Comprehensive training material for technicians
Khurja ceramic cluster

GEF-UNIDO-BEE Project

Promoting Energy Efficiency and Renewable Energy in selected MSME clusters in India

Prepared for:

Bureau of Energy Efficiency

The Energy and Resources Institute

...towards global sustainable development

This document has been originally prepared by TERI as a part of 'Capacity Building of LSPs' activity under the GEF-UNIDO-BEE project 'Promoting Energy Efficiency and Renewable Energy in selected MSME clusters in India'.

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GEF-UNIDO-BEE Project, Bureau of Energy Efficiency, 2018

"Capacity Building of Local Service Providers"

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About this manual

This manual provides, in a direct and simple manner, guidance on improving energy efficiency for local service providers (LSPs) in the 'technicians' category.

The aim is to build their capacities and equip them with the necessary knowledge and skills and to provide background information and tips regards energy efficiency (EE)/renewable energy (RE) options in important ceramic manufacturing process viz. energy conservation opportunities in ceramic units, construction of gas based tunnel kiln system and advanced technologies for ceramic industries.

The manual is designed to complement the knowledge shared with the participants through a series of four one day training/capacity building programs undertaken by TERI in Khurja Ceramic Cluster between February to April 2018 under the GEF-UNIDO-BEE Project "Capacity Building of Local Service Providers".

1.0 Introduction

1.1 Background

The overall aim of the GEF-UNIDO-BEE project is to develop and promote a market environment for introducing energy efficiency and enhancing the use of renewable energy technologies in process applications in selected energy-intensive MSME clusters in India. This would help in improving the productivity and competitiveness of the MSME units, as well as in reducing the overall carbon emissions and improving the local environment.

The following three ceramic clusters are targeted under the assignment – Thangadh, Morbi and Khurja.

This comprehensive training material for Khurja ceramic cluster is targeted at 'technicians' category. The material is structured in the following 3 modules.

Module 1	Energy conservation opportunities in ceramic units
Module 2	Construction of gas based tunnel kiln system
Module 3	Advanced technologies for ceramic industries

2.0 Module 1 – Energy conservation opportunities in ceramic units

2.1 Fundamentals of gas based combustion systems

2.1.1 Combustion of fuel

Combustion is a chemical process that converts chemical energy to thermal energy. There are three types of combustion:

- *Perfect combustion* is achieved when all the fuel is burnt using only the theoretical amount of air, but perfect combustion cannot be achieved in actual operating conditions
- ***Complete combustion*** is achieved when all the fuel is burnt using the minimal amount of air above the theoretical limit. Complete combustion should be the goal. With complete combustion, the fuel is burned at the highest combustion efficiency with low pollution.
- ***Incomplete combustion*** occurs when all the fuel is not burnt, which results in the formation of unburnts such as carbon monoxide and soot.

During combustion, heat energy is released due to oxidation of fuel composition depending upon the type of combustion takes place. The quantity of energy released from fuel constitute depends on type combustion product generated during oxidation.

$C + O_2 \rightarrow CO_2 +$ 8084 Kcal/kg of carbon

$2C + O_2 \rightarrow 2\,CO +$ 2430 Kcal/kg of carbon

$2H_2 + O_2 \rightarrow 2H_2O +$ 28,922 Kcal/kg of hydrogen

$S + O_2 \rightarrow SO_2 +$ 2,224 Kcal/kg of sulphur

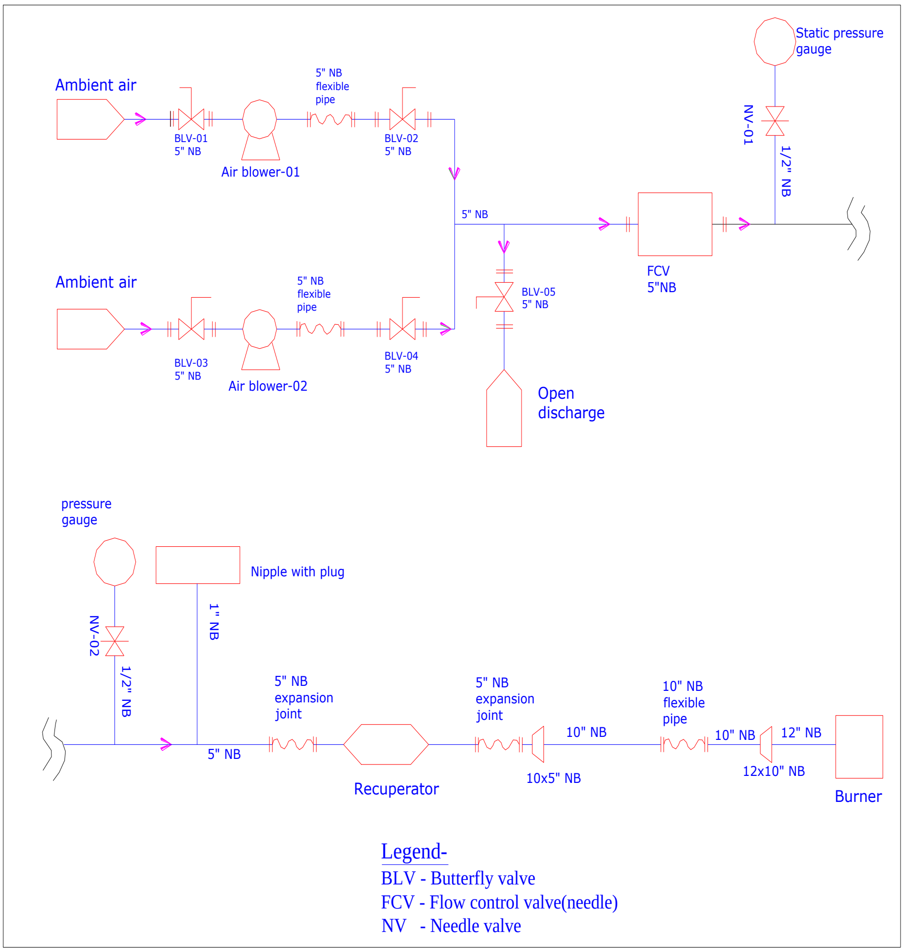
2.1.2 Excess air for combustion

The theoretical air to fuel ratio for complete combustion of the fuel is known as stoichiometric air-fuel ratio. If the quantity of air is less than the stoichiometric, the air–fuel mixture is known as 'rich mixture' and in case air is more than the stoichiometric, the air–fuel mixture is known as 'lean mixture'. The amount of air that is supplied more than the theoretical requirements to ensure complete combustion is referred to as the 'excess air'. The level of excess air is dependent on the type of fuels and their composition, which is shown below.

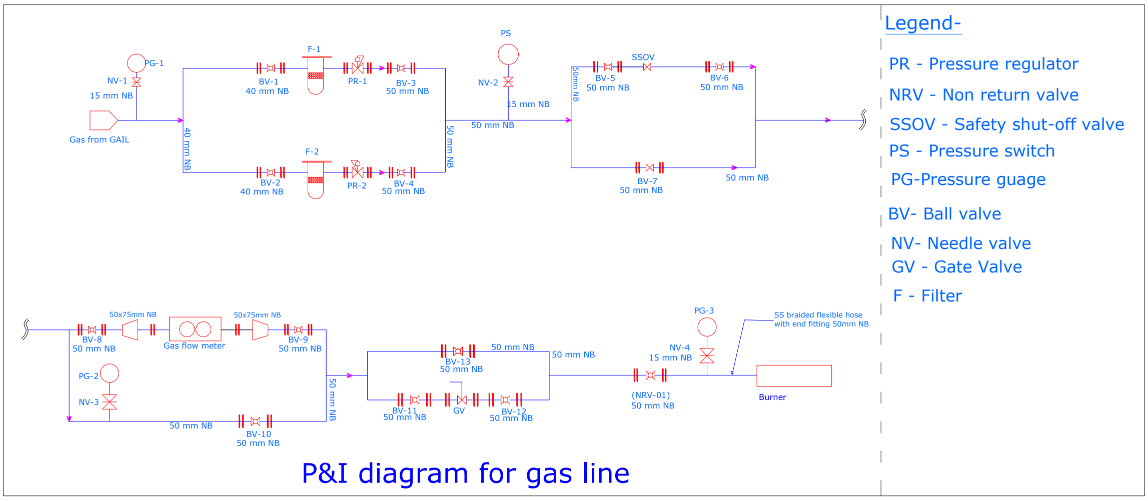
Fuel type	Excess air (%)
Solid fuels	25 – 60
Liquid fuels	15 – 35
Gaseous fuels	10 - 20

2.1.3 Gas based kiln system

The important components of a gas based kiln are air train and gas train. The air train comprises ID/FD fans, control valves, heat recovery systems (WHR), bypass lines, etc. The gas train comprises gas meter, filter, pressure regulator, non-return valve, pressure gauge, pressure switch, burner, etc. A typical schematic view of air train and gas train are shown below.



Gas train



Air train

2.1.4 Draft system

The purpose of providing a draft system is to exhaust the products of combustion from the furnace into atmosphere after effectively recovering the heat. Different types of draft systems used are briefed below.

- Natural draft system is produced using chimney
- Mechanical draft system
    - Induced draft system draws sufficient draught for flow into the furnace using a fan
    - Forced draft system uses a fan to force combustion products to flow through the system
    - Balanced draft system uses both induced draft and forced draft systems

2.1.5 Combustion controls

Combustion controls assist the burner in regulation of fuel supply, air supply, maintaining air-fuel ratio and removal of flue gases in an effective manner to achieve optimum thermal efficiency. The fuel firing rate must be in line with the production level in the furnace. The combustion controls are necessary as safety systems to ensure safety operation of furnace system. Different control systems used in combustion system include the following.

- *On-off control*: In this, the burner is on at full firing rate or switched off when not required.
- *High-low-off control*: The burner can operate at full firing or low firing depending on load requirements
- *Modulating control*: This operates on the principle of matching furnace load by altering firing rate on the entire operating range. It controls combustion air supply as well as fuel supply to the burner.

Any ineffectiveness in generation of heat from fuels will affect the overall performance

The industry has to follow 3-R principle - Reduce, Recover and Recycle to reduce fuel consumption.

Every 22 ^{o}C reduction in flue gas temperature or preheating combustion air by 20 ^{o}C leads to 1% fuel saving

Regular maintenance and cleaning of WHR system to be scheduled when the preheat temperature drops by 50 ^{o}C

2.1.6 Instrumentation of firing kiln

The important instruments that will be useful for monitoring and recording the key parameters to assess the performance of the kiln are provided below.

Instrument	Purpose
Gas flow meter	Gas consumption rate of the kiln
Air flow meter	Air flow rate which will be used to ensure required air to gas ratio
On-line temperature indicator	Monitor and control temperature of kiln in different zones
Non-contact temperature indicator	Surface temperature of kiln structure to assess insulation status

2.2 Energy efficient and renewable energy technology options

The efficiency of a kiln will depend on how efficient the combustion system is and secondly how best the generated heat is utilized. About 5 - 15% energy saving is possible from kilns used in ceramic industries. Some of the potential energy efficiency options are given below.

- Use of low thermal mass kiln car and furniture
- Conversion of kiln from oil to gas fired system
- Complete combustion with minimum excess air
- Operating the kiln at desired temperature.
- Reducing heat losses from the openings
- Minimizing wall losses by improving kiln insulation.
- Recovery and reuse of waste heat from fuel gasses
- Control of Chimney draught and kiln pressure
- Adoption of automation in kiln operation
- Use of variable frequency drives
- Replacement of flat belt with cogged V-belt in drive system
- Rooftop solar system

Adoption of energy saving measures would largely depend on base case scenario and other operating parameters. Some of the important options are summarised below.

2.2.1 Use of low thermal mass cars

Heavy refractory cars and saggers are generally used for carrying ceramic products inside the kiln. The dead weight of the refractories used in the cars is quite high in the ratio of 3 : 1. However, it may be noted that these refractories are only support structure for holding the products inside the kiln and they do not take part in reactions taking place in formation of ceramic products. They are subjected to alternate heating and cooling cycles in each batch, which leads to substantial loss in heat input. This supporting deadweight used in the cars can be reduced to a large extent using hollow silicon carbide (SiC) pipes and thin cordierite plates with minimum width to provide required support. With this arrangement, the deadweight to product ratio can be brought down to about 1:1 or less. The reduction in deadweight further helps in improving the productivity by 100% or more.

2.2.2 Fuel switch over and insulation improvements in kilns

Fuel switch over to NG firing offers significant scope for improving energy efficiency. This would require inclusion of gas train and modification in air train. The oil burners have to be replaced with gas burners or dual fuel burners that would help in improving the combustion efficiency. Improved firing practices and use of better insulation material would help in improving the thermal efficiency of kilns. The overall energy saving potential of kilns is about 5%.

2.2.3 Application of energy efficient motors & VFDs

Generally, most of the existing motors in ceramic industries are old and inefficient. The energy saving measures in a ceramic unit include use of energy efficient motors in polishing area, replacement of smaller motors with a single large motor, adoption of energy efficient motors and VFD (variable frequency drives) in agitating tanks, material conveyor, kiln blower. These measures would help in achieving energy saving between 5-8%.

2.2.4 Adoption of rooftop solar system

Use of roof top solar system is a potential option for the ceramic industry considering the availability of large roof area and solar insolation. The actual generation potential will vary from one unit to another which would require detailed assessment. While installing the roof top solar system, the industry has to take into account the particulate matters in ambient air.

2.3 Best operating practices in a pottery unit

Adoption of advance and energy efficient technologies would definitely help in energy efficiency improvements of the pottery units. However, in order to realize the maximum benefits of the improved technologies, it is essential to operate the kiln optimally. This would require routine monitoring and maintaining various kiln parameters close to optimum levels. Optimum operating parameters can be achieved and maintained by adopting "Best Operating Practices" (BOP) in day to day kiln operation. Functionality, performance and deterioration of an equipment as well as facility as a whole would also depend on quality of "preventive" and "predictive" maintenance. Routine such maintenances include visual inspection, schedule servicing and functional testing to ensure optimum performance during entire life cycle of the equipment. With a combination of efficient technologies, schedule maintenance and better operating practices, pottery industries could reduce energy consumptions as compared to other similar units operating in the cluster without such measures.

2.3.1 Kiln

Kilns are important segment in ceramic industries accounting for about 75% of energy consumption. The operating parameters of kiln like temperatures at different zones, excess air level, surface temperature etc. can influence energy consumption. Routine maintenance and keeping the key operating parameters within specified limits would help in reducing specific energy consumption. Some of the common practices may be adopted in order to ensure smooth operation of the kilns.

2.3.1.1 Maintaining correct air–fuel ratio

Correct air–fuel ratios must be maintained in order to ensure optimum combustion of fuel with minimum heat losses. An air–fuel ratio of 11 to 12 (volume by volume) is recommended for the kiln using natural gas. When the natural gas flow is increased or decreased, the air quantity is also increased or decreased proportionately to maintain the required air–fuel ratio. During the operation, the gas flow needs to be varied to maintain the kiln temperature depending upon the product being fired. Air flow is to be set in such a manner to avoid high excess air but at same time ensure proper and complete combustion. Higher excess air could be detected by (i) presence of oxygen, (ii) flame colour and (iii) low flue temperature.

In absence of airflow meter and pressure gauge, a unit-specific chart could be prepared by installing a U-tube manometer in air pipeline for calibration of air to fuel ratio. The chart comprises air pressure corresponding to gas flow to ensure complete combustion. Based on the chart, the air flow can be adjusted for variations in gas flow.

2.3.1.2 Flame colour

For the kiln operator, the colour of the flame is an important indicator of the status of combustion. A flame, like a snake's tongue indicates proper combustion occurring inside a furnace. If the air–fuel mixture is rich, the flame will be yellow and non-transparent. Smoke may be observed from the flame under such conditions. If the air–fuel mixture is lean, the flame will be red. If the air–fuel ratio is correct, the flame will be white or pale blue and transparent, indicating proper combustion. Correct air–fuel ratios must be maintained based on type of fuel in order to ensure optimum combustion while minimising formation of unburnts. When the firing rate of fuel is increased or decreased, the air quantity is also proportionately increased or decreased to maintain the required air–fuel ratio. The table provides the temperature for different flame colours.

Flame colour vs. kiln temperature

Colour of flame	Temperature (°C)
Initial red	500-550
Dark red	650-750
Cherry red	790-800

Bright red	850-950
Yellow	1050-1150
Initial white	1300
Full white	1500

2.3.1.3 Optimum capacity utilization

The capacity utilization (commonly known as "loading") of a kiln is one of the key factors affecting the efficiency. The loading of a kiln includes preparation of material to feed, amount of material placed, arrangement inside the kiln and the residence time inside the kiln.

2.3.1.4 BOP for gas based kiln

A typical gas based tunnel kiln used in pottery industries can achieve the following benefits using better operating practices.

Best practices in gas based tunnel kiln

Area	Target	Approach	Benefits
Kiln top and side walls	Reduction of average surface temperature	Routine measurement of surface temperature Improve insulation	Potential scope to reduce NG consumption Low workplace temperature
Kiln internal temperature	Maintain optimum temperature	Monitor kiln temperature at regular interval Gradually control gas and air flows	Achievement of optimum gas consumption
Excess air flow	Maintain optimum air-fuel ratio for complete combustion	Routine monitoring of oxygen level in flue gas	Reduction in flue gas losses
Kiln furniture	Kiln cars	Low thermal mass cars	Increased productivity

2.3.2 Raw material processing

The improvement in existing milling practices can be achieved through the following.

i. Always operate the ball mill at its critical loading point. The material loading of the ball mill is a critical parameter in determining the energy consumption. Specific energy consumption (SEC) will increase if the ball mill is loaded below/above the critical loading point.

ii. Use grinding media (pebbles) in three different sizes for better and efficient grinding of raw material.

iii. Preferable to use high alumina balls and internal lining for consistent quality with higher efficiency

iv. Check the mesh size of the slurry - when it reaches the required value, switch off ball mill/ blunger.

v. Regularly monitor batch time.

2.4 Fault diagnosis and trouble shooting

Kiln system in a pottery industry consumes maximum energy and this is the heart of the process steps in manufacturing pottery products. This section provides some of the common fault diagnosis and troubleshooting approaches in kiln system (kiln, gas train and air train) for easy reference of kiln operators.

2.4.1 Kiln operation

K–1

Temperature variations within the kiln

(1) Incorrect burner fitment
(2) Improper sizing or location or partial blocking of flue path
(3) Incorrect draught within the furnace

(1) Burner installation – should be such that combustion products gets evenly distributed in the entire firing chamber
(2) Clear blocking of flue path.
(3) Furnace draught – Adjust for positive pressure using the damper near the chimney.

K–2

Improper furnace draught

(1) Incorrect setting of damper near chimney
(2) Air ingress in flue path or chimney, lowering the temperature of flue gases

(1) Check furnace draught through indirect method. Ensure positive draught in the furnace by adjusting the setting of damper near chimney.
(2) Check the flue temperatures after damper in main flue path. If the drop in temperature is insignificant, check the chimney for air ingression.
(3) If the temperature drop is significant, check and arrest air leakage in flue path.

K–3

Incorrect kiln temperature

(1) Faulty temperature indicator
(2) Improper furnace draught
(3) Incorrect air and gas flow

(1) Cross check temperature indicator. Use different indicator/ compensating cable. Repair/ replace the faulty meter.
(2) Ensure slightly positive furnace draught. You will observe furnace temperature start rising immediately.
(3) Slowly increase gas and air flows. Maintaining pre-set air to gas ratio. Re-adjust the furnace draught.

K–4

Delay in firing schedule

(1) Extra-long flame emerging from car entry
(2) Improper filling of kiln car
(3) Incorrect furnace temperature/ draught
(4) Change of chemicals in batch requiring higher temperatures

(1) Check with Problems 2 & 3 to adjust furnace temperature
(2) Adjust damper and ensure slightly positive draught as per Problem K–2.
(3) Check and follow routine car loading practices

K–5

Abnormal flame colour

Improper air and gas ratio

Adjust air and gas flows to obtain a flame of transparent blue or bright white colour.

- *With "lean mixture" (higher air level), flame becomes bright red*
- *With "rich mixture" (higher gas level), flame becomes yellow*

2.4.2 Gas train

G–1

Kiln temperature not increasing with increased gas flow

↓

(1) Faulty gas flow meter/valve opening
(2) Inappropriate furnace draught
(3) Insufficient air and gas flows

↓

Take corrective actions as discussed under Problem K–3

G–2

High air to gas ratio

↓

(1) Faulty air/ gas flow meter
(2) Air leakage in airline

↓

(1) Repair/ replace faulty flow meters
(2) If flow meters are working, carry out leakage test of airline and repair the faults

G–3

Incorrect reading of gas flow meter

(1) Gas flow meter not installed as per supplier's instructions.
(2) Absence of earthing wire in electrical power connection
(3) Flow meter is due for calibration/ maintenance
(4) Flow meter is not properly calibrated maintenance

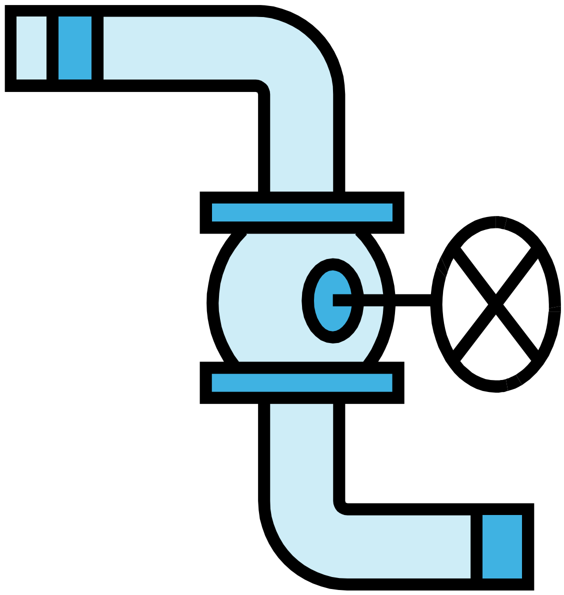
(1) Ensure proper installation of gas flow meter according to the supplier's instructions
(2) Check power connection including earthing
(3) Consult the supplier for guidance/ repair

G–4

High pressure drop in gas line

(1) Improper functioning of Pressure Reducing Valve (PRV)
(2) Higher resistance of gas piping due to burrs, choking and improper lining
(3) Leakage from joints/flange/welding points

(1) Check PRV with a calibrated pressure gauge for proper functioning. If required, reset or repair PRV
(2) Carry out leak test, check for choking or blockage in gas line



2.4.3 Air train

A–1

No air flow in spite of motor operating

(1) Faulty power connection
(2) Faulty impeller/ coupling

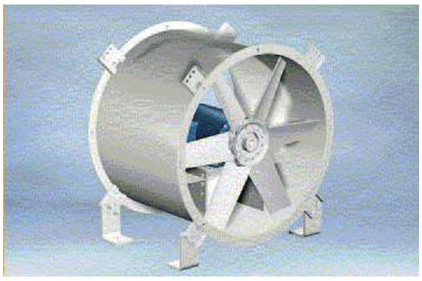
(1) Check power connection
(2) Check the direction of rotation of impeller and change by correcting the polarity of connection
(3) Contact supplier in case impeller does not rotate or incorrect rotation

A–2

High vibration of motor

(1) Improper balancing of impeller
(2) Loose foundation and fittings

(1) Contact supplier for rectification or replacement
(2) Repair foundation and fittings



A–3

High air flow ratio

↓

(1) Faulty air/ gas flow meter
(2) Leakage in air line

↓

(1) Check combustion. In case of proper combustion, check air and gas flow meters
(2) Check air leakage lest to find leakage points and repair the line

A–4

Incorrect reading of air flow meter

↓

(1) Suppliers' instruction not followed during installation of air flow meter
(2) Improper power connection/ earthing
(3) Improper calibration of air flow meter
(4) Air flow meter is due for scheduled maintenance

↓

(1) Ensure installation of air flow meter as per supplier's instructions
(2) Correct power connection/ grounding
(3) Calibrate air flow meter
(4) Contact supplier for repair and maintenance

List of references

(1) Energy efficiency in thermal utilities, Bureau of Energy Efficiency (BEE), Government of India
(2) Reports prepared by TERI under TERI-SDC partnership project
(3) Discussions with stakeholders in Khurja ceramic cluster

3.0 Module 2 – Construction of gas based tunnel kiln

3.1 Kiln types

There are more than 200 ceramic units operating in Khurja ceramic cluster which mostly cater to domestic market. The cluster is known for the manufacture of stoneware and bone china crockery products. The produces include table wares, decorative wares, and porcelain insulators, both HT (high tension) and LT (low tension) types. Other products manufactured in the cluster are hospital ware, chemical porcelain, electro ceramics, kiln furniture, special ceramics, toys and non-china crockery products.

The cluster was earlier using coal based downdraft (DD) kilns for the production process. The DD kilns were quite inefficient resulting in substantially higher fuel consumption as well as high level of smoke. Over a period of time, the DD kilns were replaced by oil fired tunnel kiln system. The tunnel kilns were using local kiln design and firing system for light diesel oil (LDO) and rubber processed oil (RPO) to meet the thermal energy requirements in firing process. The choice of fuels is mostly dependent on cost economics of fuel used and ease of procurement.

Apart from tunnel kilns, a number of ceramic units in the cluster are also using oil-fired shuttle kilns. The shuttle kilns are batch operated systems and are mainly used for value added products. The shuttle kilns are also inefficient as these kilns are generally not equipped with any waste heat recovery (WHR) systems. It is envisaged that over a period of time, the shuttle kilns used in the cluster will be invariably replaced with tunnel kilns – a change from batch production to continuous

Tunnel kiln in Khurja cluster

production process.

3.2 Typical dimensions of tunnel kiln in Khurja

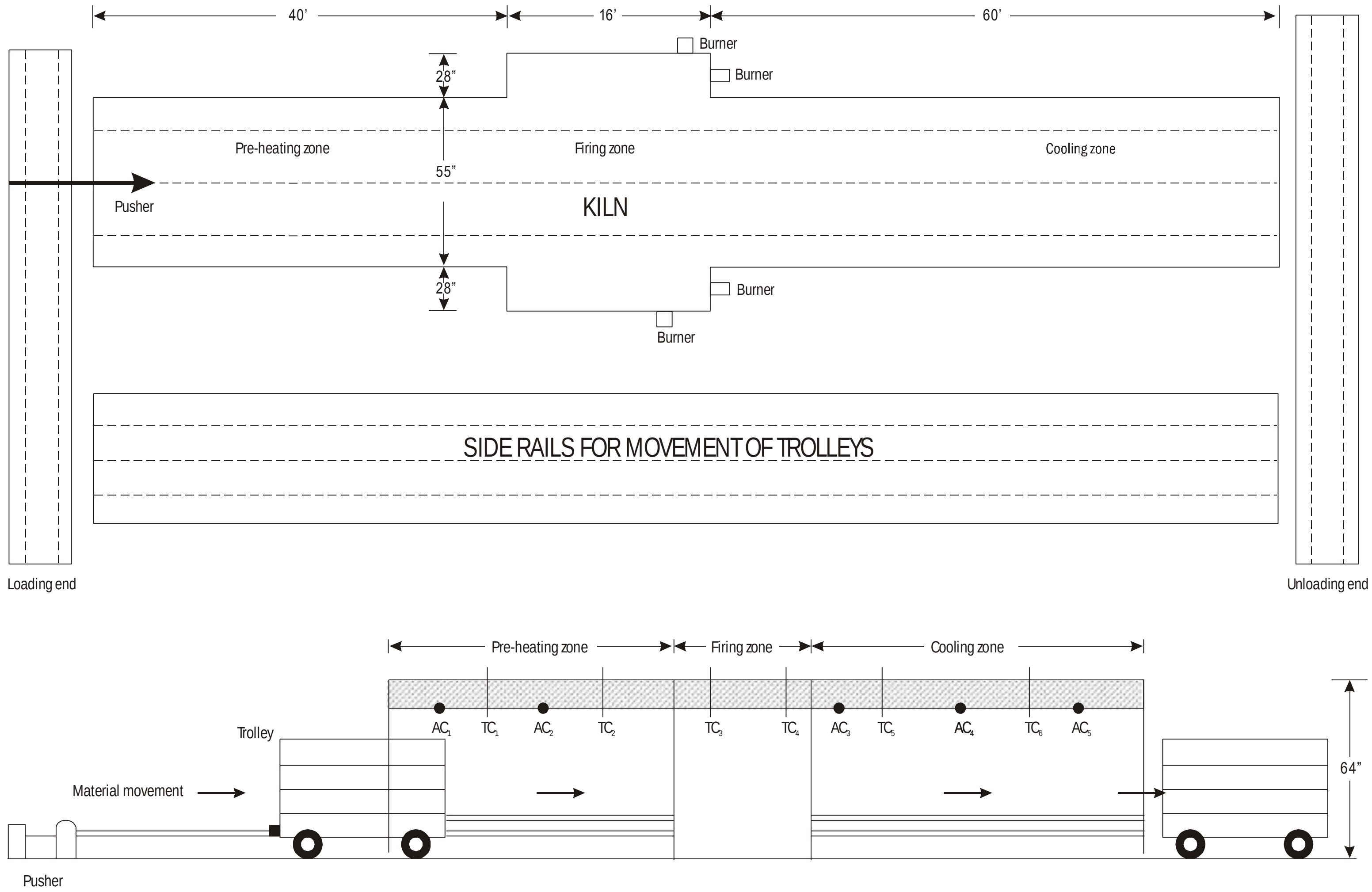
The dried products are kept in cars and pushed inside the tunnel kiln. A tunnel kiln comprises three distinct zones – preheating zone, firing zone and cooling zone. The products inside the kiln are heated slowly on its exposure to high temperature flue gases in preheating zone during travel towards firing chamber thereby reduces heat load in sintering the products in firing zone.

In the firing zone, the heat is provided with oil/ gas fired burners to increase the temperature of the products at about 1100-1200 ^{o}C. The set temperature in firing zone is dependent on type, dimensions and thickness of products being fired. The products are soaked at high temperature in firing zone. The approximate travel rate of cars inside the tunnel kiln is about 2 metre per hour. In a typical tunnel kiln, during steady state operation, about 6 cars will be present in preheating zone and 3 cars in soaking zone and 10 cars in cooling zone.

After soaking, the products are slowly cooled inside the kiln while moving forward. The total length of a tunnel kiln is about 35 metre. The width and height of tunnel kiln are dependent on type and size of products manufactured in the unit. The typical dimensions of a tunnel kiln used in Khurja ceramic cluster are shown below.

Typical length of tunnel kiln

Zone	Length (metre)
Exhaust area	3
Preheating zone	12
Firing zone	6
Rapid cooling zone	3
Slow cooling zone	8
Cooling to ambient	3
Total	35



AC: Air curtain
TC: Thermocouple

Plan and elevation of tunnel kiln

3.3 Key components in tunnel kiln construction

All the activities in a ceramic industry are centred around the tunnel kiln. Besides the kiln, the products are kept for drying in cars which need to be fired in the kiln. Therefore, greatest care should be taken in choosing the site for tunnel kiln in order to ensure safe, smooth and efficient operations within the unit both at entry and exit sides of the products after it is commissioned. The site for tunnel kiln should allow sufficient space for construction of the kiln and its associated systems: namely, gas train, air train and chimney. It is necessary to mark the exact positions of the various systems and sub-systems associated with the kiln before starting civil work and fabrication. The positions must be chosen in such a way that sufficient space will be available for workers to function safely and efficiently during kiln operation. The exact locations of systems or sub-systems should be finalized and demarcated under the supervision of the main fabricator (who is going to undertake construction activities) and the entrepreneur.

The construction of tunnel kiln comprises fabrication of kiln framework, refractory lining, lagging of kiln with best insulation and cladding and providing instrumentation for monitoring key operating parameters. Other main utilities components in tunnel kiln fabrication include various equipment gas train and air train system.

3.3.1 Refractory lining

The fundamental of refractory lining is not much different from that of the conventional brick laying practices. In both cases lining materials are by large joined together with mortar and laid in a pre-determine manner so as to give desirous strength and stability to the construction. IS – 8 refractory is used in firing zone and other areas use normal refractory/brick.

The strength and stability are imparted with the use of proper bonding as well as various combinations of header and stretcher courses. The type of bond for any particular kiln construction depends upon the factors like, the design of the kiln, the thickness of the wall, the operating conditions and the maintenance practices during operation. Proper application of bonding during lining would ensure the following.

- Provide sufficient overlapping of a brick across and over, at least two other bricks in the course below it.
- Break continuous vertical joints both along the length and the thickness of the wall.
- Interlock the bricks in the same course and create unity between the individual blocks in a brick work.

The campaign life of an industrial kiln greatly depends upon the quality of workmanship and the construction technique employed which include selection of proper refractory materials, refractory bond, proper joint thickness including quality of jointing material, adequate expansion allowances etc. it is essential to depute skilled and experienced mason for the construction under qualified supervisor for the refractory lining during kiln construction. Some of the commonly used refractory tools during masonry work is provided below.

Mason's hammer

Chisel

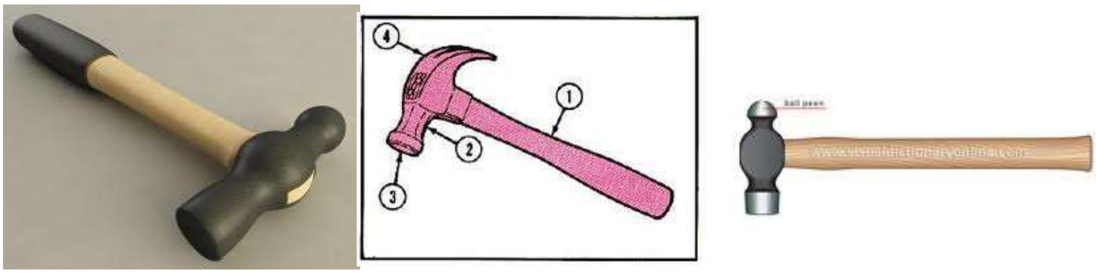
Trowel

Clay Pan

Try- Square

Plumb-BOB

Grinding Wheel



Ball Pan Hammer

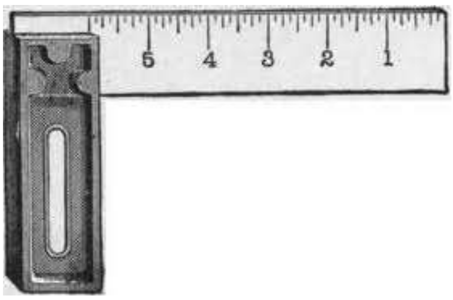
Wooden hammer

Mason's thread


Straight (PATA)



Spirit level

Measuring scale

3.3.2 Kiln insulation

The kiln insulation forms a critical component especially in retaining high temperature in firing zone while losing minimum heat to atmosphere through convection and radiation. Provision of high quality insulation such as ceramic fibre blankets in firing zone would help in minimising heat losses from the kiln thereby ensuring effective heat transfer to products and attaining high thermal efficiency of the kiln. Suitable insulation thickness both on side walls and roof side are prerequisite in minimising radiation heat losses to the atmosphere. The industry should follow the sequence of lagging as per recommendations of suppliers of insulating materials. Moreover, the insulation should be properly covered with aluminum foil cladding to avoid dust deposition, which would otherwise deteriorate the quality of insulation over a period of time and reduce effectiveness of the lagging. Properties of some insulating material are provided below.

Specifications of insulating material

Product	Main feature
Standard Ceramic board	Application - hot face insulation Density - 320–384 kg/m^3 Temperature range – 0 to 1260°C Length - 1000 mm Width - 500 mm Thickness - 25 mm
Ceramic blanket	HD grade with density of 128 kg/m^3 Temperature range – upto 1425°C RTZ grade for low temperature application in pre-heating zone of kiln. Density - 128 kg/m^3
Lagging ceramic blanket	Application - lagging Temperature range: less than 1000°C Lagging sequence : • 1st layer of ceramic wool with density of 128 kg/m^3 (hot face). • 2nd layer of ceramic wool with density of 96 kg/m^3 over the 1st layer of ceramic wool • 3rd layer of aluminium foil cladding, as final cover over the ceramic wool

Thickness of ceramic blanket or module will largely depend on quality of insulating material and maximum temperature of the area. Normally, 11 inch thick insulation is provided in vertical wall and roof section. In the roof section 1 inch ceramic blanket and 10 inch thick module is provided. In the firing zone better quality of HD grade insulation is used and pre-heating zone is insulated using RTZ grade with similar density; 128 kg/m^3. The external surface facing ambient air is to be provided with aluminium cladding to avoid dust deposition on the ceramic surface.

3.3.3 Rails for car movement

The cars are moved inside the tunnel kiln from one zone to another using a mild steel rail structure. Apart from the rails inside the kiln structure, side rails are provided wherein the products are kept for drying before being pushed inside the kiln.

3.3.4 Temperature indicators

Sufficient number of temperature indicators should be provided across the kiln length on both sides of vertical wall and on the roof side. This would ensure proper maintenance of set temperatures in different zones thereby ensuring better quality of products and the yield. The details of kiln temperature monitoring systems are given in the table below.

Specifications of temperature sensors and indicator

Item	Type	Specifications
Temperature sensor	Type K	Temperature range : 0 - 1370°C
		Material: aluminium–chromium
Crown temperature sensor	R-type	Temperature range : 0–1760 °C
		Material: Pt (87%)–Rh (13%) (platinum–rhodium)
Digital temperature indicator	Multi-channel	Display: 4 digit (absolute figure)
		Resolution: 1 °C
Digital temperature indicator	Stand-alone	Display: 4 digit (absolute figure) Resolution: 1°C
Miscellaneous	Cable	Compatible compensating cable for electrical connection

3.3.5 Gas train

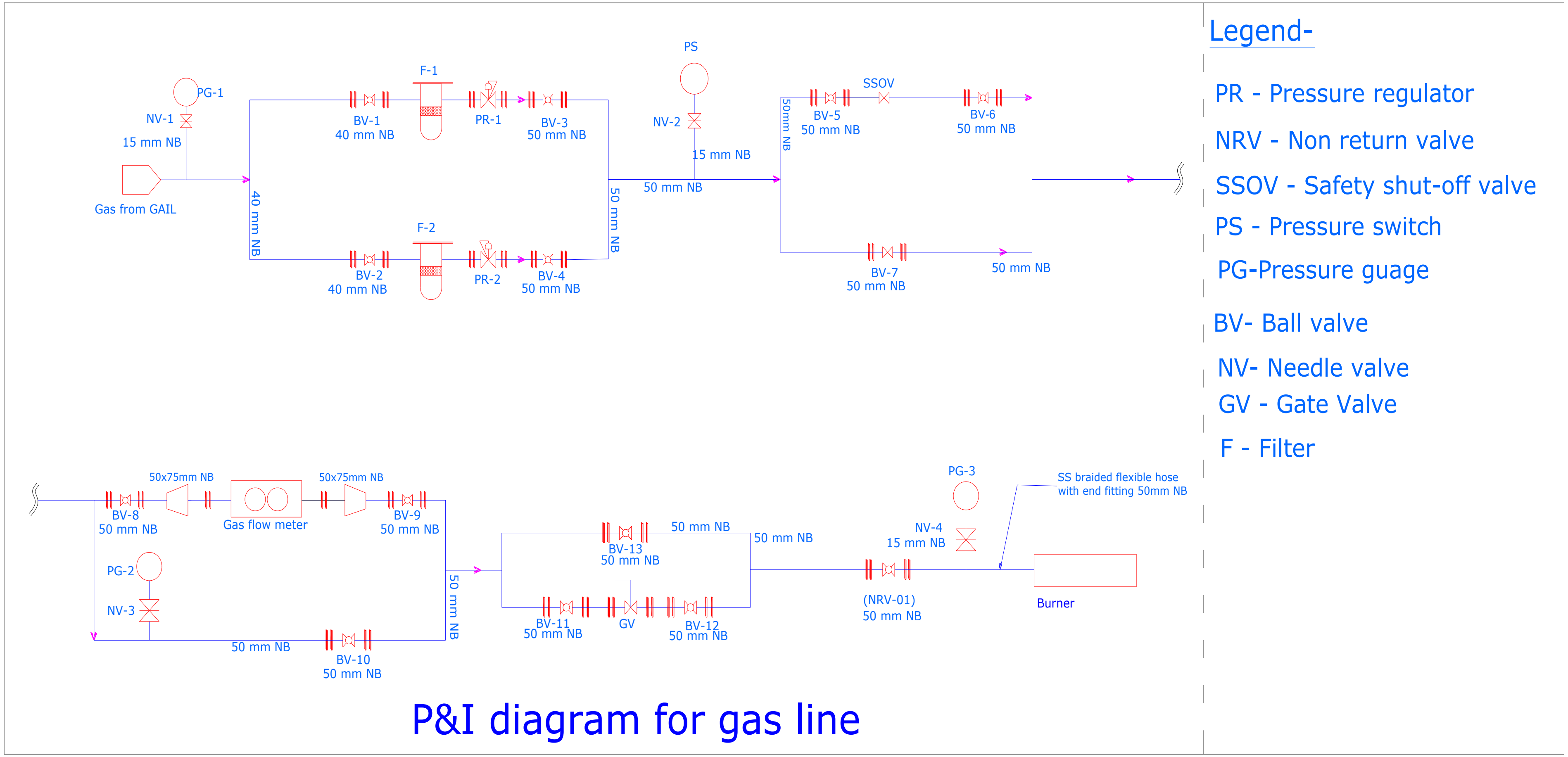
The supplier of natural gas provides gas piping up to the premises of the industry. The supplier also installs a flow meter to record gas consumption for the purpose of billing. It is the responsibility of the individual industry to install required pipelines and other related equipment within the industry to distribute gas supply from the gas meter to the burner provided in the kiln.

During the use of piped gas in an industry, it is important to monitor and regulate both pressure and flow rate of gas supplied to the burner, which otherwise may lead to higher consumption of gas and hence higher energy costs per unit of product manufactured.

In addition, the industry should install all necessary safety systems in place. These safety systems would require regular replacement as per guidance provided by the supplier. Various equipment that are used to serve these functions together constitute gas train. The main components of gas train are as follows:

- Filter
- Pressure regulator valve
- Gas flow meter
- Controlling and isolation valve
- Pressure gauge
- Safety shut-off valve
- Pipe and fittings as required for integration

A typical gas train used in a small scale industry is shown below.


Legend-
PR - Pressure regulator
NRV - Non return valve
SSOV - Safety shut-off valve
PS - Pressure switch
PG-Pressure guage
BV- Ball valve
NV- Needle valve
GV - Gate Valve
F - Filter
PG-1
NV-1
15 mm NB
Gas from GAIL
40 mm NB
F-1
BV-1
40 mm NB
PR-1
BV-3
50 mm NB
F-2
BV-2
40 mm NB
PR-2
BV-4
50 mm NB
50 mm NB
PS
NV-2
15 mm NB
50 mm NB
50mm NB
SSOV
BV-5
50 mm NB
BV-6
50 mm NB
BV-7
50 mm NB
50 mm NB
50x75mm NB
50x75mm NB
BV-8
50 mm NB
Gas flow meter
BV-9
50 mm NB
PG-2
NV-3
50 mm NB
BV-10
50 mm NB
50 mm NB
BV-13
50 mm NB
50 mm NB
BV-11
50 mm NB
GV
BV-12
50 mm NB
50 mm NB
PG-3
NV-4
15 mm NB
SS braided flexible hose
with end fitting 50mm NB
(NRV-01)
50 mm NB
Burner
P&I diagram for gas line

Gas train

The typical specifications used in gas train are provided below.

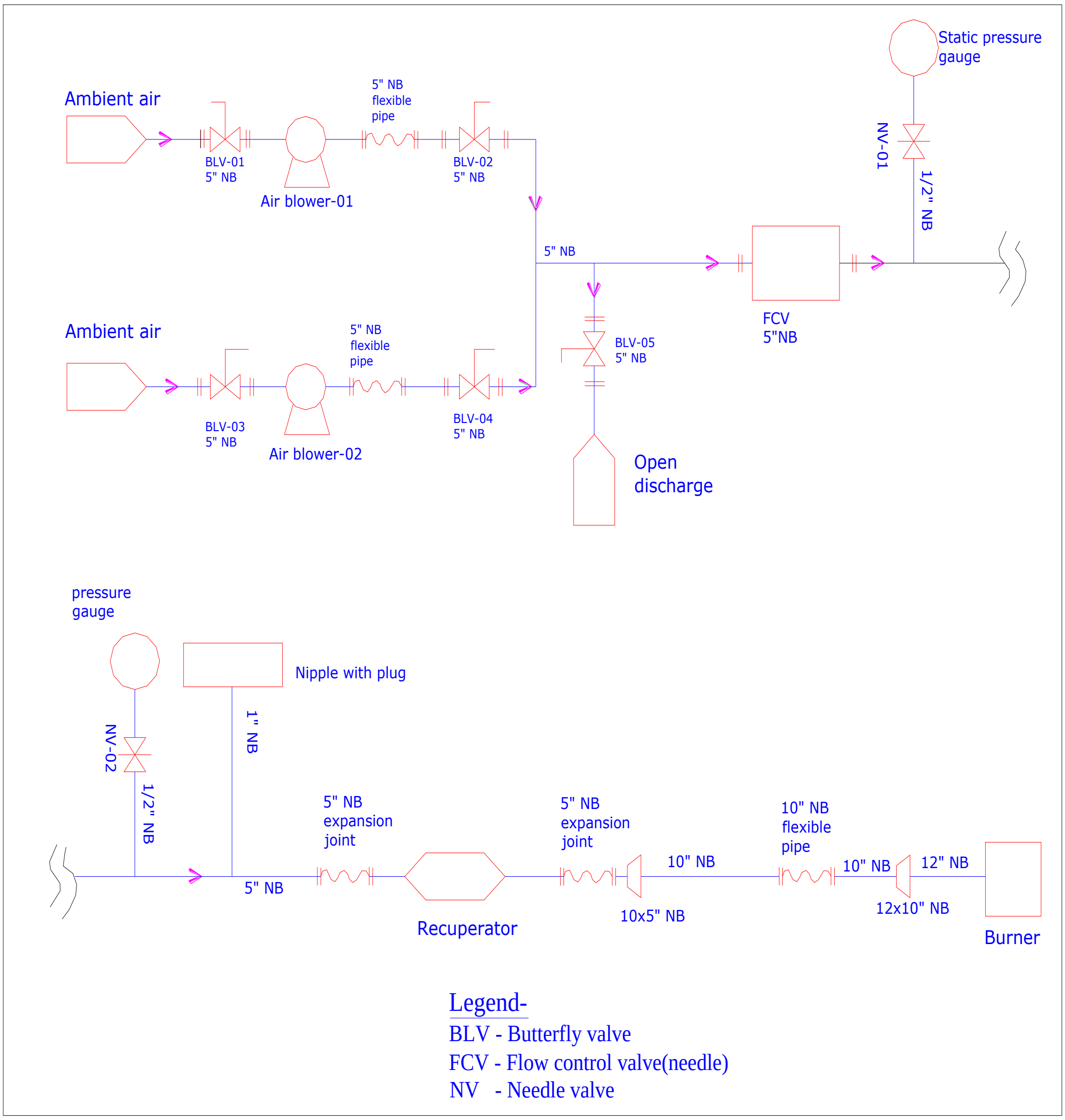
Typical specifications for gas train

Item	Specifications
Gas filter	Type: Simplex
	Filtering element: Cartridge
	Housing material: Mild steel
	Medium: Natural gas
	Flow rate: As per requirements (compatible for maximum and minimum gas flow rate)
	Gas temperature: 25 °C
	Minimum inlet pressure: 0.8 kg/cm² (assumed)
	Maximum inlet pressure: 3 kg/cm² (assumed)
	Flow direction: Out to in
	Filtration rating: 3 µm (absolute)
	Line size: 50 mm NB with screw end fitting
	Accessories: drain valve and common differential pressure gauge
Regulator (PRV)	Type: self-operated
	Housing material: Cast iron
	Medium: Natural gas
	Flow rate: As per requirements
	Gas temperature: 25 °C
	Inlet pressure: 3 to 0.8 kg/cm² (gauge)
	Outlet pressure: As per requirements
	Line size: 50 mm NB
	End connection: NPT Screw
	Feed quality: filtered up to 3 µm
Safety shut-off valve	Type: pneumatic with flame-proof enclosure
	Size: 50 mm NB; operating fluid—natural gas; valve orientation—horizontal
	Three operating conditions: 1. Low pressure e.g. 200 mm WC 2. High pressure e.g.1200 mm WC 3. Electrical power failure during operation
Gas flow meter	Type: Turbine flow meter or Vortex flow meter
	Body material: Mild steel Size 50 mm NB
	Medium: Natural gas
	Flow rate: As per requirements (for maximum flow conditions)
	Gas temperature: 25 °C
	Operating pressure: 200 mm WC–800 mm WC (gauge)
	End connection: Flange

Item	Specifications
	Display: Both mechanical totaliser and real time flow rate (Digital)
	Accuracy: ±1%
	Least count: 1
Miscellaneous	2-inches gun metal gate valve to control gas flow; Mild steel pipes, reducers, bends, isolation valves, flanges, non-return valve (NRV); Stainless steel braided flexible hose as required to complete the gas train piping.

3.3.6 Air train

Along with gas, combustion air needs to be supplied at a controlled pressure and rate in order to regulate the flow to the burners. The various components of air train include air blower, air flow meter, controlling and isolation valve, pressure gauge, temperature indicator and pipes & fittings as required for system integration.



Air train

The typical specifications used in air train are provided below.

Typical specifications used in air train

Item	Specifications
Blower with motor	Material: Mild steel
	Discharge volume: As per requirement
	Discharge pressure: As per requirement
	Type: Centrifugal
	Drive: Direct coupling
Flexible pipe	ID: Compatible to pipe size
	Length: 1000 mm
	Material: Corrugated SS-304
	End connection: flange
Flow control valve	Size: Matching with pipe size
	Type: Gate valve
	Material: Gun metal
	End connection: Flange
Air flow meter	Size: Matching with pipe size
	Flow rate: As per requirement
	Operating temperature: 50° C (maximum)
	Operating pressure: 200 to 1000 mm WC
	Display: digital (real time and totaliser)
	Type: Vortex flow meter
	Material: Mild steel
	End connection: Flange
Burner	Low pressure nozzle mix burner Fuel flow: As per maximum requirement Fuel pressure at burner input: As per requirement Turndown ratio: higher is preferable Type of fuel: Piped natural gas Burner support: Locally fabricated MS structure
Damper	Locally fabricated MS housing
Insulation	Ceramic fibre blankets of suitable density to meet high temperature requirements
Miscellaneous	Mild steel and stainless steel pipes, reducers, bends, valves, flanges to complete piping.

Notes: Sm^3/h – standard cubic metres/hour; WC – water column; SS – stainless steel; MS – mild steel; ID – inner diameter; OD – outer diameter; NB – nominal bore

3.4 Instrumentation in tunnel kiln

The key to energy efficiency in a kiln system is two-fold viz. (i) optimizing combustion i.e. extraction of maximum heat from combustion of fuel for driving industrial processes and (ii) minimizing heat losses at each stage of the process through measures such as better equipment design, improved insulation, use of materials having superior thermal qualities in fabrication and recovery and reuse of waste heat from flue gases. It is therefore essential to monitor different operating parameters during kiln operation. Instrumentation is vital for measurements and monitoring of various processes and the operating parameters.

The most important parameter is to monitor heat flow pattern in important sections of the kiln through suitable on-line temperature measurements. In traditional kilns, either a single thermocouple is used to check temperature of the kiln or mostly the kiln operation is left to the eye judgment or skills of the operator. However, it is important to measure temperatures in all zones of the kiln – firing, preheating and cooling to understand heat gains and control firing operation. The thermocouples must be set to indicate the absolute (real time or actual) operating temperature. The type of thermocouple is dependent on temperature required to be measured. The firing of kiln is controlled through the set temperature in the firing zone. Different instruments used in tunnel kiln operation are provided below.

- *Gas/oil flow meter*. To monitor consumption of gas/oil in different kilns and the plant as a whole.
- *Air flow meter. To adjust the air flow and keep air to gas/oil ratio at the required level of the burner suppliers*
- *Oxygen analyser. Helps in monitoring O2 (oxygen) content in flue gases which provides indication of excess air level. Higher level of excess air will result in more heat losses through flue gases. Low level and presence of CO indicate combustion inefficiency.*
- *On-line temperature indicators. This is a very important parameter. Any high temperatures above the required level would lead to loss of fuel and below the required level means poor quality of products.*
- *Non-contact temperature indicators. These are useful in measuring the surface temperatures thereby assessing the status of insulation of the kiln and associated heat losses.*

3.4.1 Monitoring and recording of operating parameters

The performance of the firing kiln system can be evaluated through monitoring and recording of various parameters like temperature of kiln in different zones, temperature of flue gases and flow rate and pressure of gas and air flow. It is also essential to monitor product loaded on the kiln car, firing time and yield from each batch. Recording and analysing process data helps in evaluating the efficiency of kiln operation. The performance of the kiln and its variations can be analysed by maintaining proper log sheet of various operating parameters such as gas consumption, gas pressure, temperatures at firing zone, preheating zone and cooling zone, etc. Analysis of data would indicate the present working conditions of the system as well as indicate the need to take corrective actions, if required.

The ceramic industry can maintain separate log sheets for all key process sections of the production process that would help in analysing the performance and undertaking remedial measures. A sample data sheet for tunnel kiln unit is shown below.

Example of log sheet

Date	Time	Temperature (°C)			Product type	Production (No.)	Yield (%)
		Firing	Preheating	Cooling			

3.5 Commissioning of new kiln

Starting up the new kiln means that it must be heated up gradually and smoothly over a period of time to bring it up to the desired operating temperature (that is, the temperature at which products are expected to be heated during firing, 1200–1250 °C. This process, called preheating, must be carried out carefully to avoid any physical damage to the kiln due to thermal shock. Typically, about 10 days are required for preheating of a new kiln.

3.5.1 Preheating schedule

The general preheating for a new kiln is to be undertaken in a proper schedule to avoid any damage to the new lining. Incremental temperature gains during pre-heating are dependent on the temperature of the lining / kiln. A typical 9-10 days pre-heating schedule for a new lining is provided below.

Schedule for preheating

Kiln temperature (°C)	Heating rate (°C /hour)	Duration (hours)	Cumulative preheating time (hours)
Up to 100	4	25	25
100–220	3	40	65
220–500	6	47	112
500–750	4	63	175
750–1200 (+)	10	45	220

The majority of the kiln operators in the cluster may find it difficult to adhere to the precise rates and durations of preheating schedule as mentioned above. In that case, preheating schedule for the kiln may be simplified as provided below.

- Stage 1. Raise kiln temperature at up to 100° C per day, that is, around 4° C per hour, till a temperature of 750 °C is attained.
- Stage 2. Increase kiln temperature at up to 240° C per day, that is, around 10 °C per hour, till the required temperature of 12000 °C is reached.

In this way, the kiln will attain the required firing temperature in about 10 days, and production may commence.

3.5.2 Holding of kiln operating temperature

The maximum firing temperature is close to 1200°C. The kiln is therefore maintained at this temperature in the course of normal operation. However, during lean periods, holidays or festival seasons, production has to be stopped for short intervals and then resumed. Complete shutdown of the kiln would be uneconomical; for re-starting the kiln from 'cold start' would take up some times, leading to considerable losses in terms of production time gone waste.

The properties of the refractories used in kiln construction are such that the kiln can be maintained at about 900–1000 °C without affecting its life. Hence, during 'idle' periods when production has to be stopped temporarily, the firing level is reduced to maintain kiln temperature at 900–1000 °C. From this idling temperature, the firing temperature of 1250 °C can be achieved within shortest duration, enabling faster recommencement of production. During kiln temperature holding period, precautions are to be observed to protect non-operating burners due to absence of air flow to it.

3.5.3 Common fault diagnosis during commissioning

The following tables describe common problems and faults observed in the course of operation of the recuperative kiln system; their probable causes; and methods to rectify them.

Details of fault diagnosis

Fault/problem	Probable causes	Rectification
Temperature variation within the kiln (cold and hot spots)	Burner fitment is incorrect Flue exit hole is not properly sized and/or placed; or it is partially blocked Incorrect draught within the kiln Burner nozzles are partially or fully blocked	Check the burner installation, which is to be perpendicular to the kiln floor and placed at the center point (eye) of the kiln crown; if required, correct it. Check kiln draught, which should be slightly positive (particularly focus on the colder zone). If required, adjust it by resetting the draught controlling damper near the chimney. Clear nozzle regularly or replace burner
Incorrect kiln temperature	Temperature indicator may be faulty Incorrect air and gas flow Burner nozzles are partially or fully blocked	If the charging time is normal, check that the temperature indicator assembly is proper. Measure the kiln temperature using a different indicator/ compensating cable. If required, repair the faulty indicator. Slowly increase gas and air flows in preset ratio till the required temperature is achieved. Re-adjust the draught again to neutral or slightly positive. Clear nozzle regularly or replace burner

Fault/problem	Probable causes	Rectification
Abnormal flame colour	Improper air and gas ratio	Generally, perfect combustion of the gas will give a flame that is transparent blue or bright white. However, for 'lean' air-gas mixtures (where the quantity of air is more than stoichiometric) the flame becomes bright red; whereas for 'rich' air-gas mixtures (where the quantity of air is less than stoichiometric) the flame becomes yellow. Correct the air flow to get the proper flame colour. That is, increase gas flow and reduce air flow if the air : gas ratio is high, and vice versa.
Kiln temperature not increasing with increased gas flow	Faulty meter Insufficient air and gas flow	Take corrective actions as provided above
Air and gas ratio is high	Gas/air flow meter is faulty Leakage of air from air line	If combustion is proper, check flow meters. If meters are in order, there may be leakage of air from the air line. Carry out leak tests along the complete airline and repair as required.
Incorrect reading in gas flow meter	Installation has not been done according to the supplier's instructions. Earthing wire is absent in electrical power connection Meter is due for calibration Meter is not properly calibrated Meter is due for scheduled maintenance	Check that the flow meter has been fitted according to the instructions of the supplier. Check the power connection if any for proper grounding. Consult the supplier for guidance/repair.
High pressure drop in the gas line	Improper function of the PRV Line offers high resistance to flow due to burrs, choking and improper lining Leakage from joints/flange/welding points	Check the PRV for proper functioning by putting a serviceable and calibrated pressure gauge across it. If required, reset or repair it. Carry out leak test, check for choking or blockage in the line.
Motor operating but no air flow in the line	Faulty power connection Faulty impellor/coupling	Check power connection. Check rotational direction of impellor and correct it by changing the polarity of the connection. If impellor doesn't rotate at all or rotation is incorrect, consult the supplier for correcting the impellor/ coupling fitment
High vibration	Improper balancing of the	Call the supplier for rectification or replacement.

Fault/problem	Probable causes	Rectification
	impellor Foundation and fitment of blower is not correct	Ensure foundation and fitment of the blower is proper.
Air flow meter reading is incorrect	Installation is not according to the supplier's instructions Power connection may not be proper; the source board may not be earthed through a conducting wire Meter is Improperly calibrated Meter requires calibration Meter is due for scheduled maintenance	Check that the flow meter has been fitted according to the instructions of the supplier. Check the power connection if any for proper grounding. Consult the supplier for guidance/repair.

List of references

(1) Reports prepared by TERI under TERI-SDC partnership project
(2) Discussions with stakeholders in Khurja ceramic cluster

4.0 Module 3 – Advanced technologies for pottery industries

4.1 Background

There are more than 200 ceramic units operating in Khurja ceramic cluster which mostly cater to domestic market. The cluster is known for the manufacture of stoneware and bone china crockery products. The produces include table wares, decorative wares, and porcelain insulators, both HT (high tension) and LT (low tension) types. Other products manufactured in the cluster are hospital ware, chemical porcelain, electro ceramics, kiln furniture, special ceramics, toys and non-china crockery products. A majority of pottery units in the cluster use tunnel kilns which is of continuous type. A few units use shuttle kilns which are of batch type engaged in the production of specialised products. Both types of kilns mainly use light diesel oil (LDO) and rubber processed oil (RPO), while a number of units have started using piped NG provided by Adani Gas, who is the local gas distributer in the cluster.

4.2 Advanced technological options for pottery industries

Although, there was a major shift in the cluster from switching over to inefficient coal fired downdraft (DD) kiln to tunnel kilns, several studies in the past clearly indicated that there are several energy efficient (EE) technology options available for the industry that would help in improving the energy performance as well as product quality. Further, there are a number of technology options available in raw material preparation and mould making areas. Some of the important EE options are discussed below.

4.2.1 Low thermal mass kiln furniture and car

Kiln cars are used in tunnel kilns to carry ceramic products for firing. Kiln furniture includes all those products used to support, hold or position ceramic wares/articles in kilns during firing process. Depending on loading pattern and the geometry of the wares, kiln furniture is designed. Hence, kiln furniture plays a vital role in energy saving. The following properties are important while selecting kiln furniture (1) retaining strength at a higher operating temperature, (2) resistance to thermal shock, (3) resistance to abrasion, (4) excellent emissivity and (5) good thermal conductivity.

Different types of kiln furniture used in the kiln include batt, post, support, beam, bar, half collar, ring, tray, sagger, setter and crank. In a tunnel kiln, about 19 cars are present at any point of time during normal operation. It comprises 7 cars in preheating zone, 3 cars in firing zone and 10 cars in cooling zone. Thus the kiln cars along with kiln furniture and ceramic products are subjected to preheating, firing and cooling on a continuous basis.

Traditional kiln furniture

With a large deadweight ratio of car to product of 3:1, this results in substantial heat losses and higher Specific Energy Consumption (SEC) of the kiln. The heavy refractory material used in kiln car can be replaced with silicon carbide beam and less thickness of support plates of varying width as per size and shape of products. Typically, the kiln furniture to product ratio reduces from 3:1 to 1:1. With use of low thermal mass material, the firing and cooling processes leads to substantial increase in push-rate of kiln cars leading to high production rates. However, the kiln needs to adhere to certain cooling rate of products after firing, which otherwise may lead to cracks in products and hence affect kiln yield. Hence it is required to increase the length of all the zones. In a typical tunnel kiln in Khurja, the modification in kiln furniture would entail an increase of kiln length from 120 feet (36 metre) to 180 feet (54 metre).

Some of the advantages of tunnel kiln using low thermal mass kiln cars include the following:

- Lower weight of kiln car as deadweight ratio of kiln car to product falls from the ratio 3:1 to 1:1
  - Increased production
  - Reduction in energy consumption

Low thermal mass kiln furniture and car

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Low thermal mass (silicon carbide) kiln furniture

Different types of kiln furniture used in the kiln include batt, post, support, beam, bar, half collar, ring, tray, sagger, setter and crank. In a tunnel kiln, about 19 cars are present at any point of time during normal operation. It comprises 7 cars in preheating zone, 3 cars in firing zone and 10 cars in cooling zone. Thus the kiln cars along with kiln furniture and ceramic products are subjected to preheating, firing and cooling on a continuous basis.

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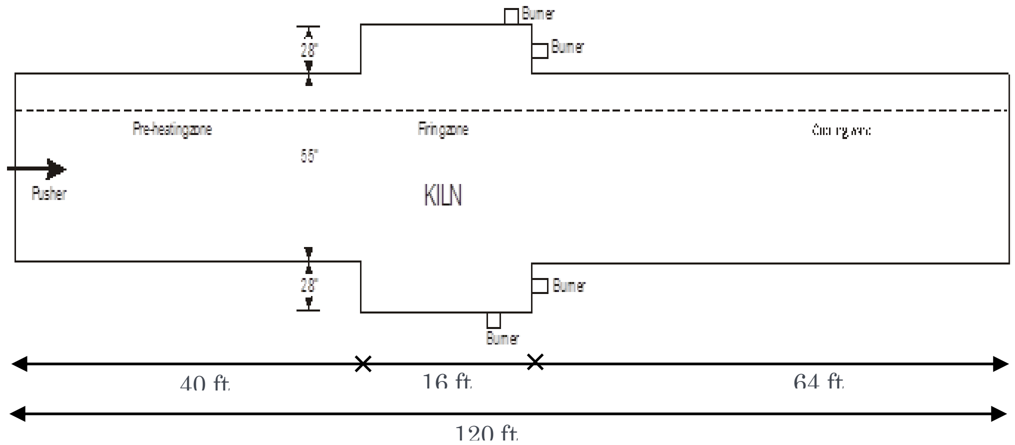
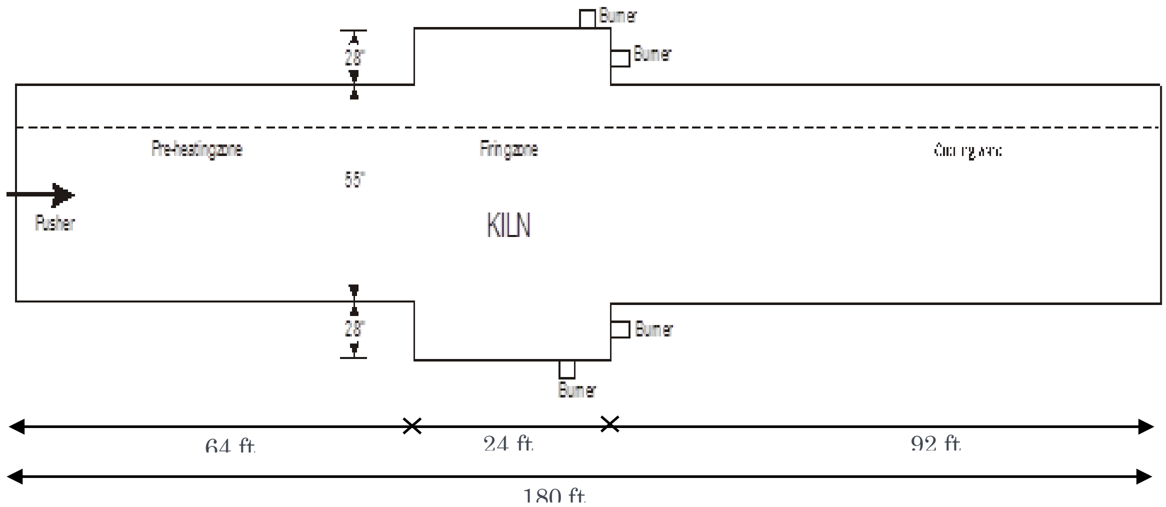


Tunnel kiln length with conventional kiln car



Tunnel kiln length with low thermal mass kiln car

Some of the advantages of tunnel kiln using low thermal mass kiln cars include the following:

- Lower weight of kiln car as deadweight ratio of kiln car to product falls from 3:1 to 1:1

- Increased production

Conventional kiln car vs low thermal mass kiln car

Parameter	Conventional kiln car	Low thermal mass kiln car
Kiln length (feet)	120	180
Kiln car : Product weight ratio	3:1	1:1
Push rate of car (minute)	50-60	20
Production (no. of pieces/day)	50,000	70,000
LDO consumption (lit/day)	500	500
Energy saving		20%
Investment (Rs lakh)	20	25

- Reduction in energy consumption

4.2.2 Pyro block insulation for kiln roof

The tunnel kilns in Khurja cluster extensively use folded ceramic fibre modules as insulation for side walls and roof structure. These modules are generally prepared at site using ceramic blanket roll. It is essential to provide sufficient insulation both at firing zone and either sides of firing zone joining with preheating and cooling zones. The select insulations are to be high temperature compatible as the temperature of firing zone is about 1150-1200^{o}C. The roof temperatures are always higher than sidewalls, as combustion products generally tend to travel upwards. Use of manually folded ceramic blanket has inherent imperfection compared to machine folded branded product offered by reputed ceramic industries. Machine folded ceramic block behaves like a monolithic structure and provides better insulation. Due to more joints involved in folded type, the performance of insulation is moderate.

Folded ceramic fibre blanket

Pyrobloc module

A few advantages of the monolithic or mono-block ceramic products such as pyrobloc modules include the following:

- High compressed density of more than 240 kg/m^3 which leads to better insulation i.e. low thermal conductivity (K-value)
- Easy to compress from all sides (both vertical and horizontal) and therefore shrinkage of fiber at high temperature can be arrested
- Easy to cut to any shape at site or procured custom designed for specific application
- Fast and easy installation

4.2.3 Kiln automation and safety systems

The tunnel kilns are operated manually in almost all pottery units in the cluster. In order to have close control of product quality, optimum yield and key operating parameters, it would be beneficial to include automation of kiln operation. Some of the important kiln automation options are given below.

Temperature control

There is limited instrumentation to monitor furnace temperatures in different zones - preheating, firing and cooling. The number of monitoring points of furnace temperature can be enhanced and a PLC based control system can be added to control temperatures across different zones. Any deviation observed can be auto corrected and corresponding interlinking can be actuated for overall control

Air to fuel ratio controller

The fuel firing is varied manually by the operators based on eye judgment and skills. However, the corresponding change in air flow is generally not done, which results in improper air to fuel ratio and higher heat losses in flue gases. An oxygen analyser can be installed to measure excess air ratio, which can be used to control motorized valves to account for variations in operating parameters. For example, if low temperature is observed in firing zone, the NG flow can be increased with PID controller to restore set operating temperature and also maintain proper air to fuel ratio by increasing air flow with respect to increased NG flow through electrical signal from PID to motorized valve correspondingly.

Cooling zone temperature trimmer

The air flow in cooling zone is generally adjusted based on the product quality as observed when they come out of tunnel kiln. With this, significant production and time loss can occur. The temperature deviations observed in cooling zone temperature can be adjusted automatically by actuating a motorized valve to increase/ decrease and trim air flow in different sections of cooling zone instead of existing manual practices.

Other safety systems

The gas train safety devices include low/high pressure safety shut-off valve (SSOV), pneumatically operated safety guard against malfunctioning of Pressure Reduction Valve (PRV) system. The PRV is a spring loaded diaphragm based mechanical device and maintains two set pressure (maximum and minimum) respective of input supply pressure of natural gas. The SSOV system locks off NG supply in case of PRV fail to maintain set pressures. In case of NG pressure either less or more than the recommended safe limit of burner. It can lead to bursting due to accumulation of NG within the kiln chamber.

The SSOV also locks off NG supply in case of electrical power failure as blower will discontinue to supply combustion air to burner still power supply is resumed. However, NG will keep accumulating inside the chamber if power supply delayed for extended period. The SSOV operates on the following conditions and locks off NG supply as well as raise an alarm to undertake appropriate corrective measures.

- ✓ PRV fails to maintain maximum set pressure
- ✓ PRV fails to maintain minimum set pressure
- ✓ Electrical power break down

Apart from SSOV, generally a non-return valve (NRV), a mechanical device is provided in gas line near to burner, which allows unidirectional flow of gas and prevents return travel of flame during sudden discontinuation of combustion air flow. This NRV acts as fire safety device during such occasion. The burner system needs to be equipped with flame monitoring and control system so that NG supply is switched off in case of flame out or no flame conditions. Further, PID system will also be integrated to switch off blower to stop combustion air flow to burner.

Similarly, airline could be equipped with pressure transducer to act in tandem when conditions of activation satisfied for switching off NG supply i.e. for low air pressure or no air supply to burner. The industry has to ensure interlink and integrate all safety devices as provided in both gas train and air train to ensure complete safety of the kiln system.

4.2.4 Roller hearth furnace

Tunnel furnaces are extensively used in the cluster for firing of ceramic products. At present the total firing cycle in a tunnel kiln is about 18-20 hours with 45 to 50 minutes push time. The industry is in the process of adopting low thermal mass kiln car & furniture to reduce heat load and increase production rate. One of the technology options available for pottery units is adoption of Roller Hearth (RH) furnace in place of tunnel kilns. RH furnaces do not use kiln cars and hence there is no initial investments towards kiln cars as well as for their maintenance during kiln operation. With elimination of deadweight completely, the total firing cycle in roller hearth furnace is about 6 hours, which is substantially lower. This type kiln is also suitable for gas fired system.

Roller hearth furnace

4.2.5 High alumina ball mill and alumina coating

A ball mill is a type of grinder used to grind and blend raw materials. It works on the principle of impact and attrition i.e. reduction in size of raw materials is achieved through impact as the balls drop from near the top of the shell. A ball mill consists of a hollow cylindrical shell. The axis of rotation of the shell may be either horizontal or at a small angle. The length of the mill is approximately equal to its diameter. The grinding media is river pebbles or mined pebbles of different sizes in a conventional ball mill. The inner surface of the cylindrical shell is strengthen with 5 inch thickness refractory lining using brick, silica sand white cement as mortar.

View of ball mill

Pebbles in conventional ball mill

The raw material clay is fed in ball mill to reduce the size and aid proper mixing. In Khurja, large size raw materials which were being used in the units have now been replaced by powdered materials. In a conventional mill, equal quantity of raw material, pebbles and water are added. The speed of motor in a ball is generally maintained low at about 8-9 rpm (rotations per minute). During regular operation, ball mills are operated for about 18 hours per day. In conventional system, the pebbles lose their shape and lining of inner surface deteriorated very frequently. Owing to this, the efficiency of ball mills reduces drastically, which increase the overall

Benefits of high alumina ball mill and refractory lining

The existing pebble-refractory lining based ball mill can be replaced with a high alumina ball and refractory lining based ball mills, which would result in significant monetary savings.
Basis:

Ball mill processing a raw material of 3 tonne per batch connected with a 15 hp (11.2 kW) motor, considering 18 hour operation per day for 300 days.

Electricity consumption with conventional system = 48, 384 kWh/yr
Electricity consumption with high alumina system = 38, 707 kWh/yr
Energy saving = 9,677 kWh/yr
Energy cost saving = Rs 64,835 per year
Monetary saving with better grinding medium = Rs 58,500 per year
Monetary saving with improved lining = Rs 5,583 per year
Total monetary saving = Rs 1,28,918 per year
Incremental investment for high alumina ball mill = Rs 2,58,000
Simple payback period = 2 years

grinding time leading to increase in electricity consumption per tonne of raw material. In typical cases, almost 75% of pebbles are replaced every 6 months. Further, the change in weight ratio between the raw material and pebbles cause dynamic imbalance, which affects the performance of the system.

The existing ball mill can be retrofitted with an energy efficient system. It uses high alumina refractory lining, the life of which is higher than conventional refractory lining due to less wear and tear. The mined/ river pebbles will be replaced with high alumina balls, which would require a replacement rate of only 20% of total grinding medium. The advantages of using high alumina based ball mills include the following:

High alumina balls

- Higher grinding efficiency reduces overall downtime and increases the availability of the system.
- Reduces energy consumption per unit of raw material prepared
- Enhances dynamic balancing and reduce pebble replacement cost
- Reduces labour cost both in batch preparation and re-lining due to low rate of wear and tear

4.2.6 Automatic roller jigger machine

Jigger machines are used to provide shape to circular products. Jigger machines are generally operated for about 8 hours per day. Manual jigger machines are extensively used in the cluster. With manual operation, the production rate is limited, which depends on skills of the operators. Moreover, the yield from fired products also goes down with manual process. To address the issues related to production rate and yield, one of the options available to the industry is automatic roller jigger head machines. Automation increases the electrical load of the system - from 1 motor (each 1 hp) to 3 motors (each 1 hp). The overall production of good quality product increases by about 20-25%.

Automatic roller jigger machine

Conventional jigger machine vs automatic roller jigger machine

Parameter	Conventional jigger machine	Automatic roller jigger machine
Connected load	1 hp	3 hp
Production rat	3000 piece/8 hr	3500 piece/8 hr
Yield	95%	100%

4.2.7 Energy efficient motors

A significant number of motors used in ceramic industries for various process applications are old and inefficient due to wear and tear. These areas include ball mills, pumps, kiln blower, etc. which consume more electricity due to use of inefficient motors. These old and inefficient motors can be replaced with energy efficient (EE) IE3 motors which would result in significant energy saving. The replacements of inefficient motors are more beneficial for areas such as ball mills which are used extensively for about 20 hours per day using 15 HP motor. An energy saving potential of 5-6% exists with replacement of standard motors with IE3 motors.

Energy efficient motors

Savings with energy efficient motors in ball mill

Parameter	Unit	Standard	IE3 motor
Rated capacity	(kW)	15	15
Efficiency of motor	(%)	90.6%	92.1%
Loading of motor	(%)	70.0%	70.0%
Operating duration	(hr)	6000	6000
Energy consumption	(kWh/yr)	69,536	68,404
Energy saving	(kWh/yr)	1,133 (1.6%)	
Price of electricity	(Rs/kWh)	8.00	8.00
Energy cost saving	(Rs/yr)		9060
Investment for EE motor	(Rs)		20570
Payback period	(year)		2.3

Energy efficiencies of Standard (IE2) IE3 motors

kW	2-Pole			4-Pole			6-Pole		
	Frame size	Efficiency%		Frame size	Efficiency %		Frame size	Efficiency %	
		IE2	IE3		IE2	IE3		IE3	IE3
0.37	71	72.2	75.5	71	70.1	73	80	69	71.9
0.55	71	74.8	78.1	80	75.1	78	80	72.9	75.9
0.75	80	77.4	80.7	80	79.6	82.5	90S	75.9	78.9
1.1	80	79.6	82.7	90S	81.4	84.1	90L	78.1	81
1.5	90S	81.3	84.2	90L	82.8	85.3	100L	79.8	82.5
2.2	90L	83.2	85.9	100L	84.3	86.7	112M	81.8	84.3
3.7	100L	85.5	887.8	112M	86.3	88.4	132S	84.3	86.5
5.5	132S	87	89.2	132S	87.7	89.6	132M	86	88
7.5	132S	88.1	90.1	132M	88.7	90.4	160M	87.2	89.1
11	160M	89.4	91.2	160M	89.8	91.4	160L	88.7	90.3
15	160M	90.3	91.9	160L	90.6	92.1	180L	89.7	91.2
18.5	160L	90.9	92.4	180M	91.2	92.6	200L	90.4	91.7
22	180M	91.3	92.7	180L	91.6	93	200L	90.9	92.2
30	200L	92	93.3	200L	92.3	93.6	225M	91.7	92.9

Source: IS 21615:2011 (3-phase, 50Hz, single speed & squirrel cage induction motors)

4.2.8 Energy efficient fans

Green-ware drying is an important process in a pottery unit before firing in the kiln. The pottery units use extensively ceiling fans for the purpose of drying. The conventional ceiling fans use about 70-80 watt of electricity at full speed. The conventional fans can be replaced with energy efficient (EE) ceiling fans of 28 watt capacity, which would help in saving energy to about 60% used by ceiling fans in pottery units.

The EE fans are equipped with brushless DC (BLDC) motors which use electronic device in place of mechanical commutator used in conventional motors. BLDC motor controls speed in a closed-loop system. Based on signal input detected by the sensor, the transistor in the drive circuit turns on and off thereby rotating the motor. The hall effect sensor, which is a transducer varies output voltage in response to changes in magnetic field. The sensor is used to detect the position of permanent magnet.

Energy efficient ceiling fan

The savings would be significant as ceiling fans are used for almost 20 hours per day throughout the year. Some of the advantages of EE fans include the following:

- Lighter in weight
- No slip due to synchronous type
- Smart remote control with sleep and timer mode
- No humming noise and heating
- Longer life as they can sustain hot and dusty environment
- Attractive payback period

Monetary benefits with energy efficient ceiling fans

Parameter	Conventional fan	Energy efficient fan
Power rating (watt)	80	28
Energy consumption (kWh/yr)	168	480
Energy saving (kWh/yr)		312
Energy costs (Rs/yr)	1344	3840
Monetary saving (Rs/yr)		2496
Investment (Rs)	1700	3500
Incremental investment (Rs)		1800
Payback period (month)		9

300 days @ 20 hours per day

4.2.9 Solar photovoltaic for power generation

SPV for power generation

The pottery units in the cluster use electricity for several applications such as raw material preparation and operating utilities such as pumps, compressors, motors and lighting. On an average, electricity accounts for about 20% of total energy share in a pottery unit. Electricity is sourced from grid and DG sets are used only in case of power failure. A part of the electricity requirements can be met by installing solar photovoltaic (SPV) panels on the roof structure of the units. Although, there are two types of solar plants are in use (on-grid and off-grid), on-grid is more suitable for industrial applications, which can be connected with grid through a 'net metering system. Some of the differences between on-grid and off-grid systems are provided below.

SPVs: On-grid system vs off-grid system

On-grid system	Off-grid system
No battery backup required	Requires batter backup
Low overall investments	Expensive
Net metering is available so that the excess electricity generated can be exported to grid	No net metering
Preferred system where grid is available	Suitable for non-access to grid
Low replacement costs as no recurring costs for battery replacement on a periodical basis	High maintenance costs

4.2.10 Quality assurance for fabrication

This section provides a ready reference for inspection and testing guidelines which need to be observed during the fabrication work for different utilities in the industry.

Inspection

The inspection activities during manufacturing are divided into the following: (1) Inspection of raw materials, (2) Inspection during fabrication, (3) Inspection of complete assembly at fabrication site and (4) Inspection of complete assembly at client (end user) site.

i) Inspection of raw materials

Inspection of raw materials should be carried out at the time of their purchase. The following conditions need to be ensured during procurement of raw materials.

- *Test certificates*. Supplier(s) must provide the manufacturer test certificates of concerned items, indicating that the materials purchased are according to the required technical specifications.

- *Chemical and physical test*. Samples from each lot of metallic are verified for their chemical composition and physical properties to ensure that the material belongs to the correct grades.
- *Visual inspection.* All materials are to be checked visually for dents, cracks, corrosion, distortion, straightness, etc. Stainless steel (SS) material must be checked by magnetic test (a magnet should not attract SS material).
- *Dimensional inspection.* (a) The length, width, thickness, outside diameter and inside diameter as applicable must be checked against the approved drawings after removing burrs, if any. (b) The lengths of bolts must be checked. Random checks must also be made to ensure proper movement of nuts over the bolts.

ii) Inspection during fabrication

- The dimensions of materials are to be checked using proper gauge against the approved drawings. Burrs if any after drilling must be removed.
- Welding of the pieces to be carried by Tungsten Inert Gas (TIG) welding after first establishing the procedure on mock-up test pieces. In order to check for welding defects in joints, the dye penetration test is to be carried out after welding.

iii) Inspection of complete assembly at fabrication site

- A final dimensional check-up must be carried out after assembly of the entire system as per approved drawings/customer requirements, to ensure proper alignment and to avoid any mismatch after integration at the client site.
- Individual sub-system of a utility is to be tested by hydraulic and pneumatic tests for leakage and pressure holding as per requirements.
- The system is to be assembled together and aligned properly, following which the complete assembly too must be subjected to hydraulic and pneumatic tests.

iv) Inspection of complete assembly at end-user site

- After receipt of the completed assembly at the client site, visual examination must be carried out to identify damages or distortion during transportation.
- Hydraulic test to be carried out by applying pressure of 3 kg/cm^2 and one hour holding period, all weld joints to be checked for water leakage. No Drop of pressure is permissible. Similarly, pneumatic test to be carried out by applying air pressure of 2 kg/cm^2, all weld joints to be checked by application of soap solution. No drop of pressure is permissible.
- The modules are to be assembled together and aligned properly. Thereafter, the complete recuperator assembly is subjected to hydraulic and pneumatic test as per Quality Assurance Plan while in stand-alone arrangement, that is, before taking it online.

List of references

(1) Reports prepared by TERI under TERI-SDC partnership project
(2) Discussions with stakeholders in Khurja ceramic cluster

(3) Information collated from various equipment suppliers