Coal quality field testing guidelines

For firing VSBK with external coal

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Preface:

To identify the correct coal quality source for firing a VSBK is one of the core issues for an economical sustainable VSBK technology based operation.

As per present practice, VSBK entrepreneurs prefer to use coal for external firing. This is absolutely possible, but experiences have shown that only a coal quality between a specific quality parameter can be used. This places an enormous pressure on the entrepreneurs to get a regular supply of a certain coal quality.

However, private entrepreneurs have no practical tools at hand to check if the delivered coal quality is suitable for the VSBK technology. Therefore, very often the VSBK brick entrepreneurs face brick quality problems because the fire schedule profile changes with every new coal delivery.

To support VSBK based entrepreneurs to run a sustainable VSBK business, it was required to develop simple field based coal quality tests. These field tests can be performed by any private VSBK entrepreneur to check the coal quality “delivered at-site” in order to accept or reject it, and hence operate his / her VSBK in an economical sustainable way.

Further, to assess the overall VSBK technology transfer feasibility to any new country, qualified staff can use these practical field test tools.

Because of its simplicity, it is possible to define in a very reliable way the availability, economics and location of VSBK technology conform coal quality for external firing. The preliminary test results will practically define the brick making methodology to be adapted for new VSBK technology transfer projects.

This manual is divided into 4 chapters. Chapter 1 deals with a general introduction to coal and its ideal properties for using it in a VSBK. Chapter 2 explains the impact different coal qualities have to the fire schedule, its related brick quality and finally its logical financial implications for a VSBK entrepreneur. Chapter 3 shows in a detailed and step by step approach how to check the coal quality with simple, but effective field based tools and methodologies. Chapter 4 finally deals with different options available for the private VSBK entrepreneurs in case there are no alternatives to obtaining the optimal coal quality required.

This manual aims to contribute towards the build up of fundamental brick making knowledge to the small and medium VSBK brick industry sector. Without this elementary brick making know-how, a change to cleaner brick production systems will not be possible.

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Chapter 1

by Dr. Sameer Maithel

1. Introduction

1.1 Basics of coal

Coal is a readily combustible black or brownish-black sedimentary rock normally occurring in rock strata in layers or veins called coal beds. It is composed primarily of carbon along with variable quantities of other elements, chiefly sulphur, hydrogen, oxygen and nitrogen.

Coal, the first fossil fuel exploited by humans for energy on a large scale is a carbonaceous rock formed from buried plants in ancient forests or swamps.

These plant materials are initially converted to peat—a loose, brown, organically rich soil that itself is an important energy resource in some areas. As more rock layers press down on the buried deposits, geothermal energy heats the peat and reduces its oxygen and hydrogen content, converting it to coal.

1.2 Composition of Coal

Coal is a fossil fuel and therefore its CO₂ emissions are high:

1 kg of coal gives rise to 1.5-2.0 kg of CO₂.

2.0 kg of CO₂ is equivalent to 1140 liters (more than 1 m³) of CO₂.

Each type of coal has a certain set of physical parameters which are mostly controlled by moisture, volatile content (in terms of aliphatic or aromatic hydrocarbons) and carbon content. The most basic analysis carried out to determine characteristics of a coal is called proximate analysis. Proximate analysis shows the composition of coal in the form of:
Moisture
Moisture is an important property of coal, as all coals are mined wet. Groundwater and other extraneous moisture that coal absorbs are known as adventitious moisture and are readily evaporated when coal is heated to 100-120 °C. The adventitious moisture can be held in coal body in the form of:

- Surface moisture: water held on the surface of coal particles
- Hydroscopic moisture: water held by capillary action within the micro fractures of the coal

Moisture held in chemically bonded form inside the coal is known as inherent moisture. Inherent moisture is not removed at low temperatures (100-120 °C), it gets released at higher temperature during the combustion of coal. It can be in the form of:

- Decomposition moisture: water held within the coal's decomposed organic compounds
- Mineral moisture: water which comprises part of the crystal structure of hydrous silicates such as clays

Total moisture is analyzed by loss of mass when coal is heated.

Volatile matter
Volatile matter in coal refers to gaseous and tarry products, (except evaporating moisture), which are liberated when coal is heated to high temperatures (900 ± 5 °C) in the absence of air. These gases are called volatile matter.

Ash
Ash content of coal is the non-combustible residue left after coal is completely burnt. It represents the bulk mineral matter after carbon, oxygen, sulfur and water have been driven off during combustion.

Fixed carbon
The fixed carbon content of coal is the carbon found in the material which is left after moisture, ash, and volatile materials are driven off from coal. However it is important to know that the fixed carbon content differs from the ultimate carbon content of the coal because some carbon is lost in hydrocarbons with the volatiles.

Apart from proximate analysis, the other important property of coal is its calorific value (CV). The calorific value is the number of heat units which are liberated when a unit weight of fuel is completely burned. Usually calorific value is defined in kcal/kg or kJ/kg. If the CV is in kcal/kg, multiplying it with 4.1868 gives the result of CV in kJ/kg.

1.3 Classification of Coal
Coal comes in several grades that reflect its thermal maturity and energy content:

- **Brown coal (lignite)**, the first type of coal to form when plant matter is compacted, has an energy (calorific) value of 2400 -3600 kcal/kg. Because it has a low energy content, larger volumes are needed relative to higher-grade coals in order to generate the same amount of heat. Therefore, it is not a good external fuel for firing bricks in a VSBK.

- **Bituminous coal** (medium calorific value of 3000 -6500 kcal/kg) is characteristically dark black and represents the most important coal grade for energy throughout the world. This type of coal is particularly suitable for brick firing in a VSBK
Anthracite coals are metallic gray and have very high energy content (calorific value > 6500 kcal/kg). It is a costly fuel and is usually not used for brick firing, except in cases when it is found in abundance (e.g. Vietnam). If available, because of anthracite's high energy output and low volatile content, it is a good fuel for VSBK

1.4 Combustion of coal

Combustion is defined as the rapid chemical reaction in which chemical energy of fuel is converted into heat. During combustion, carbon, hydrogen and sulphur present in the fuel reacts with oxygen and releases heat.

A simple word equation for this chemical reaction is:

\[
\text{Fuel} + \text{Oxygen} = \text{Heat} + \text{Carbon dioxide} + \text{Water}
\]

Coal must be heated to its ignition point, or kindling temperature before it can burn. Although the ignition point of a substance is essentially constant, the time needed for burning to begin depends on factors such as the size of the fuel particle and the amount of oxygen in the air. A finely divided substance is more readily ignited than a massive one; e.g., sawdust ignites more rapidly than does a log. The vapours of a volatile fuel such as gasoline are more readily ignited than is the fuel itself. The rate of combustion is also affected by these factors, particularly by the amount of oxygen in the air.

Therefore, for the combustion of coal three basic conditions must exist, namely:

1. Sufficient fuel and air are available.
   Optimum: fuel is uniformly distributed and mixed with air

2. Ignition temperature and limits of inflammability are exceeded

3. To allow combustion to continue it is necessary to remove products of combustion from the vicinity of the coal particle, so that fresh oxygen can come in contact with coal.
The process of combustion of coal consists of four major steps:

**Drying:** As the coal is heated; the moisture present in the coal (except inherent moisture) is released in the form of water vapour. By the time the coal temperature reaches 120 °C, the drying is over.

**Release of volatile matter:** As the coal particles are further heated, they start emitting volatile gases. This volatile matter release generally starts at a temperature of around 250-300 °C. Most of the gases which are released are combustible gases.

**Combustion of volatile matter:** Volatile gases coming out of the coal particles, mixes with the air and forms a combustible mix, which ignites. The combustion of volatile matter is seen as flames. Wood has in general the highest volatile matter among various solid fuels and therefore has in general the longest flames.

**Combustion of char:** After all volatile matter is burned out; the coal particle now consists only of carbon (char) and ash. Char ignition temperature is higher compared to that of the volatile matter. In a brick kiln, normally the char combustion takes place once the temperature exceeds 600 °C.

### 1.5 Firing schedule of a VSBK

The key to establishing an ideal firing schedule is to see that the fire temperature rising- and cooling down- rate is always within 70 to 100 degree centigrade per hour and to ensure that the firing residence (soaking-) time allows a proper vitrification process. However, the recommended 70 to 100 degree centigrade per hour is very much dependant on the raw material and should only be considered as a rough guideline.

Translating these rough guidelines into an ideal fire-schedule related to the VSBK shaft length and a 24 hrs unloading time, the following graphics developed.
To establish and maintain a fire schedule a fire-master needs fire controlling and steering mechanisms and tools; whereof coal is one of the most important parameter (tool). Therefore, the use of the correct coal quality, with ideal chemical properties, for the VSBK technology is essential.

1.6 Ideal coal properties required for VSBK

The following main coal properties that are important while selecting coal as external fuel for VSBK have been defined by a group of experienced VSBK experts from India, Nepal, Pakistan and Afghanistan. However, the ideal coal properties for a VSBK are guidelines and are not linked to other than normal soil properties of a brick.

Ash
In general, the less ash content a coal has the better it is. Praxis shows a coal having ash content between 10 to 25% should be used; coal having ash content higher than 40% should be rejected.

Calorific Value
The calorific value of the coal should ideally between 4500 to 5500 kcal/kg. Coal having a CV of less than 3500 kcal/kg and more than 7500 kcal/kg should be rejected.

Moisture Content
An acceptable percentage of external coal moisture content should be between 5% and 10%. Excessive moisture content results in poor combustion as well as energy losses.
Sulphur
A reasonable sulphur content of coal is between 0.5% and 1%. Coal having Sulphur >2% should not be used because higher content of sulphur causes Sulphur Dioxide (SO₂) pollution which has a direct negative effect on the health of workers and damages vegetation, life-stock and human population in the surrounding area.

Volatile Matter
The Volatile Matter in coal should be between 15% and 25%; any coal having a higher content than 40% should be rejected. Coal with high volatile matter content burns with a long flame which is not desirable in a VSBK.

Particle Size
Particle size of coal determines how fast or slow the coal would burn. If the particle size is large, the burning rate of the coal would be low. In case the particle size is small, the burning rate would be fast. An ideal size of coal as external fuel should be between 20 to 50 mm. Coal size less than 10mm and coal size bigger than 75mm should not be used as external fuel for a VSBK.

Ash Fusion Temperature
Ash fusion temperatures give an indication of the softening and melting behaviour of fuel ash. If the ash fusion temperature is lower than the firing temperature of bricks, then the coal ash would melt, form clinkers and would also stick to the bricks. Thus it is important that the ash fusion temperature of the coal should be at least 50°C higher as the required maximum brick firing temperature.

1.7 Graphical coal test presentation, “Spider Net” (Cobweb)
In order to establish and maintain a fire schedule that produces the required fired brick quality, the brick entrepreneur needs to know the actual properties of the coal supplied by the coal dealer.

A practical coal test-kit for entrepreneurs is introduced in chapter 3. In order to asses and compare the recommended ideal coal properties for a VSBK with the actually supplied coal quality; a “Spider Net” graphic tool is used. By applying this “Spider Net” graphic tool, one can immediately see whether the tested coal has the recommended ideal coal properties or not.

The “Spider Net” tool will be used as a practical guideline throughout the presentation of this coal manual.
Chapter 2

2. Effects of coal properties to fire schedule

Since coal is the main energy for operating a VSBK, the correct quality of coal defines in many cases success or failure of the VSBK business. However, a brick entrepreneur is always trying to purchase the least costly energy to fire the bricks. This mind-set is acceptable as long as the entrepreneur knows exactly what the likely impact of his cheaply purchased coal quality has on the VSBK fire schedule.

The ideal coal properties for operating a VSBK are described in chapter 1.6. However, those ideal coal properties are linked to the ideal firing schedule for a VSBK described in chapter 1.5 under the assumption that the green brick raw material (soil) is heated up and cooled down with an average of 100 degrees Celsius per hour, an average rate which soil normally tolerates.

However, this situation will obviously change significantly if a soil possesses either less or more heat tolerance than the average of 100 °C per hour. Therefore, each brick entrepreneur has to establish the ideal firing schedule according to the available soil and purchase the coal quality required to maintain the best firing schedule for the selected soil.

An average soil tolerance is the basic hypothesis for the following chapter where the impact of the coal quality on the fire schedule is described.

2.1 Size of coal

Recommended coal particle size range:

Minimum: 20 mm
Maximum: 50 mm

Introduction:

The size of the coal is one of the most important fire controlling and fire schedule steering mechanism and tool at hand for a fire-master. It defines the:

- Position of the fire
- Length of the fire zone
- Soaking time

To control unwanted fire movement, a fire master needs to have different sized coal available.
• In case the fire position moves up, bigger sized coal (up to 50mm) needs to be added to bring down the fire zone.
• In case the fire position moves down, smaller sized coal (approx. 10mm) needs to be added to lift up the fire zone.

Therefore, as a working rule, about 100 kg of big sized coal (50mm) as well as 100 kg of small sized coal (10mm) should always be stored and at ready hand for fire position correction and stabilization use.

The correct sizing of the coal for maintaining the best fire schedule is an absolute must and has consequent economical implications. Each entrepreneur must assess the economical viability of coal sizing before deciding to use it as internal or external fuel for his VSBK operation. The coal size supply from the coal quarries needs always and without exception to be processed to the correct size either manually or mechanically. If, due to the specific characteristic of the coal, it cannot be processed to the required fraction then the coal must be rejected for external firing. The economical implications of coal size is discussed in greater detail in chapter 3.1.1

2.1.1 Effect on fire schedule with the use of correct size of coal

It is possible to control the appropriate fire schedule by using the correct size of coal. The correct size of coal will ignite at the determined batch and at the correct time. It will burn down at the same rate and firing stops after the intended brick vitrification / soaking time. The fire zone remains stable, the danger of it moving up or down due to different coal size is minimized. The application of the ideal coal size varies according to different coal quality properties as well as green brick soil properties.

Defining the ideal coal size requires ongoing practical experimentation by the entrepreneur to counter the supply of irregular coal quality. Therefore, the appropriate coal size needs to be regularly adjusted according to the available type and quality of coal supplied.

• Brick quality

Feeding the correct size of coal ensures that the ideal fire schedule can be achieved. Therefore, temperatures during heating up, vitrification and cooling down of the bricks
are adjusted to the requirements of the brick clay. Maintaining the ideal fire schedule will result in a good brick quality.

- **Economics**
  By maintaining the ideal fire schedule the best possible brick quality can be achieved, hence there will be an absolute minimum of breakage or other damages. This results in the maximum sellable bricks and consequently in the highest profit for the VSBK brick entrepreneur.

2.1.2 **Effect on fire schedule with the use of too small coal size**

**Case 1:**
If too small sized coal is used (<10mm) for brick firing in a VSBK, the coal will ignite too soon, hence the fire position is always above the centre of the shaft, total firing time will be very short since the small coal particles are burned out very quick. It is likely that the required maximum firing temperature will not be achieved within the predetermined amount of energy, since the small coal grain size will burn out too quickly.

- **Brick quality**
  Since the small coal pieces will ignite very quickly, the heating up time of the green bricks will be reduced. Further, the quick burning out of the coal will not allow a proper vitrification of the bricks. Therefore, it is likely that already during the quick heating up phase small cracks will develop, the quartz inversion temperature of 573 degree will be approached and passed too quickly, again creating small brick cracks. Together with the short vitrification time, the brick will not be properly fired and will eventually result in cracked, under-burned bricks with a bad ring, a high percentage of breakage and no colour.

- **Economics**
  The selling of under-burned bricks with a bad ring and no colour is not possible without a major reduction of the price. Hence this brick quality, in addition to a high percentage of breakage, will cause a serious business threat and profit cannot be sustained in the long run.

**Case 2:**
If only dust particles are used for firing, the total amount required to achieve a reasonable fire temperature is probably very high. In order to accommodate the total coal amount, even the “Chulas” need to be filled, hence an oxygen deficiency will be created. This will not allow the timely ignition of the coal, resulting in a delayed heating up fire schedule. Once the coal does ignite in these conditions the fire will catch strength only slowly and the maximum firing temperature cannot be achieved within time. Due to the need of unloading, the coal is pulled
down where it gets more oxygen supply and the fire is actually gaining strength at a place where the cooling down should take pace. The feeding of coal dust creates a total distracted fire schedule which cannot be controlled.

This will result in a too long fire zone and the ideal heating up-, vitrification- and cooling down-time cannot be maintained. Due to this distracted fire schedule and depending on the green brick soil properties there is a danger of a localized overheating which can result in melting the part of a brick where too many small coal particles are stored.

- **Brick quality**
  Since it is unlikely that the required maximum brick firing temperature will be achieved, there will be no proper vitrification of the bricks, resulting in under burned brick quality. Due to the temperature rise in the cooling down area of the shaft, the bricks will be exposed to a thermal shock; resulting in small cracks that will reduce the ring and hence the compressive strength of the bricks.

  Due to this distorted fire schedule, it is certain that under-burned bricks with a bad ring, low compressive strength, a high percent of breakage and no colour will be produced. Additionally, depending on the soil properties, a local overheating can partly melt and damage not only the bricks, but in the worst case the shaft itself.

- **Economics**
  The selling of under-burned bricks with a bad ring and no colour is not possible without a major reduction of the price. Hence, this brick quality, linked with a high percentage of breakage, will cause a serious business threat and profit cannot be sustained in the long run.

### 2.1.3 Effect on fire schedule with the use of too big coal size

Using only big size coal (approx. above 50 mm) will result in a very slow temperature heating up rate. The big size coal will finally ignite; but too late, and once ignited, the fire gains too much strength too quickly, and the quartz inversion temperature of 573 degree will be approached and passed too quickly. A big sized coal will burn for too long a time, resulting in an elongated fire zone and a too hot cooling down zone.
• **Brick quality**
  It is likely that quartz inversion temperature of 573 degree will be approached and passed too quickly, creating small cracks in the bricks. The elongated fire zone does not allow normal cooling down rates and it is likely that the bricks will be exposed to thermal shocks. Although the bricks might have a good colour, they will have a high rate of breakage, absolutely no ring and a reduced compressive strength.

• **Economics**
  The main problem of these bricks will be that they will have no good ring and will have most likely a relative high percentage of breakages. Since the market demands bricks with a good ring, these bricks will definitely sell at a lower price. Moreover, if too big coal is fired, it might well be that no proper combustion takes place and unburned coal will be unloaded. This unused energy is expensive and cannot be recovered by the entrepreneur.

2.1.4 **Effect on fire schedule with the use of mixed coal size**

In the case of firing small sized coal mixed with big sized coal, the small sized coal will ignite too soon, resulting into an unwanted high temperature rise per hour and hence a too steep fire schedule, leaving the green bricks at the top of the shaft prone to blasting and splitting. The big size coal will ignite late, and will burn for too long a time. This will result in a very long fire zone, no proper cooling can take place and the bricks will be exposed to thermal shocks. The mixing of different coal size creates a fire schedule that does not allow for proper heating up and proper cooling down of the bricks.

- **Brick quality**
  The steep heating up curve indicates that that quartz inversion temperature of 573 degree will be approached and passed too quickly, creating small cracks in the brick. The too long fire zone in combination with correct firing temperatures may allow proper vitrification and hence a good colour of the bricks but the distortion of the fire schedule due to the too long fire zone does not allow normal cooling down rates and it is likely that the bricks will be exposed to thermal shocks. Hence these bricks will likely have a good colour but absolutely no ring and no compressive strength.

- **Economics**
  The main problem of these bricks will be that they will have a high breakage and no good ring. But since the market demands bricks with a good ring, these bricks will definitely sell at a lower price. Moreover, if too big coal size is fired, it might well be that no proper combustion will take place and unburned coal will be unloaded. This unused energy is expensive and cannot be recovered by the entrepreneur.
2.2 Moisture content of coal

Recommended coal moisture content range:

<table>
<thead>
<tr>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 5 %</td>
<td>10%</td>
</tr>
</tbody>
</table>

Introduction:

Since the coal must be transported from the coal mine to the VSBK site, there is a real danger of self-ignition if the coal is too dry. Therefore, each coal supplier will add some water to cool down the coal temperature and to reduce this risk especially during the summer months. However, some coal suppliers have the tendency to add too much water in order to increase their profit since coal is being supplied by the ton and on trucks. The ideal coal moisture content for a VSBK operation is as low as possible, not only for economic reasons but also for reducing the water smoking which many people consider as negative air pollution.

Air humidity

Depending on the climatic condition, the moisture content in the air has a major impact on the overall coal consumption of firing the bricks. During monsoon time the coal consumption in a VSBK can reach an average of 10 to 15% more coal for firing the same dry green bricks compared to the dry season. This percentage is even more aggravated if the coal is not properly stored and wet coal is fed for firing.

Proper coal storage

Once the coal is un-loaded it is important that it is protected against rain so that the added water during transportation can dry out as much as possible. It is advisable to store the sized coal under a shed that prevents direct exposure to rain. Thereafter it should be stored at the VSBK platform level as soon as possible where it should remain under a protected roof for as long as practicably possible to ensure that coal with minimum moisture content is used in the VSBK.

2.2.1 Effect on fire schedule

The moisture content of coal has in general a minimal effect to the fire schedule. However, if a coal has higher moisture content than 10% the resulting water will be evaporated probably within the first two to three batches, the temperature will increase slightly delayed, resulting in a neglectable impact to the fire schedule.
Brick quality

The moisture content of the coal has no negative impact on the brick quality. However, firing green bricks with high moisture content will lead to brick splitting/blasting damages.

- **Economics**
  Drying off moisture from coal requires expensive energy. If for example one batch requires 25 kg of coal and the coal has a moisture content of 10%, it would mean using additional energy to evaporate 2.5 lt. of water per batch.

To evaporate 1 lt. of water requires total of 650 kcal/kg or 2717 kJ/kg

Per day: 24 batches x 2.5 lt. = 60 lt. (2 shaft VSBK)
Per month: 30 days x 60 lt. = 1800 lt.
Per year: 12 months x 1800 lt. = 21600 lt. x 2717 = 58687.2 MJ

Therefore, in order to evaporate a total of 21600 lt. of coal moisture requires total **3.12 ton** of additional coal per year (with an average calorific value of 4500 kcal/kg)

However, much more attention has to be given to the total moisture content of the green bricks and not so much to the moisture content of coal.

**Example:**

A dry green brick has a total weight of 2.5 kg. If the same green brick has a moisture content of 9% then the total weight of the water inside the green brick is 225gr.

Per batch 500 green bricks with each 225gr. moisture = 112.5 lt. of water
In a day for a 2 shaft VSBK: 24 batch x 112.5 lt. of water = 2700 lt. of water
In a month= 30 days x 2700 lt. = 81000 lt. of water = 220007.7 MJ or 11.6 9ton/month or 140 ton per year

Whereas coal with a moisture content of 10% requires **3.12 ton** of additional coal to evaporate this moisture per year, a green brick fired with 9% moisture content requires a staggering **140 tons** of additional coal to evaporate this moisture content. In the present context (July 2010) this represents an amount of approx **20’000.- US$** additional and unnecessary expense per year for the brick entrepreneur.
Accordingly, one need not to place too much emphasis on the moisture content of the coal, the correct moisture content of the green brick is economically more important.

2.3 Ash content of coal

Recommended ash content range:
Minimum: 10%
Maximum: 25%

Introduction:
Mineral impurity or ash content of coal is what is left when the coal is completely fired.
It represents the bulk mineral matter after carbon, oxygen, sulphur and water (including water from clay) has been driven off during combustion.
The coal ash content provides an important indicator of the heating value of the coal.
Low coal ash content indicates a high heating value of the coal which in general indicates low emissions, hence is very suitable for VSBK.
However, high coal ash content indicates the direct opposite, and therefore is not very suitable for VSBK.
2.3.1 Effect on fire schedule

If the ash content is higher than 25%, it will have a negative effect on the fire schedule because the higher the ash content, the lower is the heating value of the coal.

In order to properly fire a brick a certain amount of energy (temperature) is required during a specific time.

Case 1: Increasing coal quantity

If coal with very high ash content is used, a higher quantity (amount) of coal is required to achieve the needed energy during a specific time to properly fire the brick. This is because it has a low heating value. Depending on the coal ash percentage, the extra amount of coal to be added to achieve the brick firing temperature and time might seriously block the required airflow within the VSBK shaft and destabilizes the counter current flow principle. As a result the fire catches late during the heating up phase (lack of oxygen and too much coal to be ignited), the fire zone will be too long and hence the cooling down phase will be too long.

- Brick quality
  The heating up is very slow and hence no damages will occur during this phase. However due to the likely lack of oxygen the fire zone will be too long and the fire itself will enter the lower part of the shaft, resulting in serious thermal shock related brick damages. Although the bricks might have a good colour, they will have a high rate of cracks and absolutely no ring.

- Economics
  It is very likely that these bricks will have no good ring and will have most likely a relatively high percentage of breakage. Since the market demands bricks with a good ring, these bricks will definitely sell at a lower price. The decision of adding more coal in the case of a high ash content coal is most likely not a very economical one. The required quantity of coal to produce a brick quality that cannot be sold at a premium price is too expensive and such a quality of coal can eventually ruin a brick business.

  However, a high ash content coal is in general quite cheap. Therefore, depending on the ash content, adding coal to achieve the required firing temperature and time might work out to be an economical solution. Therefore, each brick entrepreneur must establish the economical facts (cheap energy versus sellable bricks) individually. There is no ‘One case’ scenario.

Case 2: Using normal amount of coal

If a coal with very high ash content is used and the same amount (kilo per batch) as with a low ash content coal is added, it will be difficult to achieve the desired maximum fire temperature to properly vitrify the bricks. This is because of its low heating value. Hence the impact on the
fire schedule is especially adverse during the vitrification phase. Since the energy content of the coal is used up too soon, the entire FS (fire schedule) will be shortened, resulting in a too quick cooling down of the FS.

- **Brick quality**
  Since it is unlikely that the required maximum brick firing temperature will be achieved, there will be no proper vitrification of the bricks, resulting in under-burned brick quality and a high percentage of breakage. Due to the sudden non-availability of energy the likely rapid temperature cooling down rate might result in quartz inversion related (573 degree) brick cracking problems.

  Due to this distorted fire schedule, it is certain that under-burned bricks with a bad ring, high percentage of breakage and no colour will be produced.

- **Economics**
  The selling of under-burned bricks with a bad ring and no colour is not possible without a major reduction of the price. Hence, this brick quality, linked with a high percentage of breakage, is causing a serious business threat and cannot be sustained in the long run.

2.4 Ash fusion

*Introduction:*

An ash fusing (melting) incident happens only if not enough air is circulating around the burning coal.

If a coal has a low calorific value, high ash content or is too small in size, a more than normal amount of coal needs to be placed between the green bricks in order to achieve the required brick firing temperature. There is a high probability of ash fusion at certain pockets where the coal does not get enough oxygen.

It is therefore essential to avoid feeding coal dust and small sized coal particles that could close air circulation around the coal.

In some cases it is difficult to say whether the damage of the bricks is caused by ash fusion or another problem perhaps related to the soil composition. Typically, a normal coal quality has
an ash fusion temperature of 1200 °C. However, if the coal has high iron content, the melting of the iron in the coal starts at around 900 °C, causing damages to the bricks.

In order to find out the actual cause of a persistent local ash melting problem it is necessary to conduct laboratory tests of the coal, in relation to the green brick soil vitrification range.

The details of such a testing process are described in chapter 4.

2.4.1 Effect on fire schedule

In general ash fusion itself does not necessarily have an influence on a fire schedule. But the type and quality of the coal used, which is most probably the origin of the ash fusion problem, will have a negative influence on the fire schedule.

- **Brick quality**
  The coal ash melting is partly causing a brick surface overheating and melting. This is damaging the colour, shape and structure of the brick in an irreversible manner.

- **Economics**
  The selling of ash fused damaged bricks is not possible and is therefore causing a serious business threat and cannot be sustained in the long run.

2.5 Volatile matter

**Recommended volatile matter range:**

Minimum: 15%

Maximum: 25%

**Introduction:**

Volatile matter in coal refers to the components of coal, except for moisture, which are liberated at high temperature in the absence of air. This is usually a mixture of short and long chain hydrocarbons, aromatic hydrocarbons and some sulphur.

In general, coals with high volatile-matter content ignite easily and are highly reactive during the brick firing process. Therefore it is important to avoid a coal quality with volatile matter content above 25% and below 15%.
2.5.1 Effect on fire schedule

A coal quality with high (> 25%) content of volatile matter will ignite too quickly during the heating up phase. This will increase the temperature per hour rate of the green bricks during the heating up phase too much, most probably also passing the quartz inversion temperature too quickly. Further, depending on the total amount of volatile matter of the coal, it is likely that the energy is burning out too soon, resulting in a reduced vitrification time and a too rapid cooling down time.

- Brick quality
  The relative quick catching of fire and burning out of the coal will not allow enough heating up time and a proper vitrification of the bricks. Therefore, it is likely that already during the quick heating up phase small cracks will be created; the quartz inversion temperature of 573 degree will be approached and passed too quickly, creating again small cracks in the brick, which in turn will result in a brick without an acceptable ring. Due to the short vitrification time, the brick will not be properly fired and will eventually result in under-burned bricks with a bad ring, high percentage of breakage and no good colour.

- Economics
  The selling of under-burned bricks with a bad ring and no good colour is not possible without a major reduction of the price. Hence, this brick quality, linked with a high percentage of breakage, is causing a serious business threat and cannot be sustained in the long run.

2.6 Calorific value (fixed carbon)

Recommended calorific value range:

Minimum: 4500 kcal/kg
Maximum: 5500 kcal/kg

Introduction

The fixed carbon content of the coal is the carbon found in the material which is left after volatile materials are driven off. This differs from the ultimate carbon content of the coal because some carbon is lost in hydrocarbons with the volatiles.

The fixed carbon content (calorific value) of a coal is the ultimate and decisive factor that must be known by a fire master for proper firing of bricks. In order to
fire a green brick with certain type of soil and specified size requires a correct maximum temperature and time for a proper vitrification.

In general, a good quality coal has a high calorific value and is expensive. A bad quality coal has a low calorific value but is on the other hand relatively cheap.

2.6.1 Effect on fire schedule

A coal quality with low calorific value will develop the same fire schedule related problems as a coal with high ash content does. Due to its low heating value it will be difficult to achieve the desired maximum fire temperature and time to properly vitrify the bricks. Hence the impact on the fire schedule is especially adverse during the vitrification phase. Since the energy content of the coal is used too soon, the entire FS will be shortened and a too rapid cooling down occurs.

- **Brick quality**
  Since it is unlikely that the required maximum brick firing temperature will be achieved, there will be no proper vitrification of the bricks resulting in under-burned brick quality and a high percentage of breakage. The likely rapid temperature cooling down due to non availability of energy might result into quartz inversion (573 degree) related brick cracking problem.

  Due to this distorted fire schedule it is certain that under-burned bricks with a bad ring, high percentage of breakage and no colour will be produced.

- **Economics**
  The selling of under-burned bricks with a bad ring and no good colour is not possible without a major reduction of the price. Hence, this resulting brick quality, linked with a high percentage of breakage, is causing a serious business threat and cannot be sustained in the long run.
2.7 Sulphur

Recommended sulphur content range:

Minimum: < 0.5 %
Maximum: 1 %

Introduction

In general the sulphur content in coal has no affect on a VSBK fire schedule. However, it is adversely affecting the health of the workers and therefore a coal quality with high sulphur content should not be used.

Further, the free sulphur is having a negative environmental impact on all steel parts that are fixed and used for the VSBK brick making infrastructure. Sulphur in combination with moisture will corrode all affected steel parts, especially the lid cover as well as the chimneys and roofing parts.
## Coal quality effect on fire schedule at a glance

<table>
<thead>
<tr>
<th>Description</th>
<th>Heating up rate</th>
<th>Vitrification</th>
<th>Cooling down rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Too quick heating up rate</td>
<td>Delayed heating up rate</td>
<td>Initial delayed, then too quick heating up rate</td>
</tr>
<tr>
<td><strong>2.1 Size of coal</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use of too small coal size (&lt; 10mm)</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
</tr>
<tr>
<td>Use only coal dust (blocking airflow)</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
</tr>
<tr>
<td>Use of too big coal size (&gt; 75 mm)</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
</tr>
<tr>
<td>Use of mixed coal size</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
</tr>
<tr>
<td><strong>2.2 High moisture content</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2.3 Coal ash content</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High ash content</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
</tr>
<tr>
<td>Low ash content</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
</tr>
<tr>
<td><strong>2.4 Ash fusion</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2.5 Volatile matter</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2.6 Calorific value</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low calorific value</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
</tr>
<tr>
<td>High calorific value</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
</tr>
<tr>
<td><strong>2.7 Sulfur content</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
How to conduct simple field tests of coal properties

The major objective to test the coal quality for specific use in VSBK technology; or for that matter in any brick firing; is to find out whether the available coal is suitable to maintain the optimal fire schedule which in turn defines the saleable bricks of an entrepreneur and hence its business sustainability.

Therefore, this chapter provides two main field-based coal quality testing methods, namely:

a) Visual (indicative observation and qualitative interpretation)
b) Field test kit (fairly accurate test result analysis)

The combined test result interpretation will provide a good understanding about the potential behaviour of the coal during the firing process and its likely impact to the optimal firing schedule. These tests are expected to give a fair idea of coal quality before undertaking expensive confirmatory tests. However, both the field-coal quality testing methods are not replacing the laboratory tests. Where the field test interpretations are not conclusive, it is recommended to perform laboratory tests also.

Getting to know your coal through visual test

Before a coal is analyzed by the coal quality test-kit, it is important to get to know the general and basic coal quality and its potential influence to the fire schedule.

Also, knowing the basic properties of the coal will enable the person who performs the coal tests to better understand the results obtained from the coal quality testing kits.

To get to know your coal, the following basic coal quality properties are required to be analyzed:

- Coal size
- Coal bulk density
- Colour of the coal
- Lustre of the coal
- Coal hardness
- Coal flame height
- Coal flame colour

Although the coal flame height and colour observations have been included in visual tests; they should be observed during the actual field testing using the test-kit.
3.1.1 Coal size

The size distribution of the supplied coal must be known to an entrepreneur in order to decide whether it is economical or not to use the coal for external VSBK firing operation.

Coal supplied from mines always needs to be processed to the correct size either manually or mechanically, without exceptions. Hence, the coal sizing work for both internal or external use will have economical implications and must be calculated into the brick production cost.

The recommended coal size to operate a VSBK with external fuel is between 20 and 50 mm. Depending on the hardness of the coal quality, the yield of correct sized coal after manual or mechanical sizing is high, medium or low. Naturally, a hard coal will have a high percentage of usable broken coal pieces, whereas a soft coal has a low yield.

The decision of using coal for either external or internal use in VSBK firing must be based on the coal size distribution by an entrepreneur. This decision will be guided by the economics of his business.

In some cases coal is available from the mines in a mixed form of fines and coarse. In case the entrepreneur has decided to use coal as an external fuel it is advisable for an entrepreneur to insist on a regular supply of lump coal.

Tentative guidelines for mixed size coal use:

Option 1:
Coal supply contains approx. 50 % fine and 50 % coarse:

- This type of coal supply tends towards the most optimum use of internal fuel and correct sizing of coarse coal for external use in the most economical manner. However, since it is not possible to produce bricks with 100% internal fuel, always a certain percentage (approx 20 to 40 %, to be defined case by case ) of coarse coal is recommended for use as an external fuel to maintain the correct fire-schedule.

Option 2:
Coal supply contains more than 50% fine and less than 50% coarse

- This type of coal supply tends towards the use of fine as internal fuel. However, with increasing percentage of fines, there will be a shortage of lump size for external fuel. Thus, to overcome this shortage, extra quantities of lump coals needs to be additionally purchased, if required from alternate sources.

Option 3:
Coal supply contains less than 50% fine and more than 50% coarse

- This type of coal supply tends towards the use of external fuel. However, in order not to waste the fine coal size it is recommended to store the fine in proper condition. Once the required quantity of internal fuel is accumulated for minimum of one month production the firing system should be changed to internal fuel schedule.
3.1.2 Coal bulk density

Density of coal is classified as either low, medium or high, depending on the amount of impurities present within the coal. In general, the VSBK firing process requires a medium density coal quality and therefore, this test provides already the first vital information about the suitability of the coal at hand.

- **Low density coal:**
  This type of coal is very light when weighed. It is not the preferred choice in a VSBK operation due to its high volatility, high calorific value and very low ash content.

- **Medium density coal:**
  Medium volatile coal in general has high calorific value and low ash content. This type of coal is the most suitable for VSBK operation.

- **High density coal:**
  In general high density coal has a high weight, i.e. they are comparatively heavier. It has a very low volatile content and a high amount of impurities. It also has a low calorific value and a high ash content which is unsuitable for any use in the field of brick production.
### Coal bulk density test procedure:

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Visual</th>
<th>Tools / Materials required</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Take the glass beaker and put the same over a level surface avoiding any slopes.</td>
<td></td>
<td>Glass cup / beaker</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Fill the beaker completely with water until the same overflows</td>
<td></td>
<td>Clean water, ca. 1lt.</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Carefully wipe out the excess water from the beaker sides and measure the weight of the glass beaker and the water, record it on record data sheet</td>
<td></td>
<td>Cotton clothes, or tissues paper</td>
<td>Enter result under point b.) in below record sheet</td>
</tr>
<tr>
<td>4.</td>
<td>Take a piece of representative coal sample enough to fit into the glass beaker</td>
<td></td>
<td>Approximate diameter of coal piece should be around 1 inch size.</td>
<td>The coal sample should not contain any loose particles</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Measure the weight of coal and record in data sheet</td>
<td>Balance &amp; record sheet</td>
<td>Enter result under point a.) in below record sheet</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Tie a string onto the coal and put into the beaker containing water carefully avoiding a splash</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Wait until the overflowing of water stops.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Take out the immersed coal sample carefully with a help of the string</td>
<td>Forceps / tong</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Carefully wipe out the excess water by the side of the beaker with tissue paper</td>
<td>Tissue paper</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
10. Weigh the beaker with remaining water and record in data sheet

11. Weight of the water that has been displaced by the coal d.) = (b.) minus c.)

12. Repeat these steps for minimum 3 to 4 other similar representative coal pieces

<table>
<thead>
<tr>
<th>Sl.</th>
<th>Testing parameters</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.)</td>
<td>Weight of coal</td>
<td>gm</td>
<td></td>
</tr>
<tr>
<td>b.)</td>
<td>Weight of beaker + water</td>
<td>gm</td>
<td></td>
</tr>
<tr>
<td>c.)</td>
<td>Weight of beaker + water after taking out coal</td>
<td>gm</td>
<td></td>
</tr>
<tr>
<td>d.)</td>
<td>Weight of water displaced</td>
<td>gm</td>
<td>(Note1)</td>
</tr>
<tr>
<td>e.)</td>
<td>Bulk density of coal</td>
<td>gm/cm³</td>
<td>(Note1)</td>
</tr>
</tbody>
</table>

**Determination of bulk density**

**Data record sheet**

**Note 1:**  
Coal bulk density recording can be done in attached excel sheet where value calculation is made automatically

As per the test results that have been conducted, the following are the approximate values for the density of coals:

- Low density coal – < 1.50 gm/cm³
- Medium density coal – 1.50 – 1.80 gm/cm³
- High density coal - > 1.80 gm/cm³
3.1.3 Colour of the coal
The colour of a coal generally varies from gray to black, depending on the ash content and other impurities present in the coal. Based on the coal colour it is possible to get initial coal quality indicators.

Deep black colour:
Indicates that it is a very good quality coal which has high carbon content, high calorific value and very low ash content.

Light black colour:
Indicates that this is a medium quality coal, having less carbon content and a high ash content.

Grey colour coal:
Indicates that this is a poor quality coal which has a very low carbon content, low calorific value and a very high ash content.

3.1.4 Lustre
Lustre is a measure of the shininess of coal. It varies from dull to shiny depending on the calorific value of the coal. Based on the coal shininess it is possible to get initial coal quality indicators.

Shiny lustre:
Indicates that it is a good quality coal having high calorific value and high volatility.

Dull lustre:
Indicates that this is a poor quality coal having very low calorific value and low volatility.
3.1.5 Hardness
Hardness of coal varies from soft to hard.

- **Soft Coal:**
  Soft coal means that it can be broken by pressing two hands together. If the same is black in colour and light then it has high calorific value. However if the same is brown in colour then it is premature type of coal i.e. lignite or peat.

- **Hard Coal:**
  Hard coal means that it cannot be broken by hand. Most often hard coals are also heavy in nature. It has in general low calorific value, very low volatility and high ash content. If its lustre is dull then it is not very suitable for VSBK operation.

3.1.6 Flame height
The flame of a coal provides useful indicators about the volatile matter present in the coal. Therefore, it is important to carefully observe the flame properties during the “Field test kit” testing process and to record it. In general it is experienced that the longer the flame, the higher the volatile matter content of the coal.

- **High flame**
  If a high flame during the initial period of burning is observed, then it is probably a 'high volatile coal'.

- **Low flame**
  If a low flame or no flame is observed, this indicates a 'low volatile coal'.

3.1.7 Fire colour
During the burning of coal the developing colour of the fire is an indicator of what temperature is reached. Determining the temperature by observing the colour of the fire is sometimes tricky and requires quite some experience. The table below provides some basic indication for fire colour assessment.

<table>
<thead>
<tr>
<th>Colour</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow</td>
<td>&lt;475</td>
</tr>
<tr>
<td>Lowest Visible Red</td>
<td>475</td>
</tr>
<tr>
<td>Lowest Visible Red to Dark Red</td>
<td>475 to 650</td>
</tr>
<tr>
<td>Dark Cherry to Cherry Red</td>
<td>650 to 750</td>
</tr>
<tr>
<td>Cherry Red to Bright Cherry Red</td>
<td>750 to 815</td>
</tr>
<tr>
<td>Bright Cherry Red to Orange</td>
<td>815 to 900</td>
</tr>
</tbody>
</table>

- **Dull red**
  If the coal burns with a dull red colour then it has a low calorific value. As per the above colour code the visible colour will be around dark cherry to cherry red.

- **Orange red**
  If the coal burns with a bright orange colour then the coal is of high calorific value. As per the colour code it belongs to the highest visible colour of bright cherry red to orange.
## Indicative visual coal test result interpretation table

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Test</th>
<th>Ash content</th>
<th>Volatile matter</th>
<th>Calorific value</th>
<th>Economics</th>
<th>Suitability for VSBK external fuel operations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>Mid</td>
<td>High</td>
<td>Low</td>
<td>Mid</td>
</tr>
<tr>
<td>3.1.1</td>
<td><strong>Coal size</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>High % of fines &lt;20mm</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>High % of sizable &gt; 20mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>3.1.2</td>
<td><strong>Coal bulk density</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.3</td>
<td><strong>Coal colour</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Deep black</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Light black</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grey</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.4</td>
<td><strong>Lustre</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shiny lustre</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dull lustre</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>3.1.5</td>
<td><strong>Hardness</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soft + black + light</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soft + brown + light</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hard</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hard + dull</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>3.1.6</td>
<td><strong>Flame height</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>X</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.7</td>
<td><strong>Flame colour</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dull red</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Orange red</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2 Getting to know your coal through the “Field test kit”

One of the major objectives of this coal manual is to equip the VSBK entrepreneur and field professionals with a simple field test which would enable coal related decision-making in the VSBK technology. It has often been observed that due to the absence of such decisive tools, entrepreneurs have to accept any quality brought by the suppliers, often paying the same price for differing coal qualities. This manual is an attempt to introduce and apply a practical and field-based coal quality test-kit to instantly confirm the coal quality being supplied to the VSBK site.

The application of this practical and field-based coal quality test-kit has essentially been developed for VSBK brick entrepreneurs and has therefore to be fine-tuned for uncomplicated operation.

Besides the VSBK entrepreneurs, this coal quality test-kit can also be used by other brick production entrepreneurs and VSBK technology associated professionals who need to locate suitable coal quality mines and coal suppliers.

A single test with this kit is estimated to take about two hours time. Therefore, the coal quality tests are limited to the following three quality parameters:

- Volatile matter indication in coal
- Calorific value of the coal
- Ash content of the coal and its fusion behaviour

3.2.1 Basic equipment for the field test-kit

The following tools and equipment are essential to conduct coal quality with the field test-kit:

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Material</th>
<th>Quantity</th>
<th>Purpose</th>
<th>Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cook stove, (locally termed as “Chula”)</td>
<td>1</td>
<td>To test the coal</td>
<td><img src="image1.jpg" alt="Picture" /></td>
</tr>
<tr>
<td>2</td>
<td>Standard pot with lid</td>
<td>1</td>
<td>For water boiling test</td>
<td><img src="image2.jpg" alt="Picture" /></td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th></th>
<th>Equipment</th>
<th>Quantity</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Electronic balance</td>
<td>1</td>
<td>For weight measurement</td>
</tr>
<tr>
<td>4</td>
<td>Fan</td>
<td>1</td>
<td>For ensuring uniform airflow combustion</td>
</tr>
<tr>
<td>5</td>
<td>Flexible thermocouple with indicator</td>
<td>1</td>
<td>For measuring water temperature</td>
</tr>
<tr>
<td>5</td>
<td>Non flexible thermocouple with indicator</td>
<td>1</td>
<td>For measuring fire temperature</td>
</tr>
<tr>
<td>6</td>
<td>Transparent glass beaker</td>
<td>1</td>
<td>For measuring bulk density of coal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>New photo</td>
</tr>
<tr>
<td>7</td>
<td>Dry wood</td>
<td>200 mg</td>
<td>Ignition material</td>
</tr>
<tr>
<td></td>
<td>Kerosene</td>
<td>40 gm</td>
<td>Ignition material</td>
</tr>
<tr>
<td>---</td>
<td>----------</td>
<td>-------</td>
<td>------------------</td>
</tr>
<tr>
<td>9</td>
<td>Stop watch</td>
<td>1</td>
<td>Record of time</td>
</tr>
<tr>
<td>10</td>
<td>Forceps</td>
<td>1</td>
<td>For handling hot materials</td>
</tr>
<tr>
<td>11</td>
<td>Spoon</td>
<td>1</td>
<td>To clean the wood ash out of the stove bottom</td>
</tr>
<tr>
<td>12</td>
<td>Calculator</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Tissue paper</td>
<td></td>
<td>To dry and wipe out excess water</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>14</td>
<td>Match box</td>
<td>1</td>
<td>For lighting of fire</td>
</tr>
<tr>
<td>15</td>
<td>Data logging sheet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Water (clean)</td>
<td>4 kg</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Coal, approx. 25mm size</td>
<td>1 kg</td>
<td>(If size is bigger than 25 mm then it takes too much time to ignite, and if it is smaller than 25mm then there is not enough airflow due to the dense coal layer and hence fire will not move up)</td>
</tr>
</tbody>
</table>
### 3.2.2 “Field test kit” testing procedure

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Description of activity</th>
<th>Remarks</th>
<th>Reference chapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Choose representative coal samples for testing (about 25 mm size)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Conduct coal colour visual test</td>
<td>Observe and record the colour of coal (black, grey or greyish black)</td>
<td>3.1.3</td>
</tr>
<tr>
<td>3.</td>
<td>Conduct the coal lustre test</td>
<td>Observe and record the lustre of the coal (shiny or dull)</td>
<td>3.1.4</td>
</tr>
<tr>
<td>4.</td>
<td>Conduct the coal hardness test</td>
<td>Take a small piece of coal and attempt to break the same by hand. Record the hardness</td>
<td>3.1.5</td>
</tr>
<tr>
<td>5.</td>
<td>Conduct coal density test</td>
<td>As per procedure described in 3.1.2. and record the data</td>
<td>3.1.2</td>
</tr>
<tr>
<td>6.</td>
<td>Observe the coal flame height</td>
<td>Observe and record the flame height of the burning coal</td>
<td>3.1.6</td>
</tr>
<tr>
<td>7.</td>
<td>Observe the coal flame colour</td>
<td>Observe and record the colour of the flame</td>
<td>3.1.7</td>
</tr>
</tbody>
</table>
The “FIELD TESTING KIT” for testing coal quality

Part B: “Field test kit” coal quality test

In order to conduct the coal field tests the following conditions must be complied with:

- Mouth protection masks must be worn during the entire test time
- No synthetic clothes should be worn due to danger of caching fire, use only cotton based clothes.
- The coal testing should be made in an enclosed space with minimum interference from external weather conditions, especially rain and wind
- Due to development of dense smoke, coal tests should not be conducted where it affects surrounding people, especially children
- Fire extinguisher must be available in order to prevent a fire accident
- The pot should be cleaned after every test. The bottom of the pot should be scratched clean to avoid false measurements due to layer of soot. The inside of the pot should be scratched clean to avoid false measurements due to deposits of scale from water.
<table>
<thead>
<tr>
<th>Step</th>
<th>Instruction</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Weigh 1 kg (25 mm) of representative coal sample on the balance and keep aside for testing</td>
<td>1 kg of coal is the minimum amount required to boil the standardized 4 kg of water. Further, the stove can only accommodate more than 1 kg of coal. Record exact coal amount in record sheet B2 point 4.</td>
</tr>
<tr>
<td>2.</td>
<td>Take the metal pot and weigh it</td>
<td>Record the weight of the pot in sheet B2 point 3.</td>
</tr>
<tr>
<td>3.</td>
<td>Keep the metal pot on the balance and add exactly 4 kg of water into the pot</td>
<td>4 lt. of water is the maximum amount required to evaporate by using 1 kg of coal. Record the exact amount in record sheet B2 point 3.</td>
</tr>
<tr>
<td>4.</td>
<td>Place the lid over the metal pot and fix the flexible thermocouple in the required position</td>
<td>The thermocouple is required for measuring water boiling temperature.</td>
</tr>
<tr>
<td>5.</td>
<td>Weigh 500gm dry and easy burning wood and keep aside.</td>
<td>The quantity of 500 gm wood is sufficient to maintain the fire till all the coal attains uniform combustion.</td>
</tr>
<tr>
<td>6.</td>
<td>Weigh 20 gm kerosene to be used as ignition material to light up the wood.</td>
<td>20gm is normally sufficient for initiating the ignition process of wood.</td>
</tr>
<tr>
<td>Step</td>
<td>Description</td>
<td>Notes</td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td>-------</td>
</tr>
<tr>
<td>7.</td>
<td>Place the weighed coal in the cook stove in an even manner</td>
<td>Coal placing pattern should allow for normal airflow to maintain the fire.</td>
</tr>
<tr>
<td>8.</td>
<td>Place the non flexible thermocouple at the required position that allows proper fire temperature measuring</td>
<td>This thermocouple is needed for measuring fire temperature.</td>
</tr>
<tr>
<td>9.</td>
<td>Place the fan at distance of 4 feet (1.2 m) from the mouth of the stove.</td>
<td>The level of the stove mouth and the fan needs to be at the same level so that air is effectively blown into the fire.</td>
</tr>
<tr>
<td>10.</td>
<td>Place the pot filled with the 4 kg of water on the stove and place the lid along with the attached flexible thermocouples on top of the pot</td>
<td>Care must be taken that no water will spill during the placing of the pot. Ensure that both thermocouples are switched on and undisturbed during the whole test.</td>
</tr>
<tr>
<td>11.</td>
<td>Gradually dip the pieces of wood in kerosene and initiate the firing process at the bottom opening of the cook stove</td>
<td>Once the fire is ignited and is gaining strength add gradually more pieces of wood to maintain a steady fire that allows proper ignition of the coal.</td>
</tr>
<tr>
<td>12.</td>
<td>Turn on the fan after exactly 10 min. of fire initiation</td>
<td>The position and operation of the fan must not be altered through the entire test.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>13.</strong></td>
<td>Record the time, temperature of water and the temperature of coal at regular intervals of 2 min.</td>
<td>Record the exact value in record sheet B2 point 2. Keep recording until the water reaches boiling point. (indicator of boiling point reached is that the temperature remains constant).</td>
</tr>
<tr>
<td><strong>14.</strong></td>
<td>Monitor the presence of flame, its height and colour of the burning coal</td>
<td>Record the observation in record sheet B point 2.</td>
</tr>
<tr>
<td><strong>15.</strong></td>
<td>Remove the wood ash from the mouth of the stove and dispose of it</td>
<td>Use a spoon or any other tool to clean the stove base properly.</td>
</tr>
<tr>
<td><strong>16.</strong></td>
<td>Once the temperature of water has reached the boiling point, remove the lid and record the exact temperature of the coal.</td>
<td>Record the exact value in record sheet B2 point 2. Do not put the lid back on the pot, keep the pot open so that maximum water can evaporate. Record the total time required to reach the boiling point and record it in sheet B point 3. Keep recording the coal temperature.</td>
</tr>
<tr>
<td><strong>17.</strong></td>
<td>Keep pot on the stove, the fan running and maintain temperature measurements of coal until the water has cooled down</td>
<td>The water boiling test can be closed once it is possible to comfortably touch the water by hand.</td>
</tr>
<tr>
<td><strong>18.</strong></td>
<td>Weigh the remaining unused wood that was meant for initial fire ignition</td>
<td>Record the exact value in record sheet B2 point 1. From this sheet calculate the amount of wood consumed.</td>
</tr>
<tr>
<td></td>
<td>Measure and record the weight of water with pot</td>
<td>Record the exact value in record sheet B2 point 3. From this sheet calculate the percentage of water evaporated.</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>20.</td>
<td>Wait till the coal ash has cooled down, measure and record the weight of ash.</td>
<td>Record the exact value in record sheet B2 point 4.</td>
</tr>
<tr>
<td>21.</td>
<td>Record all the final results in sheet B for further processing</td>
<td></td>
</tr>
</tbody>
</table>

### 3.3 Determination of coal heat value

The water evaporation percentage is solemnly depending on the amount of heat generated by the coal. Therefore, the entire test procedure mentioned above is to measure the heat value through the means of water evaporation. Once the main indicator, the water evaporation percentage for a given coal is known, two types of information can be concluded:

- By plotting the percentage of water evaporated in the graph the **suitability** of the coal for use in VSBK firing can be determined
- The percentage of water evaporated can be put into the equation (calorific value of the coal = to 656 x percentage of water evaporated to the power of 0.6) to determine the **heat value** of the coal

**Example:** Percentage of evaporated water is 35

\[ 656 \times 35^{0.6} = 656 \times 8.44 = 5536.64 \text{ say } 5536 \text{ KCal/kg} \]

The more coal samples are tested and plotted, the more accurate can the coal suitability range as well as the heat value be defined for the use in a VSBK.

Below shown master graph is the result of several coal tests made in India and in Nepal. These types of master graphs are assumed to be **country specific** depending on coal type.
quality, proximate and ultimate analysis, mineralogical composition, altitude and climatic condition of testing place. Thus, it is necessary to develop similar kind of master graphs for each country that intends to use this field coal testing methodology for determining its coal suitability for the VSBK firing process.

To develop a master graph it is advisable to test at least 10 different coal samples to achieve representative table master graph.

During the coal testing period in India and Nepal, some coal samples could not be tested since the testing procedures applied were not sufficient to ignite the coal. Therefore, it is normal that variation with such an elementary testing method will happen. However, it is advisable not to use a coal for a VSBK that could not be tested with this methodology.

**Determination of Heat Value of Coal**

- **Left axis:** Shows the calorific value
- **Horizontal axis:** Shows the percentage of evaporated water during the coal sample tests

This graph clearly indicates that a coal quality that achieves a water evaporation percentage between **30 to 45%** is suitable for use in VSBK. The recommended range of 4500 to 5500 Kcal/kg (see chapter 2.6) has been applied to define the recommended water evaporation range.

- If a coal has less than 30 % evaporation percentage: Please refer to chapter 2.3, 2.6 and 4.6
- If a coal has more than 45 % evaporation percentage: Please refer to chapter 2.3, 2.4.2.6 and 4.6
3.4 Determination of volatility (volatile matter)

Plot the time taken to reach the boiling point of each tested coal sample in the graph given below:

*Defining Choice of Coal in VSBK for Volatility*

Above graph provides a qualitative overview of the volatility of the coal suitable for use in VSBK operation.

**Left axis:** Shows the time (minutes) that was needed to reach the boiling point of the water

**Horizontal axis:** Shows the number of coal sample tests

The recommended calorific value range between 4500 to 5500 (see chapter 2.6) has been applied to define the volatility of coal suitable for VSBK. The resulting time (left axis) of achieving boiling temperature is the main indicator for assessing the suitability of the coal for a VSBK.
Coals which take less than approximately 15 minutes to boil water are considered as a high volatile coal and of high quality. Similarly more than 30 minutes water boiling time (for a fixed quantity of 4 kg water) is considered as a low volatile and poor quality coal not recommended for use in a VSBK.

Thus the time taken to initiate boiling in 4 kg of water should be between 15 – 30 minutes for coals which is considered to be suitable for use in VSBK.

**Note: Disclaimer**

It must be mentioned that the field test-kit gives only a qualitative indication of the coal. It is not a quantitative analysis. Due to variation in coal quality (due to its natural process of formation) there might be variation in extrapolation. However, exceptions will always be there. With more and more testing of coal and updating the graph, the reliability of interpretation will become more accurate.
# FIELD TESTING OF COAL QUALITY

Data logging sheet

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Date of testing</th>
<th>Time of testing</th>
<th>Place of testing</th>
<th>Conducted by</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>LABORATORY DATA:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test</td>
</tr>
<tr>
<td>Calorific value</td>
</tr>
<tr>
<td>Ash content</td>
</tr>
<tr>
<td>Volatile matter</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FIELD DATA:</th>
</tr>
</thead>
</table>

1. **Physical property of coal**
   - Colour
   - Lustre
   - Bulk density
   - Hardness
     - Hard
     - or
     - Soft

2. **Visual observation (during testing)**
   - Flame
   - Flame height
   - Fire colour

3. **Testing data**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time taken to reach boiling point</td>
<td>minutes</td>
<td></td>
</tr>
<tr>
<td>Maximum temperature reached during coal combustion</td>
<td>deg C</td>
<td></td>
</tr>
<tr>
<td>Initial ignition temperature of coal</td>
<td>deg C</td>
<td>(after full burning of ignition material)</td>
</tr>
<tr>
<td>Amount of water evaporated</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Ash remained</td>
<td>%</td>
<td></td>
</tr>
</tbody>
</table>
# Determination of bulk density

<table>
<thead>
<tr>
<th>Sl.</th>
<th>Testing parameters</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Weight of coal sample</td>
<td>gm</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Weight of beaker + water</td>
<td>gm</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Weight of beaker + water after taking out coal sample</td>
<td>gm</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Weight of water displaced</td>
<td>gm</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Bulk density of coal</td>
<td>gm/cm³</td>
<td></td>
</tr>
</tbody>
</table>
## ANNEXURE 3

**FIELD TESTING OF COAL QUALITY**

Data logging sheet

### Water boiling tests

1. **Ignition material**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Fixed quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kerosene</td>
<td>20 gm</td>
<td></td>
</tr>
<tr>
<td>Dry wood</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of wood</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight of wood remaining</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight of wood consumed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. **Water boiling test**

<table>
<thead>
<tr>
<th>Time (in minutes)</th>
<th>Water temperature (in deg C)</th>
<th>Coal temperature (in deg C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Temperatures after (boiling point) removing pot lit

|                   |                              |                             |
|                   |                              |                             |
|                   |                              |                             |
|                   |                              |                             |
|                   |                              |                             |
|                   |                              |                             |


### Water evaporation test

<table>
<thead>
<tr>
<th>Water measurement (in gms)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of pot</td>
<td>gm</td>
</tr>
<tr>
<td>Weight of water</td>
<td>gm</td>
</tr>
<tr>
<td>Weight of pot + 4 kg water</td>
<td>gm</td>
</tr>
<tr>
<td>Weight of pot + water after test</td>
<td>gm</td>
</tr>
<tr>
<td>Weight of water remaining</td>
<td>gm</td>
</tr>
<tr>
<td>Weight of water evaporated</td>
<td>gm</td>
</tr>
<tr>
<td>% of water evaporated</td>
<td>%</td>
</tr>
</tbody>
</table>

### Ash content

<table>
<thead>
<tr>
<th>Initial coal sample weight (in gms)</th>
<th>Ash content (in gms)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4. Practical solution to coal properties outside recommended value

Getting hold of the correct and ideal type of coal quality to operate a VSBK is not always possible, be it for economical reasons or country specific coal quality limitations. Therefore, it is important to understand the technical possibilities (solutions) to continue VSBK brick firing operation with coal properties that are not within the recommended values.

The most extreme change due to non availability of suitable coal would be to shift from external fuel brick firing to internal fuel brick firing. Coincidentally, because the VSBK is performing best with internal fuel, this is in most cases the only viable solution.

“Spider Net” graph

The ideal coal properties required for operating a VSBK with external fuel are represented in a spider net graph. The coal test results obtained in the field (or even laboratory) can be entered into this graph and it becomes visible whether the tested coal properties are within the recommended values or not.

If they are within the recommended values, the respective coal can be used for VSBK operation. If they are not, the following chapter provides some recommendations for how to proceed with the respective coal quality.
4.1 Size of coal

There are certain coals which have a large proportion of powdery or fine particles; this can be due to its softness or extreme high amount of small particles (see chapter 3.1.1) at the coal mining stage.

The moment coal particles below 20mm are used, the required natural air flow with needed oxygen to timely nourish the fire is distorted, causing the problems described in chapter 2.1.2 and 2.4

Solution 1: Sieving
The coal can be sieved to separate large-sized particles to be used as external fuel in VSBK.

Solution 2: Fuel briquettes
Powdered coal can be mixed with dung and other binding materials to form briquettes. One of the possible options is to produce briquettes as it is done for initial firing of VSBK. The briquettes can also be made using a briquetting machine or are sometimes available in the market as ready-made fuel.

Solution 3: Internal fuel
If the above mentioned methods are not possible, the only practical solution is to use the coal for internal brick production firing.

4.2 Moisture content of coal

Problem area:
Coal moisture content above 10%

Too high coal moisture content can be avoided:
**Solution 1: Keep the coal dry**

This can be done by storing the coal under a rain- and leak-proof roof. Further, it is recommended to store a fair amount of sized coal at the plat-form of the kiln for some time, protected from rain and stored safely to prevent it from accidental self-ignition in order to reduce the coal moisture content.

However, as per example shown under 2.2.1, in general one can neglect the importance of the coal moisture content.

4.3 **Ash content of coal**

**Problem area:**

Ash content between 25 and 40 % and in particular above 40%

High ash content coal is economically interesting for a brick entrepreneur and hence preferred. However, high ash content indicates a low heating value (calorific value) of the coal. In order to achieve the necessary brick vitrification temperature a relative high amount of coal must be placed among the bricks. This poses the danger of low oxygen flow within the shaft.

On the other hand, if a coal has low ash content, in particular ash content below 10%, it indicates that this coal has a very high calorific value. Therefore, by using this type of coal there is a danger that the energy is released very slowly, hence creating a longer than desired soaking or vitrification length of the fire and therefore a too short cooling down time for the bricks, resulting in thermal shocks and high rate of breakages.

**High ash content:**

**Solution 1: Double Chula**

In order to accommodate a larger quantity of coal without blocking the airflow, it is recommended to stack the bricks in the ‘double Chula’ system.

**Solution 2: Small sized coal**

High-ash coal should be broken down into smaller size. Breaking of coal into smaller pieces increases the surface area of the coal particles and exposes the combustible material available inside the coal to come in contact with air. This action supports the complete combustion of coal.

**Solution 3: Mix low ash content coal**

There is a possibility to mix a low ash content coal (if available) in 50% to 50% proportion, to start with. The final amount of low ash content coal that can or should be mixed must be experimented in an empirical manner. The two types of coal can be separately weighed for each batch and fed one after the other in each layer. However, coal mixing is not such an
easy task and one must have a proper site management and a ‘more than average’ disciplined work force at the VSBK firing place.

**Solution 4: Internal fuel**
If a coal has more than 40% ash content then it is practically very difficult to properly operate a VSBK. The only real practical solution would be to use this coal quality for internal fuel brick firing.

### 4.4 Ash fusion of coal

Ash fusion, if it is considered as a problem, must be assessed in a holistic manner and always in combination of the coal quality and the green brick soil properties. The ash fusion temperature should ideally be minimum 50°C higher than the soil vitrification temperature. In order to find out, the following two tests must be conducted and analyzed in a qualified laboratory.

**a.) Laboratory ash fusion test**

Ash fusion temperatures are determined by viewing a moulded specimen of the coal ash through an observation window in a high-temperature furnace. The ash, in the form of a cone, pyramid or cube, is heated steadily past 1000 °C to as high temperatures as possible, preferably to 1,600 °C (2,910°F). The following temperatures are recorded:

- **Deformation temperature:** This is reached when the corners of the mould first become rounded
- **Softening (sphere) temperature:** This is reached when the top of the mould takes on a spherical shape.
- **Hemisphere temperature:** This is reached when the entire mould takes on a hemispherical shape
- **Flow (fluid) temperature:** This is reached when the molten ash collapses to the form of a flattened button on the furnace floor.

**b.) Optimal soil vitrification range test**

Each soil has an individual soil characteristic dependent vitrification range. There are so called tolerant soils, where the compressive strength is stable or slightly increasing during the vitrification, until the soil melts; and there are difficult soils where the compressive strength is collapsing relatively shortly (melting) after reaching the vitrification temperature, hence, possesses a very narrow temperature range tolerance.
Determination of optimum firing temperature

Soil sample with a low firing temperature range, not recommended for VSBK

Soil sample with a good firing temperature range, good and recommended for VSBK
Analyzing the test results:

Compare ash fusion temperatures with the soil vitrification temperatures. If the ash fusion temperature is not minimum 50 °C higher than the soil vitrification temperature, then it is not advisable to use this coal for firing this soil.

In general, a soil with a low vitrification tolerance is difficult to fire in a VSBK. The worst combination would be to have a low vitrification tolerance soil fired with a coal quality that has a low ash fusion temperature. For such a combination there is only one solution, namely: search for a different soil- and/or coal-quality.

**Solution 1: Increase air flow**

When there are occasional instances of melting of ash in the kiln, it can be controlled to some extent by increasing the air flow through the shaft. Increased air flow results in better distribution of heat, reducing the hot spots and helps in reducing the probability of melting of ash. This can be achieved by:

- Less dense brick setting
- Opening of dampers

**Solution 2: Internal fuel**

If the coal fusion temperature is not minimum 50°C higher than the soil vitrification temperature it will be very difficult to operate a VSBK without serious brick damages (melting where the coal is placed). The only real practical solution would be to use this coal quality for internal fuel brick firing.

### 4.5 Volatile matter

#### Problem area:

- **‘Mild rated’ problem area:**
  Volatile matter of coal between 25 & 40% as well as between 15% and 10%
- **‘Severe rated’ problem area:**
  Volatile matter of coal below 10% and above 40%

The use of coal quality that is rated within the “**Mild rated’ problem area”** is most of the time manageable and its appropriateness to maintain the optimal fire schedule is very much linked to the soil quality. Therefore, it is difficult to recommend solutions to mitigate the anticipated problems.

In general, a high volatile type of coal is igniting far too quickly and will in all likelihood create quartz inversion related problems. A low volatile coal on the other hand will not easily ignite and will result in a too long heating up rate, too short vitrification time and too quick cooling down rate.
High volatile coal:

**Solution 1:** Use big coal chunks
In order to ensure that the added coal still has the necessary energy to properly vitrify the brick, the use of bigger sized coal pieces must be tested. The large coal particles reduce the burning rate of the coal.

**Solution 2:** Reduce air flow through;

**Tight brick stacking**
In order to avoid the high volatile coal not igniting too quick and burning out too soon it is advisable to reduce the overall air flow circulation inside the shaft by changing to a tighter brick stacking pattern.

**Closing of lid cover and dampers**
Another method of reducing unwanted air circulation in the shaft is closing the lid cover and changing the position of the dampers.

**Solution 3:** Mix low volatile coal
In case air reduction or the use of bigger coal size pieces does not yield the desired improvement, there is a possibility to mix a low volatile coal (if available) in 50% to 50% proportion, to start with. The final amount of low volatile coal that can or should be mixed must be experimented in an empirical manner. However, coal mixing is not such an easy task and one must possess a proper site management and a ‘more than average’ disciplined work force at the VSBK firing place.

Low volatile coal:

**Solution 1:** Use small size coal
In order for the coal to ignite at the right moment, (a low volatile coal has difficulties to ignite) it is recommend to size the low volatile coal into small pieces (the actual size needs to be determined through practical experiments) which should ensure quicker ignition. However, care must be taken that no other problems, such as mentioned under 3.1.1 are created.

**Solution 2:** Increase air flow
Increased air flow results in better distribution of heat, a rise in temperatures and reducing the hot spots. This can be achieved by:

- Less dense brick setting
- Opening of dampers
Solution 3: Mix high volatile coal
In case using smaller sized coal pieces does not yield the desired improvement, there is a possibility to mix a high volatile coal (if available) in 50% to 50% proportion, to start with. The final amount of low volatile coal that can or should be mixed must be experimented in an empirical manner. However, coal mixing is not such an easy task and one must have a proper site management and a ‘more than average’ disciplined work force at the VSBK firing place.

The use of coal quality that is rated within the “Severe problem area” is not recommended for external VSBK brick firing fuel.

Solution 4: Internal fuel
If a coal has more than 40% or less than 10% volatile matter then it is almost impossible to properly operate a VSBK. The only real practical solution would be to use this coal quality for internal fuel brick firing.

4.6 Calorific value (fixed carbon)

![Diagram of calorific value (fixed carbon)]

Problem area:
Mild rated problem area:
Calorific value of coal between 3500 kcal/kg and 4500 kcal/kg as well as between 4500 kcal/kg and 7500 kcal/kg.

Severe rated problem area:
Calorific value of coals below 3500 kcal/kg and above 7500 kcal/kg

The use of coal quality rated within the “Mild rated problem area” is most of the time manageable and its appropriateness to maintain the optimal fire schedule is very much linked to the soil quality. Therefore, it is difficult to recommend solutions to mitigate the anticipated problems. In general, a lower end calorific value of a coal implies the same problems as stated under 4.3, ‘High ash content’.

Low calorific value:

Solution 1: Double Chula
Due to the relatively high amount of low calorific value coal that needs to be loaded in order to achieve the required brick vitrification temperature, and at the other hand avoiding airflow blockages, it is recommended to stack the bricks in the double Chula system.

Solution 2: Mix high calorific value coal
In case the double Chula does not yield the desired air flow improvement, there is a possibility to mix a low calorific value coal (if available) in 50% to 50% proportion, to start with. The final amount of high calorific value coal that can or should be mixed must be
experimented in an empirical manner. Again, coal mixing is not such an easy task and one must have a proper site management and a ‘more than average’ disciplined work force at the VSBK firing place.

High calorific value coal:

Solution 1: Small sized coal
In order to ensure that the energy (heat) of the coal is released at the right time, the size of a high calorific value coal must be reduced. It is particularly important that the sizes of the coal pieces are as regular as possible to ensure that the energy is released and consumed uniformly.

The use of coal quality that is rated within the “Severe rated’ problem area” is not recommended for external VSBK brick firing fuel.

Solution 2: Internal fuel
If a coal has less than 3500 kcal/kg or more than 7500 kcal/kg then it is nearly impossible to properly operate a VSBK in praxis. The only real practical solution would be to use this coal quality for internal fuel brick firing. Additionally, a coal with more than 5000 kcal/kg is usually very expensive and might not be economical viable for using as internal fuel.

4.7 Sulphur

Problem area:
Sulphur content between 1% and 2%, particularly above 2%

As the sulphur content of the coal is mainly harmful to the health of the workers and the nearby environment, it is in general advisable to use a coal with lowest possible sulphur content. However, this is unfortunately, in most cases, not realistic to reject a coal quality due to high sulphur content due to lack of alternative coal quality.

Solution 1: Internal fuel
In order to minimize the release of SO₂ it is recommended to utilize high sulphur content coal for internal brick firing fuel.

However, one must be aware that the release of SO₂ with internal fuel can only be reduced by max. 20 to 25%.

The release of SO₂ can be further reduced if very fine limestone powder is mixed into the brick making soil. Mixing of limestone powder at 2% by mass has been found to be effective in Vietnam. This ratio has also to be established through experimentation. However, one should note that until and unless limestone powder is available in close vicinity, at a cheap
price and for a calculated period of time, this method may not be economically viable. It also requires good supervision. Additionally, adding limestone powder to a soil might increase the overall energy consumption for firing the bricks.

**Solution 2: Personal protection**

It is worth mentioning here that it is always important that a workers’ health is well protected during his/her working shift on the kiln. Therefore, mouth masks to protect the open inhalation of $\text{SO}_2$ and/or other harmful gases must always be made freely available by the entrepreneurs. It should also be insisted upon that the workers are also wearing them correctly.

**Solution 3: Using limestone/lime**

In the larger furnaces or boilers which are using fluidised bed technology, $\text{SO}_2$ emissions can be controlled by adding a sorbent (a substance used to absorb any $\text{SO}_2$ present, for example lime or limestone) to the bed of inert material. The limestone effectively absorbs the $\text{SO}_2$ as it is released from the coal and retains it within the ash, which is removed regularly. This has not been tried in VSBK, but addition of limestone in powdered form or in small particles during coal feeding has a high probability of reducing $\text{SO}_2$ emissions in VSBK.

The other possible system is the scrubbing of flue gases, which is widely used in other industries. In this system, crushed limestone / lime is mixed with water to form slurry which is then sprayed into the flue gases containing sulphur. This absorbent reacts with the $\text{SO}_2$ to form aqueous slurry of calcium sulphite. This has been tried in a VSBK in Vietnam by using an exhaust fan in the chimney and passing the flue gases through lime water. No reports are available on the effectiveness of this procedure in VSBK.

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**Final remarks:**

Finding the correct coal quality for external brick firing in a VSBK system demands a high degree of brick making professionalism. This is basically expected from any brick making entrepreneur and cannot be substituted by VSBK project staff in the long run.

Therefore, before an entrepreneur is entering into a VSBK technology based brick business it is important that the critical issue of coal quality for commercially sustaining the VSBK technology based brick business is made known to him.

A lot of coal quality based problems can be solved by deciding to use as much as possible internal fuel for brick firing. Hence, it is recommended to standardize the operation of the VSBK firing system on the basis of internal fuel.