Comprehensive training material for fabricators and maintenance operators 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

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For more information

GEF-UNIDO-BEE PMU
Bureau of Energy Efficiency
4th Floor, Sewa Bhawan, Sector-1,
R.K. Puram, New Delhi-110066

Email: gubpmu@beenet.in
pmc@teri.res.in
Website: www.beeindia.gov.in
www.teriin.org

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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 'fabricators and maintenance operator's' 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. fuel shift and related challenges, issues and benefits, energy conservation opportunities in ceramic units and construction of gas based tunnel kiln system.

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 'fabricators and maintenance operators' category. The material is structured in the following 3 modules.

Module 1	Fuel shift and related challenges, issues and benefits
Module 2	Energy conservation opportunities in ceramic units
Module 3	Construction of gas based tunnel kiln system

2.0 Module 1 - Fuel shift: Issues, challenges and benefits

2.1 Fuel types

A variety of fuels like solid, liquid and gaseous fuels are used in industry sector to meet the thermal energy requirements such as heating and melting processes. The selection of fuels for a particular industrial application is dependent on factors such as availability, cost economics and suitability to process requirements.

2.1.1 Calorific value of fuels

The calorific is the measurement of heat or energy produced when combusted. It is measured either as gross calorific value (GCV) or net calorific value (NCV). The GCV is widely used for calculations. The calorific values are dependant the chemical composition of fuels. The GCV of different fuels and typical composition of fuels are provided below.

GCV of fuels

Fuel	Gross calorific value
Coal	(kcal per kg)
Grade-A Above	6200
Grade-B	5600-6200
Grade-C	4940-5600
Grade-D	4200-4940
Liquid fuels	(kcal/kg)
LDO	10700
Furnace oil	10,500
LSHS	10,600
Gaseous fuels	(kcal/Sm^3)
Natural gas	9350
Propane	22200
Butane	28500

Source: BEE

The majority share of chemical constituents of most of the fuel is carbon and hydrogen, which are the major sources of heat energy released during combustion of fuel. The chemical composition of commonly used fuel is given below.

Typical chemical composition of fuels (%)

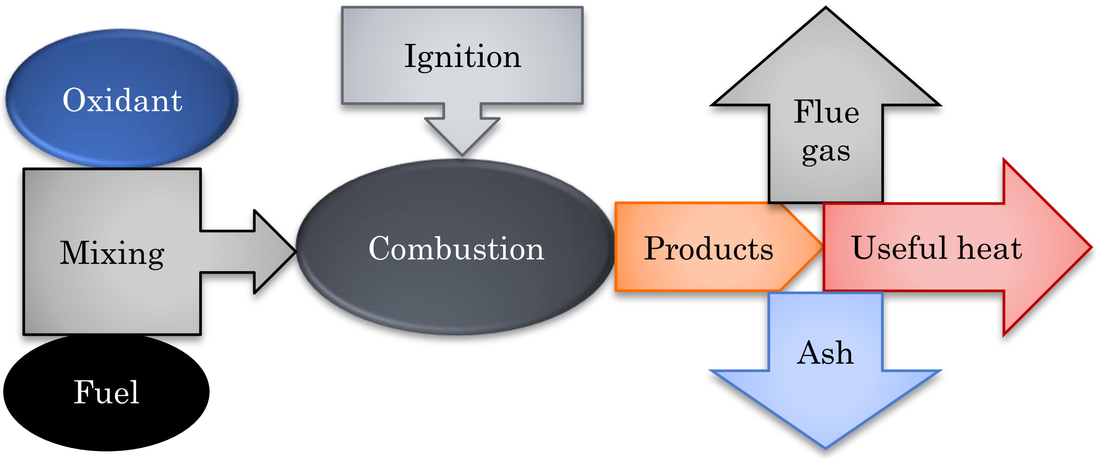
Constituent	Fuel oil	Coal	Natural gas
Carbon	84	41	74
Hydrogen	12	2.9	25

Constituent	Fuel oil	Coal	Natural gas
Sulphur	3	0.4	-
Oxygen	1	9.8	Traces
Nitrogen	Traces	1.3	1
Ash	Traces	38.6	-
Water	Traces	5.9	-

Source: BEE

2.2 Combustion of fuels

The fuels, when burnt, react with oxygen present in atmosphere to release heat. Oxidation rate of fuel depends on surroundings temperature. The temperature of the fuel surroundings depends on the oxidation rate of fuels. At ignition temperature, the oxidation rate is such that the temperature of the surroundings is maintained by the rate of heat generation. The heat in the products of combustion is used for various thermal applications e.g. heating, drying, melting, etc. The balance heat is exhausted in flue gases leaving the furnace through a chimney after cleaning as per requirements. In case of solid fuels such as coal and biomass, ash is formed which also carries away heat which is a loss. The basic steps



Basic steps of fuel combustion

of combustion phenomenon are shown below.

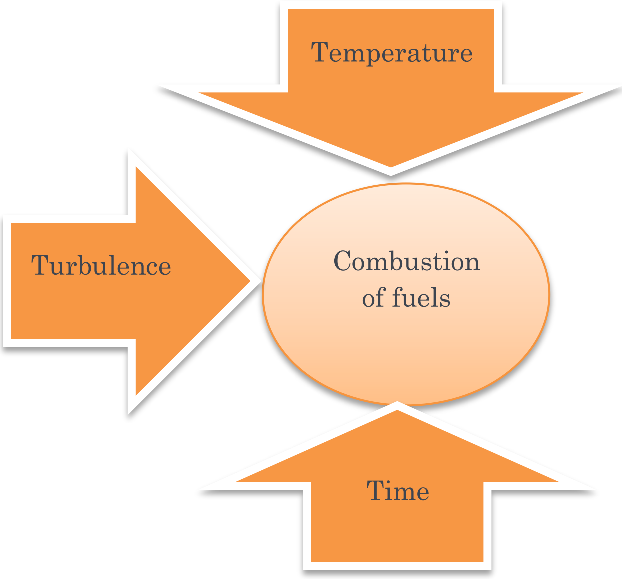
The ignition temperature is different for various fuels as shown below.

Ignition temperature of fuels

Fuel	Ignition temperature (°C)
Bituminous coal	454
Anthracite	600
Diesel	316
Heavy fuel oil	407
Natural gas	538

N-Butane	405
Propane	468

For combustion of fuels, three factors viz. Temperature, Turbulence and Time (TTT) are most important which would dictate effectiveness of combustion in a thermal system.



Factors affecting combustion

The temperature (T) inside the system should be sufficient enough to ignite and maintain ignition of fuel. The second factor is turbulence (T) which needs to be created and would ensure intimate mixing of air (oxygen) with fuel, thereby ensuring complete combustion. The third important factor is time (T) which should be sufficient enough to complete the combustion and release the heat from fuel. Any deficiencies in one of the T's will lead to incomplete combustion releasing less heat than the heat content of the fuel.

Maintain correct air fuel ratio i.e. excess air to minimise unburnt formation and flue gas losses

2.2.1 Stoichiometric air fuel ratio

A certain quantity of air is required for complete burning of fuel. The quantity of air required for complete combustion depends on the presence and quantities of various elements such as carbon, hydrogen and sulphur in the fuel. The exact quantity of air required for complete combustion, based on oxygen requirement of the fuel, is known as "stoichiometric air". It is important for the fuel to burn completely within the given furnace volume in order to convert all its chemical energy into heat before the products of combustion (flue gases) leave the furnace.

3Ts - Temperature, Turbulence and Time are most important which dictate effectiveness of combustion in a thermal system

2.2.2 Excess air and maintaining correct air-fuel ratio

At the end of combustion process, no reactants are present in the products. If the fuel does not burn completely, the presence of "unburnts" in flue gases will carry way some share of heat energy. These heat losses affect the thermal efficiency of the furnace (defined heat input minus heat losses). However, in actual practice, more quantity of combustion air will be required to react completely with all the reactants present in the fuel and release all the heat available in fuel. The combustion process is helped by thoroughly mixing air and fuel (for instance, by using a 'nozzle mix' burner). The additional quantity of combustion air provided to fuels during combustion is known as "excess air", which helps in completing the combustion process.

There are limits for the quantity of excess air as well. Too much excess air will only take away the heat generated during combustion of fuel, leading to heat losses through flue gases. If the quantity of air supplied is less than the stoichiometric, the air–fuel mixture is known as 'rich mixture'. If the quantity of air supplied is more than the stoichiometric, the air–fuel mixture is known as 'lean mixture'. Neither rich nor lean mixture is desirable for efficient furnace operation. The level of excess air is dependent on the type of fuels and their composition, which is shown below.

Excess air and air to fuel ratio of different types of fuel

Fuel type	Excess air (%) (by volume)	Air to fuel ratio (kg/kg fuel)
Solid fuels	25 – 60	7 – 8
Liquid fuels	15 – 35	14 – 15
Gaseous fuels	10 - 20	15 – 17

The total combustion air fed into a system is calculated as follows"

Total air supply = Stoichiometric (theoretical) air + Excess air

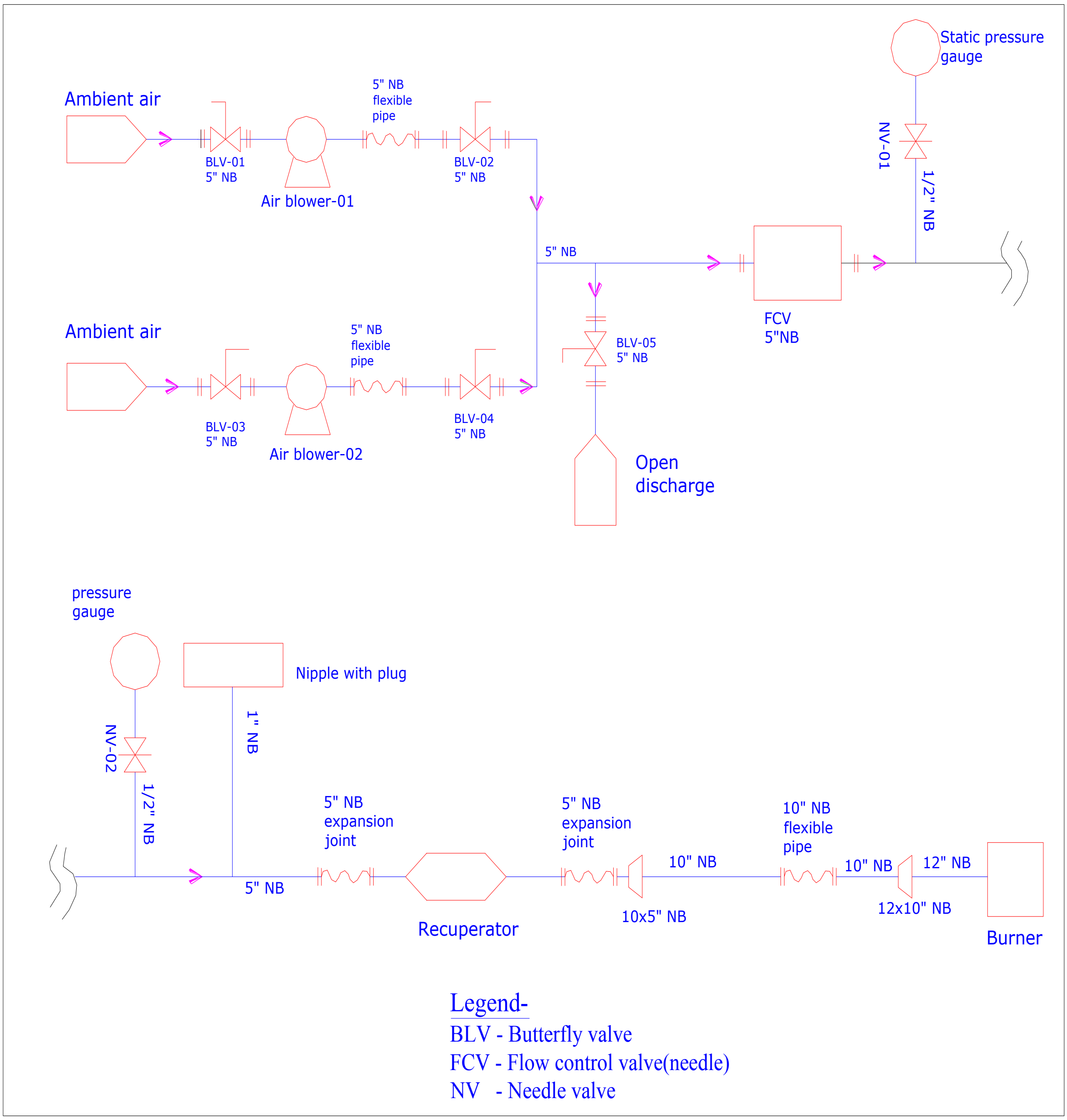
2.2.3 Flame colour

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.

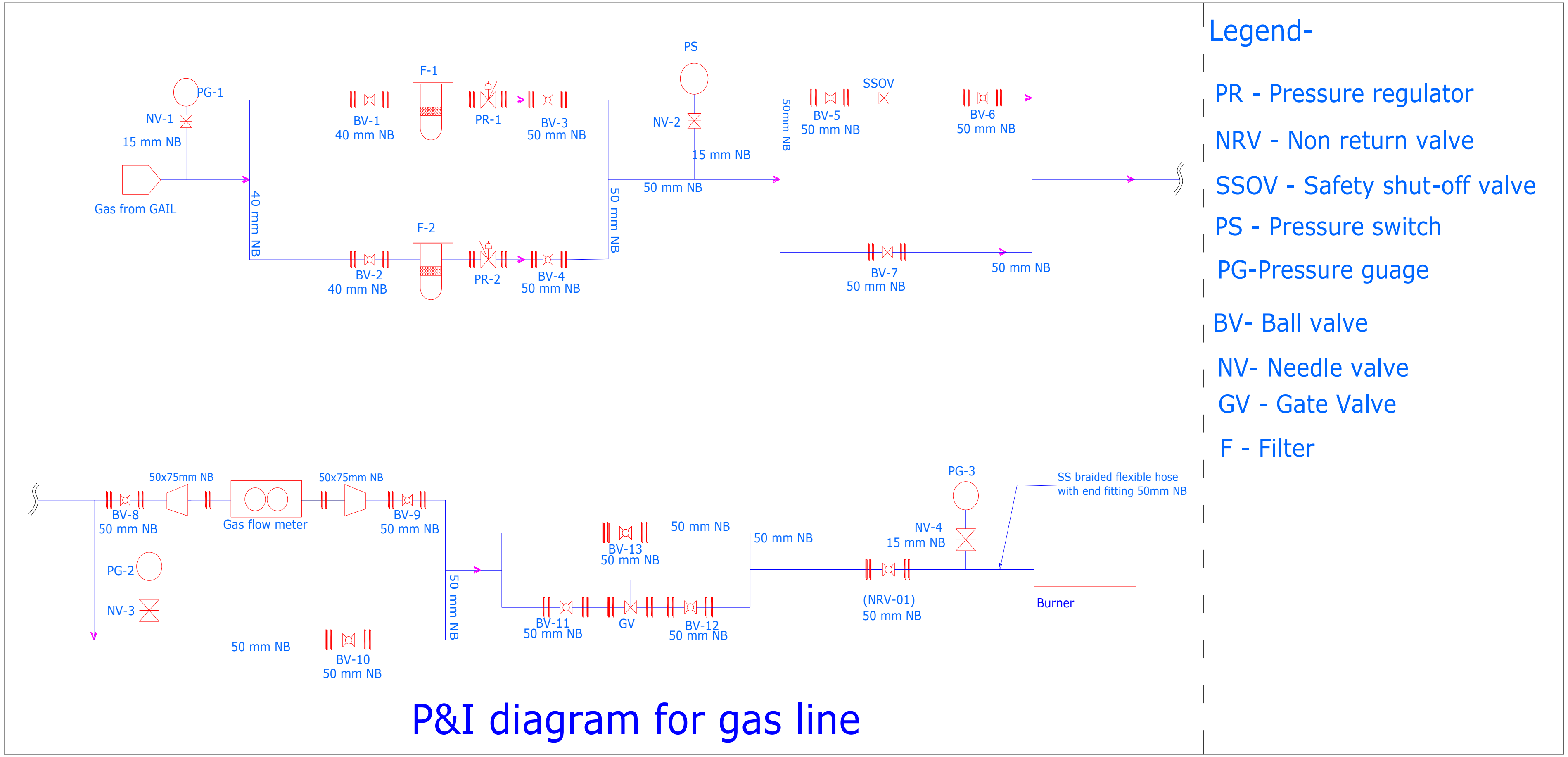
2.3 Gas based combustion system

In a gas based combustion system, the important components involved are (1) air train and (2) gas train, which are briefed below. The gas train comprises gas meter, pressure regulator, non-return valve, pressure gauge, pressure switch, burner, etc. The air train comprises

ID/FD fans, control valves, heat recovery systems (e.g. recuperator, regenerator, etc.), bypass lines etc. A typical gas train and air train used in a furnace system are shown below.



Air train


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
PS
NV-2
15 mm NB
50 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
(NRV-01)
50 mm NB
SS braided flexible hose
with end fitting 50mm NB
Burner
P&I diagram for gas line

Gas train

2.3.1 Gas contract assessment

The foremost factor important for an industry during fuel switch over is gas contract assessment. At present, the ceramic units in Khurja cluster are mainly using light diesel oil (LDO) and rubber process oil (RPO) based on economics of fuel. Each industry is required to estimate its gas consumption requirements based on existing consumption and type of fuels, their gross calorific values (GCV) and overall production including both existing and envisaged in future. Further, factors such as use of inefficient furnace design, local burners and poor insulation would greatly affect the gas consumption in the industry.

Load assessment for gas contract is very important to estimate requirements of the plant and avoid excessive billing.

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Evaluate gas requirements based on existing consumption of fuels, gross calorific value and planned addition in production

Considering all these factors, the industry has to carry out useful heat gains and losses. The next step would include estimation of heat load while switch over to natural gas based kiln considering same amount of heat gain by the products and envisaged heat losses from gas based system. On confirming average gross calorific value of piped natural gas from the service provider and envisaged combustion efficiency of burner to be used in the kiln, gas consumption can be estimated, which would help in deciding the contract amount of gas required for a ceramic unit planning to obtain gas supply for conversion to gas based firing system.

2.3.2 Security deposit and gas billing

The gas supply agency has standing check points before getting into a service agreement to supply natural gas to an interested plant. Generally, the industry interested in gas connection needs to make security deposits towards commercial and administrative requirements. The security deposit includes for initial connection to cover expenses towards providing gas skid and payment guarantee, which is estimated considering expected consumption for three consecutive billing cycles. The industry is planning to obtain gas contract from the service provider has to pay for a minimum billing of 85% of gas contract irrespective of gas consumption during billing cycle. At present there is no "minimum guaranteed off-take (MGO) for no-gas consumption on a daily basis, which is also generally common practice for industrial gas supplier agency. The billing cycle is generally fort-nightly based, which includes either actual consumption as recorded in the gas meter provided with skid or minimum billing amount whichever is more. The industries are generally unaware of pricing of natural gas supplied to an industrial unit. Apart from commercial benefit, pricing depends on average GCV of gas supplied during billing cycle and also includes to take care of capital and operating expenses.

2.3.3 Installation of gas trains and safety measures

The scope of work of service provider of natural gas is limited to main gas meter installed at the industry premises before distribution, which is normally known as gas skid. The industry is responsible for laying of distribution lines such as gas train to respective burner while taking into account all safety precautions of gas piping. Hence, the industry availing gas connection should avail the services of "accredited vendors" to ensure (i) standard materials used for commissioning of gas, (ii) installation of safety equipment in gas distribution line and availability of fire extinguishers and (iii) trouble shooting services during emergency situations.

Avail the services of accredited vendors to ensure quality of installation, safety and services during emergency situations

2.3.4 Training and capacity building on operation and safety issues

The usage of natural gas depends on skill levels of operators and supervisors. The kiln operators traditionally inherit operating skills and gain experience through hands-on work experience. Though natural gas based system are being adopted in the cluster, the local industries are not used to handling of natural gas for its efficient and safe operations. Therefore, regular training of operators as well as entrepreneurs on handling of NG based system and safety aspects will be required by service providers and vendors.

2.4 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

2.5 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 operating 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.

2.6 Energy efficiency in combustion of fuels

Efficient combustion of fuel is an important aspect which would ensure availability of all heat available in fuel for useful purposes. Any ineffectiveness in generation of heat from fuels and their utilisation will affect the overall performance of a thermal system which would lead to increased energy costs for the industry. Some of the best operating practices commonly used for efficient combustion of fuels is summarised below.

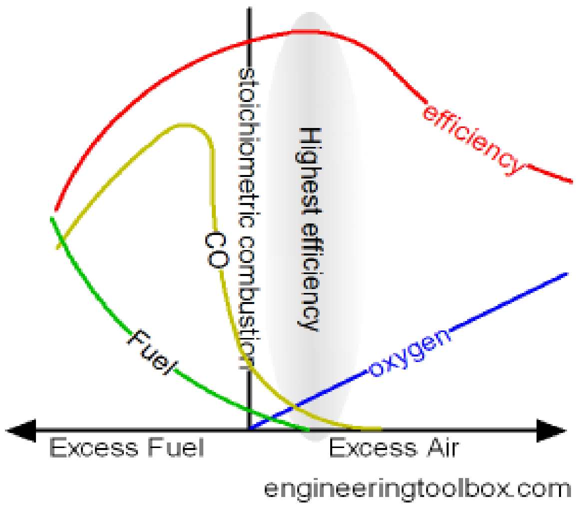
2.6.1 Optimisation of excess air

The excess air utilised in actual operation of a thermal system is calculated using the following formula.

$$\text{Excess air} = \frac{\%\ oxygen\ in\ flue\ gases}{21 - \%\ oxygen\ in\ flue\ gases}$$

The recommended level of excess air should be maintained close to the optimum level as mentioned under the section "*Excess air and maintaining correct air-fuel ratio*". Any increase of in excess air than the recommended level would lead to increased heat losses in the system. The impacts of high excess air are as follows.

- Increased flue gas losses due to higher quantity of combustion air is passed through the system
- Reduced flame temperature (reducing radiative heat transfer)
- Increased convective heat transfer slightly (for increased flue gas flow rate)
- Reduced overall heat transfer as resident time of flue gases inside the system is reduced



Combustion of fuels

Similarly, low level of excess air level than the recommended value also leads to increased level of heat losses. The deficiency of air leads to non-availability of air to complete combustion of fuels thereby leads to formation of unburnts. Thus the level of carbon monoxide (CO) in flue gases is a direct indication of combustion efficiency of fuels in thermal system. In case of solid fuels such as coal, unburnt carbon is also present along with ash, which leads to overall reduction in thermal efficiency.

During complete combustion,

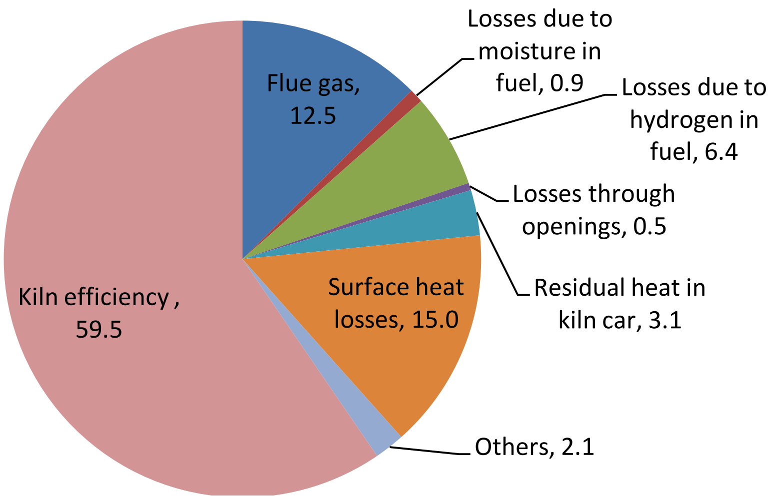
$$C + O_2 \rightarrow CO_2 + (-393 \text{ kJ/kg})$$

In case the combustion is incomplete,

$$2C + O_2 \rightarrow 2CO + (-99 \text{ kJ/kg})$$

2.6.2 Waste heat recovery

The heat generated from combustion process is transferred to the product for heating or melting (which is the useful heat or efficiency of the system). The balance heat is generally lost in various forms such as out-going flue gases, heat losses from system surfaces, cooling of furnaces surfaces, etc. Of these, flue gas heat losses generally used to be the largest share among various heat losses. Thus, the waste heat available in flue gases can be extracted using a suitable waste heat recovery (WHR) system such as recuperator or regenerator based on requirements. As a thumb rule, about 1% fuel saving can be realised with every 20 ^oC increase in combustion air temperature supplied to burner or 22 ^oC reduction in flue gas temperature leaving the furnace.



Typical Heat balance in a tunnel kiln

Source: CGCRI, Khurja

2.7 Benefits of using natural gas

Natural gas is a clean fuel as compared to solid or liquid fuels used in industries for various thermal applications. The benefits of using natural gas in ceramic industries at Khurja cluster are summarised below.

- A combination of properly designed tunnel kiln with natural gas as fuel can enhance the overall yield of the plant and reducing rejections to a minimum level
- High combustion efficiency for natural gas is possible thereby extracting maximum heat from fuel
- A properly designed kiln can be equipped with automation and reduce dependency on skills of operators
- Being clean fuel, use of NG will reduce greenhouse gas (GHG) emissions
- Helps in better workplace environment
- Easy to handle fuel
- Since it is a piped gas, there is no need to keep inventory of fuel
- Pricing of natural gas is decided based on calorific value

2.8 Safety aspects in an industry

Natural gas being highly inflammable, safety issues for its handling and usage are of paramount importance. Some of the common safety aspects that the industry need to adhere are mentioned below.

- Wear safety helmets during operation
- Install safety shut-off valves in gas supply line and do periodical checking for proper functioning
- Equip with portable fire extinguishers at industry premises
- Familiarize all factory fraternity with dummy fire fighting practices and use of equipment periodically
- Train workers on better operating practices
- Install natural roof exhaust equipment
- A water pool may be available very close to working place
- Insist workers to wear fire shoes at the workplace near kiln
- Provide heat-resistant material such as gloves and shirts to workers involved in high temperature operation
- Install electric shock-proof system
- Ensure proper earthing of electric wiring
- Keep first-aid box
- Gas distribution pipings within the premises of the industry are to be made by experienced and accredited vendor.
- Pressure holding and leak test to be carried for all gas distribution piping covering both installed during initial connection and any future expansion of gas piping within the industry as per the instruction of gas supplier.

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

(4) Reports prepared by CGCRI, Khurja

3.0 Module 2 – Energy conservation opportunities in ceramic units

3.1 Fundamentals of gas based combustion systems

3.1.1 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

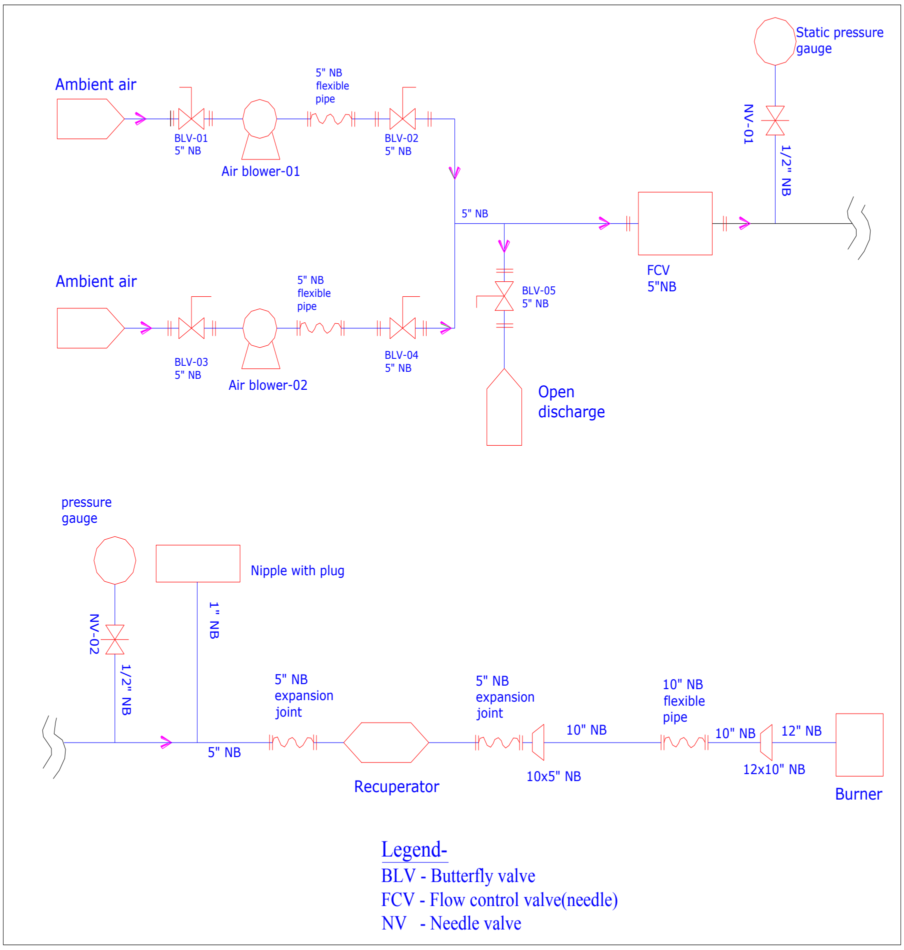
3.1.2 Excess air for combustion

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.

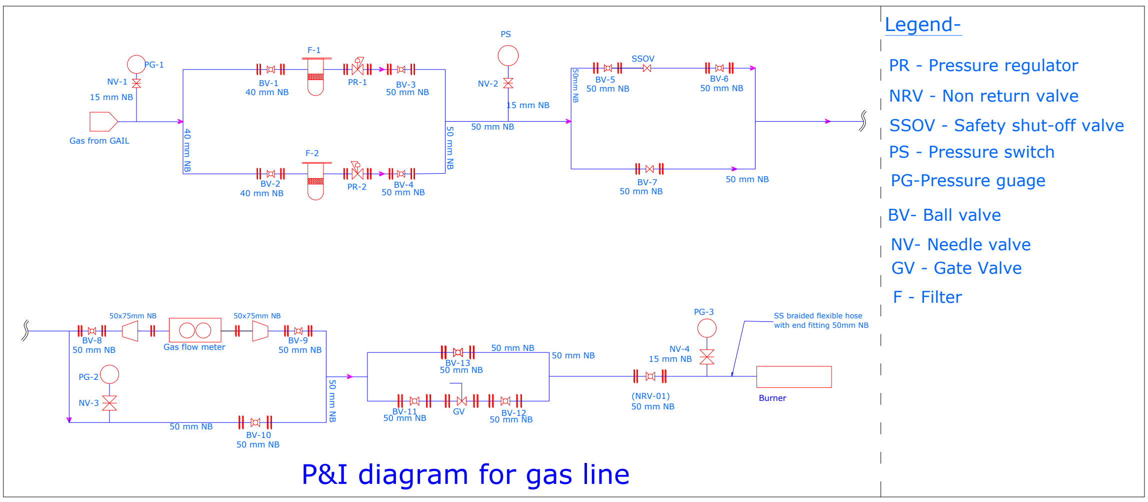
Fuel type	Excess air (%)
Solid fuels	25 – 60
Liquid fuels	15 – 35
Gaseous fuels	10 - 20

3.1.3 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

3.1.4 Draft system

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- *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

3.1.6 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

3.2 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.

3.2.1 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.

3.2.2 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%.

3.2.3 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%.

3.2.4 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.

3.3 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.

3.3.1 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.

3.3.1.1 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.

3.3.1.2 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

3.3.1.3 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.

3.3.1.4 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

3.3.2 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.

3.4 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.

3.4.1 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

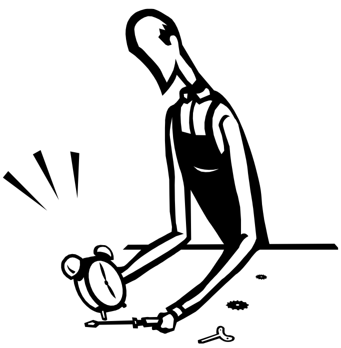
(1) Cross check temperature indicator. Use different indicator/ compensating cable. Repair/ replace the faulty meter.
(2) Ensure slightly positive furnace draught. You will observe furnace temperature start rising immediately.
(3) Slowly increase gas and air flows. Maintaining pre-set air to gas ratio.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

3.4.2 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

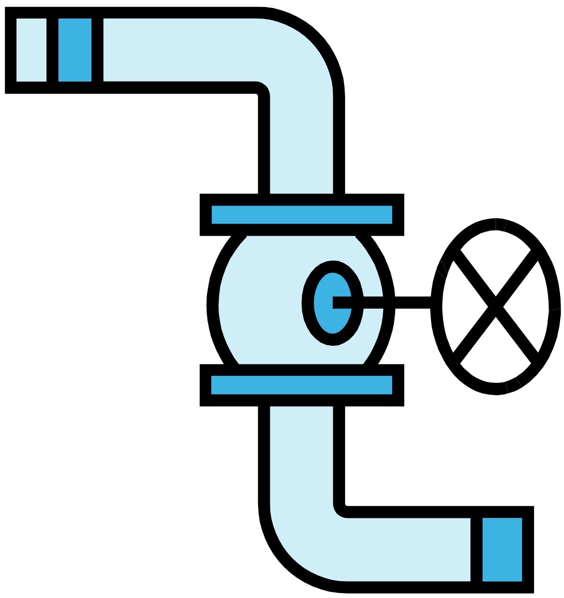
(1) Ensure proper installation of gas flow meter according to the supplier's instructions
(2) Check power connection including earthing
(3) Consult the supplier for guidance/ repair

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



3.4.3 Air train

A–1

No air flow in spite of motor operating

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

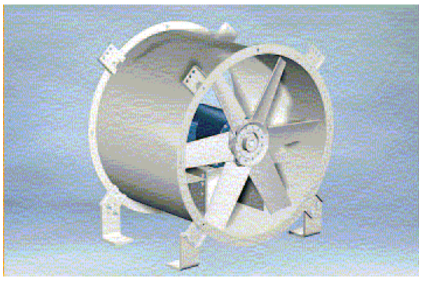
(1) Check power connection
(2) Check the direction of rotation of impeller and change by correcting the polarity of connection
(3) Contact supplier in case impeller does not rotate or incorrect rotation

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

4.0 Module 3 – Construction of gas based tunnel kiln

4.1 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 production process.

Tunnel kiln in Khurja cluster

4.2 Typical dimensions of tunnel kiln in Khurja

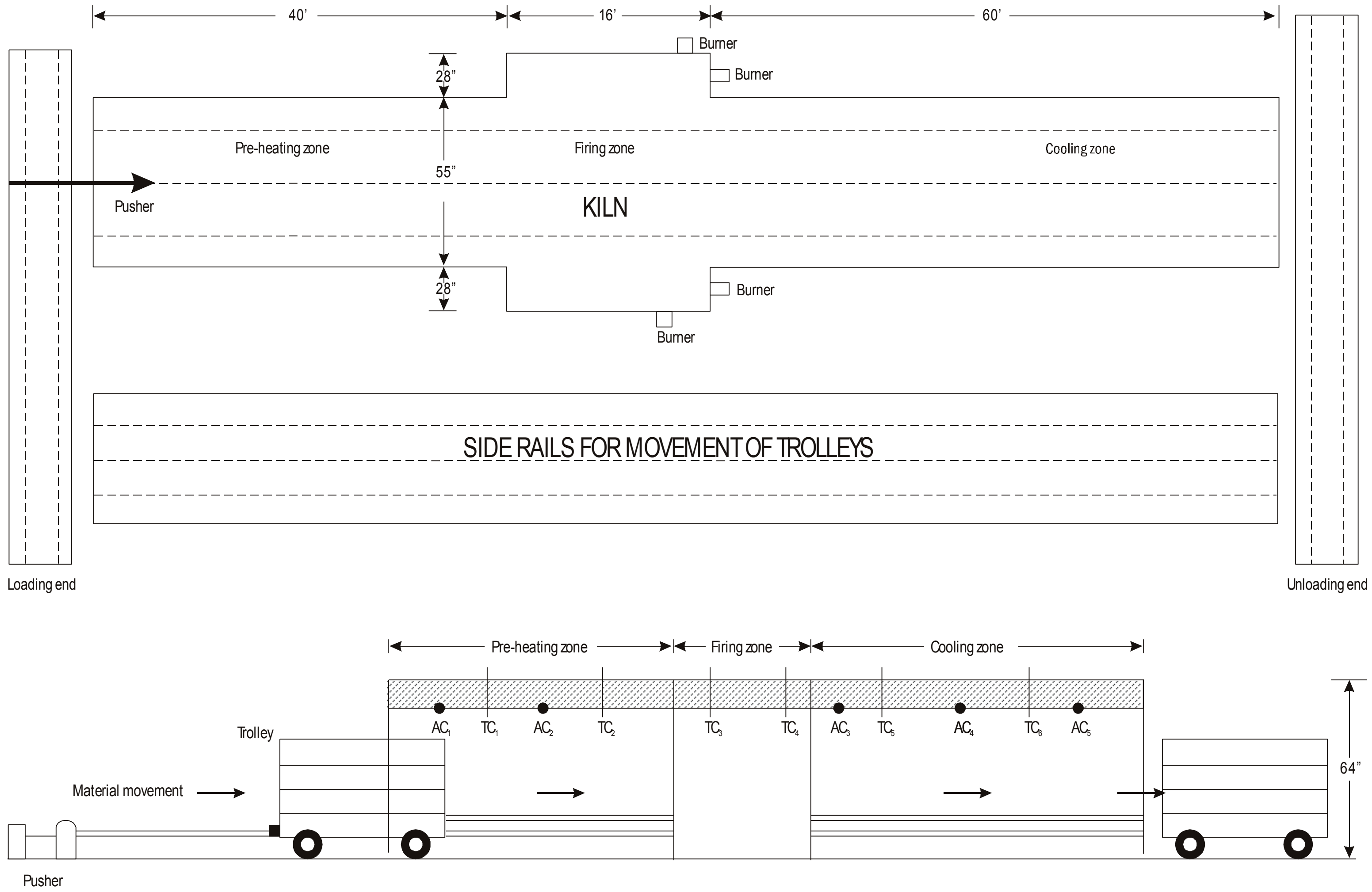
The dried products are kept in cars and pushed inside the tunnel kiln. A tunnel kiln comprises three distinct zones – preheating zone, firing zone and cooling zone. The products inside the kiln are heated slowly on its exposure to high temperature flue gases in preheating zone during travel towards firing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

4.3 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.

4.3.1 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.

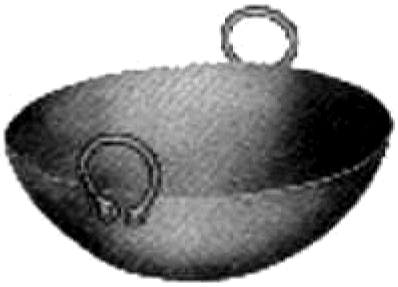
- Provide sufficient overlapping of a brick across and over, at least two other bricks in the course below it.
- Break continuous vertical joints both along the length and the thickness of the wall.
- Interlock the bricks in the same course and create unity between the individual blocks in a brick work.

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

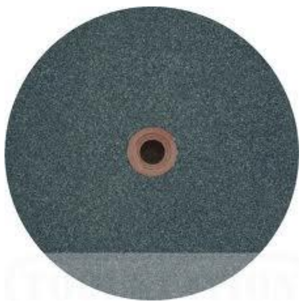
Trowel



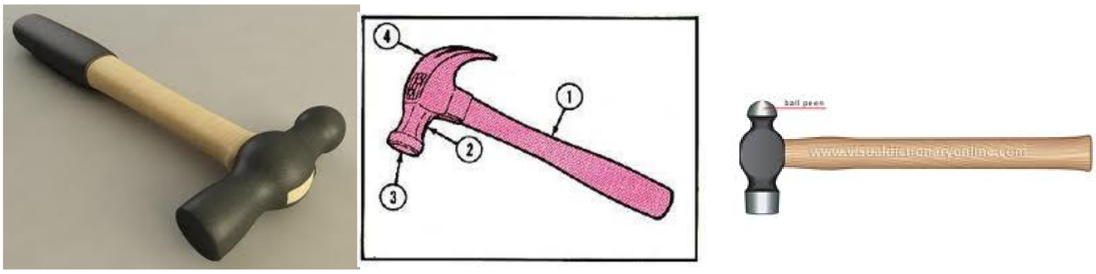
Clay Pan

Try- Square

Plumb-BOB



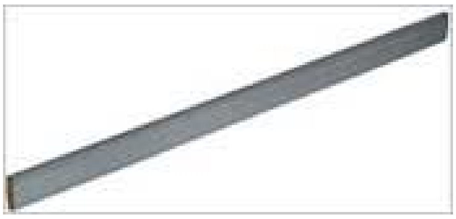
Grinding Wheel



Ball Pan Hammer

Wooden hammer

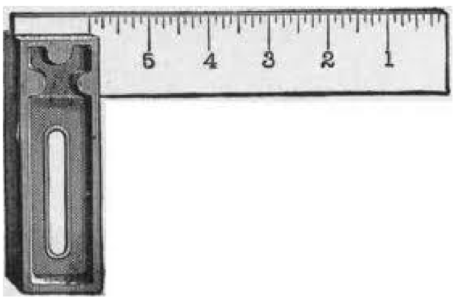
Mason's thread

Straight (PATA)



Spirit level

Measuring scale

4.3.2 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/m³ Temperature range – 0 to 1260°C Length - 1000 mm Width - 500 mm Thickness - 25 mm
Ceramic blanket	HD grade with density of 128 kg/m³ Temperature range – upto 1425°C RTZ grade for low temperature application in pre-heating zone of kiln. Density - 128 kg/m³
Lagging ceramic blanket	Application - lagging Temperature range: less than 1000°C Lagging sequence : • 1st layer of ceramic wool with density of 128 kg/m³ (hot face). • 2nd layer of ceramic wool with density of 96 kg/m³ 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/m³. The external surface facing ambient air is to be provided with aluminium cladding to avoid dust deposition on the ceramic surface.

4.3.3 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.

4.3.4 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

4.3.5 Gas train

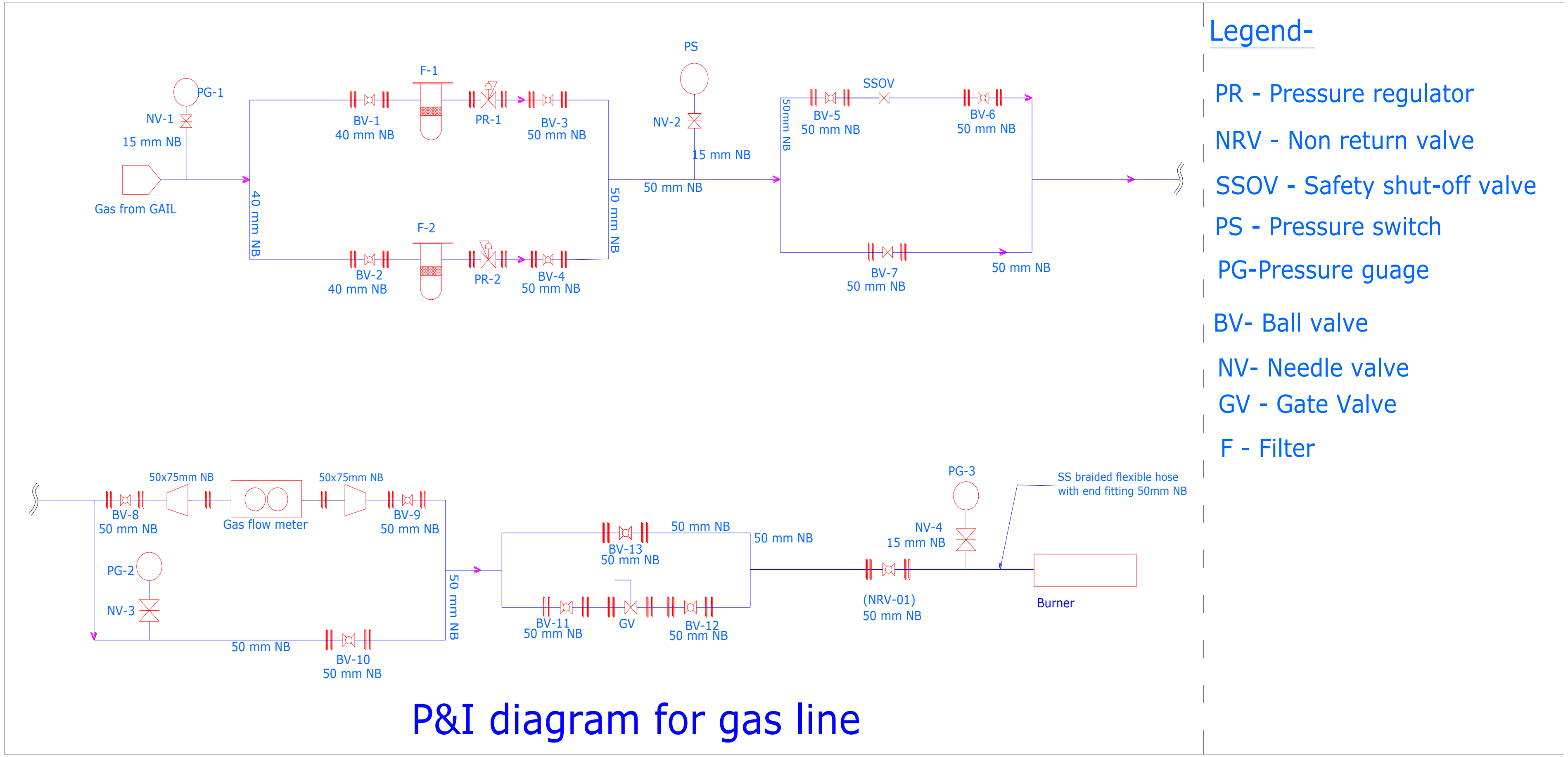
The supplier of natural gas provides gas piping up to the premises of the industry. The supplier also installs a flow meter to record gas consumption for the purpose of billing. It is the responsibility of the individual industry to install required pipelines and other related equipment within the industry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


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
BV-5
50 mm NB
SSOV
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
(NRV-01)
50 mm NB
SS braided flexible hose
with end fitting 50mm NB
Burner
P&I diagram for gas line
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

Gas train

The typical specifications used in gas train are provided below.

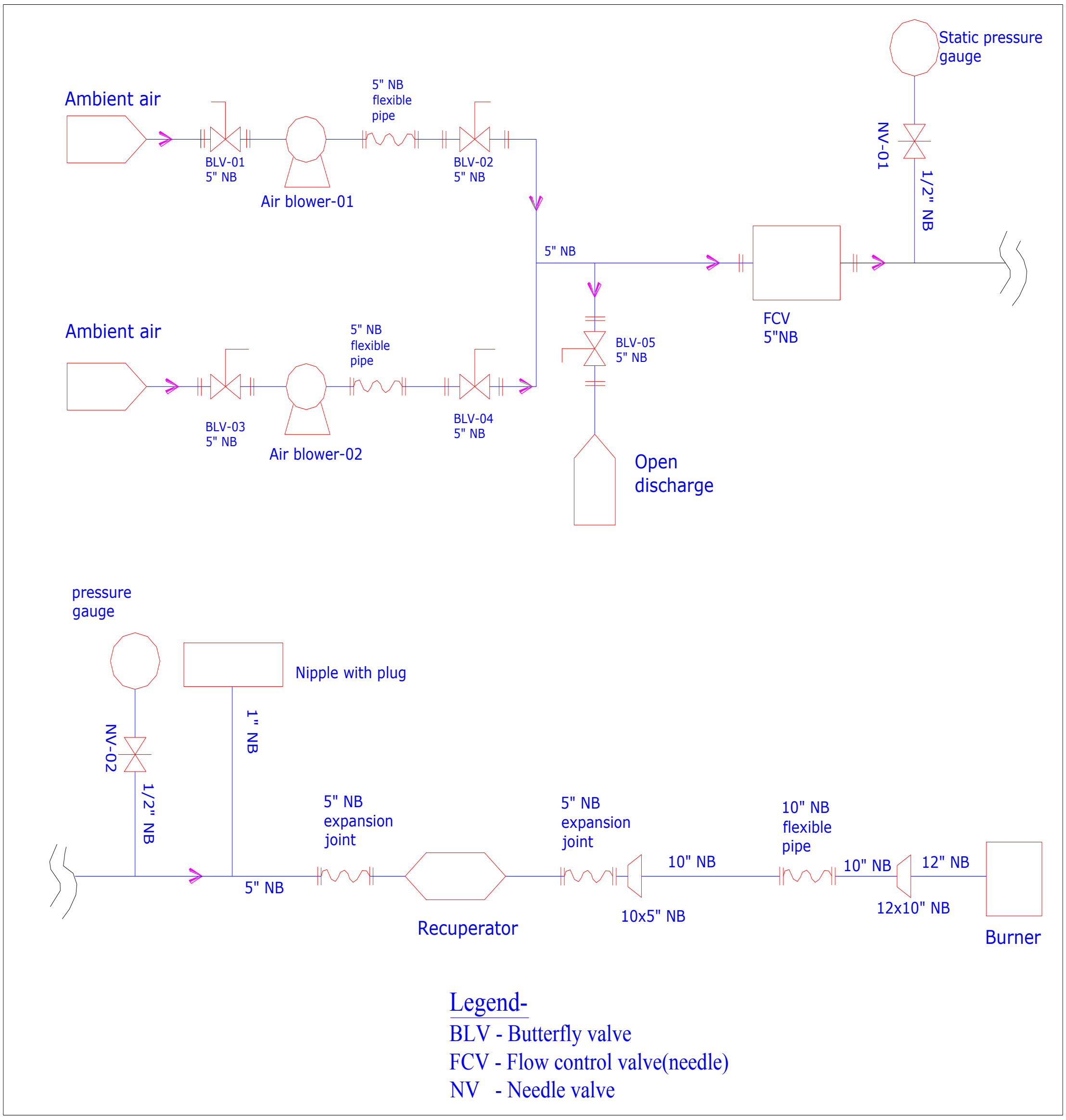
Typical specifications for gas train

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/cm^2 (assumed)
	Maximum inlet pressure: 3 kg/cm^2 (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/cm^2 (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.

4.3.6 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

4.4 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.*

4.4.1 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 (ºC)			Product type	Production (No.)	Yield (%)
		Firing	Preheating	Cooling			

4.5 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.

4.5.1 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.

4.5.2 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.

4.5.3 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