≤4.5 %(v), the existing limit value for motor cycle emission. About 36.5% of these vehicles emitted CO concentrations greater than 7.0 %(v), which may be considered very high emission.

II. Motor cycles were also found high HC emitters among the CNG/Octane category. It is seen from figure 5b that only 37% of the motorcycles emitted HC ≤1500ppm. About 58.8% of the motorcycles emitted HC ≤3000ppm. The figure also shows that about 24% of the motorcycles emitted HC greater than 5000ppm that may be considered very high.

Figure 5 Cumulative distributions of motor cycles for (a) CO and (b) HC emissions



3.2.4 Comparative positions of CNG/Octane vehicles with respect to Idle CO at1%v and idle HC at 1200 ppm

Irrespective of the manufacturing year, the vehicles were sorted according to their performances in emitting CO within 1%v concentration and HC within 1200 ppm concentrations which are the existing limit values for the CNG/ gasoline vehicles registered after 01 September 2004. It is found that cars ranked at the top with 71.6% meeting the limit values of CO and HC simultaneously, while Auto Rickshaws placed at second with 68% compliance. LDVs and Buses performed very closely with 59.1 and 59.6 % compliance respectively (Table 09).

Table 09 Comparative positions of the CNG/Octane vehicles in meeting simultaneously CO and HC concentrations of 1%v and 1200 ppm respectively

Vehicle Category	% of vehicles meeting CO and HC emissions of 1%v and 1200 ppm respectively	Rank
Auto Rickshaw	68.0	2nd
Car	71.6	1st
Bus	59.6	3rd
LDV	59.1	4th

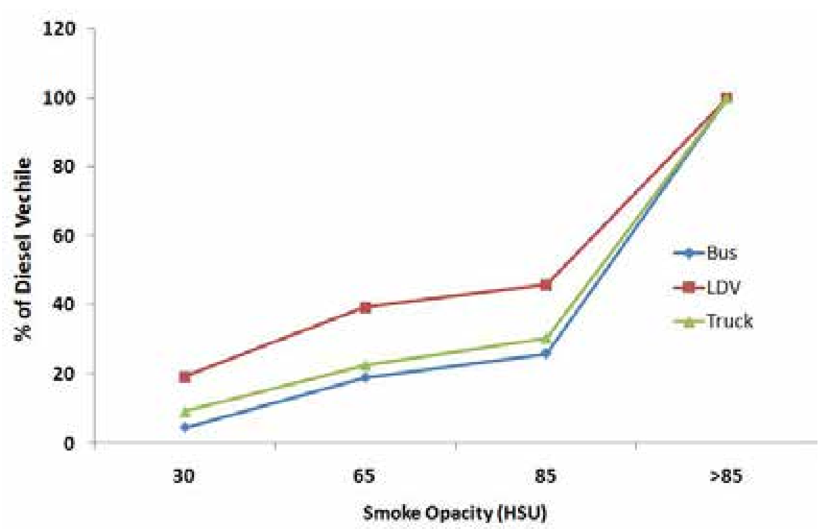
3.2.5 Analysis of smoke emissions from Diesel Vehicles

I. Buses were found the most polluters among the diesel vehicles. This category includes heavy duty buses which are mainly district bound vehicles, and mini buses which ply within the city. Most of the minibuses in Dhaka city are converted to the CNG system, but a fraction of them are still running on diesel. It is seen from the data analysis that only 18% of the buses could meet the national limit value of 65 HSU opacity. More than 70% buses emitted smoke with opacity greater than 85 HSU. Figure 07 shows cumulative distribution of smoke opacity of different category diesel vehicles.

II. Trucks followed nearly the same status as buses did. Only 24.6% of the trucks could satisfy existing limit value of 65 HSU, and about 65% of trucks emitted smoke with opacity greater than 85 HSU (Figure 07). As heavy duty trucks and buses are allowed entering Dhaka City after 10.00 pm, large number of those vehicles waiting outskirt of the city from the evening rush to enter the city at 10:00 pm. High amount of soot particles are thus expected to get into the atmosphere at that time, stimulating ambient air pollution in the city.

III. Among the diesel vehicles LDVs performed little better compared to buses and trucks (Figure 7). 40.9% of LDVs could satisfy limit value of 65 HSU and about 50% of them had smoke opacity greater than 85 HSU.

Figure 6 Cumulative distributions of diesel vehicles for smoke opacity



4 KEY ACHIEVEMENTS OF THE VEIP

The VEIP carried out by the Clean Air and Sustainable Environment (CASE) Project was not limited to the testing of the vehicular emission only it also raised awareness among the drivers, helpers and the passersby about the dangerous effect of the vehicular emission onto the human health, climate and the plants. The responses from the public were enormous and impressive. They urged for conducting such programs very frequently in their cities. The CASE project through this program counseled with the drivers and helpers on how to decrease emissions from the vehicles. A simple penalty was also imposed on the "Failed" vehicles under the Motor Vehicles Ordinance or sometimes under Environment Conservation Act.

The vehicular emission database developed from this program will help the environmental modelers to calculate the emission loads from the vehicle sector and to determine the extent of the threat being posed by this sector. Policy makers may use these result to formulate/revise laws in order to ensure safe environment for the city dwellers. On the basis of these databases the CASE project has prepared a draft on the "Revision to National Vehicular Emission Standard" and submitted to the respective authority. CASE project has also drafted a Vehicular Inspection and Monitoring Program that may be practiced to bring the vehicles in complying the emission standards.

5 GOVERNMENT STEPS TO CONTROL VEHICULAR EMISSION

The Dhaka City was once recognized as the "Gas Chamber" in 90s when a good number of two stroke baby taxis would run in the roads. People in the roads felt eye irritation due to the hydrocarbons and particulate matters emitted from those vehicles. The Government of Bangladesh has taken a number of exemplary decisions proved beneficial for improving air quality. Following steps/measures were taken/ implemented by the Government so far to control the emissions from the vehicle sector,

- Elimination of Lead from automotive fuel (July, 1999)
- Complete phase out of 2 stroke 3 wheelers from Dhaka city in 1st January, 2003. Bangladesh Atomic Energy Commission, in a study, showed that about 40% instant reduction in $PM_{2.5}$ concentrations in Dhaka City happened as a result of the phase-out of the two-stroke three wheelers (Begum, 2006).
- Introduction of CNG as a clean fuel, 1983: it was the most efficient steps for improving the air quality in Dhaka and Chittagong Cities. Although the introduction of CNG initiated in 1983, adequate infrastructure set up and massive scale conversion of petrol engines to CNG engines started from early 90s.
- Vehicle emission standards were revised in 2005.

6 CONCLUSIONS

The Clean Air and Sustainable Environment (CASE) Project of the Department of Environment regularly conducted roadside vehicle emission inspection program (VEIP) in Dhaka and other parts of Bangladesh. This report has illustrated the analyses of the emission data produced from the testing of 815 CNG/gasoline and 502 diesel vehicles in Dhaka city. Overall objective of this testing program was to assess the vehicle compliance scenario and to raise public awareness about the danger of vehicle emission. The result of these vehicle emission monitoring will help to understand the needs and spaces of revising the existing vehicle emission standards in Bangladesh. The VEIP offers several outcomes that may be utilized to formulate the policy on controlling the emissions from the vehicle sector; the outcomes are as follows,

(a) CNG vehicles in Dhaka city were very miser in emitting; about 75% of the CNG vehicles emitted CO ≤1%(v) concentration and about 88% of the vehicles emitted CO ≤3%(v) concentrations. HC emissions from these vehicles were also promising – about 85% of CNG vehicles emitted HC ≤1200ppm concentrations.

(b) Only 40% of the motorcycles could meet the CO emission standard of 4.5%(v); about 35% of the motorcycles emitted CO concentrations more than 7%(v). The scenario for HC emission from motorcycle was about the same; only 30% of motorcycles satisfied the limit value of 1200ppm.

(c) Diesel vehicles were found the worst polluters in vehicle sector. Only 23% of diesel buses and trucks could meet the limit value of 65 HSU opacity and about 67% of them had emissions with opacity >85 HSU.

7 RECOMMENDATIONS

CASE project gained a lot of knowledge and experiences on the vehicle emission scenario and ongoing practices in the vehicle sector. The project could identify gross polluting vehicles that were contributing greatly to the air pollution in Dhaka city. On the basis of such experiences the project offers the following recommendations that might be helpful for managing pollutions from this sector:

- Comprehensive vehicle emission inventory in Dhaka city should be prepared.
- Traffic congestion to be minimized in order to alleviate ambient air pollution through better traffic management, imposing parking and pollution charge, fiscal measure to discourage private vehicles and measures to improve mass and rapid transport with ensuring economic and safe workplace journey.
- Vehicle emissions standards should be revised and enforced accordingly.
- Massive awareness program on Vehicle Emissions Standards, maintenance of vehicles and on emission impact on health to be carried out all over the country.
- Aged buses and trucks should be dumped out.
- Adequate infrastructure in the city should be built for emission testing/checking.
- All vehicles should be tested both at port of entrance and at places of registration.
- Adequate infrastructure for maintenance of vehicles to be developed.
- Quality of all types of fuel must be ensured.

APPENDIX – I

VEHICULAR EMISSION TESTING IN PICTURES

Van fitted with equipment

Emission testing of a CNG car

Emission from a diesel Micro Bus

Emission Testing of a CNG Taxi

Emission testing of a diesel Pick-up

Emission from a diesel Covered-Van

Emission Testing Van with equipment

Testing of a Heavy Duty Bus

Testing of a Heavy Duty Truck

Testing of a Motorcycle

APPENDIX – II

TRAINING ON VEHICLE EMISSION TESTING

One of the objectives of the Clean Air and Sustainable Environment Project was to strengthen the capacity of the Department of Environment on different issues of air quality management. Several trainings on principles and measurement of vehicular emissions were provided to the DoE and CASE project officials to ensure quality data generation from the vehicular testing program. Dr. B. P. Pundir, former professor of Indian Institute of Technology (IIT) and international consultant to CASE project conducted training in Dhaka, and engineer Ram Krishna Saha, local consultant provided some trainings in Dhaka and Chittagong. In all of these arrangements, participants are provided with adequate hands-on training on operation, maintenance and calibration of the testing equipment, and data recording and processing.

APPENDIX – III

MEASUREMENT PROCEDURES

A. GUIDELINES FOR MEASUREMENT OF CO AND HC EMISSIONS FROM SPARK IGNITION ENGINE VEHICLES (IDLE TEST)

Abbreviations

CO	Carbon Monoxide
CO_2	Carbon Dioxide
HC	Hydrocarbon
NDIR	Non Dispersive Infra-Red
RPM	Revolution per minute
CO_{corr}	Corrected concentration of Carbon Monoxide
HC_{corr}	Corrected concentration of Hydrocarbon

The idle CO and HC emission inspection test is completed in the following phases:

(a) Test equipment set up

(b) Vehicle Preparation

(c) execution of idle test

(d) Reporting of results

(a) Test preparation and Equipment setup

(a) A NDIR gas analyzer for measurement of concentration of CO and HC as hexane shall be used. In addition, CO_2 will also be measured for correction of measured CO and HC for any leakage or air into the exhaust system. The exhaust gas analyzer shall have capability to measure Lambda for testing of vehicles equipped with 3-way catalytic converters.

(b) Follow instructions provided by the manufacturers of analyzers for operation of the gas analyzers.

(c) Analyzers should be calibrated daily at the beginning of work but no more than 4 hours before use. Each time the instrument is moved or transferred to new location, perform a span and zero calibration using calibration gas. Follow the instructions in the user manual of the analyzers.

(d) Ensure any filters in the sampling line are clean.

(e) Ensure that there are no leaks in the sampling line. Carry out leak test on analyzer in there is provision.

(f) Ensure that the sampling handling line and probe are free from contaminants buy carrying out periodic hang up test. HC reading should drop to 20 ppm or less within 5 minutes when the probe is removed from the exhaust. If it takes more than 5 minutes for HC reading to drop to 20 ppm or less, then replace the probe with a new one.

(g) Purge the system after measurements on each vehicle as per the manufacturer's instructions.

(h) If the analyzer has provision to key in vehicle data such as registration no., make, date or test, etc., then feed in the information.

(b) Vehicle Preparations

Prior to conducting the test, following items must be completed,

(a) Vehicles should have been warmed up by operation for 10 km or 15 minutes before emission measurement.

(b) If the vehicle is equipped with a manual transmission, the transmission must be placed in neutral gear and clutch must be released. If the vehicle is equipped with an automatic transmission, the transmission must be placed in the park position, if available, or otherwise in the neutral position.

(c) Vehicle wheels or the vehicle must be restrained to prevent from moving during testing.

(d) Vehicle accessories such as air conditioning, fan, radio, etc., should be turned off.

(e) The vehicle should be inspected for exhaust leaks. Severe leaks in the system may cause air to enter into the exhaust stream, which may give erroneously low test results.

(f) Ensure that manual choke control has been returned to rest position.

(g) Where the vehicle is equipped with an exhaust system having multiple outlets, either these shall be joined to a common pipe or the CO, CO_2 and HC content from each of them shall be measured and the result of the test would be reached by taking arithmetical average of these concentrations for each pollutants.

(c) Execution of Idle Test

(a) Ensure vehicle is prepared as discussed above.

(b) If an engine RPM tachometer is available, note engine idle speed.

(c) Insert analyzer probe into vehicle tail pipe at least 300 mm. Use an exhaust pipe extension if necessary.

(d) Allow the exhaust emissions measurement reading to stabilize for approximately 1 minute.

(e) Record or print out results. Note any abnormalities.

(f) For vehicle equipped with a catalytic converter and where an engine RPM tachometer is available, an additional test is to be carried out with the engine idle speed held constant at approximately 2000 RPM.

(d) Reporting of Results

For a 4-stroke petrol engine sum of CO% and CO_2% should be 15 or higher and for CNG engine it should be 12 or higher. When this sum is less, exhaust gas dilution is suspected and the observed CO% and HC concentration are corrected. Similarly, for a 2-stroke petrol engine CO% + CO_2% should be 10 or higher and the concentration of CO and HC should be corrected when the sum is less than 10.In all cases corrections should be done as per the following equations,

(c) For 4-S Petrol Engine:

$$CO_{corr} = CO_{meas}(\%) \text{ x } \frac{15}{[CO\%+CO2\%]meas} \%$$

$$HC_{corr} = HC_{meas}(ppm) \text{ x } \frac{15}{[CO\%+CO2\%]meas} \text{ ppm}$$

(d) For 2-S Petrol Engines:

$$CO_{corr} = CO_{meas}(\%) \text{ x } \frac{10}{[CO\%+CO2\%]meas} \%$$

$$HC_{corr} = HC_{meas}(ppm) \text{ x } \frac{10}{[CO\%+CO2\%]meas} \text{ ppm}$$

(c) *For 4-S CNG Engines:*

$$CO_{corr} = CO_{meas}(\%) \text{ x } \frac{12}{[CO\%+CO2\%]meas} \%$$

$$HC_{corr} = HC_{meas}(ppm) \text{ x } \frac{12}{[CO\%+CO2\%]meas} \text{ ppm}$$

B. GUIDELINE FOR DIESEL SMOKE MEASUREMENT- FREE ACCELERATION TEST (ADOPTED FROM SAE J1667, FEB.96)

Definition and Symbols

Diesel Smoke: Particles including aerosols, suspended in the exhaust stream of a diesel engine, which absorb, reflect, or refract light.

Transmittance (T): The fraction of light transmitted from a source, which reaches a light detector.

Opacity (N): The percentage of light transmitted from a source, which is prevented from reaching a light detector.

Effective Optical Path Length (L): The length of the optical path obscured by smoke between smoke meter light source and light detector. Note that the portions of lithe total optical path between light source and light detector which are not obscured by smoke do not contribute to the effective optical path length.

Smoke Density (k): A fundamental parameter quantifying the ability of a smoke plume or a smoke containing gas sample to prevent passage of light. By convenience, smoke density is expressed on a per meter basis. (m^{-1}).

The complete Free Acceleration Test Procedure consists of five phases as following,

a. Vehicle preparation and safety check
b. Test preparation and equipment setup
c. driver familiarization and vehicle preconditioning
d. Execution of the free acceleration test
e. Calculation and reporting of final results

a. Vehicle preparation and safety check

Prior to conducting free acceleration test, following items must be completed;

(a) If the vehicle is equipped with a manual transmission, it must be placed in neutral gear and clutch must be released. If the vehicle is equipped with an automatic transmission, it must be placed in the park position, if available, or otherwise in the neutral position

(b) Vehicle wheels or the vehicle must be restrained to prevent the vehicle from moving during testing.

(c) Vehicle air conditioning should be turned off.

(d) If engine is equipped with an engine brake, it must be deactivated during the free acceleration testing.

(e) Verify the speed – limiting capability of the engine governor using the following procedure:

With the engine at low idle, slowly depress the engine throttle and allow the engine speed to gradually increase toward its maximum governed high no load speed. As the engine speed increases, carefully note any visual or audible indications that the engine or vehicle may be of questionable.

If there are no indications of problem, allow the engine speed to increase to the point that it possible to verify that the high speed-limiting capability of the governor is functioning. Should there be any indication that the speed-limiting capability of the governor is not functioning, or that potential engine damage, or unsafe conditions for personnel or equipment may occur, the throttle should be immediately be released and the free acceleration testing of the vehicle shall be abandoned.

(f) The vehicle should be inspected for exhaust leaks. Severe leaks in the system may cause air to enter into the exhaust stream, which may give erroneously low test results.

(g) Users must be cautioned regarding the observance of blue or white smoke in the exhaust. Blue smoke can be an indicator of unburned hydrocarbons (most probably oil burning or malfunctioning nozzle), and white smoke can an indicator of water vapor (possible internal coolant leaking conditions). Such vehicles should not be tested.

Driver Familiarization and Vehicle Preconditioning

Prior to the preconditioning test the vehicle should be operated under load for at least 15 min to ensure that the engine is warmed up. Vehicle water and oil temperature gauges may be checked to verify that the engine is within its normal operating temperature range.

Free Acceleration Cycle The vehicle operator shall be instructed on the proper execution of the free acceleration test sequence. It is of critical importance that the vehicle operator fully understands the proper movement of the vehicle accelerator during the testing. With the vehicles prepared as stated above and with the engine warmed and at low idle speed,

(a) The operator shall move the throttle to the fully open position as rapidly as possible.

(b) The operator shall hold the throttle in the fully open position until the time the engine reaches its maximum governed speed, plus an additional 1 to 4s.

(c) Upon completion of the 1 to 4s with the engine at maximum governed speed the operator shall release the throttle and allow the engine to return to the low idle speed.

(d) The operator shall wait for a minimum of 5s once the engine reaches its low idle speed but no longer than 45s, before initiating the next free acceleration test cycle. The time period at low idle allows the engine's turbocharger (if so equipped) to decelerate to its normal speed at engine idle. This helps to reduce the smoke variability between free acceleration cycles.

(e) Steps (a) through (d) shall be repeated as necessary to complete the preliminary free acceleration cycles.

The vehicle shall receive at least three preliminary free acceleration test cycles using the sequence described above. These preliminary cycles allow the vehicle operator to become familiar with the proper throttle movement, and also remove any loose soot which may have accumulated in the vehicle exhaust system during prior operation.

Execution of Free Acceleration Test

Before the free acceleration testing can proceed, the smoke meter data processing unit must be properly set up. The operating instructions supplied by the processing unit manufacturer should be consulted for specific set up procedures. However, the following functional steps must be accomplished,

(a) If a multimode test system is used, the appropriate mode for free acceleration testing must be selected.

(b) The desired smoke output units (opacity/density) must be selected.

(c) If the Beer-Lambert corrections are to be performed within the data processing unit, values must be supplied for the standard and as measured effective optical path length if smoke density output is desired.

(d) Any additional test identification information consistent with the needs of the test program and capabilities of the data processing unit should be supplied at this time. Usually this includes test date, test operator, vehicle identification and other such information.

Smoke Meter Zero and Scale

Prior to conducting smoke measurement, the zero and full-scale readings of the smoke meter shall be verified. Some smoke meter systems may automatically perform the zero and full scale checks. For other meters this sequence will need to be done manually. Should optional recording devices be part of the test setup, this equipment should also be checked for proper operation and calibration.

(a) Smoke Meter Warm-up: Prior to any zero and /or full scale checks or adjustment, the smoke meter shall be warmed up and stabilized according to the manufacturer's recommendations. If the smoke meter is equipped with a purge air system to prevent sooting of the meter optics, this system should also be activated and adjusted according to the manufacturer's recommendations.

(b) With the smoke meter in the opacity readout mode and with no blockage of the smoke meter light beam, adjust the readout to display 0.0% ± 1.0% opacity.

(c) If the above technique is not possible, set the zero and span of the smoke meter in units of smoke density with the use of a neutral density filter of known value as follows;

(i) With the smoke meter in the smoke density read out mode and with no blockage of the smoke meter light beam, adjust the read out to display $0.0m^{-1} \pm 0.1m^{-1}$

(ii) With the smoke meter in the smoke density read out mode, place a neutral density filter of known value between the light source and detector. The neutral density filter will have a known nominal value in the range of $1.5m^{-1}$ and $5.5\ m^{-1}$. Adjust the smoke meter read out to display the filter nominal value in the range of $1.5m^{-1}$and $5.5\ m^{-1}$. Adjust the smoke meter read out to display the filter nominal value $\pm 0.10\ m^{-1}$

Free Acceleration Test Cycles

Within 2 minutes of the execution of the preliminary free acceleration cycles, conduct three free acceleration test cycles, actuating the vehicle throttle in the manner and sequence described in (Free Acceleration Cycles above).

Determine the corrected maximum 0.5 s average smoke values for each of the three free acceleration cycles.

At the conclusion of the test sequence, and where needed as per manufacturer's recommendation, determine the degree of smoke meter zero shift by eliminating all exhaust from between the smoke meter light source and detector and noting smoke meter display.

Test Validation Criteria

The test results from the acceleration test cycles shall be considered valid only after the following criteria have been met,

(a) The post test smoke meter zero shift values shall not exceed;

(i) ±2% opacity – for smoke measurement made in opacity

(ii) $\pm 0.1m^{-1}$ – for smoke measurements made in smoke density.

(b) The difference between the highest and lowest corrected maximum 0.5s average smoke values from the three test cycles shall not exceed;

(i) 5% opacity – for smoke measurement made in opacity

(ii) $0.5m^{-1}$ – for smoke measurements made in smoke density

Invalid Test

Should the smoke test data from free acceleration test not meet the test validation criteria mentioned above the following items should be checked,

(a) If engine did not meet the operating temperature requirements, run the engine under load for at least 15 min or until the vehicle oil and water temperature gauges indicate that normal engine operating temperatures have been achieved. Return to Smoke Meter Installation and repeat the test sequence.

(b) If improper or inconsistent application of the vehicle accelerator paddle/throttle is suspected, re-instruct the vehicle operator as to the proper execution of the free acceleration test, especially the movement of the vehicle throttle. Continue with the procedures for free acceleration test.

(c) If the post test smoke meter zero check was exceeded due to positive zero drift, the probable cause is soot accumulation on the smoke meter optics. It is recommended that the free acceleration test sequence be repeated and while doing so, the smoke meter zero may be readjusted during the low idle period between each of the free acceleration test cycles. If the measured low idle smoke level of the vehicle is less than 2.0% opacity of 0.20 m^{-1} smoke density, it is permissible to re-zero the meter while it remains exposed to the vehicle exhaust. If the idle smoke level exceeds these limits, it is necessary to discontinue exposure to exhaust before re-zeroing the meter.

If it is not possible to re-zero the meter, the meter optics should be cleaned according to manufacturer's recommendation and the test sequence should be repeated. If zero drift and re-zeroing difficulties persist, the meter purge air system (if so equipped) should be checked for proper operation.

Calculation and Reporting

If the validation criteria are met, the data shall be deemed valid and the test complete. The average of the corrected maximum 0.5 s average smoke values from the three free acceleration test cycles shall be computed and reported as the final test result.

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