Tunnel kiln: Technology Overview and Project Assessment Guideline

TECHNICAL ASSISTANCE FOR FINANCING BRICK KILN IMPROVEMENTS IN BANGLADESH

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## Disclaimer

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1 Introduction

This report describes the general overview of tunnel kiln technology and presents the brick making process, design elements of tunnel kiln and key technical aspects of its different components and processes that should be optimised during operation. Key performance indicators such as investment and operating costs, expected lifespan, productivity level, land use, fuel consumption and fuel type, energy efficiency, emission level and emission type are analysed for tunnel kiln technology.

The document is prepared for Infrastructure Development Company Limited (IDCOL) as part of technical assistance for financing brick kiln improvements in Bangladesh. IDCOL has a development mandate to stimulate the renewal of the stock of clay brick firing kilns in operation in Bangladesh through replacing the incumbent, polluting technologies with low emission, energy efficient technologies. The document provides best practices recommendations on the acceptable range of the described parameters as a guide for the evaluation of tunnel kiln projects in Bangladesh and can also be used as a reference document for other parts of the world where similar operating conditions exist.

2 Principle of Brickmaking Process Using Tunnel Kiln

The following figure shows the principle of the brick making process from pit to delivery.

Clay Pit (raw material extraction)
The raw materials for bricks are loams and clays of various natural compositions. Mining takes place in pits close to the surface utilizing selected deposits. Already during the exploitation phase, the pits should be prepared for re-cultivation, e.g. as biotopes. Equipment for mining are mainly excavators and scrapers.

Storage
The raw material is transported by vehicles to the brickworks for intermediate storage before mechanical preparation. The raw material is stored in large piles to ensure a constant production. Especially in Bangladesh this is very important, because the digging of clay in the monsoon season is difficult or impossible.

Feeder
The clay from the stockpile is transported to the feeder. If different clay types or additives are used, there may be several feeders.

Raw material preparation
The preparation, in particular mixing and crushing, takes place in the grinding pan and/or rolling mills. After this preparation, the material is transported to a souring house (storage, mixing of different clay types, uniform moisture penetration, and homogenization). Additional porosification is required for the production of highly
heat-insulating bricks. This is achieved by adding fine cellulose fibers (e.g. untreated sawdust or paper waste resulting from paper production) and/or coal dust.

**Grinding pan**
If hard clays are used or if the raw material contains hard impurities, a grinding pan should be used. Alternatively, a disintegrator can be installed that is cheaper than a grinding mill. This step is important when dried bricks with failures or waste fired bricks are returned to the clay preparation, the first step of the grinding process.

**Rolling mill**
The next step of preparation is the grinding by rolling mills. Depending on the necessary grain size distribution for different products, there can be more than one rolling mill installed.

**Souring house**
The prepared clay mixture is transported by conveyer belts to the souring house. At this stage of preparation, a homogenization of the clay moisture takes place and a further clay digestion by bacteria happens.

**Moulding**
The next step is the moulding of the clay to get the final shape of the un-burnt product, the so-called “green brick”. Moulding technique depends on the produced products. For bricks either extruders or moulding machines are used. Using extruders, a column is formed which is cut to the right length of the product. By using moulding machines, the bricks have the right size after pressing.
For the production of roofing tiles, a short column is extruded and pressed to the final form by a revolver press.

**Drying**
The wet green bricks are dried either at natural air or in controlled dryers. Controlled dryers are essentially operated with the non-hazardous waste heat from the tunnel kiln. Depending on the variety of products either chamber dryers or tunnel dryers are used. The drying time varies according to product format and bulk density and is in the range of 24 to 48 hours. For solid bricks, the drying time can range to 72 hours. The final moisture content before feeding into the kiln should not be more than 2%. This is required to avoid that moisture from within the clay evaporates suddenly in the kiln and causes damage to the product.

**Kiln**
After drying, the dried bricks are burnt (“fired”) in a thermally insulated tunnel kiln. First, they are heated gradually in the preheating zone, and then to the final firing temperature of 900 to 1050°C in the firing zone. The maximum temperature and the holding time at this temperature depend on the clay mixture and the product and should be evaluated in a laboratory. The firing zone is followed by the cooling phase. The heat available in the cooling zone is fed into the dryer via a heat compound. The firing of the dried bricks is mainly done in tunnel kilns, but also other kilns are available. For small batches of special products, batch kilns are used.

**Quality monitoring**
The quality monitoring is a highly important point in the production of bricks. A good supervision of the entire process assures quality products and less waste of fired material. Therefore, the self-monitored quality assurance takes place by internal staff, and in addition external quality assurance is carried out during and after the production process according to the National Standards by state-authorised institutes.

**Packing, storage and delivery**
After quality control, the fired bricks are bundled into small packages, grouped on pallets and fed to the packaging plant. There, the bricks are either strapped with steel or recyclable plastic straps or packed in PE shrink film. The films and pallets are usually taken back by the brick manufacturer and reused or forwarded for recycling. After packing, the bricks are stored in the brick yard and then sold.

### 3 Project Design

Before the brick factory can be designed, substantial tests of the available raw material and the final mixture (e.g. coal additive) must be done. These results are very important for preparation and forming and especially for the drying and firing process. It is not decisive whether the tests are made in house or with partners. Based on the characteristics of the clay or the mixture the type of machines in the preparation line can be selected. In addition, the drying behaviour must be known to design the drying conditions (climate) in the dryer. Also, the
kiln design is based on the clay characteristics and, of course, the final properties depend on the clay and its mixture.

Furthermore, the analysis of the added coal as internal fuel must be known. Not only the calorific value is important, but also the composition of the residual ashes because this has an influence on the sintering (vitrification) process in the firing zone of the kiln. Ash ingredients can act as fluxes, which means it may be possible to decrease the maximum firing temperature or that the compressive strength of the bricks increases.

4 Preparation of clay ware

4.1 Clay Preparation and Storage

The process of clay preparation and storage is done depending on the raw material quality and can use different machines.

A disintegrator is used for crushing hard particles as a first step of preparation. This machine is necessary if pebbles or small stones are in the clay or if dried bricks are recycled.

A magnetic iron remover in the preparation line might be useful in the preparation process to obtain good quality clay.

If the soil is taken from the surface where agricultural area had been, it might also be helpful to use a clay purifier which is a machine for purifying clay of plastic and plasticized consistency. The purifier uses baskets with slotting holes of 2.0 mm through which the clay is pressed. Thus inclusions and impurities such as stones, silica, pyrite, pebbles, wood, roots, metal and plastic parts can be separated efficiently and be removed from the machine without interruption of the cleaning process. While shelling the body from the auger that presses the clay through the basket, a shearing effect is created that has an additional positive effect on the solubilizing of the mineral body. Compared to other separation methods this is the reason for the low specific energy expenditure.

![Figure 2: Clay purifier](image)
The prepared mixture is stored in the souring house where a homogenization of the clay moisture takes place and a further clay digestion by bacteria happens. In addition, this step acts as a buffer that ensures a constant production in forming, drying and firing if one of the preparation machines fails or is inoperable.

4.2 Green Brick Production

Extruders are the most common techniques for green brick production, but also dies are used for forming of the products. In case of extruders, vacuum extruders should be used to get better green brick quality.

The die to form the green bricks should have the typical size to form bricks according to the Bangladesh Standard. While a standard brick size is desirable, the most important aspect for successful marketing is to produce higher quality brick products with the new factory than other brick makers with traditional techniques.

Green brick handling options preferred for Bangladesh depend on the clay features, moisture, clay storage and clay processing. It also depends a lot on the level of automation required whereas each technology has pros and cons.

Only after knowing the raw materials the best method for shaping (stiff, semi-stiff or plastic) can be determined. This defines the options for the brick setting. For example, if only plastic shaping with an amount of mixing water of nearly 20% is needed, direct setting poses a great risk of de-formation of the green bricks.

The advantage of the direct setting is that after the extrusion the bricks are loaded directly on the kiln car, which is used in the tunnel dryer as well as in the kiln. There is no additional step with additional handling equipment between drying and firing. This reduces the installation costs. For this case the bricks have to be extruded “semi-stiff”, which means with a mixing water content of about 16%. This is necessary because the strength of the freshly extruded bricks have to be high enough to support the weight of the stacking. In the following figure an example from Germany is shown.

In this case the height of the setting is limited to 8 bricks to prevent deformation.
5 General Overview of Drying Technology

The principally different dryer types are:
- open-air dryer
- discontinuous chamber dryer
- continuous tunnel dryer

Tunnel dryers are always of advantage when the customer requires mainly uniform drying times. Depending on the layout of the whole plant, the products are either travelling through the dryer on special dryer cars or they are placed directly on kiln cars that take them both through the tunnel dryer and through the tunnel kiln.

Chamber dryers are always used when the customer needs individual drying times. The green products (non-burnt clay products) are at first put on special drying pallets. These are loaded on dryer cars and are then forwarded into the individual drying chambers. The drying process of each dryer car can individually be controlled by the dryer control system. After drying, the products are removed from the drying pallets, and the setting plant transfers them to the kiln cars.

If brick companies in Bangladesh want to produce different products with very different weights and dimensions, like solid bricks or hollow blocks, which show different drying behaviour, chamber dryers would be selected. Solid bricks or hollow blocks show a different drying behaviour because of the thickness of the solid material. The heat and mass transfer is different because of the different air flow conditions around the brick or, in case of hollow blocks, through the block. This is the reason why the different brick types need different drying time and drying conditions. Drying is an important part of the whole process. Mistakes or failures in this step will cause bad quality which will not be rectified in the firing process.

The time for drying as well as for firing depends on the quality of the clay which is analysed in laboratory tests. The drying time may be totally different for solid or perforated bricks and depends greatly on the size of the bricks and the type of dryer.

5.1 Open Air Dryers

The distinguishing characteristic of open-air (natural) dryers is that the charge is dried exclusively in atmospheric air. This is ideal from the heat engineering point of view as no external energy is needed for the process. Compared with artificial drying, however, natural drying has two grave disadvantages:

- It is weather-dependent.
  Brick and tile production with purely open-air drying is therefore usually seasonal and is often supplemented by artificial drying. Variations in wind and climatic conditions can only be partly offset by adjustable apertures and louvres. Quality defects are therefore likely.

- It takes longer.
  Naturally, the climatic conditions are a major factor. Even under favourable conditions, open-air drying takes very much longer than artificial drying. It requires more space and the ware has to be transported over longer distances.

5.2 Chamber Dryers

The feature common to all chamber dryers is periodic feeding, discharging and drying of the entire drying charge simultaneously in the chamber. During drying the charge is stationary and drying air is circulated over and around it. Normally a chamber dryer contains a number of separate units so that a quasi-continuous drying cycle is obtained. Depending on the type, size and shape of the clay products and on the level of mechanization of the works, all variants of feed and discharge are possible from manual to fully automatic conveying systems with transfer car operation.

Another characteristic shared by all chamber dryers is that the heat and air volume flows are adapted during the drying process to the particular phase of the drying charge so as to obtain faster, more energy saving and
better quality drying of the products. The big advantage of a chamber dryer is the possibility to be very flexible when producing different products.

5.3 Tunnel Dryers

As opposed to chamber drying, in tunnel dryers the ware is pushed on cars through a corridor or tunnel. This creates more favourable conditions for automation of production both of the conveying system and of combined heating of kiln and dryer. This is particularly relevant with round-the-clock operation over the entire week, so that the drying processes affecting the green product can be designed to resemble those in a climatic chamber dryer, i.e. uniform drying times can be obtained.

Without round-the-clock operation at the extruder, continuous operation of a tunnel dryer requires considerable reserve areas on the wet part, i.e. on the feeding side of the process. The dryers must also have thermostatic control to avoid drying damage and obtain a high degree of thermodynamic effectiveness. If only 1-shift working of 8 hours’ production time for a 5-day week is done, the storage area at the entrance to the process (wet reserve) will in fact be 3.2 times the dry area demand. A sufficient storage space (drying reserve) is also recommended for tunnel dryers, essentially as a buffer between the dryer and the kiln.

Tunnel dryers in most cases are in fact not designed as continuous dryers but are dependent on the feed from the extruder during operating time and the cars remain idle in the dryer during non-production time. No wet reserve may be needed, but a dry reserve will be required as normally the kiln has to be charged continuously. Irregular feed to the dryer also increases the average drying time and hence the required size of the dryer.

5.4 Comparison of Chamber and Tunnel Dryers

Many aspects have to be considered when choosing the most suitable type of dryer, the conveying system and the drying process itself and to decide on the production policy’s economic viability. Only five of the essential criteria are dealt with here.

- **Capital and operating costs**
  Generally, the capital costs of tunnel dryers are higher but their operating costs (for energy and personnel) are lower.

- **Change in capacity**
  Chamber dryers can be more easily enlarged if space permits and adaptation to a reduced throughput certainly adds much less to the operating costs than in the case of tunnel dryers.

- **Flexibility**
  With frequent changes of size, and hence changes in drying times and variations in heat consumption, preference should be given to chamber dryers.

- **Drying time**

1 Green product is the expression used for unfired clay ware, i.e. ware after forming.
With continuously operating tunnel dryers it is possible to obtain short drying times equivalent to those of climate chamber dryers; with increased drying sensitivity of the ware and at the same time a shorter charging period for tunnel dryers, drying times in tunnel dryers are longer than in chamber dryers.

- **Operating reliability**
  The more complicated conveying and control systems used in chamber dryers represent higher chances of breakdown. In contrast, repair of the individual units in chamber dryers is usually possible without involving downtime.

- **Residual moisture**
  In any cases the moisture content of dried bricks should be lower than 2%, otherwise the risk of brick damage in the first part of the tunnel kiln will be very high.

### 6 General Overview of Tunnel Kiln Technology

Top-fired tunnel kilns, i.e. with fuel feed via the roof, are the predominant type in the brick and tile industry. The ware to be burnt (firing charge) is set directly on the tunnel kiln cars with gaps to allow air circulation (firing slots) of 250 to 400 mm width at right angles to the direction of travel. The distance between firing slots depends on the type of clay, the size of products to be fired or the pack loading and ranges from 1.00 to 1.60 m. There are tunnel kilns that are also operated with longitudinal slots.

Tunnel kiln car pushing through the different zones of the kiln is intermittent and usually the cars keep a spacing of half a car length (also 1/3 or 1 car length are used) from one firing slot to the next. The length of the push depends on the arrangement of the setting from one firing slot to the next. The tunnel kiln cars with the dried green ware pass into the entrance air lock (sluice chamber), which is also often designed as a preheater. The tunnel kiln and air locks/preheater are separated by a set of lifting doors or gates which seals off the entire firing channel cross-section to avoid an interruption of the kiln draught during the pushing process and to prevent sucking of ambient air into the exhaust system. From the air lock the cars are pushed into the kiln’s pre-heating or firing section.

Through the car pushing at suitable intervals the clay is heated at a constant temperature gradient and it is then fired by passing through the firing zone at the required temperature. This temperature is continuously reduced in the cooling zone so that the finished products upon discharge from the kiln will have a temperature of nearly ambient air temperature.

The fuel feed is vertically via the stokehole openings in the kiln roof. The fuels typically used are light or heavy fuel oil, coal, natural gas and liquefied gas. In South East Asia mainly coal is used. Each fuel is introduced by a special purpose designed stoking device in the combustion chamber. The feed volume must be exactly pre-set and the final firing temperature should be automatically controlled.

Because a certain number of stokehole are arranged next to each other per firing slot, top-fired tunnel kilns have the advantage of keeping heat consumption per fire-hole at a low level and controlling the exposure time of the ware to the heat source and therefore preventing any local temperature peaks or overheating.

Part of the combustion air enters the firing channel at the exit side or is introduced via a forced air system, is heated up with simultaneous cooling of the exiting air, and arrives in the firing zone as an oxygen carrier. The combustion gases produced here pass through the heating zone via the waste gas flues to the chimney. Hot air is removed from the cooling zone of the firing channel and, together with the hot air volumes recovered from the below car cooling and the wall and roof cooling, is utilized for green brick drying purposes.
Figure 7: Design of a tunnel kiln
For the firing cycle, which means the time from cold to cold or from kiln entrance to exit, for solid bricks or typical Bangladesh bricks, 40 to 60 hours seem to be realistic.

The following figure shows the zoning of a tunnel kiln in longitudinal section and plan view and the respective temperature chart.

Because of the equalization of temperature and atmosphere, the height of the setting should not be more than 1.5 m for the production of high-grade clay ware products. Loading and unloading should be fully automatic. It has been found in industrial practice that with these tunnel kilns the most favourable and economical energy consumption is obtainable because no kiln furniture are required for the heavy clay products, such as racks, shelves, spacers, etc. The only exception is the firing of clay roofing tiles in tunnel kilns, in which stability of the setting has to be ensured by use of refractory supports, setters, U-cassette etc.

7 Fuel Consumption

Nowadays, the fuel consumption for firing represents the largest cost item in the production of heavy clay products and must be minimized.

7.1 Heat of Reaction

This is the main process of brick production by burning molded clay. In this process, the water of crystallization and/or the carbon dioxide from lime-containing materials is expelled and the sintering reaction happens.

Virtually no energy savings are possible in this process by simple changes in the mode of firing. Depending on the initial clay properties, the type of additives and the proportion of kiln furniture used, between 125 and 500 kJ/kg bricks are needed.

7.2 Radiant Heat from Tunnel Kilns

The waste heat of the kiln is determined by the external surface temperature of the kiln walls and roof. These losses have been measured at a number of tunnel kilns. The values are of the order of 40 to 270 kJ/kg ware. The minimum value may be obtained in the case of new tunnel kiln construction through the correct choice of insulating materials and suitable installation.

7.3 Discharge Losses from the Tunnel Kiln Cars

This loss refers to the energy loss through the heat of the kiln cars themselves leaving the chamber. It is hardly possible to influence the discharge heat losses due to heat storage in the tunnel kiln cars. With normal operation this value is typically between 40 and 125 kJ/kg ware.

7.4 Discharge Losses from Setting Bricks on the Tunnel Kiln Car

The discharge heat losses from the brick setting can be largely influenced both by the mode of operation and by the setting pattern. An open tunnel kiln car setting under normal operation displays a lower discharge heat loss (approx. 50 kJ/kg ware), than a tight setting (146 kJ/kg ware). In order to recover these discharge losses, forced cooling systems at the exit side of the kiln should be used. The heat recovered can then be utilized as supplementary heating for drying purposes. The volume of hot air recovered for drying is only partly influenced by the type of setting and depends, for instance, on the overall firing curve prevailing in the cooling zone. Where the hot air from the cooling zone is used for drying purposes, it shall be ensured that sufficient air is available in the combustion zone for the clean combustion of the fuel (coal).

7.5 Flue Gas Losses

The flue gas losses are composed of waste gas losses resulting from the minimum air volume required by the counter flow operation in the preheating zone, and the “false air” through leakage in the firing channel up to
the main collecting flue, e.g. through the sand sealing or incorrect sealing of the kiln cars against the under-car area.

Modern tunnel kilns should be operated with flue gas volumes of less than 2.0 m³/kg bricks. Higher proportions entail much greater false air losses compared with other loss sources. In the context of energy-saving operation all supplementary air volumes introduced into the firing chamber, e.g. by gasifying burners, recirculating fans or other devices should be regarded as false air.

The flue gas losses are as follows:
- with 1.3 m³/kg these amount to approx. 250 kJ/kg ware,
- with 2.5 m³/kg these amount to approx. 500 kJ/kg ware, and
- with 4.0 m³/kg these amount to approx. 750 kJ/kg ware

The reduction to a minimum of all false air inward leakage into the firing chamber of the tunnel kiln by careful sealing of the kiln cars, of the sand seals and of the kiln structure itself are important measures for energy conservation. These components require great attention and appropriate maintenance.

By including the waste heat volumes from the cooling zone of the firing channel and also the wall, ceiling and control process, approx. 840 kJ/kg ware can be made available as a net heat volume for actual firing operations (at approx. 1000°C final firing temperature and with a setting density of 600 kg/m³).

To give an orientation for realistic primary energy demands for brick production: The German brick makers industry has committed to limit the primary energy demand for brick production by 2005 to 1,645 kJ/kg fired brick. This benchmark seems to be a good value to be adapted in Bangladesh.

8 Emissions from Brick Kilns

Environmental protection covers the preservation of clean air, the prevention of water pollution, noise abatement, proper waste disposal, treatment of toxic wastes and landscape preservation. In the brick and tile industry environmental protection is almost exclusively confined to the problem of clean air. The main emissions from the tunnel kiln process are based on the emissions from the soil and are shown in figure 8.

Figure 8: Emissions from Tunnel Kiln and the temperature zones where they take place

\[ m^3 \text{ always refer to the standard state} \]
The different pollutants from the soil are emitted in different temperature zones in the kiln. In addition, there are emissions from the firing fuel, e.g. from coal matters like sulphur oxides, mercury and nitrogen oxides are emitted from the firing process, the magnitude of which depends on the composition of the coal or other fuel. So the emission from the firing process is not only the so called black smoke but also other harmful gases. Carcinogenic substances can be found in the carbonization gases, while damage to harvests caused by hydro fluorine or sulphur oxides can be observed especially in bananas and rice.

By using internal fuel, which means mixing a certain portion of the fuel into the clay itself, the process energy is given directly to the material and is released directly in the kiln. When using coal as internal fuel, it is important to use coal with less volatile substances. Otherwise these substances are emitted as harmful carbonization gas at temperatures between 150°C and 450°C where the temperatures in the kiln are too low to ignite these emitted gases. They will be emitted through the chimney. The residual carbon will only ignite at temperatures above 600°C.

Of all the pollutant substances emitted with the exhaust gases from brick and tile kilns, fluorine (F) in particular has special importance. Very slight amounts of fluorine, of the order of 0.01 to 0.1%, are present in the raw materials. During firing the fluorine is partly released as hydrogen fluoride (HF) gas and emitted with the waste gases. Calculated with an average amount of fluorine in the clay of 0.06% and based on a production capacity of about 600 tons of fired bricks, there will be emissions of hydro fluorine of about 360 kg/day in the worst case. The absolute volumes for a tunnel kiln amount roughly to 0.6 to 0.9 kg F/h. Measurements of flue gases at kilns in the brick and tile industry recorded levels of 1 to 200 mg F/m³.

The gaseous fluorine compounds, even in very small concentrations, can result in damage to sensitive plants as mentioned before.

Damage to plant life can occur as a result of long-term exposure, or of a high short-term fluorine concentration, particularly during the main growth period. Damage is particularly apparent where flue gases occur at low levels (chimney heights of 30 m and below). Hardly any damage occurs with chimney heights of 50 to 60 m. The critical threshold for animals and human beings is well over the concentrations occurring in the environment of brick and tile works.

Based on a heat consumption of 1,340 kJ/kg fired bricks and a coal consumption of 29,700 kg/d with a calorific value of 28,470 kJ/kg of coal, the emission of carbon dioxide will be about 80 tons per day. The amount of the total carbon and CO emissions depends on the firing process in the kiln and the emissions of volatiles. In addition, the coal also contains chlorine and sulphur. Based on the above mentioned coal consumption and an estimated sulphur content in the coal of only 1% and Chlorine content of about 0,15%, in the worst case, which means if all the sulphur and chlorine are emitted, there will be emissions of sulphur dioxide of about 590 kg/d and of hydrochloride of about 40 kg/d from the coal.

The above mentioned emissions depend on the contents of sulphur, chlorides, nitrogen and other matter in the fuel. The highest emissions of sulphur oxide will be by burning heavy fuel oil.

Among the typical fuels, the cleanest combustion will be achieved using natural gas. There are no fuel based emissions of sulphur oxides, for example. Nevertheless, there are emissions of nitrogen oxide based on the combustion with ambient air which contains 78% of Nitrogen. Depending on the firing temperature the amount of Nitrogen oxides will vary.

The measured emission at the chimney will vary from factory to factory based on the fuel, the quality of the combustion process, the composition of the raw material as well as the management of the kiln.

Regarding the climate-damaging carbon dioxide CO as well as the fuel based sulphur emissions the difference among the various fuels is shown in the following table.
Table 1: Carbon dioxide emissions, calorific value and sulphur content according to the fuel

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>98-100</td>
<td>28 – 32.5</td>
<td>1</td>
</tr>
<tr>
<td>Heavy fuel oil</td>
<td>78</td>
<td>40</td>
<td>3.5-4.5</td>
</tr>
<tr>
<td>Light fuel oil</td>
<td>74</td>
<td>42.6</td>
<td>0.5-1.0</td>
</tr>
<tr>
<td>Liquefied gas</td>
<td>65</td>
<td>45.5-46.3</td>
<td>93-124</td>
</tr>
<tr>
<td>Natural gas</td>
<td>56</td>
<td>32.45</td>
<td>0</td>
</tr>
</tbody>
</table>

The permissible emission limits of brick factories are typically governed by national emission law and regulation. The factories as a whole have to adhere to the limits stipulated in the laws, which means that the emission from the fuels and the emissions from the raw materials are taken into account. If necessary, appropriate filter technology must be applied to comply with the limits.

9 Guideline for Tunnel kiln Project Evaluation

9.1 Factors Influencing the Cost of Brickmaking

As the brick sales price is determined by the market mechanisms and can only be adjusted to account for cost increases slowly and with difficulty, it is essential to constantly monitor the cost development and the causes of cost fluctuations. Knowledge of cost-influencing factors is a valuable instrument for deciding on measures to lower the costs.

The production cost in heavy clay works is equivalent to the sum of all goods and services which are utilized to achieve the factory output. To obtain the specific production cost, the production cost is divided by the factory output.

Production cost also includes costs which are entered as profits in the tax balance sheet and have to be taxed, e.g. entrepreneurial remuneration, interest on invested equity capital, the difference between depreciation of capital goods and their actual value as well as contingencies. Costs that must be taken into account include:

- Initial investment cost/depreciation (= annualized investment cost)
  - Buildings
  - Real estate
  - Machinery, including kiln, dryer, processing equipment, hauling equipment, power supply, including all equipment installation
- Financing cost (weighted average cost of capital)
- Repairs and maintenance costs: On average 10% of CAPEX incl. workshop wages and costs for spare parts
- Personnel costs
  - Wages, salaries
  - Social insurance
- Power/energy supply costs for:
  - Preparation
  - Shaping
  - De-hacker
  - Automatic handling
  - Setting machines
  - Fans
  - etc.
- Fuel costs (kiln)
- Fuel oil costs
  - Quarry equipment
  - Transportation
- Clay costs
  - Royalties
  - Concession fees
  - etc.
− Packaging cost
− Possibly: body additives
− Possibly: costs for any special environmental protection measures

In order to calculate the primary costs, company administration and marketing costs have to be taken into account in addition to the production cost. These cost components mainly include:
− Personnel expenses
− Entrepreneurial remuneration
− Annualized CAPEX, financing costs and operating costs of office buildings, office machines and vehicles
− Communication costs
− Costs for product marketing and sales
− Interest costs for financing average stocks during the year,
− Costs arising from taxes
− Insurance

9.2 Guideline for Economic Analysis of Tunnel Kiln Projects

The brick production costs are very site specific and depend greatly on the entrepreneurial talent of the factory manager and the cost of energy and raw materials. The main cost items driving the brick production cost are, in order of relevance:

1. Fuel costs
2. Cost of manufacturing equipment
3. Labor cost
4. Clay cost

Due to the great variability of the cost items it is very difficult to give reliable cost ranges for clay bricks in Bangladesh. The costs need to be analyzed on a case-by-case basis.

To provide guidance for staff of financing institutions for the economic evaluation of a brick tunnel kiln project, the following criteria are highlighted:

• For assessment of the project economics, the entire business plan needs to be analyzed and verified. The business plan must include detailed descriptions of the process and materials to be used, equipment to be installed, expected equipment performance, and investment and operating cost of the plant. During the assessment, all items in the production process need to be scrutinized for plausibility and realistic cost assessment.

• Particularly the description of the technologies to be used will be critical and the benchmarks provided by the manufacturer relating to specific energy consumption and the plant’s production performance will be key information.

• All cost items in the business plan will need to be confirmed against typical benchmarks for the cost level on the local market. This includes particularly energy cost depending on the fuel type, personnel cost, and cost of raw materials.

• For all equipment to be procured, at least three different quotations should be obtained and analyzed for comparability to gauge the price level on the local market. When analyzing the quotations, expected quality level of the equipment needs to be taken into consideration, and respective provisions for maintenance and repair cost and the overall equipment lifetime must be considered in the economic analysis relative to the selected quality level. Technical expertise and experience is indispensable for this step. However, since over the lifetime of a project the operating cost (foremost the energy cost) typically outweigh the equipment CAPEX by far, minor and even moderate errors in assessing the CAPEX can be forgiven.

• It is very important that the equipment supplier is contractually tied to the actual performance of his equipment by means of performance benchmarks (such as primary energy need per kg brick output) to be stipulated in the contract. Respective penalties upon non-achieving must be defined to compensate for revenue losses as a result from underperformance, up to the point of contract annulation in case of extreme underperformance. Respective performance guarantees must be foreseen in the contract to
empower the respective contract clauses. Performance tests should be foreseen upon handing over of the equipment and upon expiration of the warranty period.

- To evaluate the project from a financial point of view, the business plan should include a financial analysis in addition to the economic analysis. From the financial analysis, the projected brick production cost will be obtained, which then can be compared to brick prices on the target market (local, regional or foreign) to gauge the project’s competitiveness.

### 9.3 Guideline for Technical Evaluation of Tunnel Kiln Projects

In this report, a general overview is provided on the drying and firing process, emissions from the process and the influences on the brickmaking costs. The following table summarizes the main aspects of technical evaluation of tunnel kiln projects.

**Table 2: Summary of key points**

<table>
<thead>
<tr>
<th>Observations</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary technology types</strong></td>
<td>- Both tunnel dryers and chamber dryers are offered in the local market&lt;br&gt;- Chamber dryers are preferred to produce different products with very different weights and dimensions, like solid bricks or hollow blocks&lt;br&gt;- Tunnel dryers allow for higher output if the same product is produced&lt;br&gt;- Open air dryers are weather dependent and drying takes a long time especially during the monsoon season</td>
</tr>
<tr>
<td><strong>Project design</strong></td>
<td>- Laboratory tests of available raw materials are absolutely necessary to design the brick factory&lt;br&gt;- Based on the characteristics of the clay or the mixture, the type of machines in the preparation line can be selected.&lt;br&gt;- Drying behaviour must be known to design the drying conditions (climate) in the dryer&lt;br&gt;- The kiln design must be based on the clay characteristics and, of course, the final properties depend on the clay and its mixture&lt;br&gt;- The analysis of the added coal must be known. Not only the calorific value is important, but also the composition of the coal (e.g. volatiles, carbon content, residual ashes)</td>
</tr>
<tr>
<td><strong>Clay preparation and storage</strong></td>
<td>- The process of clay preparation and storage needs to be described clearly and the different machines to be used need to be listed.&lt;br&gt;- A disintegrator for crushing hard particles as a first step of preparation is suggested&lt;br&gt;- The use of a magnetic iron remover in the preparation line is necessary in the preparation process to protect the rollers of the mills from damage.&lt;br&gt;- If the soil is taken from the surface where agricultural area was before, it might also be helpful to use a clay purifier for purifying clay of roots, plastic and plasticized consistency.</td>
</tr>
</tbody>
</table>
### Observations

<table>
<thead>
<tr>
<th><strong>Green brick production</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Vacuum extruders must be used to get better Green Brick quality</td>
</tr>
<tr>
<td>- The die to form the Green Bricks should have the typical size to form bricks according to the Bangladesh Standard</td>
</tr>
<tr>
<td>- Green Brick handling options (direct set, drier cars/racks) depend on the clay features, moisture, clay storage and clay processing options as well as on the level of automation.</td>
</tr>
<tr>
<td>- Only after knowing the raw materials the best method for shaping (stiff, semi-stiff or plastic) can be determined. If only plastic shaping with an amount of mixing water of nearly 20% is needed, direct setting is not possible because of the risk of damaging the Green Bricks by deformation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Drying</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Due to high ambient humidity and high moisture level of clay in Bangladesh, drying should be done in one tunnel in three steps to prevent brick cracking: 1) high moisture low temperature (30-40 hours natural drying); 2) middle moisture middle temperature (10-12 hours open drying with minimum heat); 3) low moisture high temperature (final drying in a tunnel dryer)</td>
</tr>
<tr>
<td>- If different bricks with different mass, size or design are to be produced, chamber dryers are to be preferred</td>
</tr>
<tr>
<td>- To ensure good quality, the drying process should be automatic controlled.</td>
</tr>
<tr>
<td>- Drying with ambient air is energy efficient, but needs a lot of time especially because of the high humidity in Bangladesh during the Monsoon season</td>
</tr>
<tr>
<td>- Because of the presumed high moisture content of the Green Bricks in Bangladesh, the direct setting process involves the great risk of damage to the Green Bricks due to deformation.</td>
</tr>
<tr>
<td>- Estimations on drying time will not be reliable without knowing the raw material composition and their properties, i.e. only after the results of the material tests are available and drying tests have been carried out.</td>
</tr>
<tr>
<td>- The energy from the hot air from the cooling zone of the kiln should be used as hot air for drying as well as combustion air for the firing of fuel.</td>
</tr>
<tr>
<td>- No exhaust gas from the chimney should be used in the drying process because this will damage the dryer racks or fans by corrosion.</td>
</tr>
<tr>
<td>- In case an extra combustion chamber is used in addition to the hot air from the kiln, it is recommended not to add the flue gas from the combustion chambers to the hot air for drying since the same problems of corrosion will occur because of firing coal.</td>
</tr>
<tr>
<td>Observations</td>
</tr>
<tr>
<td>--------------</td>
</tr>
</tbody>
</table>
| Firing       | – Mechanized fuel (coal) feeding such as coal blowing, burner/pumped pulverized is preferred over manual feeding to achieve optimum firing result.  
– Coal gasification is another good solution. This technique, however, requires a much higher level of process safety than solid fuel feeding and introduces an additional process in the factory that requires well trained workers.  
– In case of internal fuel use, the amount of internal fuel depends of the calorific value and the analysis of the coal. This requires laboratory tests before designing the final process. To add a higher amount of coal as internal fuel is only possible if the coal is of poor quality and has a low calorific value, less volatiles and a high amount of residual ashes. |
| Plant performance issues | – Drying time is a very important issue in daily operation. The time for drying as well as for firing will depend on the analysis of the clay in the laboratory test. This time may be totally different for solid or perforated bricks and depends greatly on the size of the bricks. This time may be totally different for solid or perforated bricks and depends greatly on the size of the bricks.  
– Furthermore, the drying time can differ between direct setting and drying on a rack because the setting on the rack is much more open than the direct setting on the kiln car so the heat- and mass-transfer can be higher.  
– Firing cycle means the time from cold to cold, which means from kiln entrance to exit. For firing solid bricks or typical Bangladesh bricks, 40 to 60 hours seemed to be realistic.  
– The moisture content of dried bricks should be lower than 2% before entering the kiln, otherwise the risk of brick damage in the first part of the tunnel kiln will be very high.  
– The air/brick ratio in dryers depends on the type of dryer and is different for direct setting and drying in a separate tunnel on drying racks. A realistic air/brick ratio taken from the kiln in the preheating zone at the kiln should be about 2.  
– The final energy consumption depends on the handling of the process. Typical final energy consumption range in Bangladesh could be between 220 kcal/kg (optimistic assumption) to 400 kcal/kg (realistic assumption)  
– Expected stack emissions of the kiln can be calculated from the analysis of the fuel and clay. Depending on the analysis of the clay, it may be that the main emissions come from the clay. Stack emissions level must comply with the local emission standards.  
– In particular, emissions of hydrogen fluoride, hydrogen chloride, oxides of sulphur and nitrogen oxides and particles should be taken into account.  
– Carbon monoxide should also be monitored as an indicator of the quality of coal combustion and the emission of the internal fuel.  
– All relevant emissions should be monitored from time to time by state-authorised institutes. If the emissions values are over the limits, lime bed filters are necessary against hydro fluorine and sulphur oxides. |
Disintegrator for crushing hard particles is necessary if pebbles or small stones are in the clay or if dried bricks are recycled. A magnetic iron remover might be also useful in the preparation process to obtain good quality clay. Clay purifier machine remove impurities such as stones, silica, pyrite, pebbles, wood, roofs, metal and plastic parts without interruption of the cleaning process.

"Vacuum" extruder is essential to get good quality green bricks.

Avoid direct setting option which is not suitable for Bangladesh. Use dryer racks or cars.

To ensure good quality, the drying process should be automatic controlled.

The heating for the drying process is done with hot air from the kiln or using extra combustion chambers. No flame gas from the combustion chambers. No exhaust gas but only the hot air in the cooling zone of the kiln be used in the dryer. Exhaust gas could damage the dryer racks or fans by corrosion.

Firing cycle shall consider the time from cold to cold. Back-up power is essential because in the case of power failures the counter current flow of the tunnel kiln will stop, the sucking of flame gas stops and there is a risk of overheating in the firing zone especially if internal fuel is used.

**Figure 9: Key performance aspects of Tunnel kiln projects**
9.4 Key Performance Criteria

The following tables 3 and 4 present key performance criteria of tunnel kiln technology, taken from one of the most advanced European brick market, in particular Germany, which can serve as benchmark for the brick-making sector in Bangladesh.

Table 3: Performance criteria for brick-making with tunnel kilns

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Average of German brick factories</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Total energy consumption of brick making</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1 Energy consumption of the dryer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Natural ventilation</td>
<td>0 kJ/kg ware</td>
<td></td>
</tr>
<tr>
<td>- Chamber dryer</td>
<td>1.100 kJ/kg H₂O</td>
<td></td>
</tr>
<tr>
<td>- Tunnel dryer</td>
<td>1.000 kJ/kg H₂O</td>
<td></td>
</tr>
<tr>
<td>1.2 Energy consumption of the ware firing in tunnel brick kilns</td>
<td></td>
<td>Including drying</td>
</tr>
<tr>
<td>- hollow blocks</td>
<td>1.300 kJ/kg</td>
<td></td>
</tr>
<tr>
<td>- solid bricks and pavers</td>
<td>1.900 kJ/kg</td>
<td>Including drying</td>
</tr>
<tr>
<td>- roofing tiles</td>
<td>1.500 kJ/kg</td>
<td>Including drying</td>
</tr>
<tr>
<td>2. Daily brick production (average output at round-the-clock operation of the kiln)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Masonry bricks (hollow blocks)</td>
<td>600 t/day (97% A-grade quality)</td>
<td></td>
</tr>
<tr>
<td>- Facing bricks and pavers (solid bricks)</td>
<td>50 – 150 t/day (95% A-grade quality)</td>
<td></td>
</tr>
<tr>
<td>- Roof tiles</td>
<td>70 – 130 t/day (93% A-grade quality)</td>
<td></td>
</tr>
</tbody>
</table>

Source: IZF

The values for the energy consumption of a tunnel kiln is most frequently given including the energy used for drying, because hot air from cooling the bricks is fed to the dryer. The distribution of the energy consumption of a modern brick factory producing solid bricks or pavers can be seen in the following figure.
Compared to these factories, the energy distribution in factories producing hollow blocks is different, which is shown in the next figure.

![Average energy distribution in a brick factory producing hollow blocks](image)

**Figure 11: Average energy distribution of German brick factories producing hollow blocks**

**Table 4: Benchmarks and limits for emissions in the German brick-making industry**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Average of German brick factories</th>
<th>Limit according to German law “TA-Luft”</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ emissions from fuel</td>
<td>&lt; 150 g/kg brick</td>
<td>-</td>
<td>CO emissions are depending on the combustion of fuel. By using internal fuel, coal has to have a low content of volatiles because these will not ignite in the kiln in the temperature zone where the emissions of volatiles from the coal will take place</td>
</tr>
<tr>
<td>CO emissions</td>
<td>&lt; 190 mg/kg brick</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>SO₂ emissions</td>
<td>&lt; 40 mg/kg brick</td>
<td>500 mg/m³ flue gas</td>
<td>This actual value is based on combustion with natural gas and limestone filters. High content of sulphur in the fuel or soil will result in higher values</td>
</tr>
<tr>
<td>NO₂ emissions</td>
<td>&lt; 180 mg/kg brick</td>
<td>350 mg/m³ flue gas</td>
<td>This value is based on combustion with natural gas</td>
</tr>
<tr>
<td>HF emissions</td>
<td>&lt; 4 mg/kg brick</td>
<td>5 mg/m³ flue gas</td>
<td>HF emissions are based on the composition of the clay. The limit is only achievable with limestone filters</td>
</tr>
<tr>
<td>Particles/dust</td>
<td>&lt; 18 mg/kg brick</td>
<td>20 mg/m³ flue gas</td>
<td>Based on combustion with natural gas. Value will be much higher by firing coal</td>
</tr>
</tbody>
</table>

Source: IZF
### 9.5 Recommended Qualification Criteria for Kiln Suppliers/Manufacturers

The following aspects are recommended as qualification criteria while selecting suppliers or manufacturers of tunnel kilns:

#### Table 5: Qualification criteria for brick kiln suppliers/manufacturers

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Minimum Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior experience for setting up tunnel kiln projects</td>
<td>3 projects recommended as minimum, including for production capacity &gt; 600 t/d</td>
</tr>
<tr>
<td>Consideration of the conditions in Bangladesh</td>
<td>Proof to have analysed and considered the soil and fuel properties, different brick sizes (solid or hollow), different climate conditions (dry and Monsoon season), etc.</td>
</tr>
<tr>
<td>Laboratory analysis of soil, fuel etc.</td>
<td>- Chemical analysis</td>
</tr>
<tr>
<td>- Mineral analysis</td>
<td>- Grain size distribution</td>
</tr>
<tr>
<td>Laboratory test for an optimal clay mixture as basis for the design of the whole process (e.g. drying and firing curve)</td>
<td>- Plasticity value</td>
</tr>
<tr>
<td>- Initial water load</td>
<td>[mm]</td>
</tr>
<tr>
<td>- Forming pressure</td>
<td>[kPa]</td>
</tr>
<tr>
<td>- Linear drying shrinkage</td>
<td>[%]</td>
</tr>
<tr>
<td>- Bending tensile strength, dry</td>
<td>[MPa]</td>
</tr>
<tr>
<td>- Max. firing temperature</td>
<td>[°C]</td>
</tr>
<tr>
<td>- Holding time at max. temp.</td>
<td>[h]</td>
</tr>
<tr>
<td>- Loss in weight (firing)</td>
<td>[%]</td>
</tr>
<tr>
<td>- Linear firing shrinkage</td>
<td>[%]</td>
</tr>
<tr>
<td>- Linear total shrinkage</td>
<td>[%]</td>
</tr>
<tr>
<td>- Water adsorption</td>
<td>[M.-%]</td>
</tr>
<tr>
<td>- Body density</td>
<td>[kg/m³]</td>
</tr>
<tr>
<td>- Bending tensile strength, fired</td>
<td>[MPa]</td>
</tr>
<tr>
<td>- Compressive strength</td>
<td>[MPa]</td>
</tr>
<tr>
<td>- Drying sensitivity</td>
<td></td>
</tr>
<tr>
<td>- Optimum drying and Firing curves</td>
<td></td>
</tr>
<tr>
<td>- Thermal conductivity</td>
<td>[W/(m·K)]</td>
</tr>
<tr>
<td>Local office in Bangladesh, so that sponsors can easily reach them</td>
<td>Local office is available.</td>
</tr>
<tr>
<td>After sales service for a certain period of time</td>
<td>- one or two years available for training</td>
</tr>
<tr>
<td>- supply of spare parts must be safe for many years</td>
<td></td>
</tr>
<tr>
<td>Supplier will have to fulfil the criteria for guaranteed output of class bricks, coal consumption/ energy consumption per 100,00 bricks (which can be set by the suppliers themselves in their offer)</td>
<td>Supplier offers guaranteed performance indices for</td>
</tr>
<tr>
<td>- output</td>
<td></td>
</tr>
<tr>
<td>- coal consumption</td>
<td></td>
</tr>
<tr>
<td>- energy consumption</td>
<td></td>
</tr>
</tbody>
</table>

There should be a provision for penalty for nonfulfillment of (i) timely completion of the project and (ii) guaranteed output of A-Grade quality & (iii) coal consumption in total (internal and external).
10 Literature

