# ASSESSMENT OF

# BRICK KILN TECHNOLOGIES OF BANGLADESH

**By**

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# Certificate of Approval

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# Abstract

Brick manufacturing is the fastest-growing industrial sector in Bangladesh. With about 7,000 operating kilns, brick-making sector is contributing about 1 percent to the country's gross domestic product (GDP) and generating employment for about 1 million people. Despite the importance of the brick sector, about 90 percent of kilns use outdated, energy-intensive technologies that are highly polluting.

New technologies such as Vertical Shaft Brick Kiln (VSBK), Hybrid Hoffman Kiln (HHK) and Tunnel Kiln (TK) are substantially cleaner than Fixed Chimney Kiln (FCK) and consume less energy and emit lower levels of pollutants and greenhouse gases (GHGs). However, the use of these technologies in Bangladesh is still in the preliminary stage of implementation, their financial viability (compared with that of the FCK) still needs to be demonstrated.

The objective of this research was to get a priority ranking of different brick kiln technology by Analytic Hierarchy Process (AHP) and Cost Benefit Analysis (CBA) which would give a specific result for thinking about installation of new technologies in Bangladesh perspective.

For analytic hierarchy process (AHP) analysis, a Multi-Criteria Decision Making (MCDM) model, we have considered five main attributes/criteria: Product Quality (PQ), Fuel Efficiency (FE), Environmental Effect (EF), Labour Intensity (LI), Investment (I) and four alternatives: Improved Zigzag Kiln (IZigzag) Technology, Vertical Shaft Brick Kiln (VSBK) Technology, Hybrid Hoffman Kiln (HHK) Technology, Tunnel Kiln (TK) Technology.

For Cost Benefit Analysis (CBA), Cost and Benefit are determined for four alternatives: Improved Zigzag Kiln (IZigzag) Technology, Vertical Shaft Brick Kiln (VSBK) Technology, Hybrid Hoffman Kiln (HHK) Technology and Tunnel Kiln (TK) Technology.

Based on the result which is found from the Technology Assessment evaluation and Cost Benefit Analysis (CBA), it would be determined that which brick kiln technology should be given highest preference in the perspective of Bangladesh.

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# List of Abbreviations

| | |
|---|---|
| AHP | Analytic Hierarchy Process |
| ADB | Asian Development Bank |
| BBMOA | Bangladesh Brick Manufacturing Owners Association |
| BSCIC | Bangladesh Small and Cottage Industries Corporation |
| BTK | Bull’s Trench Kiln |
| BUET | Bangladesh University of Engineering and Technology |
| CASE | Clean Air and Sustainable Environment |
| CBA | Cost Benefit Analysis |
| CBRI | Central Building Research Institute |
| CDM | Clean Development Mechanism |
| DA | Development Alternatives |
| DoE | Department of Environment |
| ESMAP | Energy Sector Management Assistance Program |
| FCK | Fixed Chimney Kiln |
| GHGs | Green House Gases |
| GDP | Gross Domestic Product |
| GOB | Government of Bangladesh |
| HHK | Hybrid Hoffman Kiln |
| IZigzag | Improved Zigzag Kiln |
| MCDM | Multi Criteria Decision Making |
| MOEF | Ministry of Environment and Forests (Bangladesh) |
| MOI | Ministry of Industries (Bangladesh) |
| PA | Practical Action (Bangladesh) |
| PM | Particulate Matter |
| ROI | Return On Investment |
| SEC | Specific Energy Consumption |
| TK | Tunnel Kiln |
| UNDP | United Nations Development Program |
| VSBK | Vertical Shaft Brick Kiln |

# Units of Measures

| | |
|---|---|
| cft | cubic feet |
| ft | foot |
| kg | kilogram |
| kWh | kilowatt hour |
| m | meter |
| $mg/m^3$ | milligram per cubic meter |
| MW | megawatt |
| $PM_{2.5}$ $PM_{10}$ | particulates with diameter less than 2.5 microns or less than 10 microns |
| ppm | parts per million |
| t | ton |
| tce | tons of coal equivalent |
| $\mu g/m^3$ | microgram per cubic meter |

# CHAPTER 1: INTRODUCTION

## 1.1 Background

Brick manufacturing is the fastest-growing industrial sector in Bangladesh. With about 7,000 operating kilns, the brick-making sector is contributing about 1 percent to the country's gross domestic product (GDP) and generating employment for about 1 million people. Brick is the main building material for the construction industry, which has been growing at about 5.6 percent annually between 1995 and 2005, leading to an estimated growth rate of 2-3 percent for brick sector [1]. Despite the importance of the brick sector, about 90 percent of kilns use outdated, energy-intensive technologies that are highly polluting. These outdated kilns are producing fine particulate which causes harmful impacts on health (from the particulate matter) and agriculture yields (from nitrogen oxides) and contributes to global warming (from carbon dioxide) [2].

New technologies such as Vertical Shaft Brick Kiln (VSBK), Hybrid Hoffman Kiln (HHK), and Tunnel Kiln (TK) are substantially cleaner than Fixed Chimney Kiln (FCK) and consume less energy and emit lower levels of pollutants and greenhouse gases (GHGs) [3]. However, because the use of these technologies in Bangladesh is still in the preliminary stage of implementation, their financial viability (compared with that of the FCK) still needs to be demonstrated.

The technology assessment, choice of technology or priority ranking of technology is generally based on a techno-economic feasibility study. The scenario at the local, as well as at the global level is changing, and that necessitates the consideration of factors, such as environmental and socio-cultural, in addition to the techno-economic factors. These lead the technology assessment to a multi-criteria decision making (MCDM) situation. Analytic Hierarchy Process (AHP) is widely used to deal with decision-making problems involving multiple criteria evaluation/selection of alternatives and it has advantages in handling unquantifiable criteria and obtained quite reliable results [4].

The main aim of this research is to demonstrate an applicable way of improving evaluation tactics in complex decision problems where there is a large number of decision-makers (group decision in multi-criteria decision making – MCDM).

Hence, Priority ranking of brick manufacturing technologies: Improved Zigzag Kiln (IZigzag) Technology, Vertical Shaft Brick Kiln (VSBK) Technology, Hybrid Hoffman Kiln (HHK) Technology, Tunnel Kiln (TK) Technology by using AHP and CBA tools would give a result where fuzziness comes closer to reality. So, the outcome of this research contributes to take decision by the decision-makers (DMs) about which type of brick kiln technology will be given preference at what level to increase the brick manufacturing to meet the essential demand in the perspective of Bangladesh.

## 1.2 Objectives of the Research

The objectives of this research are as follows:

(i) To make a priority ranking table using Analytic Hierarchy Process (AHP) of Improved Zigzag Kiln (IZigZag), Vertical Shaft Brick Kiln (VSBK), Hybrid Hoffman Kiln (HHK), Tunnel Kiln (TK) technologies in the perspective of Bangladesh.

(ii) To perform a Cost-Benefit Analysis (CBA) for Improved Zigzag Kiln (IZigZag), Vertical Shaft Brick Kiln (VSBK), Hybrid Hoffman Kiln (HHK), Tunnel Kiln (TK) technologies.

(iii) To prepare recommendations for adopting new technologies.

# CHAPTER 2: LITERATURE REVIEW

This chapter reviews the literature to provide a background on the issue discussed in this thesis. It describes the brick making process, different brick kiln technologies, China's experience in brick manufacturing, the global scenario of brick manufacturing, an overview of Bangladesh's brick sector and barriers of the brick sector.

## 2.1 Brick Making Process

A brick is building material used to make walls, pavements and other elements in masonry construction. Traditionally, the term brick referred to a unit composed of clay, but it is now used to denote any rectangular units laid in mortar. A brick can be composed of clay-bearing soil, sand, and lime, or concrete materials. Bricks are produced in numerous classes, types, materials, and sizes which vary with region and time period, and are produced in bulk quantities.

The production process of bricks can roughly be divided into several major steps: Clay digging, Clay preparation, Clay mixing, Forming or Molding, Drying, Firing and Cooling.

### Clay Digging

Clay is usually dug from the local vicinity of the brick kiln. The clay is then processed as to be free from gravel, lime, and other biowastes/ matter. This soil once excavated is then watered and left for weathering and processing.

### Clay Preparation

This process is done depending on the clay properties and the finished product requirements. The preparation process typically involves crushing the raw material, mixing with water, blending and screening to ensure its consistency.

### Clay Mixing

It is normal to mix different types of clay and even sand at this stage to achieve the correct plasticity, optimum drying and firing conditions. Waste fuels or other carbonaceous materials can be added to the clay to enable green bricks to bum internally during the firing process. Such a process not only saves field for brick firing but also makes the brick lighter, cheaper, portable during transportation and contributes to faster drying rates. It also reduces the losses through breakage.

**Brick Molding**

The most commonly used molds are steel and timber molds, which are open at both top and bottom having two compartments. A mass from the prepared clay mix cut off and rolled up in a clot slightly exceeding the volume of the mold. The clay is then thrown with some force into the mold; the surplus shift is removed away by hand and demoulding takes place at drying platform.

**Brick Drying**

Newly formed bricks are called green bricks and can be dried naturally under the sun. This entails leaving the freshly molded bricks for about 24 hrs exposed to the sun, then turned over on edge and left for another 1 -2 days to ensure uniform drying. Total drying period depends on the capacity of the kiln and daily output of green bricks. It is a common practice that the first molded batch undergoes a drying period of 18-25 days while last molded batch takes 2-4 days.

**Brick Firing**

Once bricks are set into the kiln, the firing is started. Firing is the main energy-intensive process of brick making. But, it again differs depending on the types of kiln used. Firing consists of subjecting the green bricks to gradually increase the temperature up to a maximum of 700-900°C depending on the fusion characteristics of clay. The firing of green bricks changes their physical and chemical structure. It renders them strong, durable and suitable for building construction.

**Cooling**

It is the period of time during which the temperature of burnt units falls down and becomes safe and convenient to be removed from the kiln.

### 2.2 Overview of Global Brick Sector

Brick is the cheapest building material all over the world. Homes, offices, and factories require large quantities of brick. The brick-making industry in developing countries is most often the industry of the very poor and underprivileged. There are approximately 300,000 polluting brick kilns throughout the developing world with over 100,000 of these estimated to be in India alone. The brick industry in India is the third-largest user of coal, over 30 million tonnes per year. In China, the brick industry is claimed to be the fourth-largest user of coal. It is estimated that worldwide brick production is 1,500 billion bricks per annum, split into three main regions:

- **China** – 1,000 billion bricks – 66.67%
- **India** – 200 billion bricks – 13.33%
- **Rest of the World** – 300 billion bricks – 20%

Among the brick producing country, China is in the 1st position and Bangladesh is in 5th position.

**Table 2-1: Overview of Global Brick Production (2015) [5]**

| Country | Production % | No. Billion P.A. |
|---|---|---|
| **China** | 66.67% | 1,000 |
| **India** | 13.33% | 200 |
| **Pakistan** | 3.00% | 45 |
| **Vietnam** | 1.67% | 25 |
| **Bangladesh** | 1.13% | 17* |
| **Nepal** | 0.40% | 6 |
| **Rest of Asia** | 0.47% | 7 |
| **Total Asia** | **86.67%** | **1,300** |
| **USA** | 0.53% | 8 |
| **UK** | 0.37% | 4 |
| **Australia** | 0.13% | 2 |
| **Rest of World** | 12.40% | 186 |
| **Total Rest of World** | **13.33%** | **200** |
| **Total World Production** | 100.00% | 1,500 |

*At present, Bangladesh is producing 22.8 billion bricks per annum [1].

### 2.3 Technology vs Workforce

China is using the most updated, energy-efficient and less polluting kiln technology to produce bricks. In China, 80,000 Hoffman Kilns & Tunnel Kilns are producing 1,000 billion bricks per year. 5 million people are engaged in the brick industry. Besides, in India, most of the kilns are outdated FCBTKs and Clams which are the most polluting brick kiln. 200 billion bricks produced per year by using more than 100,000 kilns.

At present, Bangladesh has 7,000 kilns, most of the kilns are Improved ZigZag Kiln which are less polluting than FCBTKs and Clams. 1 million people are engaged to produce almost 23 billion bricks per year.

**Table 2-2: Technology VS WorkForce (2015) [5]**

| **Country** | **Major Kiln Types** | **No. of Kiln** | **No. of Bricks Produced (in billion/year)** | **No. of People Employed** | **No. of Bricks Produced per Employee** |
|---|---|---|---|---|---|
| China | Hoffman Kiln & Tunnel Kiln | 80,000 | 1,000 | 5 million | 200,000 |
| India | FCBTKs, Clams, Hoffman Kiln & Tunnel kiln | 100,000 | 200 | 10 million | 20,000 |
| Pakistan | Clamps & MCBTKs | 12,000 | 45 | 9 million | 5,000 |
| Vietnam | Tunnel Kiln & VSBKs | 10,000 | 25 | - | - |
| Bangladesh* | IZigZag, Hoffman Kiln & Tunnel Kiln | 7,000 | 23 | 1 million | 23,000 |
| Nepal | Clamps & BTKs | 700 | 6 | 140,000 | 42,875 |

For Bangladesh, updated data has been included in table 2.2.

## 2.4 Key Problems of Global Brick Sector

- Brick making industry is the single largest emitter of industrial black carbon in Asia - a major contributor to Asian Brown Cloud (ABC).
- Significant impact on global warming.
- The large emitter of $CO_2$ & GHG due to high coal use - emitting 890 million tonnes $CO_2$ p.a.
- At a conservative estimate, 300,000 outdated brick kilns burn 1,500 billion bricks p.a., consuming 375 million tonnes of coal - plus scavenged fuels

- Significant social problems - clean air, health, safety, living and working conditions, in addition to regional problems.

### 2.4.1 Global Warming

Awareness of the issues surrounding global warming and climate change are currently at an all-time high. Due to the increasing volume of compelling and indisputable research, combined with the education and awareness of the general public, businesses and governments around the world are increasingly acknowledging the impact of climate change on both the environment and local economies. They are also recognizing that they must actively become involved in seeking solutions.

$CO_2$ emissions have been acknowledged as a significant contributing factor to global warming and the focus is now more than ever to actively seek out solutions to reduce these emissions and their impact on the environment.

**The Impact of the Brick Industry on Global Warming**

The brick industry has long been identified as a major contributor to these emissions. Worldwide annual clay brick production is estimated to be over 1,500 billion per annum. The majority of these bricks are produced in developing countries using inefficient polluting kilns that have devastating environmental impact resulting in irreparable harm to the environment and the lives of those working in them.

There are over 300,000 of these kilns worldwide that currently [6]:

- produce over 750 million tonnes of carbon dioxide emissions into the atmosphere every year;
- burn 315 million tonnes of fossil fuel every year, plus millions of tonnes of scavenged highly-polluting fuel, e.g. tires, wood, waste oil, cow dung, paper, liquid tar (mazoot) battery cases, etc. frequently burnt under cover of darkness;
- create hazardous working conditions for workers, including young children;
- Use inefficient technology, producing sub-standard bricks.

Under increasingly strict environmental laws many developing countries have banned polluting kilns particularly the Bull's Trench Kiln and the Clamp Kiln. Despite bans, many of these kilns continue to operate undeterred.

### 2.4.2 Black Carbon

Black Carbon results from the incomplete combustion of fossil fuels, wood, and other biomass. Many of the sources of Black Carbon relate to human activity: transportation, shipping, agricultural burning, diesel engines, residential cooking and heating, and brick kilns. Black Carbon is an important component of airborne particulate matter, it is a deadly air pollutant. Globally, the WHO estimates that outdoor particulate matter is responsible for 865,000 premature deaths each year. Black Carbon is described as even more particularly dangerous, recent studies suggesting that it has an even greater effect on health than general particle emissions [7].

Studies indicate that there are specific links between particulate emissions and heart attacks, cancer and respiratory illness. Together with ozone in the lower atmosphere Black Carbon has global and regional impacts disturbing tropical rains and the Asian monsoon, affecting the livelihoods of millions. Melting of snow and ice in the Arctic and the snowpack and glaciers of the Himalayas are directly attributed to Black Carbon emissions. Risks of flooding are associated with melting. Black Carbon contributes to atmospheric brown clouds (ABC's), these eventually become transcontinental plumes, with large impacts on clouds and rainfall patterns and which also contribute to glacial melting.

Black Carbon severely affects both indoor and outdoor air quality in workplaces, homes, cities, and villages. Together with ozone and methane it also contributes to damaging agriculture; emissions severely affect soil quality and crop yields particularly of wheat, rice and soya bean in the developing world.

Black Carbon significantly impacts on the living standards, health and working conditions particularly of the poor in developing countries.

## 2.5 Policy Interventions in Different Countries

Different countries in the world have taken different policies to control environment pollution due to brick production. Policy interventions in different countries are discussed below (Table 2-3).

**Table 2-3: Policy Interventions in Different Countries**

| COUNTRY | POLICY INTERVENTIONS |
|---|---|
| Nepal | Banned the movable bulls trench kiln |
| Bangladesh | Banned FCBTK, moving towards zigzag, Hoffman kiln and Tunnel Kiln. |
| | Banned use of agricultural soil. |
| India | Banned Moving bulls trench kiln in 1996 and introduced emission standard for VSBK kiln. |
| **COUNTRY** | **POLICY INTERVENTIONS** |
| South Africa | Government incentive to move from energy inefficient clamps to cleaner technology. |
| | Carbon tax on the brick sector. |
| Vietnam | Establish Department of Building Materials. |
| | Encourage to replace brick by glass and ceramic. |
| China | Organized the brick sector into Township and Village Enterprises & State-Owned Enterprises to regulate easily. |
| | 1999: Banned the use of solid clay bricks in coastal cities. |
| | 2004: Controlled Use of solid clay brick in small towns and rural areas. |
| | 2005: Controlled Use of solid clay brick in 170 cities. |
| | 2007: Phasing out outdated technologies. |

### 2.6 China's Experience In Brick Sector

China is the world's largest developing country with the fastest economic growth rate, averaging to more than 10 percent during the past 3 decades. With 54 percent of global production, it is also the world's leader brick producer and has the most advanced brick industry among all developing countries. Brick production is highly concentrated in four countries – China, India, Pakistan and Bangladesh – which account for about 75 percent of the world's total production [8]. Yet, it is hard to claim China as a success story in brick-industry development. Although the country has achieved dramatic improvement in productivity, energy, and land saving, and product diversity and quality, small-scale brick kilns using inefficient, high-emission technologies still dominate the industry. Indeed, the existence of numerous small enterprises means that the average efficiency for its brick industry is much lower than that of developed countries.

Both Bangladesh and China have high population densities, and most economic activities occur within limited geographical areas, putting serious pressure on natural resources. Bangladesh's current stage of development similar to that of China in the early 1990s in terms of low-efficient kiln technologies, fuel use, single raw material, and brick product and dominance of small brick factories. This suggests that China's brick-industry experience was maybe even more relevant for Bangladesh than that of developed countries. Moreover, the fast economic growth prompted the evolution of the brick industry in a relatively short period of time, which may result in lessons to be learned for the short, medium and long run. This chapter summarizes the evolution of China's brick industry in recent decades and draws lessons that could be useful for the future development of Bangladesh's brick sector.

It should be noted that available data are not always comparable across countries. While the information for Bangladesh focuses on kiln technologies and control of emissions, most of the literature for China focuses on alternative raw materials, new brick products, and energy-saving materials. Thus, any lessons drawn from China's experience must be adapted to Bangladesh's unique country conditions prior to implementation.

### 2.6.1 Economic Development: The Driving Force of China's Brick Industry

The development of China's brick industry is closely linked with the country's economic development. In the 1970s and 1980s, the brick industry - referred to as "the mother of the township and village enterprises" - played a pivotal role in the development of the rural and township economy. However, with the reform policies introduced in the 1990s, the brick industry gradually began to take a back seat to the boom in other sectors. Yet, the government introduced regulations to promote new wall materials to save clay, land, and energy - a move that brought dramatic changes to the industry.

Economic development in Bangladesh in 2008 is similar to that of China in 1990. For comparison, all the indicators in this section are expressed into the unit of Bangladesh bricks. In China, bricks are counted in "Standard Bricks" which are smaller than the bricks produced in Bangladesh. The size of standard bricks in China is 240mm×115mm×53mm, and the size of a normal brick in Bangladesh is 9.5"×4.5"×2.75" (about 241mm×114mm×70mm). Therefore, 1 Bangladesh brick = 1.317 Standard Chinese bricks.

Comparisons in terms of per capita GDP (US$1,200 in Bangladesh versus US$1,100 in China) and rate of urbanization (27 percent) suggest that economic development in Bangladesh in 2008 was similar to China's status in 1990 (Table 2-4). More importantly, the energy intensity of China in 1990 (13.8-14.5 tce/100,000 bricks) was very similar to that of Bangladesh's current level (15 tce/100,000 bricks). However, China showed better performance than Bangladesh for most economic indicators, including GDP growth rate (11 percent versus 6 percent), per capita brick production (350 versus and unit brick production (4.1 million in 1990 and 5.3 million in 1995 versus 3 million). China's mechanical molding process led to higher labor productivity per employee (70,000 bricks versus 15,000 bricks). The number for Bangladesh also includes employment in upstream (supply of clay and coal) and downstream sectors (transport of bricks and marketing). If these sectors were omitted, the difference between China and Bangladesh in terms of labor productivity would be even higher. Similarly, by 1995, the energy intensity had been reduced to 10.5 tce per 100,000 bricks, which is 30 percent less than that in Bangladesh.

**Table 2-4: Comparison of Economic Development in China and Bangladesh for Selected Years [9, 10]**

| Economic indicator | China | | Bangladesh |
|---|---|---|---|
| | 1990 | 1995 | 2008 |
| **Macroeconomic** | | | |
| Urbanization (% of urban population) | 27 | 31 | 27 |
| Population (million) | 1,100 | 1,200 | 160 |
| GDP per capita, PPP (US$) | 1,100 | 1,800 | 1,200 |
| GDP growth rate (%) | 11 | | 6 |
| **Brick-industry status** | | | |
| Total brick production (billion) | 350 | 530 | 15 |
| Total employment (million) | 5 | | 1 |
| Brick production per capita | 305 | 340 | 94 |
| Brick-sector annual growth (%) | 9 | | 5.6 |
| Production units (no.) | 85,000 | 100,000 | 5,000 |
| Unit brick production (million bricks/factory or kiln/year) | 4.1 | 5.3 | 3 |
| Labor productivity (1,000 bricks/employee) | 70 | 106 | 15 |
| Energy intensity (tce[2]/100,000 bricks) | 13.8-14.5 | 10.5 | 15 |
| Fuel use | Exclusively Coal | Exclusively Coal | 99% Coal |
| Dominant kiln type | Hoffman (~93%) | n.a. | FCK (75%) |
| Brick-molding mechanization level | High | n.a. | Very low |

### 2.6.2 Development of China's Brick Industry

The following subsections present the evolution of China's brick industry over the last two decades (Table 2-5).

**Table 2-5: Snapshot of China's Brick Industry, 2008 [9, 11]**

| **Parameter** | **Value (approximate)** |
|---|---|
| Brick-making enterprises (all types) (no.) | 80,000 |
| Brick-making fuel used | Exclusively coal |
| Annual brick production (standard Chinese bricks) | 900 billion–more than 1 trillion |
| Contribution to GDP (%) | 1.74 |
| Contribution to the industry value added (%) | 4.06 |
| Coal consumption (million tce) | 50 |
| $CO_2$ emissions (million t) | 150 |
| Clay consumption (billion $m^3$) | 1.4 |
| Total employment (million employees) | 5 |
| The growth rate of the construction industry (1998–2008) (%) | 7.1 |
| The growth rate of the industry of building materials (1998–2008) (%) | 20 |

### 2.6.3 Brick-Making Processes in China

China uses various brick-making processes. As the brick industry started to diversify, comparing the energy efficiency among processes became more complicated. Energy efficiency depends on the raw material used, the final product, and the techniques applied in the processes of brick molding, drying, and firing. According to the energy-efficiency and production scale, considering external fuel consumption only, fired brick-making processes in China can be categorized into three types [9]:

- The first type relates to the firing process with coal consumption below 1 tce per 100,000 bricks. The firing process relies mainly on the residual heat from industrial wastes. The main raw materials are shale, coal gangue, and coal ash. Products mainly include hollow bricks, perforated bricks, and hollow blocks. The production process uses vacuum extruder (for molding), artificial drying, and the Tunnel Kiln. The enterprises have a production scale of more than 30 million bricks per year and account for 2–3 percent of total enterprises in the brick sector.
- The second type relates to a coal consumption of 6.6–9.2 tce per 100,000 bricks. Shale or clay is the major raw material, mixed with low-quality coal. Coal gangue or coal ash is internal fuel. The main products are perforated fired bricks, and the

production processes combine natural and artificial drying using either the Hoffmann or Tunnel Kiln.

- The third type is the least efficient, with 10.5–14.5 tce per 100,000 bricks, accounting for the majority of brick-making enterprises (70 percent of the total). It includes numerous small enterprises that produce solid clay bricks by natural drying and firing. It uses the Hoffmann or primitive Hoffmann kilns, located in rural areas, with an annual production of 6–15 million standard Chinese bricks per kiln. Replacing clay with industrial waste can save energy by using the residual heat as internal fuel, but this alone cannot contribute to reducing $CO_2$ emissions.

### 2.6.4 Pollution Levels in China

Among the various brick kilns in China, the Intermittent kiln emits the highest levels of $SO_2$ and $CO_2$ (Table 2-6).

**Table 2-6: Emissions of $SO_2$ and $CO_2$ in China by kiln technology, 1990 [11]**

| **Kiln technology** | **$SO_2$ emissions** (t/million Bangladesh bricks) | **$CO_2$ emissions** (t/million Bangladesh bricks) |
|---|---|---|
| **Intermittent** | 6.6 | 149 |
| **Hoffmann** | | |
| Natural drying, solid bricks | 3.6 | 82 |
| Artificial drying, solid bricks | 3.6 | 83 |
| Artificial drying, hollow bricks | 2.1 | 49 |
| **Tunnel** | | |
| Artificial drying, solid bricks | 4.6 | 105 |
| Artificial drying, hollow bricks | 2.6 | 63 |

Overall, increasing the use of new brick products has accounted for the dramatic growth in China's brick industry. As the industry began to employ newer technologies and materials, energy efficiency and resource conservation (e.g., clay and arable land) increased. The industry also became more conglomerated, with larger emerging product lines and enterprises. In 2005, the new product lines had an annual average capacity of more than 15 million standard Chinese bricks per line. The capacities of new coal gangue brick and coal ash brick lines are more than 30 million bricks per line on average, with the largest reaching 160 million standard Chinese bricks.

### 2.6.5 Government Intervention

The Chinese government has promoted a series of policies, laws, and regulations to control solid clay bricks and promote new wall material to save clay, land, and energy. It has also invested considerably in developing new technologies to promote the use of locally available materials for clay replacement. This section reviews the major regulations issued by the Chinese government on the brick industry and the institutions and organizations that have contributed to managing and facilitating its healthy development.

**Laws and Regulations [11]**

- In 1988, regulation of the brick and tile industry was initiated by the Chinese government with two objectives: (i) to control the use and production of solid clay bricks and (ii) promote research and development (R&D), production, and use of new wall materials. Many government offices at the ministry level are involved in issuing, monitoring, and implementing the regulations.
- In 1992 the Government started to control solid clay bricks by issuing the "Circular of advice on how to accelerate wall material renovation and to promote energy-efficient buildings".
- In 1999 the Government banned the use of solid clay bricks in coastal cities and cities where land was scarce. In the same year, the State Office of Wall Material Renovation of the National Development and Reform Commission identified the first 170 cities expected to limit the use of solid clay bricks to certain targets by 2003.
- In 2004, the Government mentioned for the first time the controlled use of solid clay bricks in small towns and rural areas. It established national targets to reduce their production by 80 billion bricks by 2006 and prohibit their use in all cities by 2010.
- In 2005, the Government banned all clay-building products in the 170 cities and extended the regulation to suburban areas. It also banned the use of solid clay bricks in other 256 cities by 2008.
- In 2007, the 11$^{th}$ Five-Year Plan established targets for China's brick and tile industry, centered on (i) developing new wall materials, (ii) conserving land

resources, (iii) saving energy and other resources, and (iv) Phasing out outdated technologies.

### 2.6.6 Current Problems and Challenges Ahead

China's brick industry is at a critical stage in the process of transforming its industrial structure, and many serious issues remain; key among them are the following:

- Solid clay bricks still account for about half of total brick production. Phasing out solid clay bricks confronts significant barriers. As demand for construction materials escalates with the economy, prices for solid clay bricks become more competitive due to relatively cheap labor and clay. Development of new bricks is hampered. Local governments have substantial influence over the brick industry, and local protectionism prevails. Once the central government removed agriculture taxes, the brick industry became a more important source of local fiscal income, especially in less developed, remote regions. Thus, phasing out solid clay bricks is against local governments' interest as tax collectors.
- Small enterprises still dominate the brick industry. About 60 percent of brick enterprises produce less than 10 million bricks per enterprise annually, accounting for about 20 percent of total bricks. These enterprises follow simple production and management models, apply outdated technologies, and use unskilled labor. Therefore, their productivity and energy efficiency are also relatively low. In addition, their dominance makes it difficult to phase out solid clay bricks and encumbers the adoption of new technologies.
- Pollutant emissions are rarely controlled and treated. Emissions from brick and tile kilns in China are usually not treated. Nationwide, there are fewer than 10 brick and tile enterprises equipped with emissions treatment facilities. For PM emitted during the processes of grinding and transport, some firms have installed bag filters, while most use air-tight treatment to reduce emissions. In addition, because environmental regulations are loose overall, treatment equipment is not operational most of the time. The brick industry faces two major hurdles to control emissions: (i) most enterprises lack sufficient capital to invest in emissions reduction equipment and (ii) the value-added and profit rate are low, leaving little margin for the cost of emissions control. For example, a sulfur scrubber is

technologically difficult and unaffordable for small producers. Promoting Tunnel kilns in newly constructed enterprises (and gradually phasing out Hoffmann kilns) and using cleaner fuels (such as industrial waste and low-sulfur coal) can help reduce emissions.

## 2.7 Overview of Bangladesh's Brick Sector

Brick making is indispensable for Bangladesh' economy. Though not formally recognized as an industry, brick-making is a significant economic activity in Bangladesh. The country's overwhelming dependence on bricks is due to its lack of stones in any sizable quantity or other alternative building materials at a comparable cost. Table 2-7 summarizes the main characteristics of the brick sector in Bangladesh [1].

**Table 2-7: Snapshot of Bangladesh's brick sector (2017) [1]**

| Parameter | Value |
|---|---|
| Estimated total number of kilns | 7,000 |
| Annual brick production | 22.8 billion |
| Value of output | TK182.40 billion (~US$2.17 billion)* |
| Contribution to GDP | ~1% |
| Coal consumption | 5.68 million tons |
| Value of imported coal | TK22.6 billion (~US$322 million) |
| Emissions $CO_2$ | 9.8 million tons |
| Clay consumption | 3350 million cubic feet |
| Total employment (including the supply of clay and coal, transport of bricks) | ~1 million people |
| The estimated future growth rate of the brick sector over the next ten years | 2-3% |

*Estimated at a per-brick price of TK 8.00.

Brick kilns in Bangladesh are mostly informal and small-scale operations. More than 90 percent of brick kiln owners are small-scale operators. Most FCKs are individually owned, with each owner possessing one kiln only. Multiple ownership of one kiln and multiple kilns under the same ownership are rare. In a few cases, established business houses own brick kilns that are part of a portfolio of industrial establishments. The kiln owners are organized as the Bangladesh Brick Manufacturers Owners Association (BBMOA). This association is expected to support actions perceived as beneficial to the interest of its members; thus, it must be involved in any reform concerning the brick sector.

Regulating the brick sector has improved considerably; however, enforcement is still needed. The Government of Bangladesh (GOB) has demonstrated a serious commitment to regulating the brick industry through a series of measures [12]:

- 1989. The Brick Burning (Regulation) Act of 1989, Bangladesh's first brick-making law, banned the use of firewood for brick manufacturing and introduced licensing for brick kilns.
- 2001. The 1989 Act was amended to regulate the location of brick kilns. The new provision required that brick kilns not be set up within 3 km of the upazilla or district center, municipal areas, residential areas, gardens, and the government's reserve forests. Despite this amendment, the location requirements have not been enforced, and the use of firewood still continues on a limited scale.
- October 2002. The GOB introduced a rule that made the use of 120-ft chimneys for brick kilns compulsory. This requirement was successfully enforced, especially in the vicinity of urban areas, and most Bull's Trench Kilns (BTKs) were upgraded to FCK technology.
- March 2007. The GOB issued a notification that environmental clearance certificates would not be renewed if the owners did not shift to alternative fuel and improved technologies by 2010. However, this regulation has not been implemented since little on-the-ground activity occurred to facilitate the switch.
- July 2010. A new notification was issued banning FCK operation three years from this date.
- November 2013. Brick making and field installation (Control) Act 2013, Bangladesh's latest brick-making law.

Outdated brick-production technology and seasonality of kiln operations hinder brick-sector productivity. FCK technology is more than a century old. The brick sector has largely grown by replication of existing kilns, with little variation in kiln design or operation. Brick-making is a seasonal operation. Because kilns are often located in low-lying areas that are flooded during the monsoon, the operational period averages about 5 months out of the year. Employment in brick kilns is therefore also seasonal, involving migrant workers who receive low wages and perform hard physical labor under hazardous conditions. As a result, annual production averages about 3–4 million bricks per enterprise compared to 12 million standard Chinese bricks (equivalent to 9.2 million Bangladesh bricks) per enterprise in China.

Most brick kilns have low energy efficiency and are highly polluting. Most brick kilns in Bangladesh burn low-quality coal imported from India with a high content of sulfur (about 5 percent) and clinker content. Dependence on this type of coal is likely to continue in the foreseeable future. Owing to Bangladesh's current energy shortage, the GOB decided not to provide natural gas for new brick kilns. Moreover, the 20 existing gas-fired kilns are facing closure.

Most operating kilns consume about 18–22 tons of coal to produce 100,000 bricks. Coal-burning by kilns releases pollutants into the atmosphere, leading to harmful effects on health (e.g., from PM) and agricultural yields (e.g., from $NO_x$) and contributing to global warming and climate change (e.g., from $CO_2$). Adopting such modern kilns as the Improved Zigzag, VSBK or HHK would mitigate some of the above-mentioned impacts due to their lower coal consumption (12–15 tons per 100,000 bricks) [12].

Brick kilns have a negative effect on agricultural productivity. Almost invariably, good-quality topsoil from agricultural fields with high clay content is used in Bangladesh's brick kilns. Depletion of topsoil with high organic content for brick-making is a major concern for agricultural production. In addition, acid deposits from the sulfur dioxide ($SO_2$) and $NO_x$ emitted from the brick kilns negatively affect agricultural productivity.

The weak financial situation of most kiln operators hinders the adoption of modern technologies. Most kiln operators have a weak financial base, with limited or no access to bank financing. Because brick-making is not formally recognized as an industry, kiln owners cannot avail themselves of the concessional loan windows of financial institutions for the SMEs. In addition, most kilns are established on rented lowlands that cannot be used as collateral to access finance. As a result, only short-term working capital financing is available to kiln owners.

### 2.8 Barriers Facing the Brick Sector Ii Bangladesh

The barriers that have contributed to the current state of the country's brick sector and its inability to bring about changes include:

(a) Lack of supporting regulations, fiscal incentives, and standards to encourage more energy-efficient practices and technologies. Except for some efforts to regulate the sector, the government has made little effort to establish effective boundary limit emission standards.

(b) Little and no governmental activity to assist the brick sector to undertake comprehensive programs so as it to make it cleaner and more profitable. Brick owners usually were left to bring in changes of their own which they have often failed to do, because of the vicious cycle of low efficiency – low income.

(c) Lack of knowledge and access to energy-efficient technology, which can lower production costs at the same time. Comprehensive dissemination programs that demonstrate the potential economic benefits of energy-efficient technologies have yet to be carried out.

(d) Lack of access to liquidity to finance the modernization of brickmaking operations. As traditional brick kilns have seasonal employment, they have not been included in the list of recognized SMEs and thus, are not eligible for concessional SME loan windows.

(e) Lack of capacity in terms of technical and business skills at the enterprise level that could bring changes towards improved efficiency and reduced pollution.

(f) Limited experience of commercial lending institutions with SMEs and in particular, brick SMEs.

(g) Lack of access to finance constraints the owners' capacity to adopt improved technologies that would reduce pollution and increase energy efficiency. Thus, for small operators, incremental, low-cost retrofit technology appears better suited for upgrading kilns. Lower-emission, higher-efficiency kilns (e.g., coal-based HHKs) cost 16 times or more than the FCKs. Moreover, these kilns operate year-round on highlands above flood level; these are scarce and those near major cities are very expensive. Because of these constraints, current FCK owners are unlikely to adopt the HHK or other modern technologies unless flood-free land is made available to them at an affordable cost.

### 2.9 Existing Brick Kiln Technologies

Bangladesh uses five main types of kiln technologies. The Fixed Chimney Kilns (FCKs) are very polluting and relatively inefficient which are now banned in Bangladesh. Most of the Fixed Chimney Kilns (FCKs) are replaced by Improved Zigzag kilns (IZigzag). The Improved Zigzag kilns (IZigzag), Vertical Shaft Brick Kilns (VSBK), Hybrid Hoffmann Kilns (HHK) and Tunnel Kilns (TK) are the existing brick kiln technologies of Bangladesh. The following sections discuss the characteristics of all these technologies.

#### 2.9.1 Improved Zigzag Kiln (IZigzag)

The improved Zigzag Kiln is a modified version of the traditional Zigzag Kiln or 'Hawa Bhatta'. It is elliptically shaped with well-insulated permanent side walls and roofs and arched firing chambers that allow easy airflow. The kiln is versatile in size ranging from 44 to 52 chambers.

Clay and coal are mixed together to form into bricks. After sun drying, the green bricks are loaded into chambers which are fired through stoke holes in the roof until the temperature rises to about 800°C. The air required for the combustion process is forced from behind by a centrifugal draft fan since the zigzag path giving long-distance and high obstacles for the flue gas to pass. As the air reaches the line to be fired, it is already preheated from the previous firing zone thus reducing firing time to about 1m/hour. A water scrubbing system is installed inside the chimney that filters before releasing into the atmosphere through the chimney.

The Improved Zigzag kilns used in Bangladesh are replications of similar Indian kilns developed by the Central Building Research Institute (CBRI) in Roorkee, India during the 1970s. They are fairly similar to Habla kilns once widely used in Germany and Australia. If properly constructed and operated, improved zigzag kilns would result in better energy efficiency and lower emissions. The energy efficiency gains are due to better insulation and improved heat transfer to the green bricks. The emission reductions are due to lesser fuel use, better brick stacking, and zigzag airflow over the longer path and flue gas scrubbing in the water-filled duct connecting to the outlet chimney.

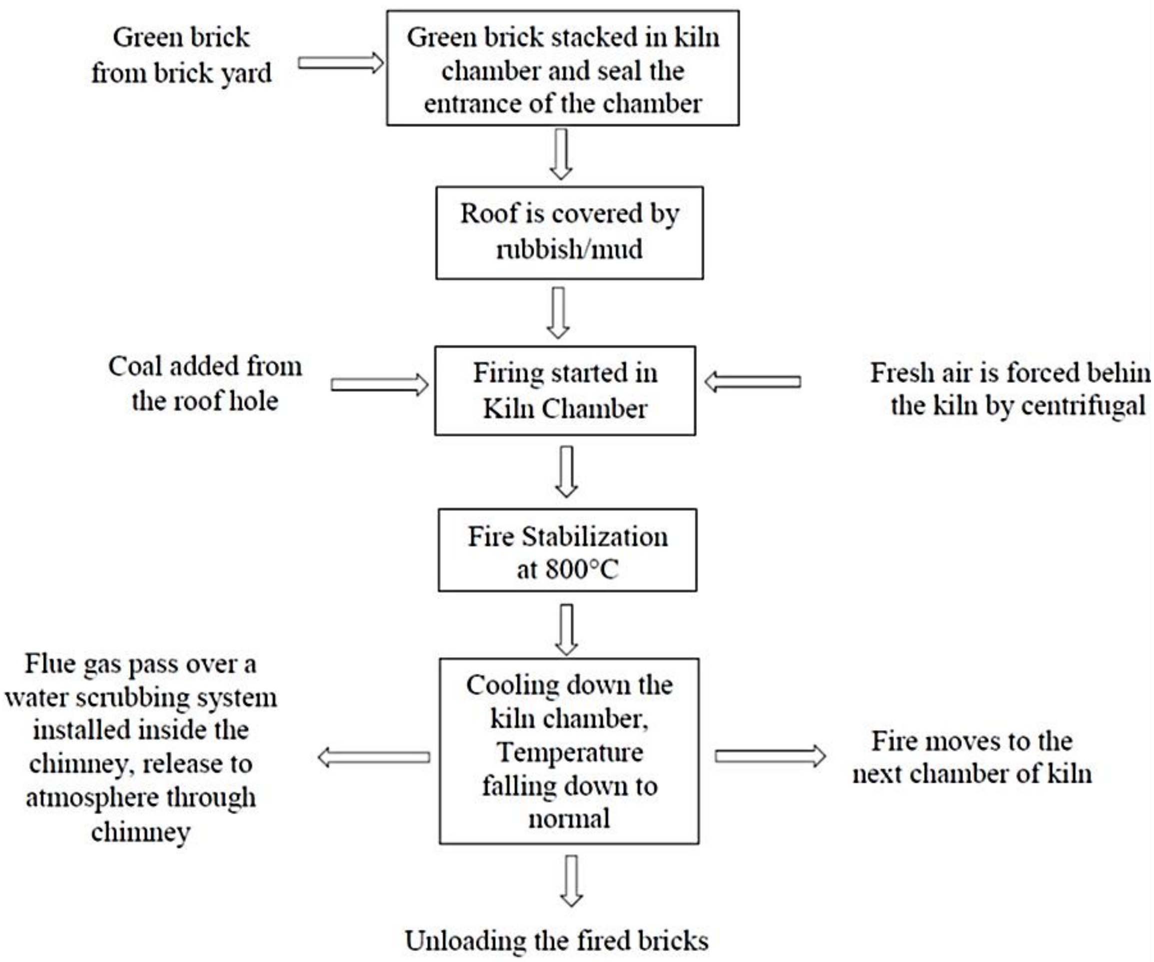


**Figure 2-1: Flow Diagram of Improved Zigzag Technology**

An improved zigzag kiln is rectangular and typically measures about 250 ft long and 80 ft wide. It has a 55 ft high fixed chimney located on one side of the kiln. An induced draft fan located at the bottom of the chimney draws the flue gas from the kiln and discharges it into the atmosphere. The induced draft fan ensures a well-controlled airflow through the kiln. The kiln is divided into 44 to 52 chambers, separated from each other by green bricks in a way that the hot gas moves in a zigzag path through small openings. The long travel path of bricks in a zigzag pattern and the contact of hot gas from the firing zone with bricks in the preheating zone contribute to the transfer of more heat in the preheating zone. Thus, the flue gas - rather than the fuel - heats up the bricks. In addition, the waste heat in the flue gas helps to better drying and reducing the moisture content in bricks. These effects promote reduced fuel consumption, greater efficiency, and higher brick quality compared to FCK's [13].

x

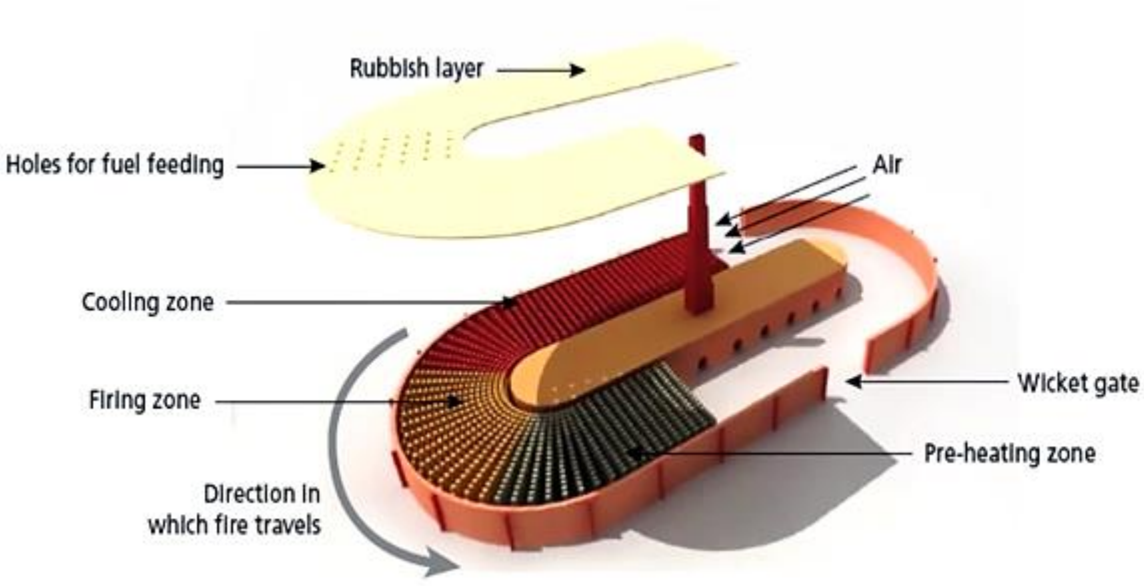


**Figure 2-2: Schematic Diagram of Improved Zigzag Technology [13]**

The flue gas' repeated changes in direction and impinging on the walls and stacked bricks lead to the deposition of significant amounts of the particulate matter mostly on the green brick surface. The deposition of particulates implies that the flue gas has much less particulate load. This could be the reason for reduced Zigzag emissions compared to FCKs emissions.

The improved zigzag kiln also incorporates a simplified flue gas scrubber. The connecting duct between the center of the kiln and the inlet of the induced draft fan is half to two-thirds 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 continued scrubbing.

The improved zigzag kilns in Bangladesh have been implemented with the help of artisans without expert supervision. Thus, it has not been possible to ensure proper construction according to certified design, which is important in reducing the level of particulate emissions. To achieve this goal, it is essential to (1) try out the technology with expert professional input; (2) develop certified design specifications for construction and standard operating procedures; (3) establish good operational practices and management. In the absence of such a systematic approach, not only there may not be significant reductions in emission levels, but the local pollution may actually increase due to reduced chimney height.

**Figure 2-3: Improved Zigzag Kiln [13]**

### 2.9.2 Vertical Shaft Brick Kiln (VSBK)

The Vertical Shaft Brick Kiln (VSBK) was first developed in China. The VSKB is fuel-efficient consuming 20 to 30% less fuel in comparison to the BTK and FCK. In addition, the kiln is simple to construct and operate making it ideal for rural areas. The VSKB requires 1 acre of land compared to 3 acres for the FCK. The VSBK has been tested and proven to be successful in China. In India and Nepal, it has enjoyed limited success. There was one effort to construct a VSBK in Bangladesh, but that was unsuccessful due to the lack of adequate technical and financial support and poor brick quality considering the incremental investment. In a VSBK, bricks are stacked in a shaft measuring 1 x 1$m^2$ up to a height of 6.0m Green bricks are loaded from the top in batches of 224 bricks arranged in four layers. At the bottom, bricks are taken out using a special unloading device. On the average one batch of 224 bricks is unloaded every 1.5 hours. The firing occurs around the middle of the shaft. The kiln uses pulverized coal, which is loaded from the top along with the green bricks. The combustion air enters at the bottom of the shaft and moves up through the bricks already fired. The combustion air gets preheated to about 750$^{o}$C by taking up heat from the fired bricks. After combustion, the hot flue gases move up through the unfired bricks and the process preheat the bricks to be fired. The VSBK is a permanent structure and can produce bricks throughout the year. It has a life of 8 to 10 years with minimum maintenance. One VSBK can have multiple shafts and can be very economical in utilizing space. A VSBK with six shafts can have the same capacity as that of an FCK but needs only 13% of the space of an FCK [14].

A standard VSBK consists of two shafts, which produce 8,000–10,000 bricks per day. A larger production facility can be built by adding more shafts. Green bricks are usually carried to the top of the kiln by a conveyor belt and stacked at the top platform. A feedstock of green bricks remains on the platform for several days to guard against supply shortfall due to inclement weather when green bricks cannot be moved. Fired bricks are unloaded at the bottom 24 hours after loading at the top.

Using green bricks with internal fuel is standard practice for the VSBK. Up to 50 percent of the pulverized coal is mixed in with clay. Internal fuel may include waste materials with some calorific value. The rest of the coal is charged along with the green bricks in the loading process. As the coal is stationary and enters the hot combustion zone slowly, it tends to burn out completely, providing higher efficiency and less pollution. This contrasts with other coal-fired kilns, where coal is charged periodically.

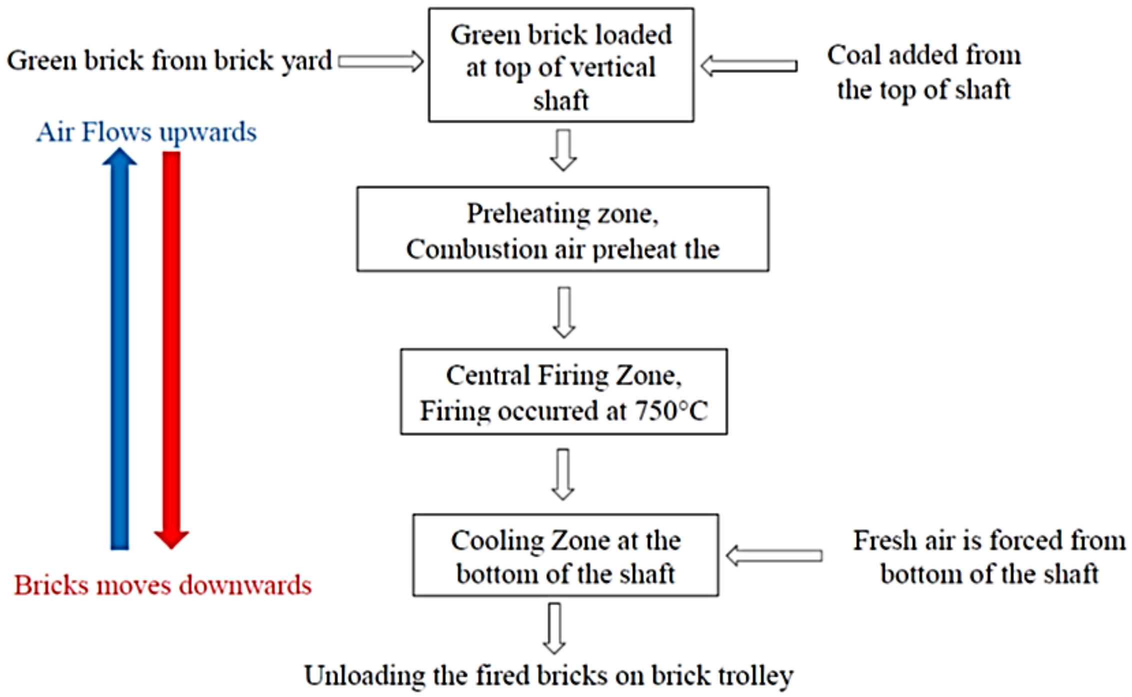


**Figure 2-4: Flow Diagram of VSBK Technology**

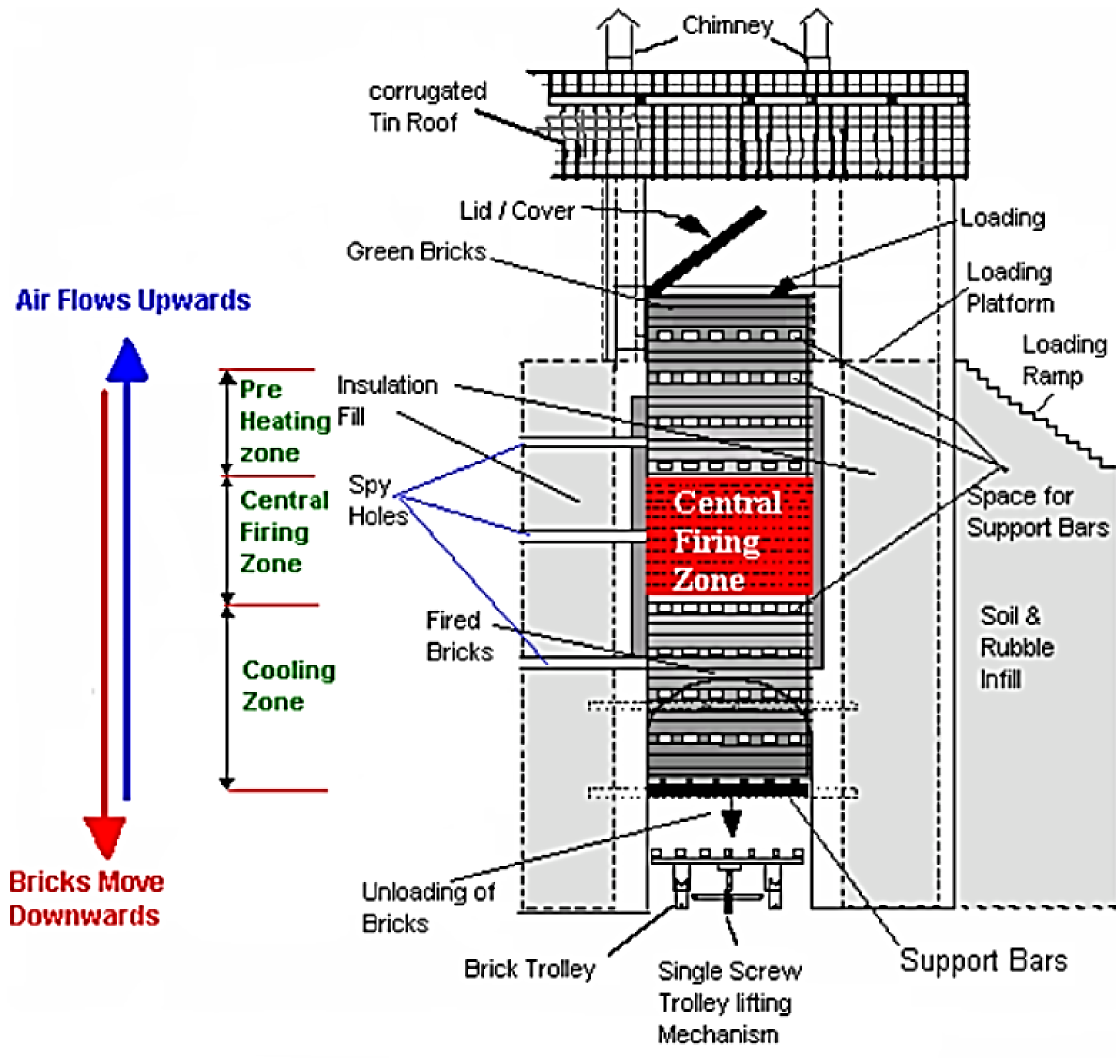


**Figure 2-5: Schematic Diagram of VSBK Technology [14]**

Some operations require more skilled labor than FCK (e.g., carrying green bricks to the top of the kiln, stacking bricks in the shaft at regular intervals, mixing internal fuel with clay, controlling the fire in the firing zone, and unloading bricks). Bricks unloading can also be challenging because bricks tend to crack if withdrawn too quickly from the hot kiln. The VSBK bricks have satisfactory compressive strength and meet Bangladesh standards. Because they have a dull (red) color, their price is usually lower than that of FCK bricks.

Despite the low capital cost, scalability, and low emissions, the adoption of VSBK has had only limited success in South and East Asia. Existing kiln owners have been reticent to move to an unfamiliar new technology, which requires additional investment. For the few new entrepreneurs entering brick manufacturing, awareness-raising and the supply chain are the main problems in adopting the VSBK. In China, most entrepreneurs are moving toward large-scale production, using the HHK and Tunnel kilns.

**Figure 2-6: Vertical Shaft Brick Kiln (VSBK) [14]**

### 2.9.3 Hybrid Hoffman Kiln (HHK)

A Hybrid Hoffman Kiln is rectangular in shape and measures 300-400 ft by 76 ft. Its construction and operation are very similar to FCK. The predominant difference between the Hybrid Hoffman Kiln and the Improved Zigzag Kiln is the fixed roof, which enables bricks to be fired throughout the year although, during the rainy season, which is called offseason, the production decreases significantly because of frequent rain, high humidity and greatly reduced availability of sunlight. Some manufacturers overproduce green bricks during the dry season and store them for the rainy season but to do that adequate storage facility must be made available. Also for off-season production clay has to be stored, as harvesting of clay becomes impossible due to widespread floods during the rainy season [15].

The roof of the kiln is arched and has a fire brick lining on the inside surface. The thick walls of the kiln and good insulation minimize heat loss to the surrounding air. There is no chimney in the kiln as the system uses a waste heat recovery mechanism to blow the heat into the dry tunnel at a regulated speed. Green bricks are stacked in the kiln is more or less the same fashion as that in the FCK. The bricks are fired from the top by introducing the fuel, coal in this case into the composition zone through stock holes on the roof. When the firing is complete in a zone, another zone is fired up and as the fire progresses from section to section-fired bricks are unloaded at the back while green bricks are stacked in front of the firing zone.

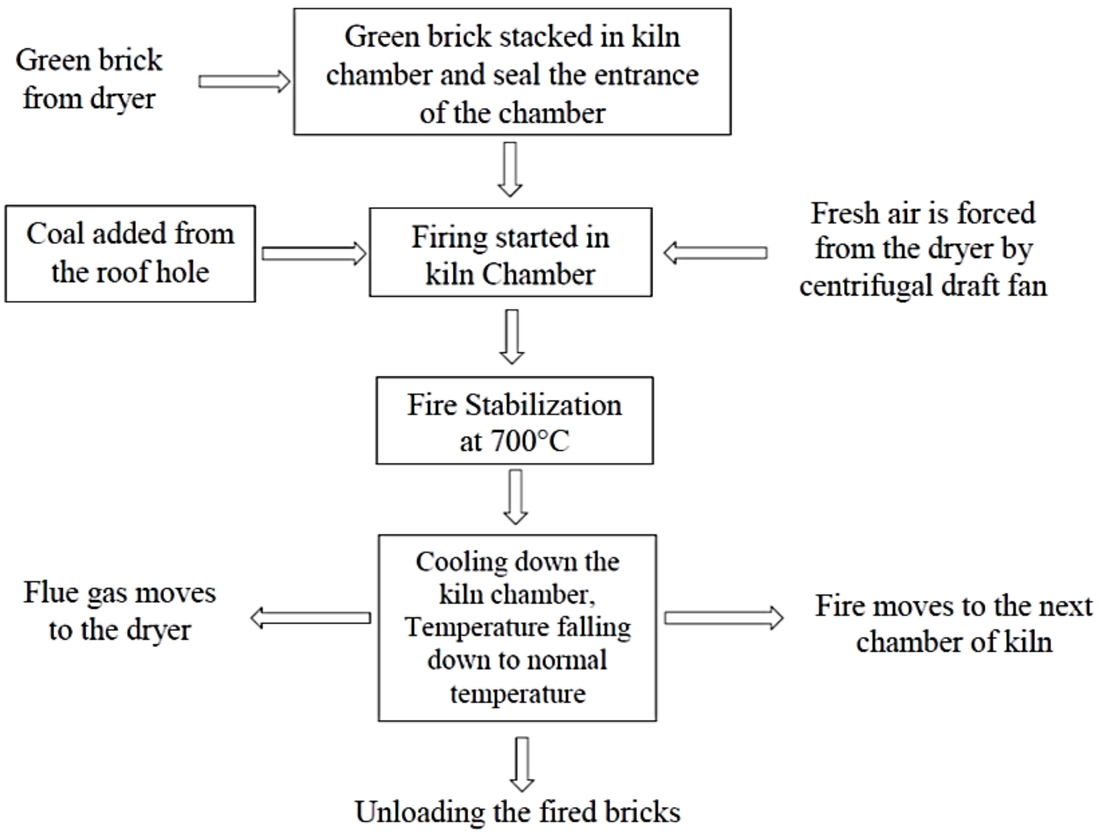


**Figure 2-7: Flow Diagram of HHK Technology**

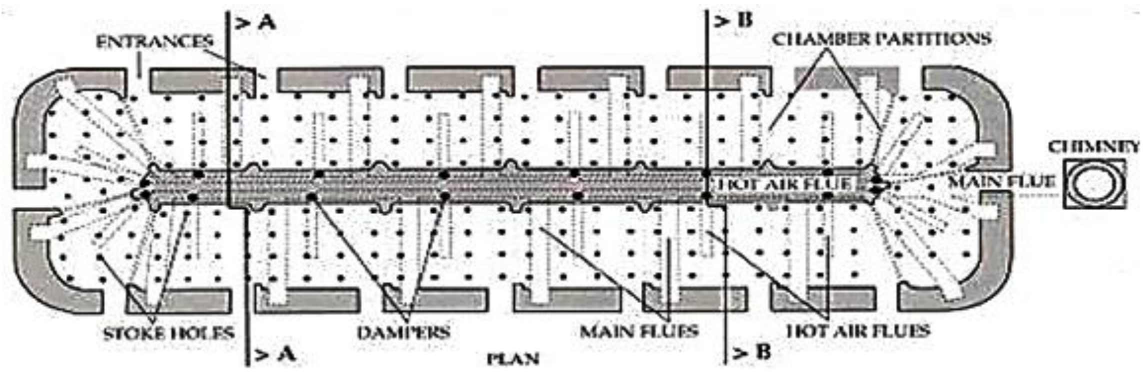


**Figure 2-8: Schematic Diagram of HHK Technology [16]**

Green bricks are stacked in the kiln is more or less the same fashion as that in the FCK. The bricks are fired from the top by introducing the fuel into the combustion zone through pipe-type burners. The burners are shifted forward from section to section as the fired progresses-fired bricks are unloaded at the back while green bricks are stacked in front of the firing zone. The flue gas is conveyed towards the drying chamber through a network of channels. Fire is controlled without the aid of any instrumentation or controllers by merely adjusting the gas flow rate and the opening and closing of dampers located at selected points in the flue gas network. Controlling the fire is the trickiest part of the whole operation. Since there is no institutional arrangement to learn the firing technique, several years of on-the-job training as an apprentice is needed to master the technique [16].

**Figure 2-9: Hybrid Hoffman Kiln [15]**

### 2.9.4 Tunnel Kiln (TK)

The tunnel kiln is considered to be the most advanced brick making technology. In a Tunnel Kiln, green bricks produced by mixing powdered fuel with clay are loaded on cars and then pushed in the kiln, a horizontal tunnel. The firing of products occurs at the central part of the tunnel. Fuel is fed into the firing zone of the kiln through feed holes provided in the kiln roof. Cold air enters the kiln for the car exit and cools the fired bricks while getting heated as it proceeds towards the firing zone. After combustion, the hot flue gases travel towards the car entrance end losing a part of the heat to the green bricks entering the kiln. Hot air/gases are extracted from the tunnel kiln at several points along the length of the kiln and are supplied to the drying tunnel/chamber.

This kiln is masonry model vault construction which referring to Germany RIEDHAMAN Corporation's advanced technology. The length of the kiln: 113m The width of the kiln: 3.3m. The masonry construction: the firing zone, preheating zone and cooling zone which adopt the vault and the dry kiln which adopt the flat topping structure. The whole kiln is equipped with different refractory material and heats insulator according to a different temperature. The forepart of the preheating zone and lining of the posterior segment in the cooling zone adopt the first-rate red brick and other parts adopt heavy chamotte bricks. The thermic insulant adopts the back-fill to preserve the heat. The outside wall of the kiln is built with first-rate bricks. The material of paltering and the material of kiln wall are same with each other [17].

The kiln foundation needs soil bearing capacity which reaches to 15t/m2. The kiln is placed in the reinforced concrete. The standard height in the up plane of the rail is 10.30m.

There is loss of exhaust port for smoke and heat in the preheating zone and cooling zone which adjust the temperature and provide more heat for use.

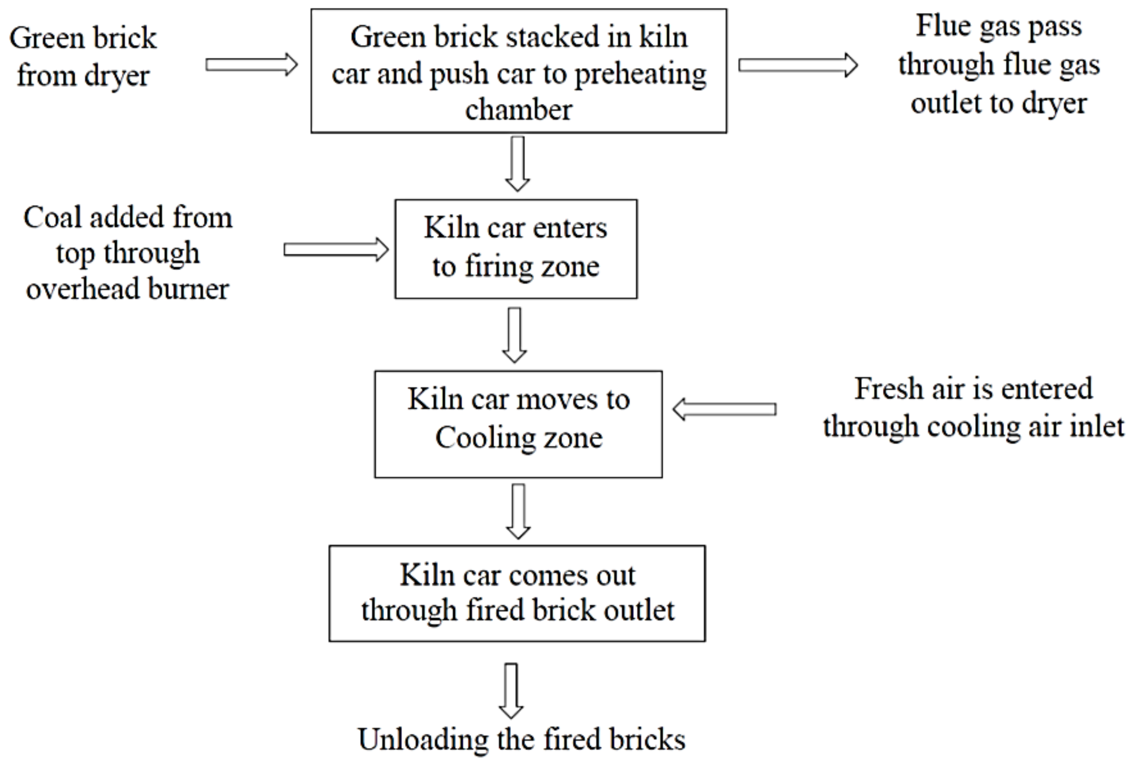


**Figure 2-10: Flow Diagram of Tunnel Kiln Technology**

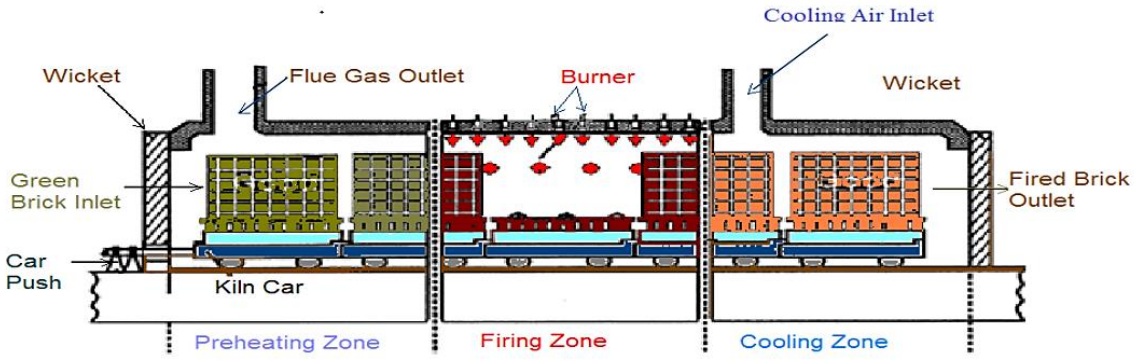


**Figure 2-11: Schematic Diagram of Tunnel Kiln Technology [17]**

Optimized hermetically sealed construction not only use for the seal of kiln wall and kiln car but also for the kiln car between kiln car. And it appears superior under the effect of burning zone sealed which can prevent flame down. Reduce the temperature under the kiln car and protect the bearing of the kiln car. In the meantime, it can balance the pressure of kiln and conserve energy.

The coating of kiln car, bricks of the corner and surrounding use the heavy refractory material but others use light refractory material. It requires that tight structure of kiln without collision between kiln car and car.

The drying system is tunnel kiln with a vault built by red bricks in 108m length and 3.3m.width.

**Wind Circulatory System:**

The kiln fans duct system can be divided into the exhaust for wet and smoke and residual hot air according to the function. Every kiln is equipped with four fans which include one smoke exhaust, one residual hot air, and two wet exhaust.

All kiln fans smoke duct system are selected and arranged on the basis of the design requirement. The main duct and branch are made of Q235 steel sheet. The ducts to drying kiln which be handled with heat preservation are packaged with STD mat. And then STD mat is decorated with glass fiber mat which brings about the good insulating efficiency, utility, and beauty [17].

All the fans adopt interconnected control. Every boot air exhaust is installed with the cooling water system and cold blast valve. The chimney is two meters higher than the roof which directs to the outside of the factory to the sky. The main gas flue has the air distribution valve which prevents from burring the fan.

**Kiln car system and change kiln car's lane system:**

According to the technological requirements, there is a rail in every kiln. Outside of two rails kiln are arranged with one turn around, three ferry rails, one six meters examine rails, two boiler setting rails and two unloading rails. The hydraulic push car comes in continuously and trailer outside kiln draws to and from. All the process is convenient, reliable and flexible. The lane changing kiln car outside of kiln is operated by the ferry car. It is very convenient for setting billet in the loading billet position without the control cabinet.

**The supervisory methods:**

The supervisory system methods of pressure and temperature in kiln include digital microcomputer display acousto-optic malfunction alarm and so on.

The kiln car passing in and out adopts the ring promotes and the color supervisory system which prevents from running from the rail and pushing in kiln door.

Both the smoke exhaust and heat exhaust are controlled by frequency control which not only convenient but also energy saving.

During the operation of Tunnel kiln the preheating, low energy consumption, the cooling process will be done in the kiln with less energy consumption compared to Down Draft kilns. Due to tunnel kiln, coal consumption is reduced to 45% per batch of production.


**Figure 2-12: Tunnel Kiln [17]**

### 2.10 Problem Identification and Motivation

Despite the importance of the brick sector, about 90 percent of kilns use outdated, energy-intensive technologies that are highly polluting. These outdated kilns are producing fine particulate which causes harmful impacts on health (from the particulate matter) and agriculture yields (from nitrogen oxides) and contributes to global warming (from carbon dioxide).

**Table 2-8: Brick Production by Different Kiln, 2017 [1]**

| Kiln Type | Number | Percentage of total | Annual Production (billions) | Percentage of Total Production |
|---|---|---|---|---|
| FCK | 2,629 | 37.56% | 7.1 | 31.14% |
| IZigzag | 4,247 | 60.67% | 12.7 | 55.70% |
| HHK | 61 | 0.87% | 1.1 | 4.82% |
| Tunnel | 58 | 0.83% | 1.7 | 7.46% |
| Others | 5 | 0.07% | 0.2 | 0.88% |
| **Total** | **7,000** | **100.00%** | **22.8** | **100.00%** |

Though FCK has been banned in Bangladesh, table 2.8 has shown that FCK still has a significant effect on brick production. At present, the total brick production in Bangladesh is 22.8 billion. FCKs are producing 7.1 billion which is 31.14% of the total brick production. New technologies such as Vertical Shaft Brick Kiln (VSBK), Hybrid Hoffman Kiln (HHK), and Tunnel Kiln (TK) are substantially cleaner than Fixed Chimney Kiln (FCK) and consume less energy and emit lower levels of pollutants and greenhouse gases (GHGs). However, because the use of these technologies in Bangladesh is still in the preliminary stage of implementation, their financial viability (compared with that of the FCK) still needs to be demonstrated.

Hence, Priority ranking of existing brick kiln technologies: Improved Zigzag Kiln (IZigzag) Technology, Vertical Shaft Brick Kiln (VSBK) Technology, Hybrid Hoffman Kiln (HHK) Technology, Tunnel Kiln (TK) Technology by using Analytical Hierarchy Process (AHP) and Cost-Benefit Analysis (CBA) tools would give a result where priority ranking comes closer to reality. So, the outcome of this research contributes to take decision by the decision-makers (DMs) about which type of brick kiln technology will be given preference at what level to increase the brick manufacturing to meet the essential demand in the perspective of Bangladesh.

# CHAPTER 3: RESEARCH METHODOLOGY

## 3.1 Introduction

This research work followed some specific methods and processes. They have been divided into sub-sections. The study has been completed by following the steps shown below:

1. The sample survey was conducted by a structured datasheet.
2. Quantitative and qualitative data were collected by arranging face to face interviews. Interviewees were entrepreneurs, technical personnel, consultants and related personnel of financial institutions.
3. Collected data were analyzed with AHP method.
4. Common problems and possible solutions were addressed.
5. Again feedback was taken on brick making cost and sale price.
6. Received feedback was analyzed with AHP method and Cost-Benefit Analysis (CBA).
7. The recommendation was given based on the final result of AHP method and Cost-Benefit Analysis (CBA).

## 3.2 Questionnaire

Two sets of questionnaire were used. Sample of questionnaires has been attached in Appendix A.

The objective of the first phase questionnaire was to find out a priority ranking of Improved Zigzag Kiln (IZigZag), Vertical Shaft Brick Kiln (VSBK), Hybrid Hoffman Kiln (HHK), Tunnel Kiln (TK) technologies on the basis of product quality, fuel efficiency, environmental effect, labor intensity, and investment.

The first part of the first phase questionnaire dealt with the criteria. Based on the interviews and interaction of relevant experts, observation, and literature review five major criteria were selected. Priority was calculated among five criteria,

(1) Product Quality

(2) Fuel Efficiency

(3) Effect on the Environment

(4) Labour Intensity and

(5) Investment.

The second part of the first phase questionnaire dealt with the pairwise comparisons of alternatives from the criterion. The alternatives are

(1) Improved Zigzag Kiln (IZigzag)

(2) Vertical Shaft Brick Kiln (VSBK)

(3) Hybrid Hoffman Kiln (HHK) and

(4) Tunnel Kiln (TK).

**AHP Priority Setting**

| AHP Scale of Importance for comparison pair | Numeric Rating |
|---|---|
| Equal Importance | 1 |
| Equally to Moderately | 2 |
| Moderate Importance | 3 |
| Moderately to Strong | 4 |
| Strong Importance | 5 |
| Strongly to very strong | 6 |
| Very strong Importance | 7 |
| Very strong to extremely | 8 |
| Extreme Importance | 9 |

Interviewees were requested to answer the questions with Numerical Rating from AHP Priority Setting.

The objective of the second phase questionnaire was to find out a priority ranking of Improved Zigzag Kiln (IZigzag), Vertical Shaft Brick Kiln (VSBK), Hybrid Hoffman Kiln (HHK), Tunnel Kiln (TK) technologies on the basis of cost-benefit analysis.

### 3.3 Data Collection

First and Second phase data are collected from face to face interview of entrepreneurs, technical personnel, consultants and related personnel of financial institutions. Total of Twenty personnel is interviewed.

### 3.4 TOOLS

#### 3.4.1 Decision Modeling

In this thesis, it is tried to formulate the modeling regarding brick kiln decision in the perspective of Bangladesh. Modeling a decision is a way to bring order to the unstructured chaos of the usual decision-making situation. A model is a representation of an object or idea that helps to better understand it. By going through the modeling process it can be clarified in someone's mind and to other people what are the important driving forces in the decision and the alternative courses of action that are available.

By building a model it can be overlooked to some crucial aspect of the decision. Specifying the alternatives inspires to look for other alternatives that may not be so obvious.

The model itself will remain as a record of the decision, which can be revisited later so someone can observe what was good and what could be improved to make better decisions in the future. By fully documenting all the elements of the model it can defend the decisions and prevent from being overruled.

#### 3.4.2 Definition of Related Terms

**MCDM:** Multi-Criteria Decision Making; The use of methods that help people make decisions according to their preferences in cases characterized by multiple conflicting criteria.

**DECISION-MAKER (DM):** The person or entity that is responsible for making a decision. The DM might be an individual, a small, homogenous group with common goals, a large group representing different elements of an organization, or a number of highly diverse interest groups.

**ALTERNATIVE:** Projects, candidates, and investment plans, among which a choice has to be made. The term is often used for actions that are mutually exclusive in terms of implementation. There can either be a finite number of explicitly defined discrete alternatives or implicitly defined continuous alternatives.

**CRITERION:** A tool constructed for the evaluation and comparison of alternatives and the degree to which they achieve objectives. The criteria offer comprehensive and measurable representations of the DM's preferences.

**QUANTITATIVE AND QUALITATIVE CRITERION:** A criterion that can be measured on a clear, concrete defined scale. The qualitative criterion is one for which evaluations cannot be made on a numerical basis. Instead, a verbal scale or an ordinal ranking can be used.

**ATTRIBUTE:** A quantitative measure of performance, used to evaluate directly or indirectly the degree to which the objectives are achieved. A good attribute both defines precisely what the associated objective means and serves as a scale to describe the consequences of the alternative.

### 3.4.3 Decision-Making Technique

When the benefits of actions are unpredictable, when relationships between variables maybe not only non-linear and stochastic but also actually unknown, the principle of standard optimization for decision-making will not help much. This is exactly the situation we face in the world of today.

Decision-making can be considered as the choice, on some basis or criteria, of one alternative among a set of alternatives. A decision may need to be taken on the basis of multiple criteria rather than a single criterion. This requires the assessment of various criteria and the evaluation of alternatives on the basis of each criterion and then the aggregation of these evaluations to achieve the relative ranking of the alternatives with respect to the problem. The problem is further compounded when there are several or more experts whose opinions need to be incorporated in the decision-making. Lack of adequate quantitative information leads to dependence on the intuition, experience, and judgment of knowledgeable persons called experts.

We can define a generic decision-making problem as consisting of the following activities:

► Studying the situation

► Organizing multiple criteria

► Assessing multiple criteria

► Evaluating alternatives on the basis of the assessed criteria

► Ranking the alternatives

► Incorporating the judgments of multiple experts

### 3.4.4 Multi-Criteria Decision-Making Problems

Making decisions is part of human life. Nevertheless, making a good decision is not always easy in the situation of today's world. This is mainly because there are many contributing factors (multiple criteria) in a problem. Even worse, many of them involve multiple objectives (multiple inputs, multiple outputs). That means the objectives of the problems in question may be conflicting with each other. On the one hand, solving such problems can entertain multiple dimensionalities. If the factors involved in such decision-making process are all quantitative in nature, the best solution can be obtained by evaluating a multi-attribute utility function as follows [18]:

$$U_i\ (x_1; x_2; \ldots; x_m) = k_1u_{i1}(x1) + K_2u_{i2}(x2) + \ldots k_mu_{im}(xm);\ i = 1; 2; \ldots; n \qquad (3.1)$$

where $U_i( x1; x2; \ldots; x_m)$ is the utility function of m attributes (i.e. inputs) of the ith alternative, $x_i$ is attributed under consideration, $k_j$ is weighing of jth attribute such that summation of $k_j$ is equal to 1 and $u_{ij}$ is the effect of ith alternative related to jth attribute, that is, $x_j$.

Therefore, the solution to such problems is the feasible solution with the maximum or minimum value of the utility function. Subject to such setting, the quality of the solutions of such problems can be maintained relatively easily. The only concern would be to determine the scientific way to measure each input (i.e. $x_i$) and its effect (i.e. $u_{ij}$). Of course, finding the right balance between the set of weightings is also crucial as this may involve subjective judgment on the relative importance of one effect to the other effects.

On the other hand, many of the real-life problems are unfortunately not that easy to solve. This is mainly because most of them involve qualitative factors. That means they cannot be modeled mathematically as in Eq. (3.1), regardless of the aforementioned shortcomings. Therefore, how to quantify such qualitative variables is always a controversial topic, if not impossible, when solving such multiple-criteria decision-making (MCDM) problems. The controversy mainly comes from the subjective judgment of the qualitative factors, which always rely on experts' opinion, and is not consistently reliable. Such judgment inevitably affects the quality of the solution obtained. This is analogous in many cases to assign the weightings in Eq. (3.1).

Prof. Thomas L. Saaty developed a ground-breaking tool to handle such MCDM problems. This is called the analytic hierarchy process (AHP). The basic idea is to represent such MCDM problems by a hierarchical structure with different criteria and their sub-criteria. Those criteria or sub-criteria can be qualitative or quantitative in nature. Then, pairwise comparisons among those criteria are performed so that the weightings of the criteria with respect to the problem can then be estimated. Although experts' judgment is also required in this procedure, at least there is a way to ensure that the judgment is consistent by examining the consistency ratio. In addition, this approach can be used to select the best alternative based on these weightings and their relative importance to each criterion.

### 3.5 Brief Review of AHP

Analytic Hierarchy Process (AHP) is one of Multi-Criteria decision-making method that was originally developed by Prof. Thomas L. Saaty. The Analytic Hierarchy Process (AHP) is a revolutionary breakthrough which empowers to relate intangibles to tangibles, the subjective to the objective, and to link both to their purposes. In short, it is a method to derive ratio scales from paired comparisons. The input can be obtained from actual measurements such as price, weight, etc., or from subjective opinions such as satisfaction feelings and preference. AHP allows some small inconsistency in judgment because human is not always consistent. The ratio scales are derived from the principal Eigenvectors and the consistency index is derived from the principal Eigenvalue [4].

Since there are different factors that can affect decision involving multiple judging criteria, trade-offs can always be found between different factors. The analysis will usually involve multiple objectives or criteria. AHP is a useful approach for evaluating such complex multiple criteria alternatives. AHP is one of the widely used approaches to prioritize multiple factors. In order to evaluate or select an alternative, a design concept or a solution, weighted rating methods are generally used. It is a combinatorial decision analysis of quantitative and qualitative methods. The basic idea of AHP is to establish an orderly hierarchical system by analyzing elements of complex systems and their mutual relations. Proposed by Saaty, AHP has been employed to aid in many MCDM problems, particularly when qualitative criteria are involved. AHP is a useful approach for evaluating two or more competing alternatives along with multiple criteria. AHP requires a decision-maker to determine the relative importance of each criterion/factor by means of pairwise comparisons between the relevant criteria/factors included in the analysis. After the development of AHP, it has been employed to solve MCDM problems [4].

AHP analyses an MCDM problem by setting up a hierarchy of criteria and sub-criteria, which could be either quantitative or qualitative in nature. This can be done by introducing a pairwise comparison between those criteria, which are assessed by professionals or experts in the corresponding area.

### 3.5.1 Pair-Wise Comparison

The pairwise comparison is the measure of importance/preference of one attributes over another with respect to the objectives/attributes/sub-attributes.

If the number of attributes is n, the pairwise comparisons are required can be calculated by:

No. of pairwise comparison = n (n-1)/2.

### 3.5.2 Consistency Index and Consistency Ratio

To check the consistency of the pairwise comparison matrix, consistency index (CI) and consistency ratio (CR) is calculated. If someone's qualitative judgment is as:

**A > B, and B> C, then in case of consistency opinion A>C**

Prof. Saaty proved that for consistent reciprocal matrix, the largest Eigenvalue is equal to the number of variables/attributes, or $\lambda_{max} = n$. Then he gave a measure of consistency, called Consistency Index as deviation or degree of consistency using the following formula.

$$CI = (\lambda_{max} - n) / (n-1) \qquad (3.2)$$

For using the consistency index, Prof. Saaty proposed that we use this index by comparing it with the appropriate one. The appropriate Consistency index is called Random Consistency Index (RI). He randomly generated reciprocal matrix using his scale and get the random consistency index to see if it is 10% or less and finally gives a table for RI.

**Table 3-1: Random Consistency Index (RI)**

| Matrix size (n) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

By using RI, We can calculate Consistency Ratio (CR), which is a comparison between Consistency Index and Random Consistency Index, or in formula

$$CR = CI/RI \tag{3.3}$$

If the value of CR is smaller or equal to 10%, the inconsistency is acceptable. If the Consistency Ratio is greater than 10%, we need to revise the subjective judgment.

### 3.5.3 Formulation/Steps of AHP

The mathematical formulation of the AHP has been well presented by Saaty. The AHP provides a means of decomposing the problem into a hierarchy of sub-problems which can more easily be comprehended and subjectively evaluated. The subjective evaluations are converted into numerical values and processed to rank each alternative on a numerical scale. The AHP uses hierarchical decision models and it has a sound mathematical basis. A model is a representation of a phenomenon. It can be manipulated the model, either physically if it is a physical model, or mathematically in the case of the hierarchical model, in an attempt to discover the important influences. The methodology of the AHP can be explained in the following steps [18]:

**Step 1:** The problem is decomposed into a hierarchy of goal, criteria, sub-criteria, and alternatives. This is the most creative and important part of decision-making. Structuring the decision problem as a hierarchy is fundamental to the process of the AHP. Hierarchy indicates a relationship between elements of one level with those of the level immediately below. This relationship percolates down to the lowest levels of the hierarchy and in this manner, every element is connected to every other one, at least in an indirect manner. A hierarchy is a more orderly form of a network. Saaty suggests that a useful way to structure the hierarchy is to work down from the goal as far as one can and then work up from the alternatives until the levels of the two processes are linked in such a way as to make comparisons possible. Figure 3.1 shows a generic hierarchic structure. This local concentration of the decision-maker on only part of the whole problem is a powerful feature of the AHP.

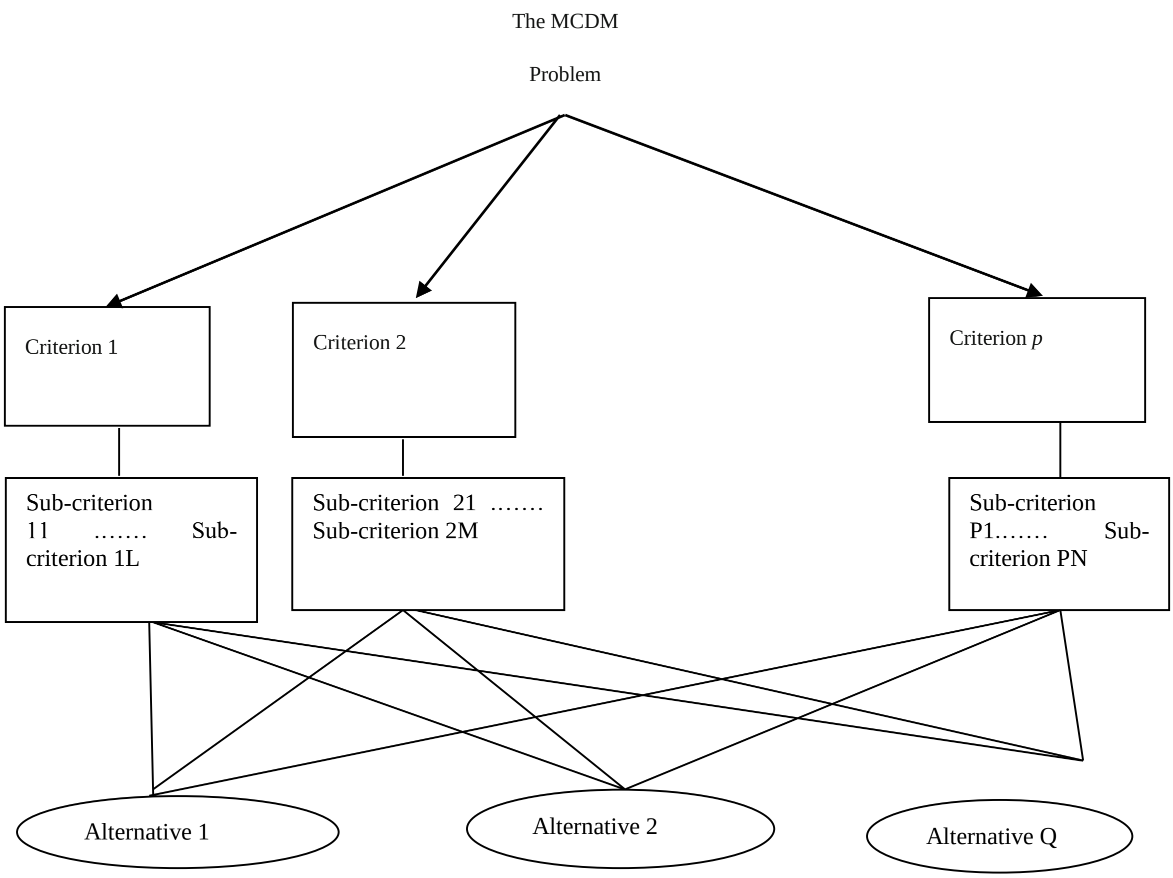


**Figure 3.1: Generic hierarchic structure of AHP**

**Step 2:** Data are collected from experts or decision-makers corresponding to the hierarchic structure, in the pairwise comparison of alternatives on a qualitative scale.

**Step 3:** The pair-wise comparisons of various criteria generated at step 2 are organized into a square matrix. The diagonal elements of the matrix are 1. The criterion in the *i*th row is better than criterion in the *j*th column if the value of the element (*i*, *j*) is more than 1; otherwise, the criterion in the *j*th column is better than that in the *i*th row. The (*j*, *i*) element of the matrix is the reciprocal of the (*i*, *j*) element.

**Step 4:** The principal eigenvalue and the corresponding normalized right eigenvector of the comparison matrix give the relative importance of the various criteria being compared. The elements of the normalized eigenvector are termed weights with respect to the criteria or sub-criteria and ratings with respect to the alternatives.

**Step 5:** The consistency of the matrix of order *n* is evaluated.

**Step 6:** The rating of each alternative is multiplied by the weights of the sub-criteria and aggregated to get local ratings with respect to each criterion. The local ratings are then multiplied by the weights of the criteria and aggregated to get global weight.

**Step7:** According to the Global weight the ranking of Alternatives can be determined.

In this thesis, AHP will be preferred in the prioritization of different brick kiln technologies since this method is the only one using a hierarchical structure among goal, attributes, and alternatives. Usage of pair-wise comparisons is another asset of this method that lets the generation of more precise information about the preferences of decision-makers. Moreover, since the decision-makers are usually unable to explicit about their preferences due to the fuzzy nature of the decision process, this method helps them providing an ability to give interval judgments instead of point judgments.

### 3.6 Cost-Benefit Analysis

A cost-benefit analysis is a process businesses use to analyze decisions. The business or analyst sums the benefits of a situation or action and then subtracts the costs associated with taking that action. Some consultants or analysts also build the model to put a dollar value on intangible items, such as the benefits and costs associated with living in a certain town, and most analysts will also factor opportunity cost into such equations.

The first step in the process is to compile a comprehensive list of all the costs and benefits associated with the project or decision. Costs should include direct and indirect costs, intangible costs, opportunity costs, and the cost of potential risks. Benefits should include all direct and indirect revenues and intangible benefits, such as increased production from improved employee safety and morale, or increased sales from customer goodwill. The analyst should then apply a common unit of monetary measurement to all items on the list, taking special care not to underestimate costs or overestimate benefits. A conservative approach with a conscious effort to avoid any subjective tendencies when calculating estimates is best suited when assigning a value to both costs and benefits for a cost-benefit analysis [19].

The final step is to compare the results of the aggregate costs and benefits quantitatively to determine if the benefits outweigh the costs. If so, then the rational decision is to go forward with the project. If not, the business should review the project to see if it can make adjustments to either increase benefits or decrease costs to make the project viable. Otherwise, the company may abandon the project may.

### 3.6.1 Purpose and Nature of Cost-Benefit Analysis

The primary method of the economic evaluation of public sector policies and projects is a cost-benefit analysis. Input-output methodology (or the use of multipliers) is not an acceptable methodology for economic evaluations.

Cost-benefit analysis is a method used to make decisions about alternative courses of action based on the net welfare gain to the community as measured by criteria such as net present economic value (NPEV) and benefit-cost ratio (BCR). Benefits and costs are ‘social’ in that they are measured irrespective of how they are distributed and they are not limited to actual market transactions. Cost-benefit analysis is particularly relevant to public sector decision making where the costs and benefits of a project are often not reflected in market transactions.

By comprehensively identifying and estimating as many costs and benefits of a project as can reasonably be measured, including those which can be thought of as social and environmental, it is possible to rank project options according to their net economic benefit.

In theory, costs and benefits are valued at their true economic value. Economic valuation of costs and benefits involves adjustments for market distortions (e.g. tax and subsidies) and the estimated valuation of inputs and outputs not traded in the market (e.g. pollution or lives saved).

These economic values of costs and benefits are forecast over the life of the project, costs are subtracted from benefits, and the sum of the resulting net benefits are discounted to give the net present economic value (NPEV) of the project. The NPEV allows project options to be compared on the same basis and hence allows the determination of the greatest net benefit to the community or the most economic use of resources [19].

### 3.6.2 Undertaking the Cost-Benefit Analysis

There are four stages in a cost-benefit analysis [19].

**Stage 1: Determine key assumptions**

An essential part of the evaluation process, to clarify understanding by readers not involved in the preparation of the analysis, is to document the assumptions used in the analysis and the reasons for choosing them.

A cost-benefit analysis should therefore contain:

- Textually and numerically explicit explanations of the assumptions underlying all capital and recurrent estimates regarding: labor costs; energy costs; demand growth; charges; etc.
- Clear and referenced data sources for validation purposes.

Before costs and benefits can be appropriately identified, the spatial reference area of the analysis needs to be determined. Do the project costs and benefits fall within the state, national or global area? The identification of the spatial area of the analysis will set the boundary for which costs and benefits are included in the analysis. Generally, for Queensland Government projects, the appropriate spatial area would be the State of Queensland. However, if it is considered that significant costs and benefits fall within the national or global area, then these costs and benefits should be identified clearly and included in the analysis. Whatever the choice, the analysis should be consistent.

**Stage 2: Identify and estimate the expected economic benefits and costs of the project**

In a cost-benefit analysis, costs and benefits are "social", rather than private or individual, as they are:

- measured irrespective of how the costs and benefits are distributed (i.e. the analysis is conducted from the perspective of the economy or society as a whole)

- valued in dollar terms at their “true” economic worth, or the value after adjusting for market distortions identified on a comprehensive basis and are not confined to transactions in the market:
- Costs and benefits are imputed in situations where a market does not exist. Imputed prices (or adjusted market prices) are known as “shadow prices”. The resources required to develop a set of shadow prices need to be commensurate with the magnitude of the project
- Where market prices inadequately reflect the opportunity cost of the resources used, the value of a cost or benefit is valued (shadow price) by imputation or by appropriate adjustment of a market price2.

Consultation with stakeholders will assist in identifying the range of costs and benefits to be incorporated into the analysis.

The cost-benefit analysis report should clearly and concisely state how market prices for inputs and outputs have been adjusted for market distortions, or where input and output values have been imputed where a market does not exist.

There are a number of techniques for determining values of costs and benefits when there are no market prices available. Benefit valuation techniques include:

- revealed preference – prices are inferred from observing consumer behavior
- Stated preference – willingness-to-pay is estimated by asking consumers what they would be willing to pay for the benefit.

For cost valuation, estimates of willingness-to-accept can be obtained by identifying how much compensation consumers would demand in order to accept the cost.

In identifying the benefits, consideration should be given to:

- avoided costs – costs which are unavoidable if nothing is done, but can be avoided if action is taken
- cost savings – measurable reductions in existing levels of expenditure if a project proceeds
- Revenues – revenues which result directly or indirectly from the project (revenues which would have occurred regardless of the project must not be included as an incremental benefit to the project). It is important that the approach is congruent with the financial analysis

- benefits to consumers and to the community as a whole
- The residual value of assets (if any) — the value of which is sourced from the financial analysis.

**Stage 3: Calculate the net present economic value**

The difference between the discounted streams of benefits and costs of each project option is the NPEV of the project option. A project is economically viable if this NPEV is greater than zero (i.e. the total discounted value of the benefits is greater than the total discounted costs). This NPEV should be carefully distinguished from the financial NPV. The discount rate(s) to be used in a cost-benefit analysis should be agreed between the agency and Queensland Treasury.

**Stage 4: Assess risks and sensitivities**

As for financial analysis, while the base case economic analysis should be based on the expected value of individual costs and benefits, an assessment should be made of the realistic range of all key variables (e.g. revenues, growth in demand, charges, etc.) and of the sensitivity of the NPEV to changes to variables within these ranges.

## 3.7 Expert Opinion

To build the pair-wise comparison matrices for the main criteria and alternatives, opinion of some technical experts and professional experts of the relevant field are collected by purposive sampling method and the distribution of the sample was as follows (table 3-2):

**Table 3-2: The Distribution of the Sample**

| Technical Experts | Professional Experts | Total |
|---|---|---|
| 10 (Ten) | 10 (Ten) | 20 (Twenty) |

### 3.7.1 EXPERT'S PERSONAL PROFILE

For eliciting the experts' judgmental opinion, 10 (ten) technical experts and 10 (ten) professional experts were selected. The personal profile of the experts is shown in table 3.3 and table 3.4.

**Table 3-3: Personal Profile of Technical Experts**

| Sl. No. | Designation | Types of Organization | Age (years Approx.) | Experience (years) | Academic Qualification |
|---|---|---|---|---|---|
| 1 | Technician | Machinery Supplier | 45 | 15 | Diploma Engineering |
| 2 | Erector | Machinery Supplier | 46 | 15 | B.Sc. Engineering |
| 3 | Erector | Machinery Supplier | 40 | 12 | Diploma Engineering |
| 4 | Consultant | Consultancy Firm | 53 | 20 | B.Sc. Engineering |
| 5 | Consultant | Consultancy Firm | 51 | 20 | B.Sc. Engineering |
| 6 | Technician | Machinery Supplier | 35 | 10 | Diploma Engineering |
| 7 | Technician | Brick Producing Enterprise | 40 | 10 | S.S.C |
| 8 | Technician | Brick Producing Enterprise | 37 | 10 | Primary Education |
| 9 | Worker Head | Brick Producing Enterprise | 50 | 20 | Primary Education |
| 10 | Worker Head | Brick Producing Enterprise | 55 | 20 | Primary Education |

**Table 3-4: Personal Profile of Professional Experts**

| Sl. No. | Designation | Organization | Age (Years Approx.) | Experience (years) | Academic Qualification |
|---|---|---|---|---|---|
| 1 | Entrepreneur | Brick Producing Enterprise | 55 | 30 | S.S.C |
| 2 | Entrepreneur | Brick Producing Enterprise | 55 | 26 | S.S.C |
| 3 | AGM | Financial Institution | 50 | 20 | MBA |
| 4 | Managing Director | Brick Producing Enterprise | 52 | 20 | MBA |
| 5 | DGM | Financial Institution | 54 | 20 | B.Sc. Engineering |
| 6 | Managing Director | Brick Producing Enterprise | 40 | 15 | Masters |
| 7 | Director | Department of Environment | 43 | 10 | Masters |
| 8 | Assistant Director | Department of Environment | 32 | 5 | Masters |
| 9 | DGM | Bangladesh Bank | 50 | 20 | Masters |
| 10 | Deputy Director | Bangladesh Bank | 34 | 5 | Masters |

# CHAPTER 4: DATA PRESENTATION AND ANALYSIS

In the thesis, AHP analysis is done for the relevant criteria and existing brick kiln technologies to make a priority ranking among the kiln technologies. CBA is done for checking the commercial viability of AHP ranking.

### 4.1 Data Calculation for AHP

The data analysis has been made using a Microsoft Excel spreadsheet and CGI online AHP software. The matrices have diagonal of unity. The lower triangles were made just reversing the corresponding component using equation (3.3). The pairwise comparison matrices are developed by expert opinion. The detailed calculation is shown below.

#### 4.1.1 AHP Calculation for Main Attributes

We will need these operation laws in order to be able to estimate priorities out of the AHP matrix. Before that, we need to assure two points: (I) we have to evaluate the consistency for each respondent, and (II) we have to find ways of aggregating the single pair-wise comparisons (group decision).

To assure a certain quality level of a decision, to increase reliability and credibility we have to analyze the consistency of evaluation. For this purpose, we calculated the consistency ratio (CR) confirming, which is defined as a ratio between the consistency of a given evaluation matrix (consistency index CI) and the consistency of a random matrix (RC).

To simplify the calculation of the CR, we used the crisp value $m_{ij}$. If the CR is within the tolerable level, we continue the pairwise comparison matrix for further analysis. The CR of the acceptable level is as follows:

CR $\leq$ 0.1, Acceptable

CR $\geq$0.1, Not acceptable

The matrix of pair-wise comparisons depicts the intensities of expert's preference/importance between the individual pair with respect to objective. The matrices with respect to the goal (Goal: To choose the best brick kiln technology) are given here:

### 4.1.2 Priority Vector Calculation for Criteria

Transform the comparisons into weights and build the following matrix:

| | Invest ment | Product Quality | Fuel Efficiency | Effect on the Environment | Labour Intensity |
|---|---|---|---|---|---|
| Investment | 1 | 1/3 | 1/5 | 1/8 | 5 |
| Product Quality | 3 | 1 | 3 | 1/2 | 7 |
| Fuel Efficiency | 5 | 1/3 | 1 | 1/3 | 5 |
| Effect on Environment | 8 | 2 | 3 | 1 | 9 |
| Labour Intensity | 1/5 | 1/7 | 1/5 | 1/9 | 1 |

We put this matrix into the online AHP software and the software produce the following chart:

| Criteria | Priority Vector | % |
|---|---|---|
| Investment | 0.068 | 6.8% |
| Product Quality | 0.268 | 26.8% |
| Fuel Efficiency | 0.147 | 14.7% |
| Effect on Environment | 0.475 | 47.5% |
| Labour Intensity | 0.042 | 4.2% |

Inconsistency is also carried out by AHP software and the value is 0.09 which is acceptable. From AHP priority vector, it has shown that priority to the Criteria is as follows:

Effect on Environment>Product Quality>Fuel Efficiency>Investment>Labour Intensity

### 4.1.3 Priority Vector Calculation for Alternatives In Relation To Criteria

(1) Transform the pairwise comparisons into weights and build the following matrix for the criterion, Investment:

| | IZigzag | VSBK | HHK | TK |
|---|---|---|---|---|
| IZigzag | 1 | 3 | 5 | 6 |
| VSBK | 1/3 | 1 | 2 | 3 |
| HHK | 1/5 | 1/2 | 1 | 5 |
| TK | 1/6 | 1/3 | 1/5 | 1 |

We put this matrix into the online AHP software and the software produce the following chart:

| Alternatives | Priority Vector | % |
|---|---|---|
| IZigzag | 0.583 | 58.3% |
| VSBK | 0.205 | 20.5% |
| HHK | 0.133 | 13.3% |
| TK | 0.080 | 8.0% |

Inconsistency is also carried out by AHP software and the value is 0.10 which is acceptable. From AHP priority vector, it has shown that priority to the alternatives regarding Investment is as following:

IZigzag>VSBK>HHK>TK

(2) Transform the pairwise comparisons into weights and build the following matrix for the criterion, Product Quality:

| | **IZigzag** | **VSBK** | **HHK** | **TK** |
|---|---|---|---|---|
| **IZigzag** | 1 | 5 | 1/5 | 1/7 |
| **VSBK** | 1/5 | 1 | 1/7 | 1/9 |
| **HHK** | 5 | 7 | 1 | 1/2 |
| **TK** | 7 | 9 | 2 | 1 |

We put this matrix into the online AHP software and the software produce the following chart:

| Alternatives | Priority Vector | % |
|---|---|---|
| IZigzag | 0.082 | 8.2% |
| VSBK | 0.052 | 5.2% |
| HHK | 0.299 | 29.9% |
| TK | 0.567 | 56.7% |

Inconsistency is also carried out by AHP software and the value is 0.08 which is acceptable. From AHP priority vector, it has shown that priority to the alternatives regarding Investment is as following:

TK>HHK>IZigzag>VSBK

(3) Transform the pairwise comparisons into weights and build the following matrix for the criterion, Fuel Efficiency:

| | **IZigzag** | **VSBK** | **HHK** | **TK** |
|---|---|---|---|---|
| **IZigzag** | 1 | 2 | 1/5 | 1/7 |
| **VSBK** | 1/2 | 1 | 1/3 | 1/5 |
| **HHK** | 5 | 3 | 1 | 1/2 |
| **TK** | 7 | 5 | 2 | 1 |

We put this matrix into the online AHP software and the software produce the following chart:

| **Alternatives** | **Priority Vector** | **%** |
|---|---|---|
| IZigzag | 0.081 | 8.1% |
| VSBK | 0.097 | 9.7% |
| HHK | 0.283 | 28.3% |
| TK | 0.539 | 53.9% |

Inconsistency is also carried out by AHP software and the value is 0.06 which is acceptable. From AHP priority vector, it has shown that priority to the alternatives regarding Investment is as following:

TK>HHK>VSBK>IZigzag

(4) Transform the pairwise comparisons into weights and build the following matrix for the criterion, Effect on Environment:

| | **IZigzag** | **VSBK** | **HHK** | **TK** |
|---|---|---|---|---|
| **IZigzag** | 1 | 1/3 | 1/5 | 1/7 |
| **VSBK** | 3 | 1 | 1/3 | 1/5 |
| **HHK** | 5 | 3 | 1 | 1/2 |
| **TK** | 7 | 5 | 2 | 1 |

We put this matrix into the online AHP software and the software produce the following chart:

| **Alternatives** | **Priority Vector** | **%** |
|---|---|---|
| IZigzag | 0.066 | 6.6% |
| VSBK | 0.110 | 11.0% |
| HHK | 0.283 | 28.3% |
| TK | 0.542 | 54.2% |

Inconsistency is also carried out by AHP software and the value is 0.03 which is acceptable. From AHP priority vector, it has shown that priority to the alternatives regarding Investment is as following:

TK>HHK>VSBK>IZigzag

(5) Transform the pairwise comparisons into weights and build the following matrix for the criterion, Labour Intensity:

| | **IZigzag** | **VSBK** | **HHK** | **TK** |
|---|---|---|---|---|
| **Izigzag** | 1 | 5 | 5 | 7 |
| **VSBK** | 1/5 | 1 | 2 | 3 |
| **HHK** | 1/5 | 1/2 | 1 | 3 |
| **TK** | 1/7 | 1/3 | 1/3 | 1 |

We put this matrix into the online AHP software and the software produce the following chart:

| **Alternatives** | **Priority Vector** | **%** |
|---|---|---|
| IZigzag | 0.643 | 64.3% |
| VSBK | 0.153 | 15.3% |
| HHK | 0.126 | 12.6% |
| TK | 0.078 | 7.8% |

Inconsistency is also carried out by AHP software and the value is 0.03 which is acceptable. From AHP priority vector, it has shown that priority to the alternatives regarding Investment is as following:

IZigzag>VSBK>HHK>TK

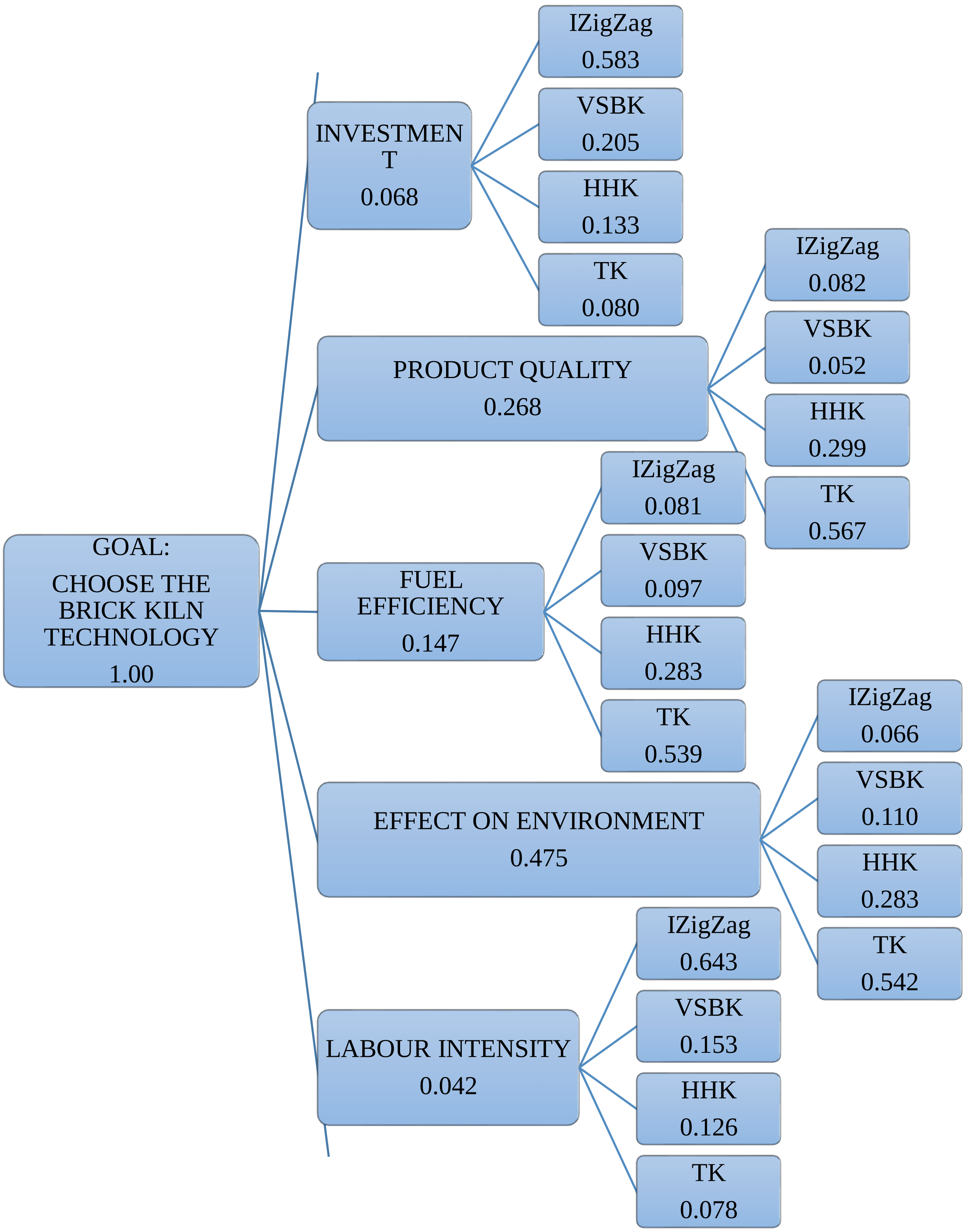


**Figure 4-1: AHP TREE**

### 4.1.4 Calculation for Priority Weight

From the above calculation, we found the weights for each alternative in relation to each criterion.

Priority Weight for Improved Zigzag Kiln (IZigzag) is calculated from the table shown below.

| Criteria | Weights Calculated from Pairwise Comparisons of Criteria from Goal Node (X) | Weights Calculated from Pairwise Comparisons of Alternatives from the Criterion (Y) | XY |
|---|---|---|---|
| Investment | 0.068 | 0.583 | 0.040 |
| Product Quality | 0.268 | 0.082 | 0.022 |
| Fuel Efficiency | 0.147 | 0.081 | 0.012 |
| Effect on Environment | 0.475 | 0.066 | 0.031 |
| Labour Intensity | 0.042 | 0.643 | 0.027 |
| **Priority Weight** | | | **0.132** |

Priority Weight for Vertical Shaft Brick Kiln (VSBK) is calculated from the table shown below.

| Criteria | Weights Calculated from Pairwise Comparisons of Criteria from Goal Node (X) | Weights Calculated from Pairwise Comparisons of Alternatives from the Criterion (Y) | XY |
|---|---|---|---|
| Investment | 0.068 | 0.205 | 0.014 |
| Product Quality | 0.268 | 0.052 | 0.014 |
| Fuel Efficiency | 0.147 | 0.097 | 0.014 |
| Effect on Environment | 0.475 | 0.11 | 0.052 |
| Labour Intensity | 0.042 | 0.153 | 0.006 |
| **Priority Weight** | | | **0.101** |

Priority Weight for Hybrid Hoffman Kiln (HHK) is calculated from the table shown below.

| **Criteria** | **Weights Calculated from Pairwise Comparisons of Criteria from Goal Node (X)** | **Weights Calculated from Pairwise Comparisons of Alternatives from the Criterion (Y)** | **XY** |
|---|---|---|---|
| Investment | 0.068 | 0.133 | 0.009 |
| Product Quality | 0.268 | 0.299 | 0.080 |
| Fuel Efficiency | 0.147 | 0.283 | 0.042 |
| Effect on Environment | 0.475 | 0.283 | 0.134 |
| Labour Intensity | 0.042 | 0.126 | 0.005 |
| **Priority Weight** | | | **0.270** |

Priority Weight for Tunnel Kiln (TK) is calculated from the table shown below.

| **Criteria** | **Weights Calculated from Pairwise Comparisons of Criteria from Goal Node (X)** | **Weights Calculated from Pairwise Comparisons of Alternatives from the Criterion (Y)** | **XY** |
|---|---|---|---|
| Investment | 0.068 | 0.08 | 0.005 |
| Product Quality | 0.268 | 0.567 | 0.152 |
| Fuel Efficiency | 0.147 | 0.539 | 0.079 |
| Effect on Environment | 0.475 | 0.542 | 0.257 |
| Labour Intensity | 0.042 | 0.078 | 0.003 |
| **Priority Weight** | | | **0.497** |

### 4.1.5 Priority Ranking by AHP

Result of responses for four technology is shown in Table 4-1.

**Table 4-1: Priority Ranking by AHP**

| Brick Kiln Technology | Priority Weight | Priority Percentage (%) | Rank |
|---|---|---|---|
| Improved Zigzag Kiln (IZigzag) | 0.132 | 13.20% | 3 |
| Vertical Shaft Brick Kiln (VSBK) | 0.101 | 10.10% | 4 |
| Hybrid Hoffman Kiln (HHK) | 0.270 | 27.00% | 2 |
| Tunnel Kiln (TK) | 0.497 | 49.70% | 1 |
| | 1.000 | 100.00% | |

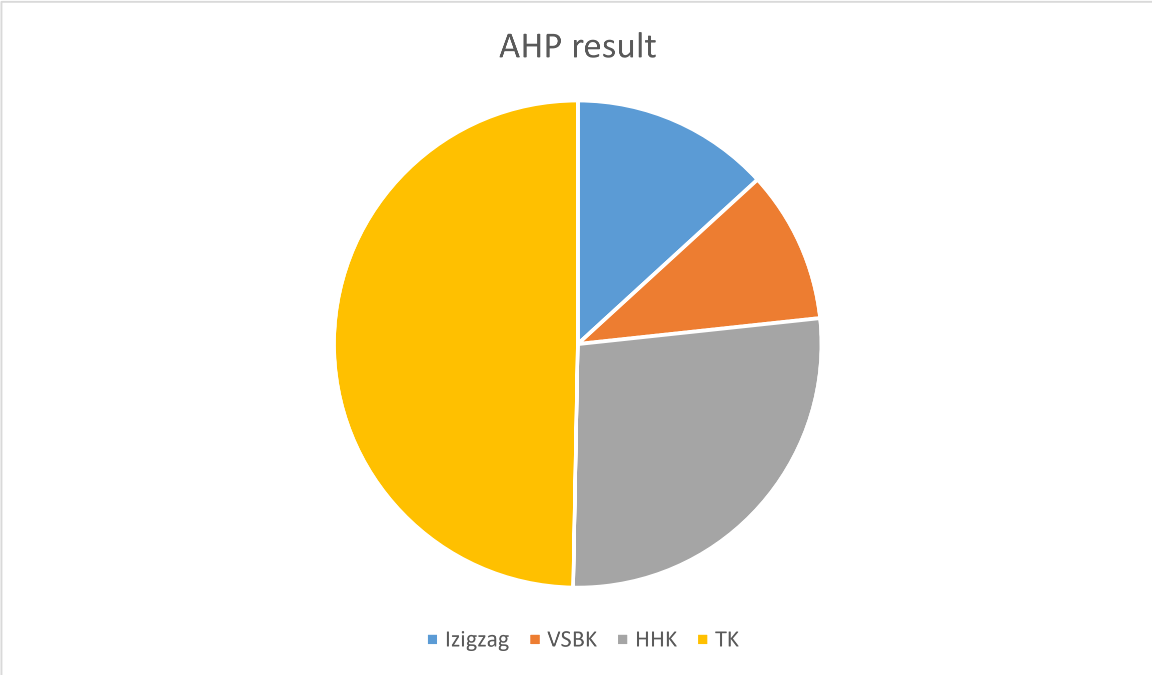


**Figure 4-2: Priority Weights by AHP**

## 4.2 Data Analysis of Cost-Benefit Analysis (CBA)

In Cost-Benefit Analysis (CBA), we consider all costs including land, civil & other civil works, machinery, operating costs, environmental cost and benefits which includes the value of bricks. Table 4-2 depicts the valuation methods used to estimate each cost and benefit. The formula used to calculate Return on Investment (ROI) and Payback Period are shown in Table 4-3.

**Table 4-2: Valuation Methods Used**

| Types of costs and benefits | Valuation method |
|---|---|
| **Costs:**<br>Land, Civil & Other Civil Works, Machinery, Operating Costs, Environmental Cost | Market prices |
| **Benefits:**<br>Value of Bricks | Market prices |

**Table 4-3: Formula Used**

| Types of Calculation | Formula |
|---|---|
| Return on Investment (ROI) | $\text{Return on Investment (ROI)} = \frac{\text{Profit}}{\text{Investment}} \text{ x } 100\%$ |
| Payback Period | $\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Actual Cash Flow in a year}}$ |

### 4.2.1 CBA Calculation for Improved Zigzag Kiln (IZigzag)

Investment BDT 1,50,00,000.00 includes 4 bigha land, civil and other civil works and machinery. Manual brick molding is considered. Improved Zigzag Kiln (IZigzag) is only workable for 6 (six) months in the dry season.

| | |
|---|---|
| Investment (BDT) | 15,000,000.00 |
| Brick Production/Year (Pcs) | 3,000,000 |
| Value of Brick/Pcs (BDT) | 8 |
| Labour/Day (Person) | 150 |
| $CO_2$ emission tons/million bricks produced | 440 |

Cost includes operation and maintenance, coal, clay and environmental cost due to pollution. All the prices calculated on the basis of the market price for the year 2018. For calculating the environmental cost, we consider the carbon credit price.

| Item | Amount (BDT) |
|---|---|
| O&M Cost | 12,800,000.00 |
| Coal | 5,400,000.00 |
| Clay | 1,875,000.00 |
| Environmental Cost | 1,496,880.00 |
| **Total Cost/Year** | **21,571,880.00** |

The benefit includes only the value of bricks.

| Item | Amount (BDT) |
|---|---|
| Total Sales | 24,000,000.00 |
| Total Benefit/Year | 24,000,000.00 |

Difference between the total benefit/year and total cost/year is considered as profit.

| Item | Amount (BDT) |
|---|---|
| Total Benefit/Year | 24,000,000.00 |
| Total Cost/Year | 21,571,880.00 |
| **Profit/year** | **2,428,120.00** |

Return on Investment (ROI) is calculated only for the 1st year of operation.

Return on Investment = (Profit/Investment) x 100%

= 16.19%

Return on Investment (ROI) of Improved Zigzag Kiln (IZigzag) for the 1st year is 16.19%.

Payback Period in Year = Initial Investment/Actual Cash Flow in a Year

= 3.82

Payback Period of Improved Zigzag Kiln (IZigzag) is 3.82 years.

### 4.2.2 CBA Calculation for Vertical Shaft Brick Kiln (VSBK)

Investment BDT 2,00,00,000.00 includes 4 bigha land, civil and other civil works and machinery. Manual brick molding is considered. Vertical Shaft Brick Kiln (VSBK) is workable for round the year. As the burning of brick is not uniform, the value of brick is less.

| | |
|---|---|
| Investment (BDT) | 20,000,000.00 |
| Brick Production/Year (Pcs) | 4,000,000 |
| Value of Brick/Pcs (BDT) | 6 |
| Labour/Day (Person) | 75 |
| $CO_2$ emission tons/million bricks produced | 291 |

Cost includes operation and maintenance, coal, clay and environmental cost due to pollution. All the prices calculated on the basis of the market price for the year 2018. For calculating the environmental cost, we consider the carbon credit price.

| Item | Amount (BDT) |
|---|---|
| O&M Cost | 15,200,000.00 |
| Coal | 4,000,000.00 |
| Clay | 2,500,000.00 |
| Environmental Cost | 1,319,976.00 |
| Total Cost/Year | 23,019,976.00 |

The benefit includes only the value of bricks.

| Item | Amount (BDT) |
|---|---|
| Total Sales | 24,000,000.00 |
| Total Benefit/Year | 24,000,000.00 |

Difference between the total benefit/year and total cost/year is considered as profit.

| Item | Amount (BDT) |
|---|---|
| Total Benefit/Year | 24,000,000.00 |
| Total Cost/Year | 23,019,976.00 |
| **Profit/year** | **980,024.00** |

Return on Investment (ROI) is calculated only for the 1$^{st}$ year of operation.

Return on Investment = (Profit/Investment) x 100% = 4.90%

Return on Investment (ROI) of Vertical Shaft Brick Kiln (VSBK) for the 1$^{st}$ year is 4.90%.

Payback Period in Year = Initial Investment/Actual Cash Flow in a Year = 8.70

Payback Period of Vertical Shaft Brick Kiln (VSBK) is 8.70 years.

### 4.2.3 CBA Calculation for Hybrid Hoffman Kiln (HHK)

Investment BDT 16,00,00,000.00 includes 12 bigha land, civil and other civil works and machinery. Mechanize brick making is considered. Hybrid Hoffman Kiln (HHK) is workable for round the year.

| | |
|---|---|
| Investment (BDT) | 160,000,000.00 |
| Brick Production/Year (Pcs) | 15,000,000 |
| Value of Brick/Pcs (BDT) | 8 |
| Labour/Day (Person) | 80 |
| $CO_2$ emission tons/million bricks produced | 315 |

Cost includes operation and maintenance, coal, clay and environmental cost due to pollution. All the prices calculated on the basis of the market price for the year 2018. For calculating the environmental cost, we consider the carbon credit price.

| Item | Amount (BDT) |
|---|---|
| O&M Cost | 40,000,000.00 |
| Coal | 18,000,000.00 |
| Clay | 9,375,000.00 |
| Environmental Cost | 5,358,150.00 |
| **Total Cost/Year** | **72,733,150.00** |

The benefit includes only the value of bricks.

| Item | Amount (BDT) |
|---|---|
| Total Sales | 120,000,000.00 |
| **Total Benefit/Year** | **120,000,000.00** |

Difference between the total benefit/year and total cost/year is considered as profit.

| Item | Amount (BDT) |
|---|---|
| Total Benefit/Year | 120,000,000.00 |
| Total Cost/Year | 72,733,150.00 |
| **Profit/year** | **47,266,850.00** |

Return on Investment (ROI) is calculated only for the 1$^{st}$ year of operation.

Return on Investment = (Profit/Investment) x 100%

= 29.54%

Return on Investment (ROI) of Hybrid Hoffman Kiln (HHK) for the 1$^{st}$ year is 29.54%.

Payback Period in Year = Initial Investment/Actual Cash Flow in a Year

= 3.04

Payback Period of Hybrid Hoffman Kiln (HHK) is 3.04 years.

### 4.2.4 CBA Calculation for Tunnel Kiln (TK)

Investment BDT 32,00,00,000.00 includes 12 bigha land, civil and other civil works and machinery. Mechanize brick molding is considered. Tunnel Kiln (TK) is workable for round the year.

| | |
|---|---|
| Investment (BDT) | 320,000,000.00 |
| Brick Production/Year (Pcs) | 30,000,000 |
| Value of Brick/Pcs (BDT) | 10 |
| Labour/Day (Person) | 45 |
| $CO_2$ emission tons/million bricks produced | 291 |

Cost includes operation and maintenance, coal, clay and environmental cost due to pollution. All the prices calculated on the basis of the market price for the year 2018. For calculating the environmental cost, we consider the carbon credit price.

| **Item** | **Amount (BDT)** |
|---|---|
| O&M Cost | 72,000,000.00 |
| Coal | 30,000,000.00 |
| Clay | 18,750,000.00 |
| Environmetal Cost | 9,899,820.00 |
| **Total Cost/Year** | **130,649,820.00** |

The benefit includes only the value of bricks.

| **Item** | **Amount (BDT)** |
|---|---|
| Total Sales | 300,000,000.00 |
| **Total Benefit/Year** | **300,000,000.00** |

Difference between the total benefit/year and total cost/year is considered as profit.

| **Item** | **Amount (BDT)** |
|---|---|
| Total Benefit/Year | 300,000,000.00 |
| Total Cost/Year | 130,649,820.00 |
| **Profit/year** | **169,350,180.00** |

Return on Investment (ROI) is calculated only for the 1$^{st}$ year of operation.

Return on Investment = (Profit/Investment) x 100% = 52.92%

Return on Investment (ROI) of Tunnel Kiln (TK) for the 1$^{st}$ year is 52.92%.

Payback Period in Year = Initial Investment/Actual Cash Flow in a Year

= 1.79

Payback Period of Tunnel Kiln (TK) is 1.79 years.

### 4.2.5 Priority Ranking by CBA

Priority ranking of brick kiln technology derived from Return on Investment (ROI) is shown in table 4-4.

**Table 4-4: Priority Ranking by ROI**

| Brick Kiln Technology | Return On Investment (%) | Rank |
|---|---|---|
| Improved Zigzag Kiln (IZigzag) | 16.19% | 3 |
| Vertical Shaft Brick Kiln (VSBK) | 4.90% | 4 |
| Hybrid Hoffman Kiln (HHK) | 29.54% | 2 |
| Tunnel Kiln (TK) | 52.92% | 1 |

Priority ranking of brick kiln technology derived from the Payback Period is shown in table 4-5.

**Table 4-5: Priority Ranking by Payback Period**

| Brick Kiln Technology | Payback Period (Years) | Rank |
|---|---|---|
| Improved Zigzag Kiln (IZigzag) | 3.82 | 3 |
| Vertical Shaft Brick Kiln (VSBK) | 8.70 | 4 |
| Hybrid Hoffman Kiln (HHK) | 3.04 | 2 |
| Tunnel Kiln (TK) | 1.79 | 1 |

# CHAPTER 5: RESULT AND DISCUSSION

In this study, five criteria's of extreme importance has been chosen. The criteria are: (i) Investment (I), (ii) Product Quality (PQ), (iii) Fuel Efficiency (FE), (iv) Effect on Environment (EF) and (v) Labour Intensity (LI). Each criterion with the remaining criteria and pairwise comparison were done. Further AHP method has been applied to assign importance weight to these criteria's. Initially, the decision matrix is established and the weights of each criterion are calculated by AHP software.

**Table 5-1: Decision Matrix and Weights of Criteria Calculated by AHP**

| | I | PQ | FE | EE | LI | Weights |
|---|---|---|---|---|---|---|
| **I** | 1 | 1/3 | 1/5 | 1/8 | 5 | 0.068 |
| **PQ** | 3 | 1 | 3 | 1/2 | 7 | 0.268 |
| **FE** | 5 | 1/3 | 1 | 1/3 | 5 | 0.147 |
| **EE** | 8 | 2 | 3 | 1 | 9 | 0.475 |
| **LI** | 1/5 | 1/7 | 1/5 | 1/9 | 1 | 0.042 |

To ensure consistency of preference for determining criteria weights, consistency check was performed. The normalized weights of Investment (I), Product Quality (PQ), Fuel Efficiency (FE), Effect on Environment (EF) and Labour Intensity (LI), 0.680, 0.268, 0.147, 0.475 and 0.042 respectively, with CR = 0.09 which is less than 0.10.

It is observed that the Effect on Environment criterion is assigned maximum weight and Labour Intensity criterion has minimum weight assignment. Further based on these criteria's four probable technology are to be ranked. Four technology are assessed over five criteria's. Result of responses for four technology has shown in table 5.2.

**Table 5-2: Priority Ranking of Brick Kiln Technology by AHP**

| Brick Kiln Technology | Priority Weight | Priority Percentage (%) | Rank |
|---|---|---|---|
| **Tunnel Kiln (TK)** | 0.497 | 49.70% | 1 |
| **Hybrid Hoffman Kiln (HHK)** | 0.270 | 27.00% | 2 |
| **Improved Zigzag Kiln (IZigzag)** | 0.132 | 13.20% | 3 |
| **Vertical Shaft Brick Kiln (VSBK)** | 0.101 | 10.10% | 4 |
| | 1.000 | 100.00% | |

On the basis of the calculated values of the four technology are ranked. From the values of Table 5.2, it is observed that Tunnel Kiln (TK) has the highest value and Vertical Shaft Brick Kiln (VSBK) has the least value, making them as the best and the last choices respectively. The final ranking of Brick Kiln Technology is Tunnel Kiln (TK) > Hybrid Hoffman Kiln (HHK) > Improved Zigzag Kiln (IZigzag) > Vertical Shaft Brick Kiln (VSBK).

According to the priority ranking of brick kiln technologies, the top 2 brick kiln technologies are Tunnel Kiln (TK) and Hybrid Hoffman Kiln (HHK) which are energy-efficient brick kiln technologies. These kiln technologies have lower Specific Energy Consumption (SEC) and therefore burn less fuel and release fewer GHGs per unit of output. Additionally, energy-efficient technologies give operators more control over the fuel combustion process, which results in more complete combustion of carbonaceous fuel and decreased emissions of black carbon and other SPM. These technologies can provide financial returns through savings in fuel cost per unit of output. Vertical Shaft Brick Kiln (VSBK) is more energy efficient brick kiln than Improved Zigzag Kiln.

The use of the correct coal quality, with ideal chemical properties, for a kiln technology is essential. The main coal properties that are important while selecting coal as external fuel include ash content, calorific value, moisture contents, sulfur, volatile matter, particle size, and ash fusion temperature. A reasonable content of coal is between 0.5% and 1%. Coal having Sulphur >2 % should not be used because higher content of sulfur causes Sulphur Dioxide ($SO_2$) pollution which has a direct negative effect on the health of workers and damages vegetation, livestock and human population in the surrounding environment.

In this study, the Cost-Benefit Analysis (CBA) is conducted on the profitability of brick kiln technologies. Operation & Maintenance Cost, Raw Material Cost (Clay & Coal) and Environmental Cost are considered in Cost. On the benefit side, the value of bricks is included. On the basis of Return on Investment (ROI) and Payback Period of four technologies are ranked.

**Table 5-3: Priority Ranking of Brick Kiln Technology by ROI**

| Brick Kiln Technology | Return On Investment (%) | Rank |
|---|---|---|
| **Tunnel Kiln (TK)** | 52.92% | 1 |
| **Hybrid Hoffman Kiln (HHK)** | 29.54% | 2 |
| **Improved Zigzag Kiln (IZigzag)** | 16.19% | 3 |
| **Vertical Shaft Brick Kiln (VSBK)** | 4.90% | 4 |

From the values of Table 5.3, it is observed that Tunnel Kiln (TK) has the highest value of ROI and Improved ZigZag Kiln (IZigZag) has the least value, making them as the best and the last choice respectively. Ranking of Brick Kiln Technologies by ROI is Tunnel Kiln (TK) > Hybrid Hoffman Kiln (HHK) > Vertical Shaft Brick Kiln (VSBK) > Improved Zigzag Kiln (IZigzag).

**Table 5-4: Priority Ranking by Payback Period**

| Brick Kiln Technology | Payback Period (Years) | Rank |
|---|---|---|
| **Tunnel Kiln (TK)** | 1.79 | 1 |
| **Hybrid Hoffman Kiln (HHK)** | 3.04 | 2 |
| **Improved Zigzag Kiln (IZigzag)** | 3.82 | 3 |
| **Vertical Shaft Brick Kiln (VSBK)** | 8.70 | 4 |

From the values of Table 5.4, it is observed that Tunnel Kiln (TK) has the lowest payback period and Vertical Shaft Brick Kiln (VSBK) has the highest payback period, making them as the best and the last choices respectively. Ranking of Brick Kiln Technologies by payback period is Tunnel Kiln (TK) > Hybrid Hoffman Kiln (HHK) > Improved Zigzag Kiln (IZigzag) > Vertical Shaft Brick Kiln (VSBK).

**Table 5-5: Comparison among the Brick Kiln Technologies**

| Particulars | Improved Zigzag Kiln (IZigzag) | Vertical Shaft Brick Kiln (VSBK) | Hybrid Hoffman Kiln (HHK) | Tunnel Kiln (TK) |
|---|---|---|---|---|
| Land Required (Bigha) | 4 | 4 | 10-12 | 12-15 |
| Investment (Crore BDT) | 1.50 | 2.00 | 16.00 | 32.00 |
| Product Quality | Medium | Low | High | High |
| Fuel Efficiency (Coal Consumption in tons per million bricks produced) | 180–200 | 100–120 | 120–130 | 100–120 |
| Effect on the Environment (CO2 emission tons per million bricks produced) | 440 | 291 | 315 | 291 |
| Labour Intensity | High | Low | Low | Very Low |
| Brick Making Process | Manual/ Mechanized | Manual/ Mechanized | Manual/ Mechanized | Mechanized |
| Brick Drying Process | Manual | Manual | Manual/ Mechanized | Mechanized |
| AHP Ranking | 3rd | 4th | 2nd | 1st |
| CBA Ranking | | | | |
| By ROI | 3rd | 4th | 2nd | 1st |
| By Payback Period | 3rd | 4th | 2nd | 1st |

In all priority ranking, Tunnel Kiln (TK) is in 1st position. 12-15 bigha land is required and investment is too high relative to other types of the kiln. Advantages of these types of kilns are high product quality, very high fuel efficiency, the very low effect on the environment and very few labors required. Related to high investment, profitability is also high. Tunnel kiln is a totally mechanized process. These types of kilns are suitable for large scale production. Only large enterprises can invest in these types of kiln. Hybrid Hoffman Kiln (HHK) is in 2nd position in all priority ranking. Investment and profitability are relatively lower than the Tunnel Kiln. Through Vertical Shaft Brick Kiln (VSBK) is a cleaner technology than Improved Zigzag Kiln (IZigzag). But VSBK technology is not commercially successful in Bangladesh due to its small scale of production and relatively poor quality of brick.

In Bangladesh, existing all brick kilns are used for solid brick burning. Tunnel Kiln (TK) and Hybrid Hoffman Kiln (HHK) can produce hollow bricks that consume much less energy for firing, use 40% less clay, and have much better insulation standards. Perforated and hollow bricks are of lower weight and volume and have a larger surface area. These bricks can be fired with 20% less energy while maintaining the compressive strength of solid bricks. Perforated and hollow bricks can only be made with a semi-mechanized extrusion press; this requires a consistent source of electricity.

# CHAPTER 6: CONCLUSION

According to the objective of this research: Priority ranking of different brick kiln technologies of Bangladesh, the priority ranking of different brick kiln technologies by AHP and CBA is found which is shown in Table 6.1.

**Table 6-1: Priority Ranking of Brick Kiln Technologies**

| Brick Kiln Technology | AHP Ranking | CBA Ranking | |
|---|---|---|---|
| | | By ROI | By Payback Period |
| **Tunnel Kiln (TK)** | 1st | 1st | 1st |
| **Hybrid Hoffman Kiln (HHK)** | 2nd | 2nd | 2nd |
| **Improved Zigzag Kiln (IZigzag)** | 3rd | 3rd | 3rd |
| **Vertical Shaft Brick Kiln (VSBK)** | 4th | 4th | 4th |

In this study, with the use of AHP, a technology assessment tool, based on empirical data it is found that Tunnel Kiln (TK) technology has got top ranking and 49.70% preferable, Hybrid Hoffman Kiln (HHK) technology with 2$^{nd}$ position in ranking which is 27.00% preferable. The 3$^{rd}$ rank is Improved Zigzag Kiln (IZigzag) technology and it is 13.20% preferable, Vertical Shaft Brick Kiln (VSBK) technology has got 4$^{th}$ rank with 10.10% preference.

On the other hand, with the use of CBA, based on cost and benefit data it is found that Tunnel Kiln (TK) technology has got top ranking which Return on Investment is 52.92% and Payback Period is 1.79 years, Hybrid Hoffman Kiln (HHK) technology with 2$^{nd}$ position in ranking which Return On Investment is 29.54% and Payback Period is 3.04 years. Improved Zigzag Kiln (IZigzag) technology has got 3$^{rd}$ rank with 16.19% Return on Investment and payback period is 3.82 years. Vertical Shaft Brick Kiln (VSBK) technology has got 4$^{th}$ rank in a ranking by Return on Investment (ROI) and Payback Period, the values are 4.90% and 8.70 years respectively.

At present, brick manufacturing of Bangladesh is mostly depending on Improved Zigzag Kiln (IZigzag) technology. But this technology is not a cleaner technology in true sense. Tunnel Kiln (TK) and Hybrid Hoffman Kiln (HHK) should get the highest preference for brick making in the perspective of Bangladesh.

# CHAPTER 7: RECOMMENDATIONS

Bangladesh's brick sector is characterized by outdated technologies with low energy efficiency and high emissions, low mechanization rate, the dominance of small-scale brick industries with limited financial capacity, and dominance of single raw material (clay) and product (solid clay brick).

This study suggests that the development of the brick industry in Bangladesh should aim at: (i) moving from traditional brick-making technologies (e.g. FCK) to cleaner ones (e.g. HHK, TK); (ii) increasing the proportion of large-scale enterprises with higher capacity to adapt to cleaner technologies. To achieve these goals, the Government and the concern authorities can consider the following recommendations.

1. Recognize brick kilns as a formal industry. This would enable easier access to financial resources (which in turn will enable investment in cleaner technologies and access to flood free land) and improved working conditions.
2. Establish a Brick Technology Center to raise awareness about the benefits of cleaner technologies.
3. Facilitate the availability of subsidized credit lines to account for reduced health impacts from pollution.
4. Train several stakeholders with regard to the benefits of adopting cleaner technologies (e.g. entrepreneurs, workers and the financial sector).
5. Develop industrial parks to accommodate a large number of industries on flood-free land. These parks would mean less cost for kiln owners, due to the economy of scale achieved by providing the basic infrastructure for all kilns (e.g. roads, electricity, water) and other facilities (e.g. schools for the employees' children). They would also require less land for kilns establishment compared to the current situation.
6. Improve working conditions by introducing higher levels of mechanization, social programs to reduce child labor, occupational safety, and health measures in kilns.

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# APPENDICES

## Appendix A: Questionnaire

### First Phase Questionnaire

Interviewees were requested to answer the questions with Numerical Rating from AHP Priority Setting.

### AHP Priority Setting

| AHP Scale of Importance for comparison pair | Numeric Rating |
|---|---|
| Equal Importance | 1 |
| Equally to Moderately | 2 |
| Moderate Importance | 3 |
| Moderately to Strong | 4 |
| Strong Importance | 5 |
| Strongly to very strong | 6 |
| Very strong Importance | 7 |
| Very strong to extremely | 8 |
| Extreme Importance | 9 |

**The first part of the first phase questionnaire:**

| | |
|---|---|
| Q.1 | How important/preferable is Product Quality when it is compared with Investment? |
| | |
| Q.2 | How important/preferable is Fuel Efficiency when it is compared with Investment? |
| | |
| Q.3 | How important/preferable is Effect on Environment when it is compared with Investment? |
| | |
| Q.4 | How important/preferable is Labour Intensity when it is compared with Investment? |

| | |
|---|---|
| Q.5 | How important/preferable is Product Quality when it is compared with Fuel Efficiency? |
| | |
| Q.6 | How important/preferable is Product Quality when it is compared with the Effect on Environment? |
| | |
| Q.7 | How important/preferable is Product Quality when it is compared with Labour Intensity? |
| | |
| Q.8 | How important/preferable is Fuel Efficiency when it is compared with the Effect on Environment? |
| | |
| Q.9 | How important/preferable is Fuel Efficiency when it is compared with Labour Intensity? |
| | |
| Q.10 | How important/preferable is Effect on Environment when it is compared with Labour Intensity? |
| | |

**The second part of the first phase questionnaire:**

**Q.1 With respect to Criterion Investment,**

1.1 How important/preferable is Improved Zigzag Kiln (IZigzag) when it is compared with Vertical Shaft Kiln (VSBK)?

1.2 How important/preferable is Improved Zigzag Kiln (IZigzag) when it is compared with Hybrid Hoffman Kiln (HHK)?

1.3 How important/preferable is Improved Zigzag Kiln (IZigzag) when it is compared with Tunnel Kiln (TK)?

1.4 How important/preferable is Vertical Shaft Kiln (VSBK) when it is compared with Hybrid Hoffman Kiln (HHK)?

1.5 How important/preferable is Vertical Shaft Kiln (VSBK) when it is compared with Tunnel Kiln (TK)?

1.6 How important/preferable is Hybrid Hoffman Kiln (HHK) when it is compared with Tunnel Kiln (TK)?

**Q.2 With respect to Criterion Product Quality,**

2.1 How important/preferable is Improved Zigzag Kiln (IZigzag) when it is compared with Vertical Shaft Kiln (VSBK)?

2.2 How important/preferable is Improved Zigzag Kiln (IZigzag) when it is compared with Hybrid Hoffman Kiln (HHK)?

2.3 How important/preferable is Improved Zigzag Kiln (IZigzag) when it is compared with Tunnel Kiln (TK)?

2.4 How important/preferable is Vertical Shaft Kiln (VSBK) when it is compared with Hybrid Hoffman Kiln (HHK)?

2.5 How important/preferable is Vertical Shaft Kiln (VSBK) when it is compared with Tunnel Kiln (TK)?

2.6 How important/preferable is Hybrid Hoffman Kiln (HHK) when it is compared with Tunnel Kiln (TK)?

**Q.3 With respect to Criterion Fuel Efficiency,**

3.1 How important/preferable is Improved Zigzag Kiln (IZigzag) when it is compared with Vertical Shaft Kiln (VSBK)?

3.2 How important/preferable is Improved Zigzag Kiln (IZigzag) when it is compared with Hybrid Hoffman Kiln (HHK)?

3.3 How important/preferable is Improved Zigzag Kiln (IZigzag) when it is compared with Tunnel Kiln (TK)?

3.4 How important/preferable is Vertical Shaft Kiln (VSBK) when it is compared with Hybrid Hoffman Kiln (HHK)?

3.5 How important/preferable is Vertical Shaft Kiln (VSBK) when it is compared with Tunnel Kiln (TK)?

3.6 How important/preferable is Hybrid Hoffman Kiln (HHK) when it is compared with Tunnel Kiln (TK)?

**Q.4 With respect to Criterion Effect on Environment,**

4.1 How important/preferable is Improved Zigzag Kiln (IZigzag) when it is compared with Vertical Shaft Kiln (VSBK)?

4.2 How important/preferable is Improved Zigzag Kiln (IZigzag) when it is compared with Hybrid Hoffman Kiln (HHK)?

4.3 How important/preferable is Improved Zigzag Kiln (IZigzag) when it is compared with Tunnel Kiln (TK)?

4.4 How important/preferable is Vertical Shaft Kiln (VSBK) when it is compared with Hybrid Hoffman Kiln (HHK)?

4.5 How important/preferable is Vertical Shaft Kiln (VSBK) when it is compared with Tunnel Kiln (TK)?

4.6 How important/preferable is Hybrid Hoffman Kiln (HHK) when it is compared with Tunnel Kiln (TK)?

**Q.5 With respect to Criterion Labour Intensity,**

5.1 How important/preferable is Improved Zigzag Kiln (IZigzag) when it is compared with Vertical Shaft Kiln (VSBK)?

5.2 How important/preferable is Improved Zigzag Kiln (IZigzag) when it is compared with Hybrid Hoffman Kiln (HHK)?

5.3 How important/preferable is Improved Zigzag Kiln (IZigzag) when it is compared with Tunnel Kiln (TK)?

5.4 How important/preferable is Vertical Shaft Kiln (VSBK) when it is compared with Hybrid Hoffman Kiln (HHK)?

5.5 How important/preferable is Vertical Shaft Kiln (VSBK) when it is compared with Tunnel Kiln (TK)?

5.6 How important/preferable is Hybrid Hoffman Kiln (HHK) when it is compared with Tunnel Kiln (TK)?

**Second Phase Questionnaire**

In the second phase, datasheet interviewees were requested to give data on cost and benefit of brick manufacturing industry using different brick kiln technology.

Questionnaire for the second phase is given below.

For Improved Zigzag Kiln/Vertical Shaft Kiln/Hybrid Hoffman Kiln/Tunnel Kiln,

| | |
|---|---|
| Q.1 | How much investment is required to set up Improved Zigzag Kiln? |
| | |
| Q.2 | What is the production capacity of this type of kiln? |
| | |
| Q.3 | How many cft clays are required for this production? |
| | |
| Q.4 | How many tons of coal are used for this production? |
| | |
| Q.5 | How many persons are required for production? |
| | |
| Q.6 | How much the O&M cost? |
| | |
| Q.7 | What is the unit sale price of the brick? |
| | |