GKSPL

# Introduction to Brick Kilns & Specific Energy Consumption Protocol for Brick Kilns

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# Contents

# 1 Brick Firing Process in the Kilns

## 1.1 Steps in brick making

The typical steps involved in brick making process are – clay preparation, moulding, drying of green bricks and then firing. Figure 1 below represents the process flow in the brick making.

Figure 1: Brick making process

## 1.2 Firing process in the kilns

Firing is the last operation in brick making process. Green bricks are fired in the kilns to convert a fairly loosely compacted blend of different minerals into a strong, hard, and stable product i.e. fired brick. The firing process determines the properties of the fired brick — strength, porosity, stability against moisture, hardness etc. Depending on nature of clay and quality of fired brick requirement, bricks are fired in a temperature range of 800–1100$^{o}$C.

The overall firing process can be categorized in three steps – heating, soaking and cooling.

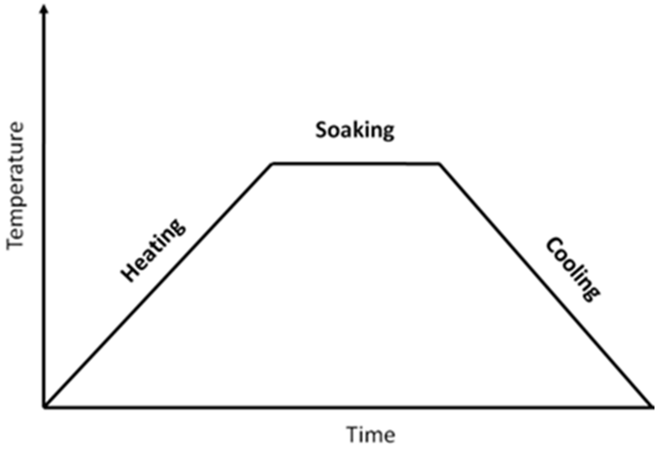

Figure 2: Steps in brick firing process

The important physical and chemical changes occurring in the brick during firing are briefly explained in the subsequent sections. It is important to understand these changes as they form the basis for proper operation of a brick kiln.

### 1.2.1 Heating:

Heating of clay leads to removal of moisture and carbonaceous material, chemical changes and colour change in the final product. A detailed description of the various processes during clay heating process is explained below.The chemical and physical changes occurring at different temperatures during the clay heating process are represented in Figure 3 and are explained below.

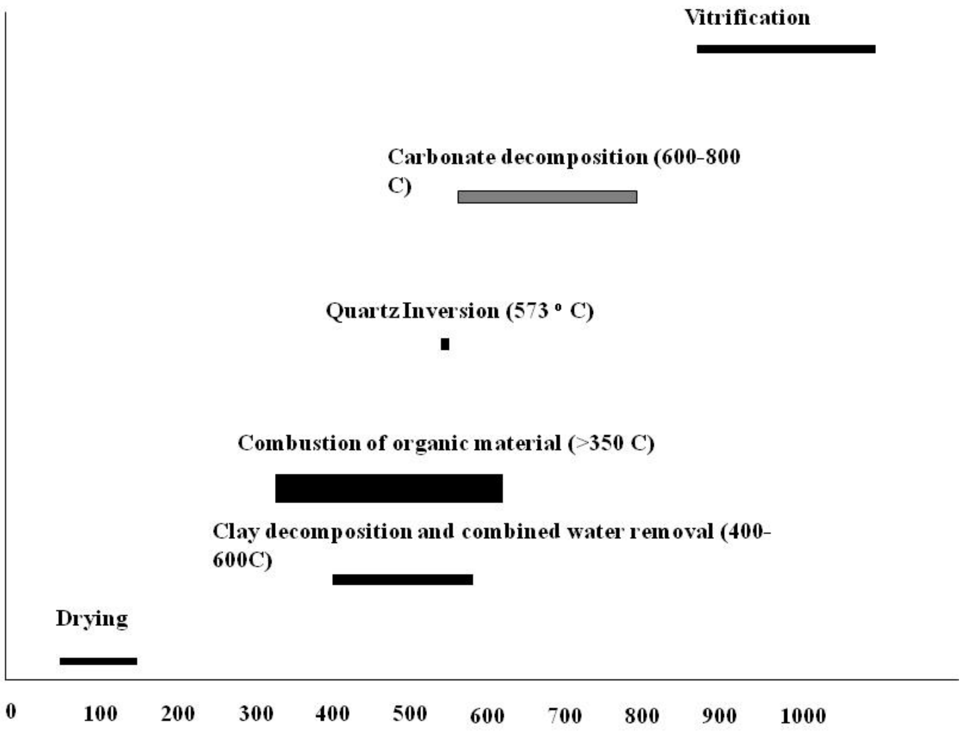

Figure 3: Changes occurring in brick during heating of green bricks

1. Removal of mechanical moisture: About 25-30% of water is added to clay during the hand-moulding or extrusion process. While most of the moisture is removed during drying, generally 3-10% moisture still remains with bricks while loaded in the kiln due to different climatic conditions. The first stage of heating involves removal of this moisture (drying). Almost all the mechanically held water is evaporated when temperature of the bricks reaches around 150 $^0$C. However, the clay still retains its original characteristics.

2. Combustion of carbonaceous materials: The clay contains carbonaceous organic matter (plant material such as roots, leaves etc.). The amount of organic matter present in clay varies from place to place. At some places, agricultural residues (wheat straw and rice husk etc.) are added to clay as internal fuel. As green bricks are heated up in the kiln and oxygen (in combustion air) diffuses inside bricks, combustion of the organic matter is initiated at about 400$^o$C. The process is completed when the temperature reaches 700$^o$C.

3. Decomposition of clay molecules and release of combined water (Dehydroxylation): Clay material consists of several chemical compounds which have water molecules or hydroxyl groups chemically combined with them. Kaoline is one such compound which is the major component in clay (the chemical formula of Kaoline is $Al_2O_3.2SiO_2.2H_2O$). When clay is heated, it starts decomposing resulting in release of combined water.

4. Quartz inversion: Silica, a common constituent of brick making soils, has its crystal structure in the form of $\alpha$–quartz (alpha–quartz) in nature. At 573$^o$C, its crystal structure changes into from $\beta$–quartz (Beta quartz) and this transformation is accompanied by an expansion of volume by around 2%. During cooling, $\beta$–$\alpha$ change occurs again at

temperature 573 $^0$C. The heating and cooling rates near quartz inversion temperature have to be controlled to obtain near-uniform temperature throughout the brick and thus avoiding excessive stresses which can lead to crack formation in bricks.

5. Carbonate and sulphide decomposition: Carbonates and sulphides present in the clay decompose at 600 – 800 $^0$C releasing $CO_2$ and $SO_2$.
6. Vitrification: Vitrification entails partial melting of clay particles at points of contact, to form a glassy bond, which binds the whole mass together and give strength (Figure 4). The extent to which a mass of clay is melted during firing depends on (i) temperature of the clay mass, and (ii) duration of the heat treatment.

   Vitrification of clay approximately commences at around 900 $^0$C. However, the vitrification temperature depends upon the type of minerals constituting clay, their proportion and particularly on how much fluxing oxides they introduce — ferrous oxide, lime, magnesia and potash. Fluxing oxides are those which bring down the temperature of vitrification. This explains for the wide variations observed in firing temperature, which ranged between 800 – 1100 $^0$C at different locations.

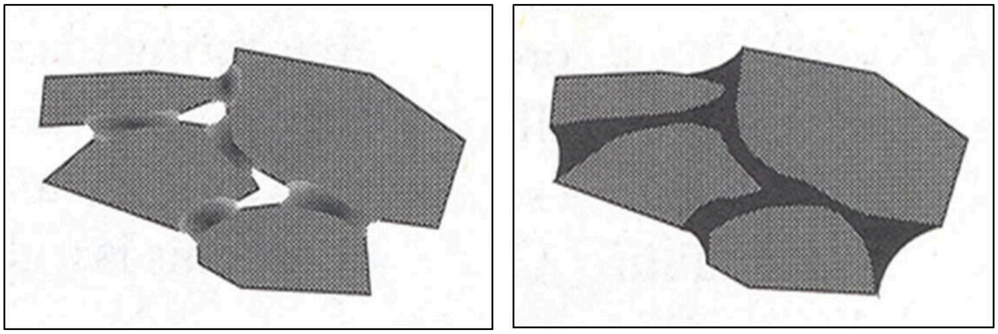

Figure 4: Vitrification of clay

As temperature increases, more melting of clay mass occurs. In practice, the heating must be restricted lest so much liquid forms that the whole brick starts to become distorted under the weight of the higher layers of bricks. In extreme cases, the bricks may get fused together in the kiln.

### 1.2.2 Soaking:

The bricks are maintained at the finishing temperature for few hours in order to attain uniform vitrification throughout the brick. This process is known as soaking.

### 1.2.3 Cooling:

During cooling the liquid solidifies to glass, bonding the whole mass together. The cooling rate should be slow to avoid excessive thermal stresses in the bricks, particularly once the quartz inversion temperature (573 $^0$C) is reached, since shrinkage occurs at this point.

## 1.3 Quality of fired bricks

The quality of the fired bricks is a function of several parameters. The important amongst them are:

- Quality and characteristics of the green bricks
- Characteristics of the firing process, e.g., the heating and cooling rate, the maximum temperature reached and the duration of the soaking period.

Many countries have notified standards in order to define the quality of clay fired bricks. Usually the standards classify bricks on the basis of three properties — compressive strength, water absorption and efflorescence.

In the same kiln or the same batch of fired bricks, the quality of fired bricks may vary due to differences in the temperature profiles and the duration of the soaking period. A good brick firing kiln should have as uniform temperature as possible throughout its cross-section so that the quality of fired bricks are uniform and the percentage of good quality bricks are high.

# 2 Introduction to Brick Kilns

A large variety of kilns are used for firing bricks. These can be classified in several ways, e.g. on the basis of the production process (intermittent and continuous kilns); direction of air flow (up-draught, down-draught and cross-draught kilns); or on the basis of the method of production of draught (natural draught and induced/forced draught kilns).

## 2.1 Classification based on nature of production process

Depending upon the nature of production process, brick kilns can be classified as intermittent kilns and continuous kilns. The classification is represented in Figure 5 below:

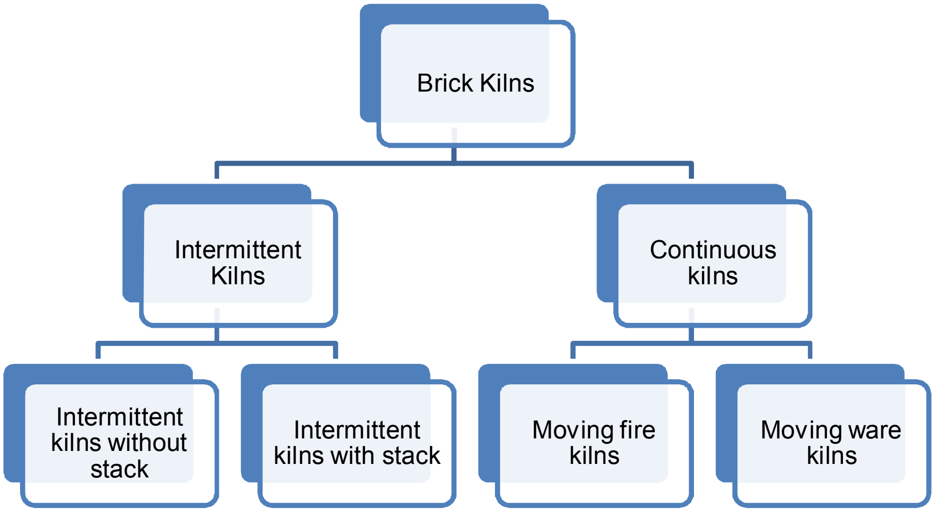

Figure 5: Classification of brick kilns based on production process

### 2.1.1 Intermittent kilns

In intermittent kilns, bricks are fired in batches; fire is allowed to die out and the bricks are allowed to cool after they have been fired. The kiln must be emptied, refilled and a new fire has to be started for each load/batch of bricks. In intermittent kilns, most of the heat contained in the hot flue gases, fired bricks and the kiln structure is thus lost. Intermittent kilns are still widely used in several countries of Asia, Africa and South and Latin America. Intermittent kilns can be further sub-divided into two categories:–

**Intermittent kilns without stack:** The kilns which do not have any stack/chimney to guide the flue gases. In these kilns the flue gases can be seen coming out of the kiln from the sides or from all over the top surface of the kiln. Clamps, scove and scotch kilns are the examples of intermittent kilns without stack.

Figure 6: Clamp (India)

Figure 7: Scotch kiln (India)

**Intermittent kilns with stack:** As the name suggest, these kilns have a stack/chimney to create draught for releasing the flue gases at a higher point in the atmosphere. Down-draught kiln and climbing kilns are the example of intermittent kilns with stack.

Figure 8: Climbing kiln (Rwanda)

Figure 9: Down draught kiln (India)

### 2.1.2 Continuous kilns

In a continuous kiln fire is always burning and bricks are being warmed, fired and cooled simultaneously in different parts of the kiln. Fired bricks are continuously removed and replaced by green bricks in another part of the kiln which is then heated. Consequently, the rate of output is approximately constant. Heat in the flue gas is utilised for heating and drying of green bricks and the heat in the fired bricks is used for preheating air for combustion. Due to incorporation of heat recovery features, continuous kilns are more energy efficient. Continuous kilns can be further sub-divided into two categories: moving fire kilns and moving ware kilns.

**Moving fire kilns:** In a moving-fire kiln, the fire progressively moves round a closed kiln circuit while the bricks remain stationary (Figure 10). The kiln circuit can have oval, rectangular or circular shapes. Figure 11 represents a part of the moving fire kiln showing the typical air flow path through the bricks stacked in the kiln. The fire travel takes place in the direction of airflow. Ambient air enters from the left and cools down the fired bricks in the kiln. After combustion, the hot flue gases pass through the green bricks stacked ahead of the combustion zone resulting in preheating of the green bricks (and cooling of flue gases). A chimney stack and/or a fan provide the necessary draught for airflow. Hoffman kilns, Fixed Chimney Bull's Trench kilns and zigzag kilns are the examples of moving fire kiln.

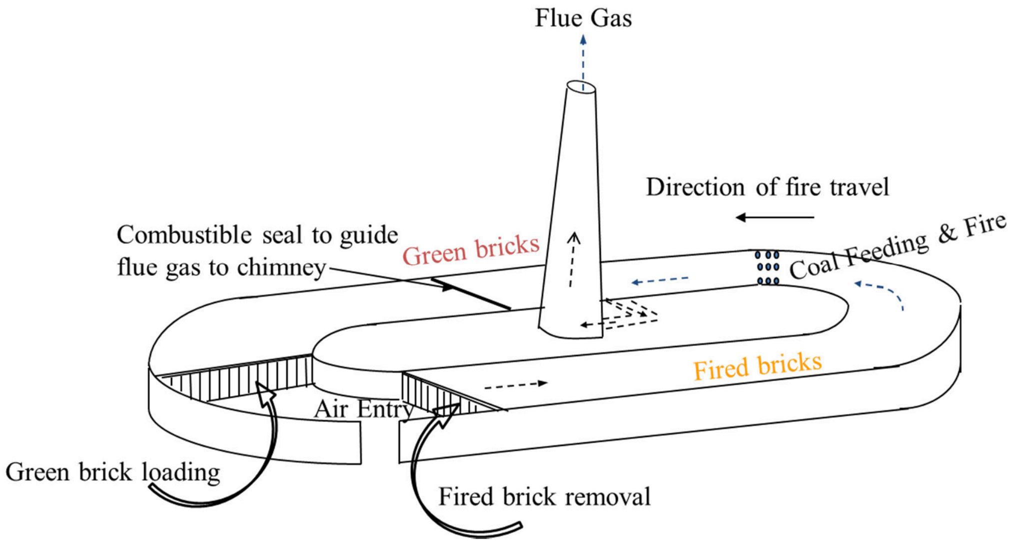

Figure 10: Moving fire kiln circuit

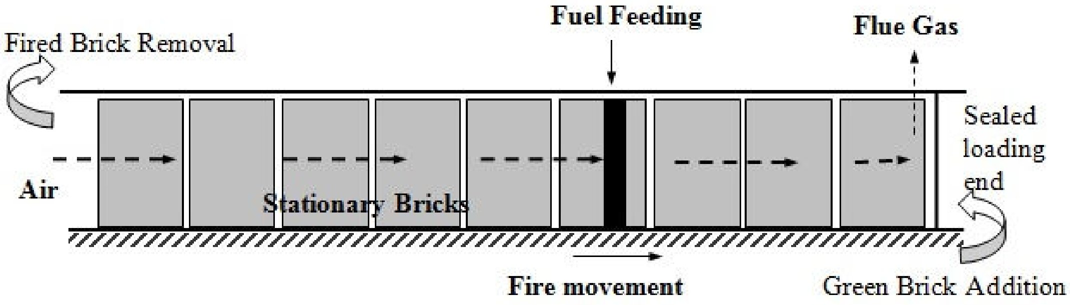

Figure 11: A part of moving fire kiln circuit showing fire travel

**Moving ware kilns:** In a moving ware kiln, fire remains stationary, while the bricks and air move in counter-current paths. In tunnel kiln, which is a horizontal moving ware kiln, goods to be fired are passed on cars through a long horizontal tunnel (see Figure 12). The firing zone is located at the central part of its length. Cold air is drawn from the car exit end of the kiln and it cools the fired bricks. The combustion gases travel towards the car entrance losing a part of their heat to the entering green bricks. The cars can be pushed either continuously or intermittently at fixed time intervals.

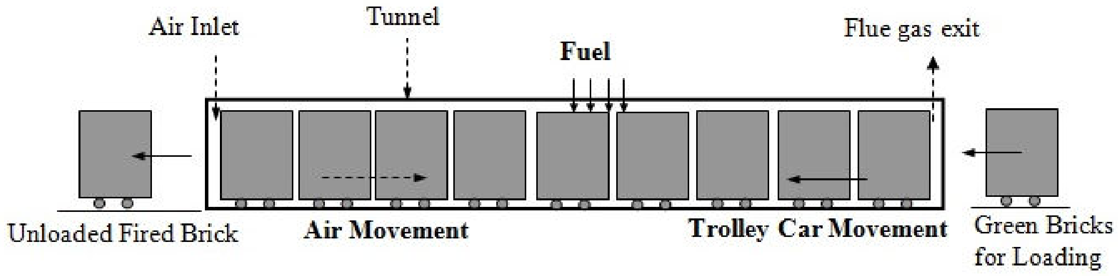

Figure 12: Tunnel kiln (moving ware kiln)

Vertical shaft brick kiln is another example of moving ware kiln. In this kiln the movement of bricks is in vertical downward direction and upward air movement is brought about by natural convection (see Figure 13).

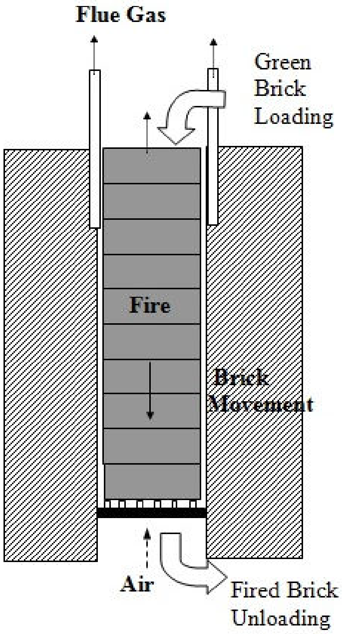

Figure 13: Vertical shaft brick kiln (moving ware kiln)

## 2.2 Classification based on air flow

Based on the direction of air flow with respect to the brick setting in the kiln, brick kilns can be classified as up draught kilns, down draught kilns and cross draught kilns. The classification is represented in the figure below:

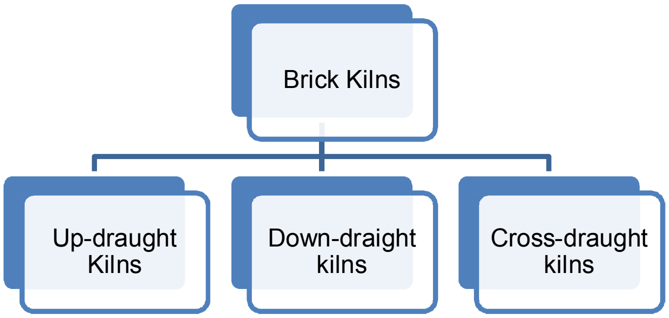

Figure 14: Classification of brick kilns based on air flow

**Up-draught kilns:** In an up-draught kiln, air enters the kiln from below, gets heated from the fire and moves upward through the brick setting transferring the heat to the bricks. The upward movement of heated air is a natural phenomenon and it does not require a stack or fan to cause the air flow. Clamps and vertical shaft brick kiln (VSBK) are examples of up-draught kilns.

**Down-draught kilns:** In a down-draught kiln, air is first heated up with the fire. The hot air is then made to enter the kiln from top and is brought down through the brick setting with the help of draught created by a stack. In this type of kilns, usually bricks are not in the direct contact with fire. Down-draught kiln, as the name suggest, is an example of this category of kilns.

**Cross-draught kilns:** In cross-draught kiln, air flows horizontally through the brick stacking. The air movement is caused by either the draught created by the chimney (natural draught) or the draught provided by a fan (forced draught). These are also called horizontal draught kilns. Hoffman kilns, fixed chimney Bull’s trench kiln and tunnel kilns are example of cross-draught kilns.

# 3 Fuels

In brick kilns, generally solid fuels are used e.g. coal; wood; sawdust; agricultural residue like mustard stalk, rice husk, coffee husk; industrial waste and bye-products like used rubber tyres, pet-coke, etc. Apart from solid fuels, bricks are also fired from natural gas, diesel, bio-gas, producer gas, etc.

## 3.1 Relevant fuel properties

The characteristics of fuel that should to be considered for assessing the suitability of a fuel for combustion process are:

1. **<u>Calorific value</u>**

   The calorific value is the measurement of heat or energy contained in the fuel. It is the amount of heat/energy which is released or available for use after complete combustion of a unit amount of fuel. Higher the calorific value, higher is its heat content. It is measured either as Gross Calorific Value (GCV) or Net Calorific Value (NCV). The difference being the latent heat of condensation of the water vapour produced during the combustion process. Gross Calorific Value assumes that all the vapour produced during the combustion process is fully condensed at the end of combustion and takes into account the latent heat of condensation. Net Calorific Value assumes that the water vapour leaves with the combustion products without being condensed.

2. **<u>Volatile matter:</u>**

   Volatile matters are the methane, hydrocarbons, hydrogen and carbon monoxide, and incombustible gases like carbon dioxide and nitrogen found in fuel. Thus the volatile matter is an index of the gaseous fuels present. Volatile matter content proportionally increases flame length and helps in easier ignition of fuel.

3. **<u>Fixed carbon:</u>**

   Fixed carbon is the solid fuel left after the moisture and volatile matter are driven off. It consists mostly of carbon but also contains some hydrogen, oxygen, nitrogen and sulphur which are not driven off with the gases. The amount of fixed carbon and volatile combustible matter directly contribute to the heating value of fuel. While volatile matter helps in initiation of the burning, fixed carbon acts as the main heat generator during the burning.

4. **<u>Ash content</u>**

   Ash is an impurity that will not burn. Lower the ash content better is the fuel. Higher Ash content reduces the burning capacity and also increases the handling costs. Ash can also cause clinkering and slagging.

5. **<u>Sulphur Content:</u>**

Sulphur content affects clinkering and slagging tendencies. It corrodes metal chimney and other equipment such as induced draught fans etc. and limits the exit flue gas temperature. $SO_2$ produced due to the combustion of sulphur affects nearby vegetation.

Following table shows properties of some important fuels.

| Parameter | Bituminous coal | Saw dust | Coffee husk | Wood chips |
|---|---|---|---|---|
| Volatile matter % | 20-35 | 65-70 | 75-77 | 55-60 |
| Fixed carbon % | 40-45 | 15-20 | ~3 | 15-20 |
| Calorific value kcal/kg | 4,000-7,000 | 3,500-4,500 | 4,300-4,500 | 3,500-4,500 |
| Ash content % | 10-35 | 5-7 | 5-7 | 2-5 |
| Sulphur % | 0.5-3 | 0-0.5 | 0-0.2 | 0 |

## Ignition Point

For fuel to burn, it requires to be heated to a minimum temperature, which is known as ignition temperature of the fuel. Therefore, it is important to know the ignition temperature of the commonly used fuels.

| Fuel | Ignition Temperature $^0$C |
|---|---|
| Coal | 450 – 750 |
| Wood, sawdust | 350 – 450 |

## Proximate and Ultimate analysis:

Proximate and Ultimate analysis are the common standard tests for determining physical and chemical properties of solid fuels. Proximate analysis indicates the percentage by weight of the Fixed Carbon, Volatiles, Ash and Moisture content in the fuel. A typical proximate analysis of various fuels on wet basis is provided in the table below:

| Parameter (%) | Bituminous coal | Saw dust | Coffee husk | Fire wood (Eucalyptus) |
|---|---|---|---|---|
| Moisture | 5.98 | 7.3 | 14.24 | 9.87 |
| Ash | 38.63 | 4.68 | 6.02 | 2.75 |
| Volatile matter | 20.70 | 68.42 | 76.82 | 69.2 |
| Fixed carbon | 34.69 | 19.59 | 2.92 | 18.18 |

The Ultimate analysis determines the mass percentage of the various elemental chemical constituents such as carbon, hydrogen, oxygen, nitrogen, sulphur, etc. as well as moisture and ash present in the fuel. It is useful in determining the quantity of air required for combustion and the volume and composition of combustion gases. Typical ultimate analysis of various fuels on wet basis is given in the table below:

| **Parameter (%)** | **Indian coal** | **Saw dust** | **Coffee husk** | **Fire wood (Eucalyptus)** |
|---|---|---|---|---|
| Moisture | 5.98 | 7.3 | 14.24 | 9.87 |
| Ash content | 38.63 | 4.36 | 6.02 | 2.48 |
| Carbon | 41.11 | 42.27 | 40.30 | 42.71 |
| Hydrogen | 2.76 | 5.75 | 4.60 | 5.78 |
| Nitrogen | 1.22 | 0.37 | 1.27 | 0.71 |
| Sulphur | 0.41 | 0.46 | 0.15 | 0.14 |
| Oxygen | 9.89 | 39.58 | 33.42 | 38.31 |

# 4 Specific Energy Consumption

## 4.1 Definition

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

The SEC of the kiln is given by:

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

Where,

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

= Average mass of fired brick x number of bricks fired in one firing cycle/batch

$= m_{fbr} \times n_{fbr}$

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

= (Energy input from external fuels fed in the kiln) + (Energy input from internal fuels added during moulding in the bricks) + (Energy input from the organic matter present in the brick soil).

$$= \sum_{i=1}^{n_1} W_{f-ext,i} \times GCV_{f-ext,i} + \sum_{i=1}^{n_2} W_{f-\text{int},i} \times GCV_{f-\text{int},i}$$

Where, $n_1$ and $n_2$ are the types/ lots of external and internal fuel used.

Notes:

1. The average mass of fired brick is determined by randomly selecting 24 fired bricks, weighing them and calculating a simple average in case of small kilns. In case of large kilns at least one brick per thousand bricks fired in the kiln should be weighed.
2. It is to be noted that while calculating SEC, the quality of fired brick is not taken into account; all the bricks that has undergone firing during the duration of the experiment are taken while calculating $M_{fbr}$
3. GCV is the gross calorific value of the fuel.
4. The energy from carbonaceous content in green bricks is often small and difficult to measure and is neglected in these calculations.

## 4.2 Measurement of energy input (external and internal fuel)

In order to accurately identify energy inputs, a material balance chart should be prepared for the kiln. A general material balance for an intermittent kiln is provided below

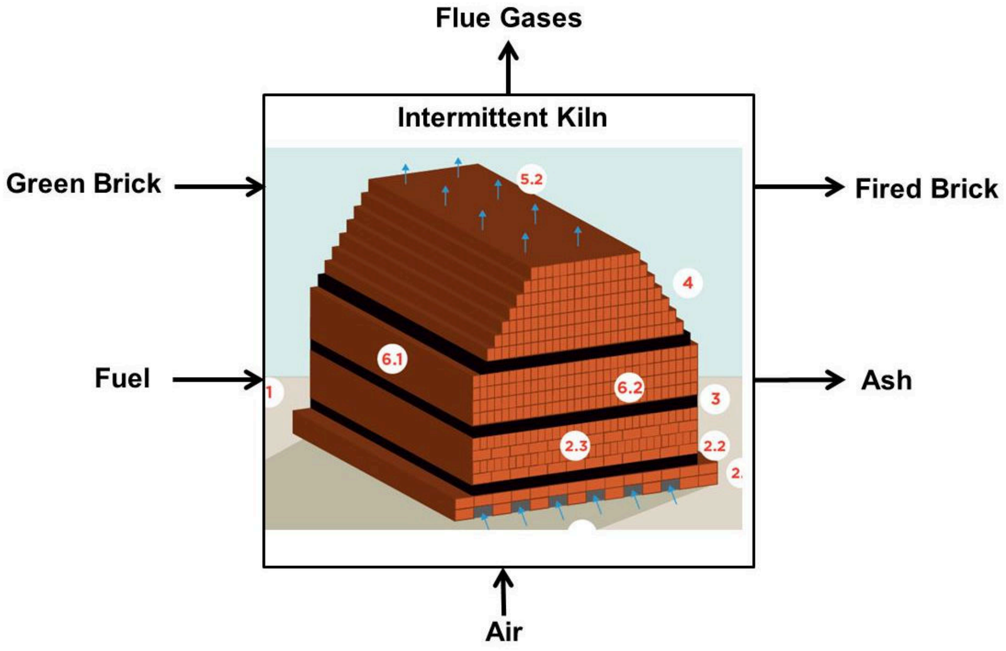

Figure 15: Material balance of brick kiln

The energy for firing of bricks is being supplied through addition of fuel and carbonaceous material present in the green bricks.

Fuel can be added in two ways – 1) externally and 2) mixed internally in the soil while green brick preparation. Both internal and external fuel needs to be accounted for calculating the heat input in the kiln.

In the batch process, as is the case of intermittent kilns, it is necessary to take measurements for firing of at least one entire batch. In case of continuous kilns, the measurements should be taken for a firing cycle of duration 24 hours or 48 hours. In order to calculate total energy input in one batch of bricks, following data is required

<u>External Fuel</u>

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

<u>Internal fuel</u>

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

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

## 4.3 Measurement of weight of fired bricks

The total weight of fired batch/cycle is obtained by determining the average weight of the fired brick and then multiplying it by number of bricks fired in the batch/cycle.

The average mass of fired brick is determined by randomly selecting 24 fired bricks, weighing them and calculating a simple average in case of small kilns. In case of large kilns at least one brick per thousand bricks fired in the kiln should be weighed.

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

Figure 16: Measuring weight of bricks

## 4.4 Determination of SEC of intermittent/batch kilns

The specific energy consumption can be computed through the equation given below

$$SEC\left(\frac{\text{MJ}}{\text{kg fired brick}}\right) = \frac{\text{Total Energy Input (MJ)}}{\text{Weight of fired batch (kg)}}$$

Please note that the specific energy consumption should also mention the firing temperature of the bricks.

<u>Example 1:</u> Calculation of SEC of a downdraught kiln in India

| | |
|---|---|
|  | No of bricks fired in one batch = 20,000 bricks |
| | Average of weight of fired brick = 3.21 kg |
| | Total weight of fired batch = 64,200 kg |
| | Type of fuel = Eucalyptus branches |
| | Weight of fuel used in one batch = 12,000 kg |
| | Moisture content in fuel at kiln site = 20% |
| | Moisture content in fuel at which the GCV was measured in lab = 10% |
| | GCV of fuel measured in lab = 17.27 MJ/kg |
| | GCV of fuel at the moisture level at kiln site = GCV of fuel measured in lab X [1- (20 - 10)/100] = 15.54 MJ/kg |
| | Total energy input = GCV of fuel at kiln site X Weight of fuel used = 186,516 MJ |
| | **Specific energy consumption = 2.91 MJ/kg fired brick** |

## 4.5 Determination of SEC of continuous kilns

In the case of continuous kilns, the unit basis for calculations is time, usually the duration of monitoring is for minimum of one day (24 hours). The rest of the concept and the parameters to be measured remain same as that of intermittent kiln. The equations used for calculating SEC of continuous kiln are given below

**Total Energy Input = $[(W_{f\text{-}ext}) \times (GCV_{f\text{-}ext}) + (W_{f\text{-}int}) \times (GCV_{f\text{-}int})]$**

Where;

$W_{f\text{-}ext}$ =Weight of the external fuel added during the monitoring duration

$GCV_{f\text{-}ext}$ = Gross Calorific Value (GCV) of the external fuel

$W_{f\text{-}int}$ = Weight of the internal fuel added to the green bricks which are fired during the duration of the monitoring

$GCV_{f\text{-}int}$ = Gross Calorific Value (GCV) of the internal fuel

**Total weight of fired brick = average weight of fired brick x number of bricks fired during the duration of the monitoring**

The specific energy consumption can be computed through the equation given below

$$SEC\left(\frac{MJ}{kg\ fired\ brick}\right) = \frac{Total\ Energy\ Input\ (MJ)}{\text{Weight of fired brick (kg)}}$$

Please note that the specific energy consumption should also mention the firing temperature of the bricks.

<u>Example 2:</u> Calculation of SEC of a Bull's trench kiln in India (24 hour duration)

| | |
|---|---|
|  | No of bricks fired in one day = 37,750 bricks |
| | Average of weight of fired brick = 2.91 kg |
| | Total weight of fired brick = 109,852 kg |
| | Type of fuel = Coal |
| | Weight of fuel used in one day = 4,236 kg/day |
| | Moisture content in fuel at kiln site = 8% |
| | Moisture content in fuel at which the GCV was measured in lab = 0.35% |
| | GCV of fuel measured in lab = 31.66 MJ/kg |
| | GCV of fuel at the moisture level at kiln site = GCV of fuel measured in lab X [1- (8 – 0.35)/100] = 29.13 MJ/kg |
| | Total energy input = GCV of fuel at kiln site X Weight of fuel used = 123,395 MJ |
| | **Specific energy consumption = 1.12 MJ/kg fired brick** |

Example 3: Calculation of SEC of a VSBK in India (48 hour duration) (multiple fuel)

| | | | | |
|---|---|---|---|---|
|  | No of bricks in 48 hours = 4,998 bricks | | | |
| | Average of weight of fired brick = 2.23 kg | | | |
| | Total weight of fired brick = 11,145.5 kg | | | |
| | Type of fuel→ | Coal (Ext. fuel) | Boiler ash (Int. fuel) | Wheat straw (Int. fuel) |
| | Weight of fuel (kg) → | 329.4 | 570 | 100 |
| | GCV of fuel at moisture level at kiln site (MJ/kg) → | 16.58 | 4.14 | 15.9 |
| | Heat Input (MJ)→ | 5,461.5 | 2,359.8 | 1,590.0 |
| | Total heat input = 9,411.3 MJ | | | |
| | **Specific energy consumption = 0.84 MJ/kg fired brick** | | | |

## 4.6 Precautions

- Moisture present in the fuel must be accounted, while calculating the energy input to the kiln.
- Weight of the fuel that is added needs to be accurately estimated.
- In case of continuous kiln, measurement of bricks fired per day needs to be estimated accurately.
- Specific energy consumption has to be reported along with the firing temperature; hence the firing temperature also has to be measured.

## 4.7 Uncertainty analysis in the measurement of SEC

### 4.7.1 Uncertainties in Products and Quotients

Let quantities x, ……, w are measured with uncertainties Δ x, ………, Δw, and the measured values are used to compute

$$q = \frac{x \times ......\times z}{u \times .......\times w}$$

If the uncertainties in x, ...,w are independent and random, then the fractional uncertainties in q is the sum in quadrature of the original fractional uncertainties

$$\frac{\Delta q}{q} = \sqrt{\left[\frac{\Delta x}{x}\right]^2 + .........+ \left[\frac{\Delta z}{z}\right]^2 + \left[\frac{\Delta u}{u}\right]^2 + ......\left[\frac{\Delta w}{w}\right]^2}$$

### 4.7.2 Uncertainty in SEC

The SEC for the brick kiln is given by the equation

$$SEC = (M_f \times GCV_f)/(w_{fbr} \times n_{fbr})$$

Hence the uncertainty in calculation of SEC can be given by,

$$\frac{\Delta SEC}{SEC} = \sqrt{\left(\frac{\Delta M_f}{M_f}\right)^2 + \left(\frac{\Delta GCV_f}{GCV_f}\right)^2 + \left(\frac{\Delta w_{fbr}}{w_{fbr}}\right)^2 + \left(\frac{\Delta n_{fbr}}{n_{fbr}}\right)^2}$$

<u>Now let us estimate the uncertainty in the calculation of SEC for the case presented in Example-2 in Section 4.5:</u>

Least count of weighing balance for weighing coal = 0.1 ton and typical weight of a coal lot = 12 ton. Therefore,

$\frac{\Delta M_f}{M_f} \approx$ 1.0%.

Least count of weighing balance to weigh bricks = 0.05 kg

$w_{fbr}$ = 2.91 kg

$\frac{\Delta w_{fbr}}{w_{fbr}} \approx$1.7 %

The uncertainty in the estimation of number of bricks $n_{fbr}$ is assumed as 2%.

$\frac{\Delta n_{fbr}}{n_{fbr}}$ = 2%

$\frac{\Delta SEC}{SEC}$ = $\sqrt{1^2 + 1.7^2 + 2^2}$ = 2.81%

## 4.8 Significance of Specific energy consumption

Specific energy consumption is a measure of energy used for firing one kg of green brick to fired brick in given conditions using specific type of kiln. The energy required depends heavily of type of clay and the efficiency of the kiln. Hence, the specific energy consumption cannot be used as a single parameter to compare the kiln technologies across geographies. One should take extra care while commenting upon the technology performance using specific energy consumption data.

# 5 Instruments for energy monitoring

Some of the important instruments required for the energy monitoring of brick kilns are described below:

## 5.1 Weighing balance

Weighing balance is a measuring instrument for determining the weight or mass of an object. These are used in the monitoring of brick kilns for measuring weights of green bricks, fired bricks and the fuel. For measuring weight of bricks, smaller weighing balances with capacity in the order of 20-25 kg and least count of 10 g are suitable. However, for measuring the weight of fuel, a larger capacity balance would be required which can measure weights of the order of 50-100 kg.

## 5.2 Thermocouple

A thermocouple is a temperature-measuring device consisting of two dissimilar conductors that contact each other at one or more spots. It produces a voltage when the temperature of one of the spots differs from the reference temperature at other parts of the circuit. The voltage is then interpreted using thermocouple reference tables to calculate the temperature. Varying with the conductors combination, there are many types of thermocouples available, each having unique characteristics in terms of temperature range, sensitivity, cost and application compatibility.

K type (Ni-Cr/Ni-Al) thermocouples are commonly used for measuring temperatures in brick kilns. It is inexpensive and can measure temperatures in the range −200 °C to +1350 °C which is suitable for brick kiln applications. These are called contact type thermometers as they measure temperatures by coming in actual contact with the object.

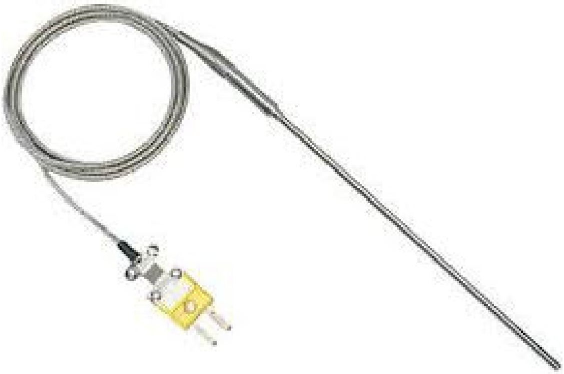

Figure 17: Probe of K-type thermocouple

Figure 18: Temperature indicator

## 5.3 Infrared thermometers

An infrared thermometer is thermometer which infers temperature from a portion of the thermal radiation emitted by the object being measured. They are sometimes called laser thermometers if a laser is used to help aim the thermometer. These are categorised as non-contact thermometers or temperature guns, to describe the device's ability to measure temperature from a distance. By knowing the amount of infrared energy emitted by the object and its emissivity, the object's temperature can be determined. In the basic infrared thermometers, a constant emissivity value is preloaded for temperature measurements. However, in the advanced meters there is an option to select the emissivity value depending on the material of the surface of which temperature is being measured.

Figure 19: Infrared thermometer

## 5.4 Moisture meter

Moisture meters are used to measure the percentage of water in a given substance. It works on the principle that conductivity of materials vary with its moisture content. It measures the conductivity of the material and with the help of conductivity characteristics curves pre-loaded in it for various materials; it determines the moisture content in the material. It can be used for determining moisture content in fire-wood fuels. The limitation with these meters is that these can measure moisture content correctly for those materials only whose characteristics curve has been preloaded. Most of the commonly found moisture meters can measure moisture content in fuel wood, however, it should be checked with the supplier whether it can measure moisture content of green bricks and other loose biomass fuels or not.

Figure 20: Moisture meter

## 5.5 Bomb calorimeter

A bomb calorimeter is a device used to measure the heat of combustion of a particular reaction. For fuels, it will be their gross calorific value. These measurements are obtained by burning a representative sample of the fuel in a high pressure oxygen atmosphere within a metal pressure vessel or ‘bomb’.

A weighed mass of the fuel sample (typically 1-1.5 g) along with some fixed amount of water is kept in the bomb. Water is added to saturate the internal atmosphere, thus ensuring that all water produced during burning is liquid. The bomb is pressurised with excess pure oxygen (typically at 30 atm.) and submerged under a known volume of water (typically 2000 ml). The charge is then electrically ignited. The bomb, with the known mass of the sample and oxygen, form a closed system - no gases escape during the reaction. Energy released by the combustion raises the temperature of the metal bomb, its contents, and the surrounding water jacket. The temperature change in the water is then accurately measured with a thermometer. This reading, along with a bomb factor (which is dependent on the heat capacity of the metal bomb parts), is used to calculate the energy given out by the sample burn.

Figure 21: Bomb calorimeter

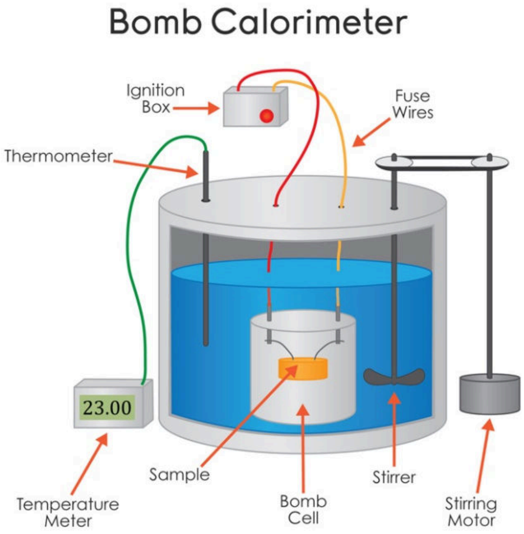

Figure 22: Components of bomb calorimeter

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