“ENERGY EFFICIENCY IN CERAMIC INDUSTRY”

Submitted in partial fulfillment of the requirement

for the award of the Degree of

Master of Technology
In
Thermal Engineering

By

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2K10/THR/09

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CERTIFICATE

This is to certify that the work which is being presented in the thesis entitled **“Energy Efficiency in Ceramic Industry”** in partial fulfillment of the requirement for the award of degree of Master of Technology in Thermal Engineering at Delhi Technological University, Delhi, which is being submitted by **Mr. Parvesh Kumar**, is a record of his own work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted elsewhere for the award of any degree.

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ABSTRACT

In this thesis an analysis of energy use and energy conservation in the Ceramic industries is presented. It has been found that ceramic industries consume a substantial amount of energy. Excessive use of energy is usually associated with many industrial plants worldwide, and Ceramic industries are no exception. This study is based on the realization that enormous potential exists for cost-effective improvements in the existing energy-using equipment. Through the method of a walkthrough energy audit, power rating, operation time of energy-consuming equipment/machineries and power factor were collected. The data were then analyzed to investigate the breakdown of end-use equipment/machineries energy use. The results of the energy audit in the R.K. ceramics and other ceramic industries showed that the kilns account for a major fraction of total energy consumption followed by motors, making systems and lighting. Since the kiln takes up a substantial amount of the total energy used in ceramic industries, energy-savings strategies such as the use of high efficient kiln, and variable speed drive (VSD) for motors have been used to reduce energy consumption of kiln and motors by 20-30% that of current use in ceramic industries. Energy-savings strategies for grinding, mixing, and making have also saves up to 10-20% of energy. It has been found that significant use of good machines and technology save the overall energy of plant by 30-40%.

NOMENCLATURE

CAGR	Compound Annual Growth Rate
LPG	Liquefied Petroleum Gas
SiO_2	Silicon dioxide
HP	Horse Power
hr	Hours
CO_2	Carbon dioxide
N_2	Nitrogen
O_2	Oxygen
CO	Carbon monoxide
C_3H_8	Propane
C_4H_{10}	Butane
Q	Heat Transfer
W	Work done

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CHAPTER 1

INTRODUCTION

1.1 Introduction to ceramic :

The word ceramic, derives its name from the Greek keramos, meaning "pottery", which in turn is derived from an older Sanskrit root, meaning "to burn". The Greeks used the term to mean "burnt stuff" or "burned earth". Thus the word was used to refer to a product obtained through the action of fire upon earthy materials[1].

Generally the term ‘ceramics’ (ceramic products) is used for inorganic materials (with possibly some organic content), made up of non-metallic compounds and made permanent by a firing process. In addition to clay based materials, today ceramics include a multitude of products with a small fraction of clay or none at all. Ceramics can be glazed or unglazed, porous or vitrified[2].

Firing of ceramic bodies induces time-temperature transformation of the constituent minerals, usually into a mixture of new minerals and glassy phases. Characteristic properties of ceramic products include high strength, wear resistance, long service life, chemical inertness and nontoxicity, resistance to heat and fire, (usually) electrical resistance and sometimes also a specific porosity[3].

Clay raw materials are widely distributed throughout World, so ceramic products like bricks which are relatively inexpensive (but which incur high transport costs due to their weight) are manufactured in virtually all Member States. Building traditions and heritage considerations result in different unit sizes from country to country. More specialised products which command higher prices tend to be mainly produced in a few countries, which have the necessary special raw materials and – equally important – traditions of skill and expertise[2].

1.2 History of Ceramic:

The History of Pottery is believed to have begun in the period 29,000 to 25,000 BC, when the earliest known ceramic (molded of clay and fired) objects were created, including the Venus or Grimaldi figurines. This period is known as the Upper Paleolithic period, sometimes referred to as the "Late Stone Age"[1].

Even though the Stone Age and Paleolithic periods were at the same time, typically the Paleolithic period refers to this period of time in Europe, while the Stone Age refers to this period in Africa[3].

During this Upper Paleolithic period in Europe, the Cro-Magnons (early Homo sapiens), began creating many sophisticated stone tools, cave art and artifacts including the Venus figurines[3].

The Venus (Grimaldi) Figurine refers to a collection of female human figurines that experts believe were individually owned amulets meant to ensure the safe completion of pregnancy. These figurines were believed to gain power with age, and were likely passed down from mother to daughter over a number of generations[1].

So far the earliest Pottery (pots and other utility items) were found in Southern China, in The Yuchanyan Cave. These items are estimated to be 18,000 years old. And there are many more from 10,000 BC in Japan and China[3].

The invention of the Pottery Wheel in Mesopotamia, sometime between 6,000 and 4,000 BC, caused the pottery industry to leap forward. The first kilns, were basically bonfires. After that the pit or trench kilns where used. Heating clay, causes the particles to fuse together. This is called sintering. For formed clay to be called pottery, it must be fired. It depends on the material used, but in general[3].

- Earthenware is bisque fired (before glazing) at about 1000 – 1150 ºF (1,000 to 1,150 ºC)[1].
- Stoneware is fired at about 2192 – 2399 ºF. (1200 – 1315 ºC)[1].
- Porcelains are fired at about 2192 – 2552 ºF. (1,200 –1400 ºC)[1].

The amount of time the clay is heated is called the Soak time. Think about what an accomplishment it must have been back in the day, just to do what they had to, to make a pot.

If you use wood or coal for firing, the ash causes the color and texture of the piece to vary. This concept is used in Malaysia, to create Labu Sayung. The Japanese call it Raku, (and all this time I thought that was Spaghetti sauce!!!) Any way to make Raku or Labu sayung, you remove the piece from the Kiln while still red hot and place it in a container, cover it with wood chips or ash, and cover the container. This causes a carbonized effect[2].

And as long as we're talking about the History of Pottery, lets cover the origin of the Piggy Bank? Well you see, the word Pygg refers to a relatively inexpensive orange clay that was once very popular for making pottery in the form of jars, cookware, and other household items. Originally the "Pygg Jar" (at the time pronounced "pug") was used to hold miscellaneous coins in the household. Over time the word "pygg" began to be pronounced "pig" (sometime you'll have to read about the "Great vowel shift" for an etymological lesson on historical changes to pronunciation that took place). After this change the spelling of "pig" was adopted. Next thing you know, the "Pygg Jar" is now being made in the shape of a (you guest it) a Pig. And the Piggy Bank was minted[1].

So as you can see, the History of Pottery is rich with innovation and function. From materials, to techniques and uses; forming and firing clay has served mankind well for many thousands of years[3].

1.3 Advanced Ceramics:

Advanced ceramics, also known as engineering or technical ceramics, refer to materials which exhibit superior mechanical properties, corrosion/oxidation resistance, and thermal, electrical, optical or magnetic properties.

Advanced ceramics are generally broken down into the following segments[4]:

- structural ceramics,
- electrical and electronic ceramics,
- ceramics coatings, and
- chemical processing & environmental ceramics

Structural ceramics include applications such as industrial wear parts, bioceramics, cutting tools, and engine components. Electronic ceramics, which has the largest share of the advanced ceramic market includes capacitors, insulators, substrates, integrated circuits packages, piezoelectrics, magnets and superconductors. Ceramic coatings find application in engine components, cutting tools, and industrial wear parts. The applications under chemical processing and environmental ceramics include filters, membranes, catalysts, and catalyst supports.

The beginning of the advanced ceramics era has been said to have started approximately 50 years ago with the expanding use of chemically prepared powders. For example, the Bayer process for the production of alumina powders initially grew from spark plug production. While these powders would be considered relatively low grade by today's standards, they were more pure and offered more control over the composition, microstructure, and crystal structure over minerals-based ceramics[5].

Today, the market for advanced ceramics is large and growing as they continue to replace more traditional materials in many applications while providing the only material solution in other applications. In many cases, ceramics are used with other materials to make up only part of an overall system. This is especially true in the electronics field[4].

1.4 Global Scenario

1.4.1 Global Trade Profile:

During the period from 2001 to 2011, total ceramics trade grew at a CAGR of 7.56%, from US$ 39.6 billion to US$ 87.9 billion. During the period exports increased from US$ 19.8 billion to US$ 44.6 billion (CAGR of 7.74%), while imports increased from US$ 19.9 billion to US$ 43.2 billion (CAGR of 7.38%)[6].

China is the largest trader of ceramics in the world, with total trade of US$ 14.7 billion during 2011, followed by US and Germany, Italy with total trade of US$ 7.4 billion, US$ 7.0 billion and US$ 6.18 billion, respectively[6].

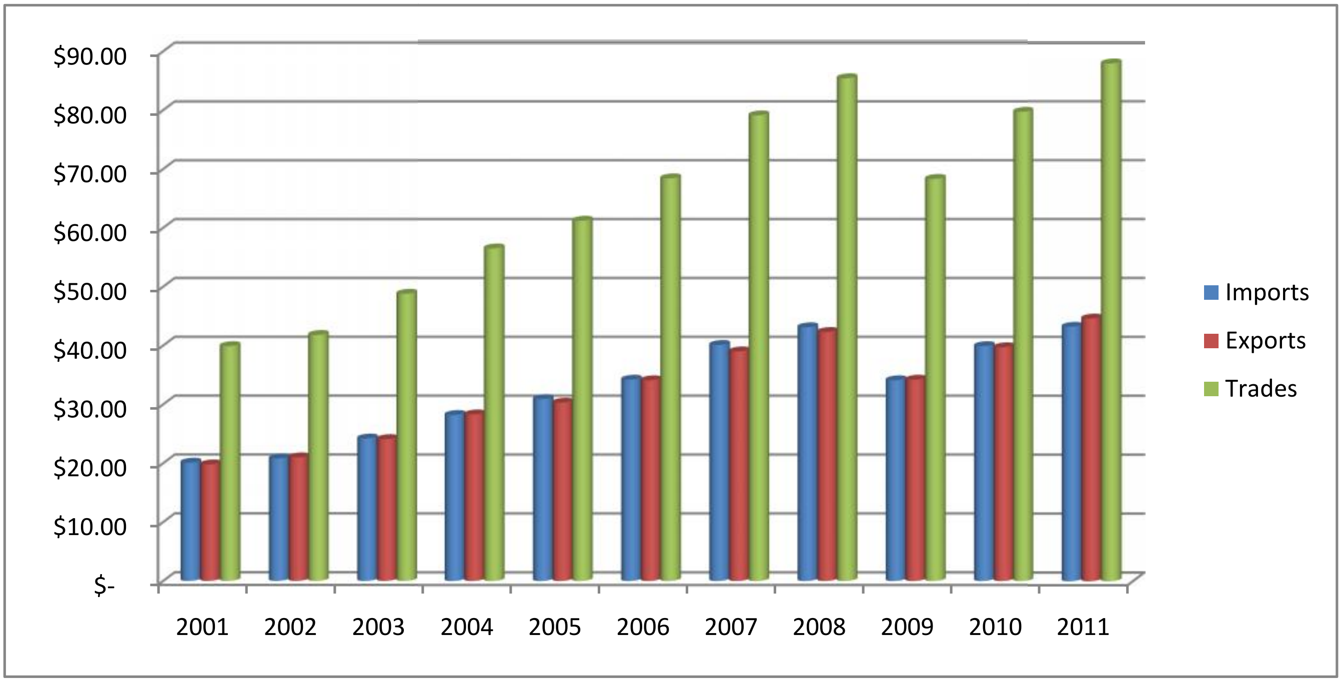

Figure 1.1: World Ceramics Trade(in Billion)

1.4.2 Major Exporters

China was the largest ceramic exporter during 2011, with exports of US$ 14.0 billion. Italy, Germany and Spain followed China with annual exports of US$ 5.18 billion, US$ 3.9 billion and US$ 3.2 billion, respectively. The top ten countries together accounted for close to 75% of total ceramics exports during 2011[6].

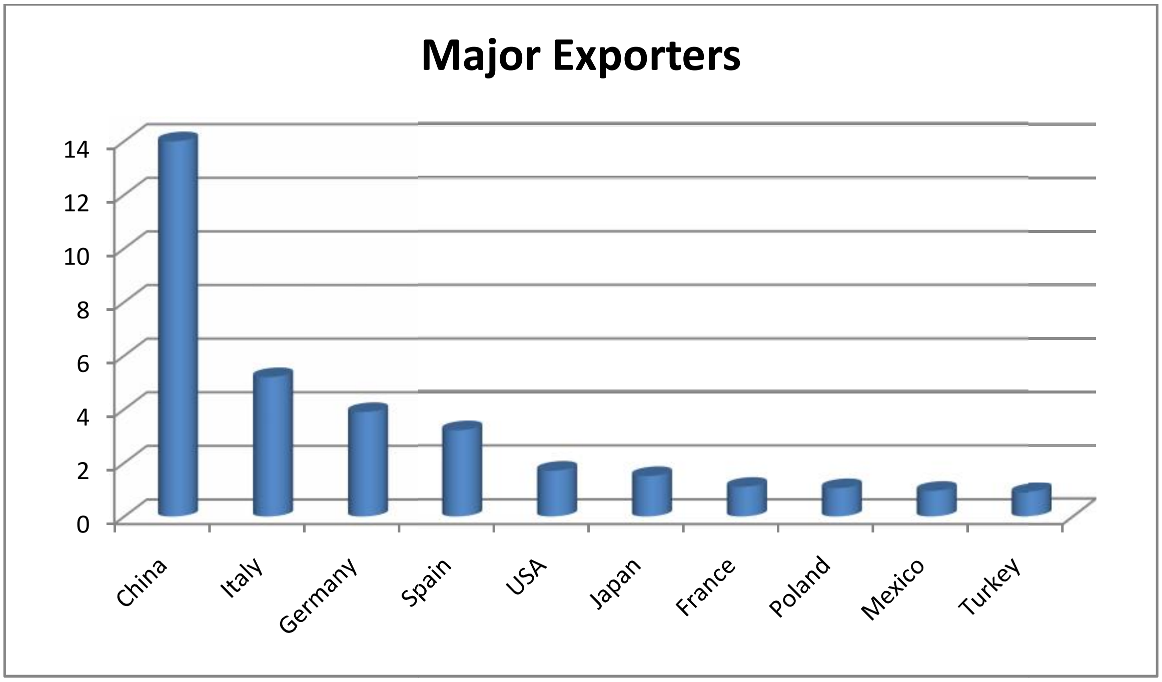

Figure 1.2: Major Exporters

1.4.3 Major Importers :

United States was the world’s largest ceramic importer during 2011, with imports worth US$ 5.6 billion. US rely heavily on imports of ceramic to meet its domestic ceramics consumption. This is also reflected in its high ceramics trade deficit of close to US$ 4 billion[6].

US is followed by Germany, France and United Kingdom with annual imports of US$ 3.1 billion, US$ 2.47 billion and US$ 1.75 billion, respectively[6].

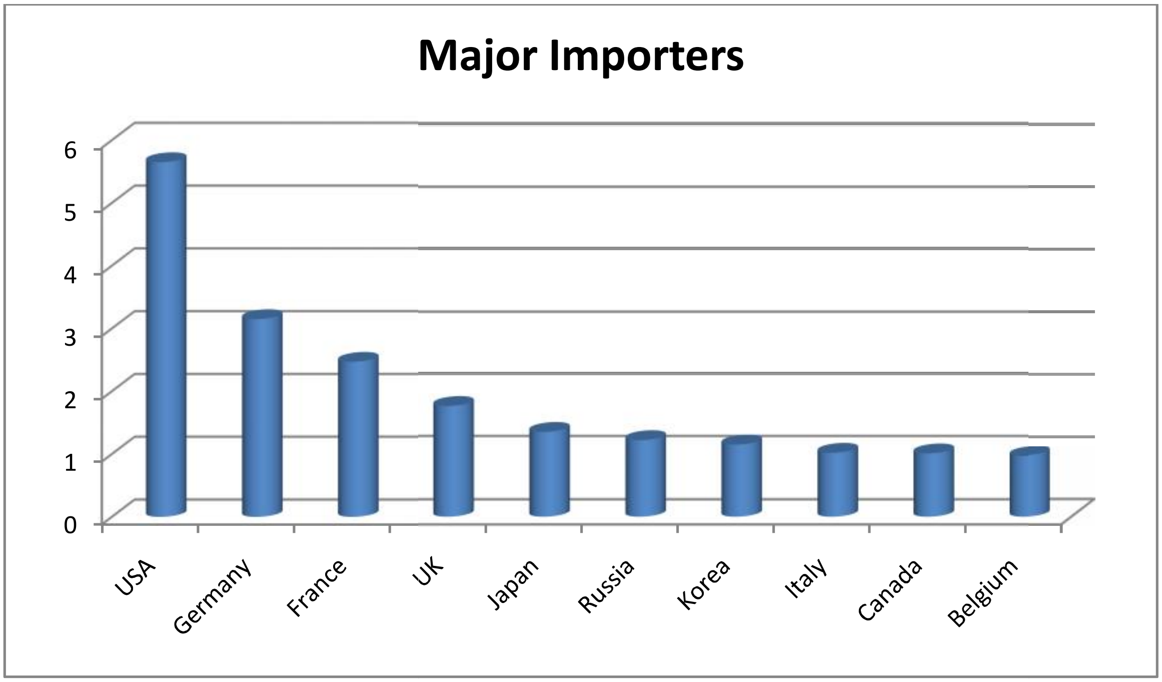

Figure 1.3: Major Importers

1.4.4 Trade situation in emerging markets:

The global ceramic industry has undergone a period of significant change over the years, driven by the demands of a globalised economy. While the traditional markets of Europe and the US continue to grow, primarily led by public sector investment, the most significant developments are however to be found in the emerging economies. They have, in recent years become the most significant players in the ceramic market, in terms of consumption, growth and investment[7].

Since the future of the ceramic sector is so intricately linked with the continued economic growth in emerging economies, the paper assesses the trade situation in emerging 4 markets, excluding India[8].

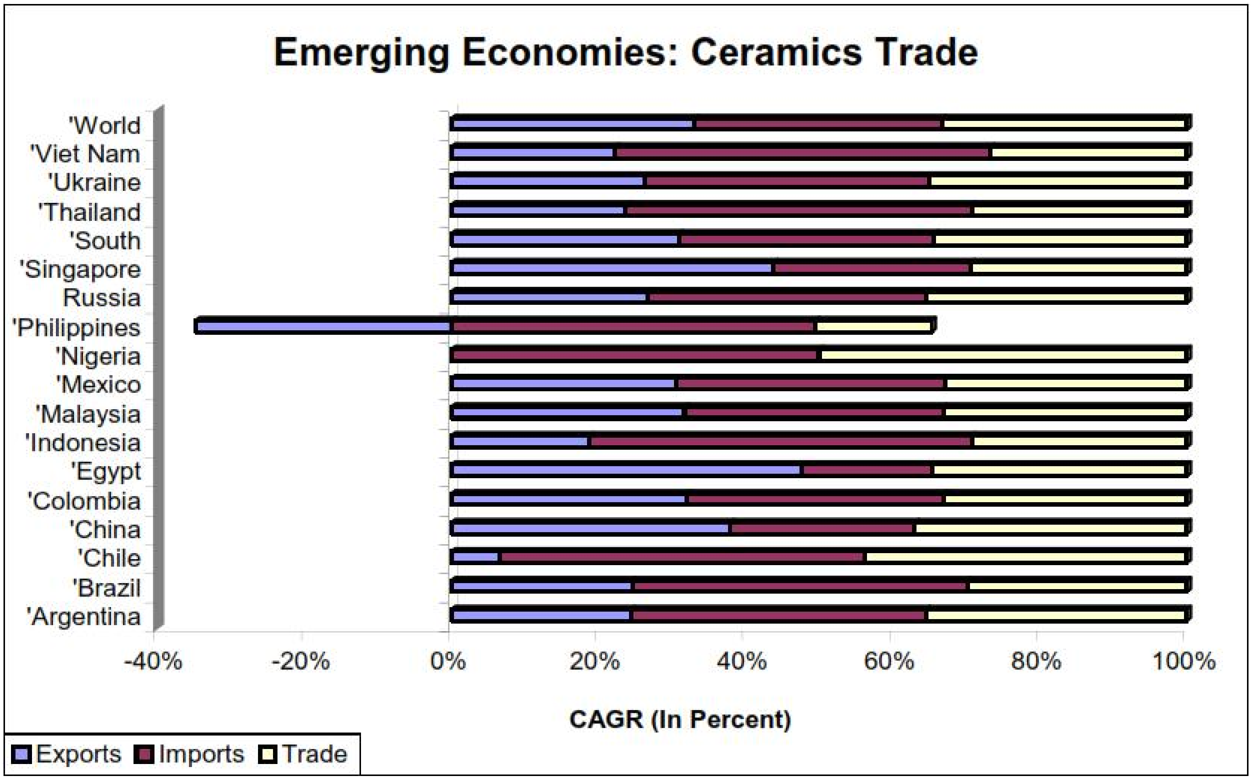

Figure 1.4: Ceramic Trade[7]

As per the data available, during the period from 2001 to 2011, while the world ceramics trade grew at a CAGR of 7.56%, the average growth in trade for these economies was around 12%. The increased demand for ceramics in emerging markets may be attributable to rapid economic growth and greater public and private sector investment in these countries[6].

Despite a high base, China's exports grew at a CAGR of 22.9% and ceramic imports increased by 16.2%[6].

1.4.5 India's Trade Profile and Market Access:

The ceramics industry in India came into existence about a century ago and has matured over time to form an industrial base. From traditional pottery making, the industry has evolved to find its place in the market for sophisticated insulators, electronic and electrical items. Over the years, the industry has been modernising through new innovations in product profile, quality and design to emerge as a modern, world-class industry, ready to take on global competition[9].

The Indian Ceramic Industry ranks at 20th position in the world and produces around 1.9% of global output. The industry provides employment to 600,000 people, of whom 85,000 are directly employed. Gujarat accounts for around 60% of total ceramic production[6,9].

The ceramic products are produced both in organised as well as in unorganized sector. The share of organised sector in total production is around 55%. The organised sector is characterised by the existence of a few large players . Small and medium enterprises (SMEs) account for more than 50 per cent of the total market in India, offering a wide range of articles including crockery, art ware, sanitary ware, ceramic tiles, refractory and stoneware pipes among others. Most of the players are grouped together in clusters.

Over the last two decades, the technical ceramics segment has recorded an impressive growth propelled by the demand for high-alumina ceramics, cuttings tools and structural ceramics from the industry. Overall, the Indian ceramics industry has emerged as a major manufacturer and supplier in the global market[9].

1.4.6 India’s Ceramic Trade:

During 2011, India was the 20th largest ceramic trading nation in the world and accounted for a share of around 1% in total ceramics trade. During the period, from 2001 to 2011, India’s ceramics trade increased from US$ 143 million to US$ 984 million at a CAGR of 23.4%. The increase in trade was led by rise in imports, which increased, from US$ 68.7 million in 2001 to US$ 750.9 million in 2011, at a CAGR of 26.3%. India’s ceramic exports on the other hand increased at a CAGR of 11.6%, from US$ 82.3 million to US$ 233.3 million[6].

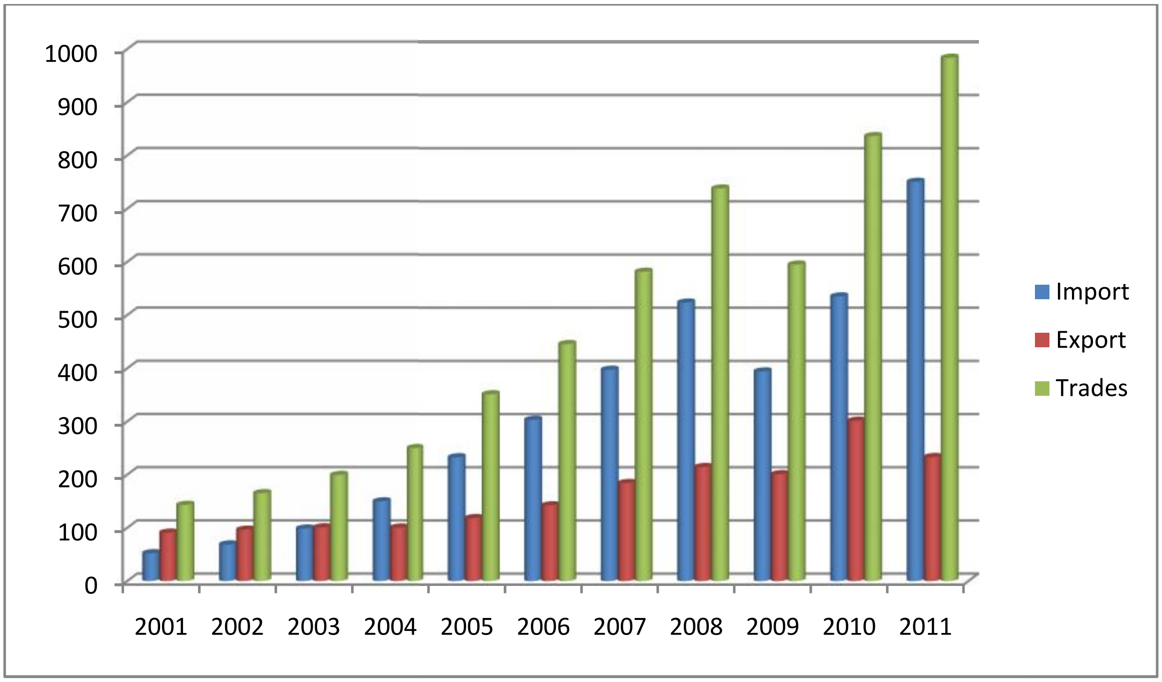

Figure 1.5: India’s Ceramic Trade

China was India’s main source of ceramics imports, during 2010 with imports worth US$ 332.3 million followed by Germany and Spain with imports worth US$ 60.7 million and US$ 18.8 million, respectively. India’s top five import sources together accounted for close to 79% of India’s total ceramics imports during 2010. China alone accounted for 63.7% of India’s ceramic imports[6].

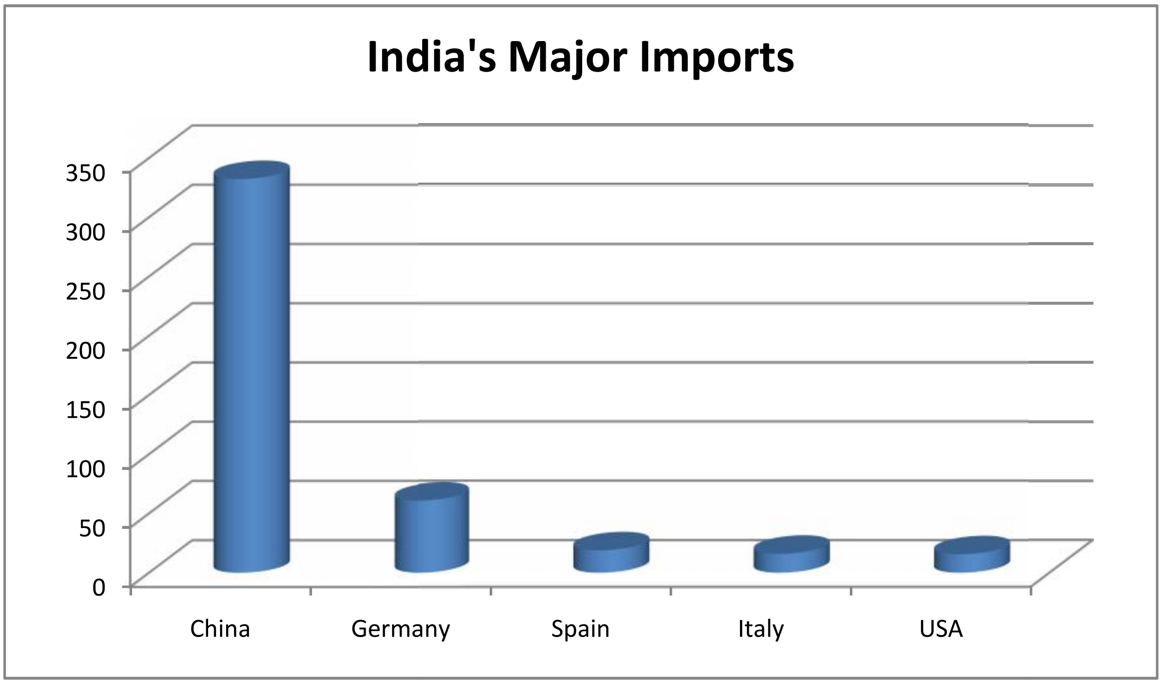

Figure 1.6: India's Major Imports

Tunisia, UAE, Saudi Arabia and USA were the major destinations for India’s Ceramics exports during 2010. India’s top five ceramics export destinations together accounted for 29% of India’s total ceramics exports.

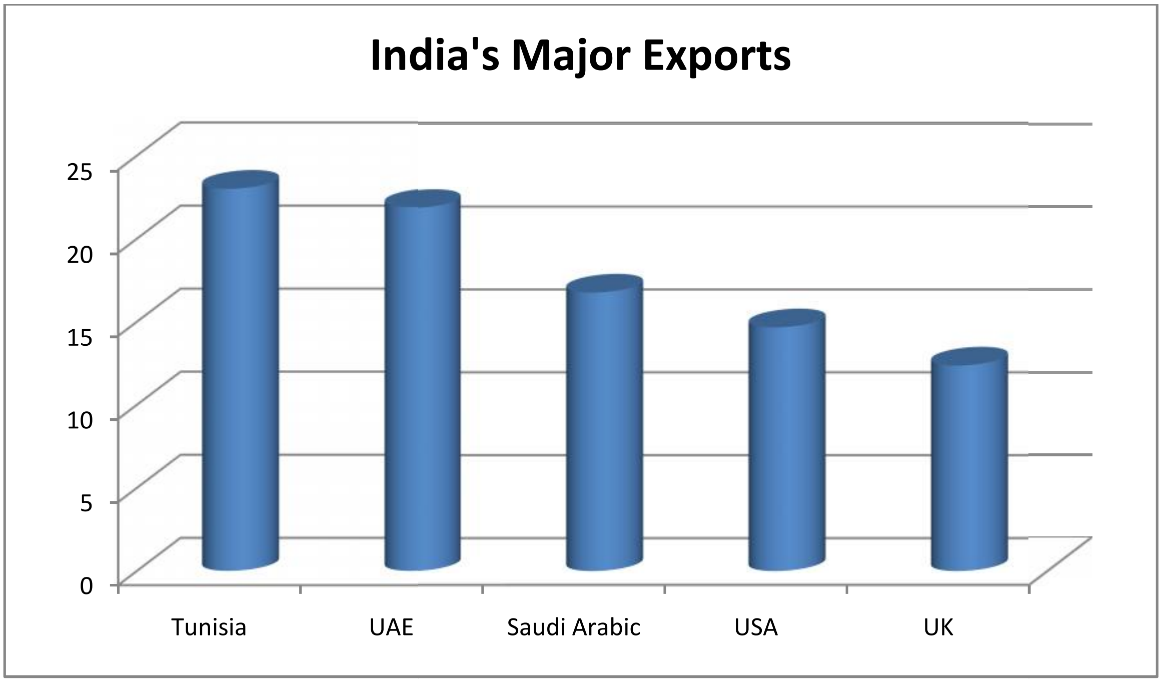

Figure 1.7: India's Major Exports

Ceramic Products Manufacturing Processes

Figure 2.1 presents a general process flow diagram for ceramic products manufacturing. The basic steps include raw material procurement, Fine Grinding or Milling, Filter Pumping, mixing, forming, Painting, Glazing, Drying, Firing, Cooling, and Final processing. The following paragraphs describe these operations in detail[10].

Naturally occurring inorganic substances are heat-treated after adjustment of the grain size and moisture, and some of them are completely molten to be formed into ceramics; while others are formed, heat-treated and made into the ceramic products in the sintered state immediately before being molten.

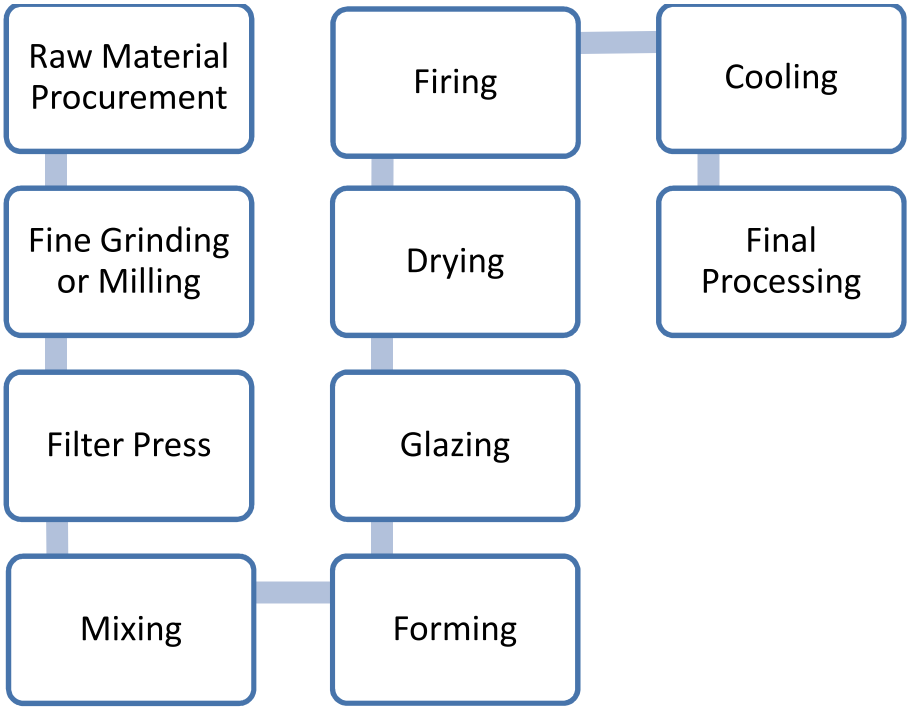

Figure 2.1: general process flow diagram for ceramic products manufacturing

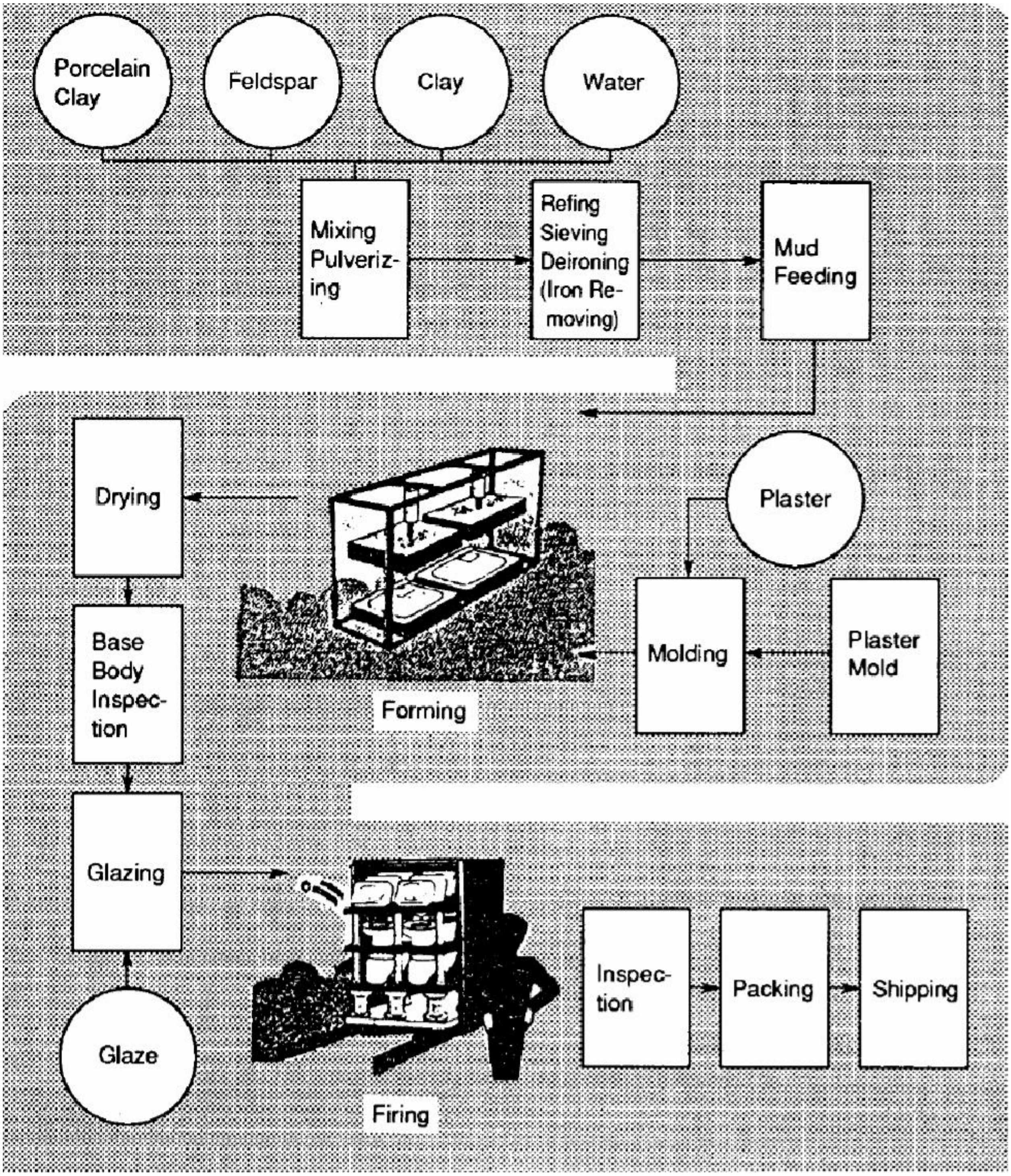

Figure 2.2: Manufacturing flow of Ceramics

2.1 Raw Material Procurement:

To begin the process, raw materials are transported and stored at the manufacturing facility. The raw materials used in the manufacture of ceramics range from relatively impure clay materials mined from natural deposits to ultrahigh purity powders prepared by chemical synthesis. Naturally occurring raw materials used to manufacture ceramics include silica, sand, quartz, flint, silicates, and aluminosilicates (e.g., clays and feldspar)[10].

Energy consumed in Raw Material Procurement is very less as compare to the overall energy consumption, in this case we can neglect the energy consumption in Raw Material Procurement.

2.2 Fine Grinding or Milling:

Many raw materials require some degree of beneficiation prior to use in ceramic production. The basic beneficiation processes include crushing, grinding, and sizing or classification. Facilities that form ceramic bodies by pressing often granulate raw materials and raw material mixes to produce a free-flowing powder. In addition, some facilities dry raw materials onsite [10]. Primary crushing is used to reduce the size of coarse materials, such as clays, down to approximately 1 to 5 centimeters (cm) (0.5 to 2 inches [in.]). The most common types of crushers used are jaw crushers, cone crushers, gyratory crushers, and roll crushers. Secondary crushing or grinding reduces particle size down to approximately 1 millimeter (mm) (0.04 in.) in diameter. Fine grinding or milling reduces the particle size down to as low as 1.0 micrometer (μm) in diameter[11].

Ball mills are the most commonly used piece of equipment for milling. Hammer mills, vibratory mills, attrition mills, and fluid energy mills also are used. Crushing and grinding typically are dry processes, but some facilities use wet ball mills to grind and mix raw materials in one step[12].

There are number of milling machines are used for milling processes, but these milling machines are used for different materials. Generally Ball mills are used in ceramic industries. Description of ball mill as follows:

2.2.1 Working Principle of Ball Mill:

This ball mill is horizontal type and tubular running device, has two warehouses. This machine is grid type and its outside runs along gear. The material enters spirally and evenly the first warehouse of the milling machine along the input material hollow axis by input material device. In this warehouse , there is a ladder scale board or ripple scale board, and different specification steel balls are installed on the scale board, when the barrel body rotates and then produces centrifugal force ,at this time , the steel ball is carried to some height and falls to make the material grinding and striking. After grinded coarsely in the first warehouse, the material then enters into the second warehouse for regrinding with the steel ball and scale board. In the end, the powder is discharged by output material board and the end products are completed [12].

Ball mill is an efficient tool for grinding many materials into fine powder. The Ball Mill is used to grind many kinds of mine and other materials, or to select the mine. It is widely used in building material, chemical industry, etc. There are two ways of grinding: the dry process and the wet process. It can be divided into tabular type and flowing type according to different forms of discharging material[13].

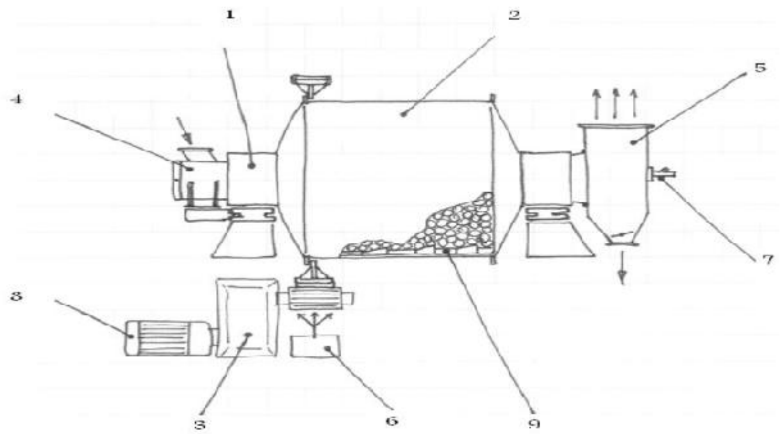

Figure 2.3: General design for {wet and dry} ball mill

Table 2.1: General description for ball mill[14]

1.	Bearing
2	Mill Shell
3	Driver • Types of driver is { Central driver and Gear rim / pinion}
4	Inlet • Types of inlet is { Inlet type, Inlet chute, and inlet screw }
5	Outlet • Types of Outlet o Types of Outlet o Discharge diaphragm- outlet casing o Central discharge
6	Gear Rim Lubrication
7	Water Injection
8	Motors
9	Lining • Type of lining { steel, rubber, and ceramic lining }

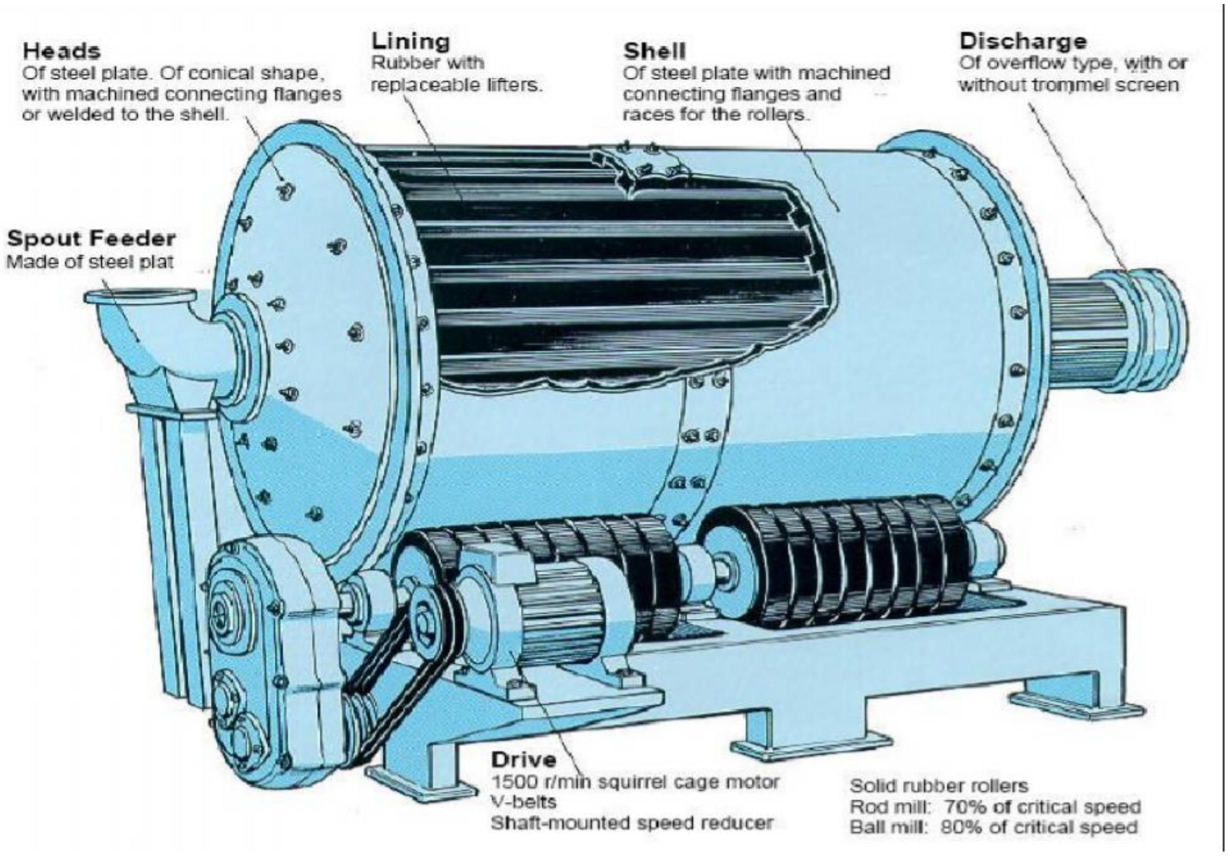

Figure 2.4: Wet ball mill description[13]

2.3 Filter Press:

Figure 2.5: Filter Press

2.3.1 Design and Operating principles:

Filter presses comprise a set of chamber plates covered by filter clothes and squeezed by a hydraulic cylinder between a stationary frame and a mobile supporting beam. The plates determine a watertight volume in which is pumped the pressurized sludge[15].

A hydraulic unit allows the watertightness between the plates at the surface of the joints. By means of a cylinder, the hydraulic unit keeps the balance between the plates squeezing and the filling pressure induced by the feeding pump throughout the filtration process. Under this pressure, the liquids pass through the filter cloth that hold the solid particles. The filtrates are drained out either by taps set on each plate or by launders at the end of the filter[16].

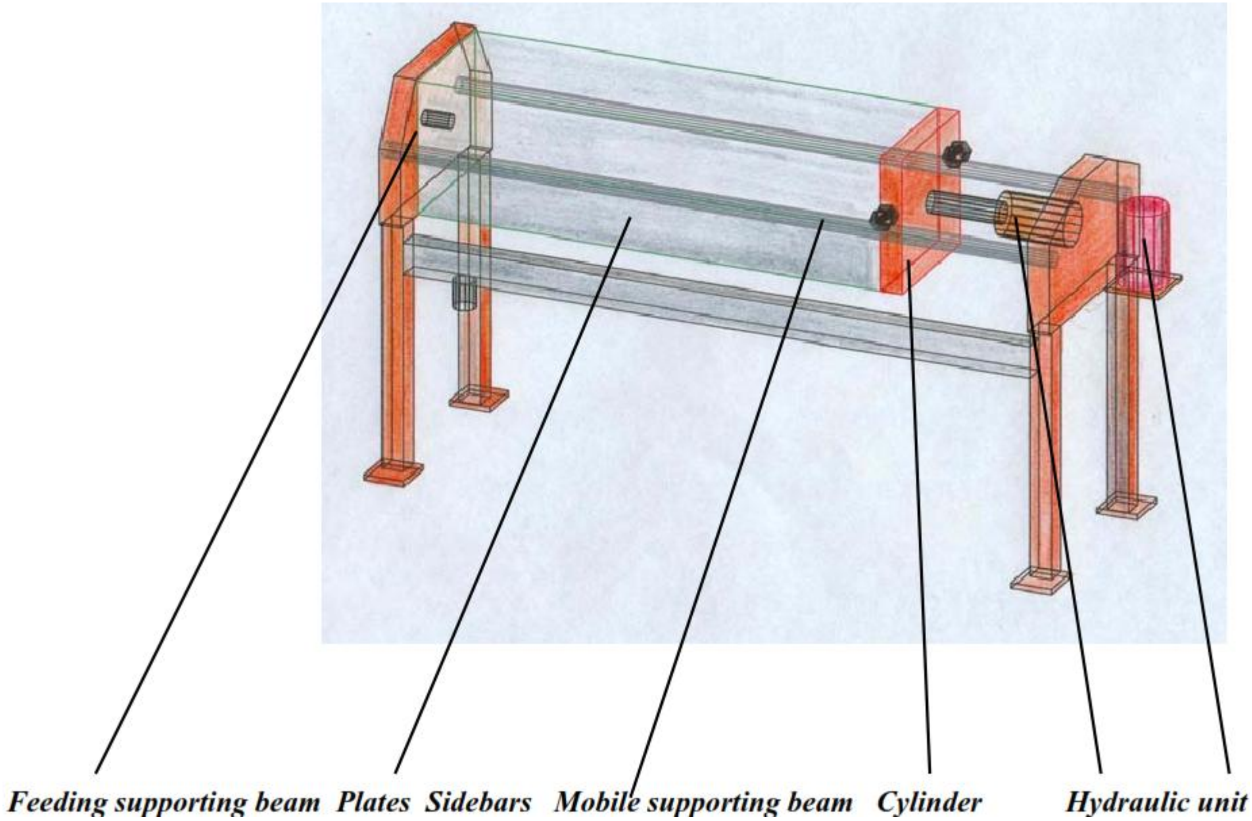

Figure 2.6: Frame Of A Filter Press

The feeding pump must regulate its flow rate according to the pressure increase produced by the formation of cakes in the chambers[10].

At the end of the plate compressing process, the cakes formed between the filter clothes are discharged by the backward movement of the supporting beam and the successive separation of the plates. A plate shifting system fitted with trolleys allows the automation of this process[15].

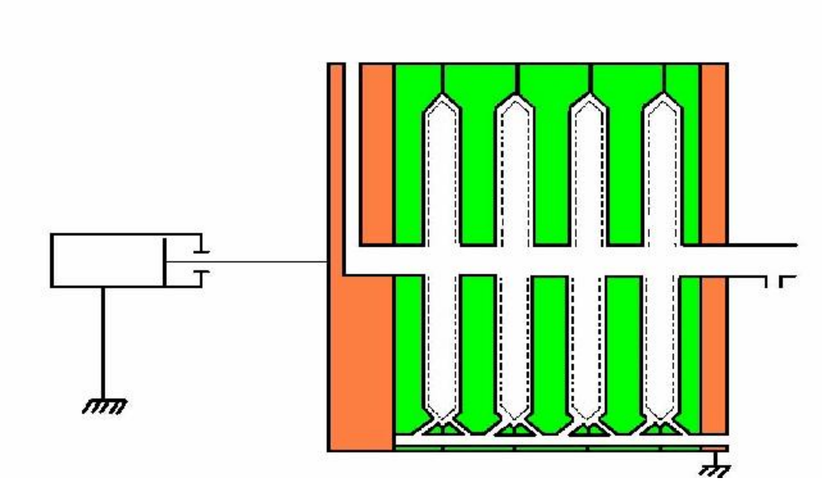

Figure 2.7: Closed filter press awaiting filtration

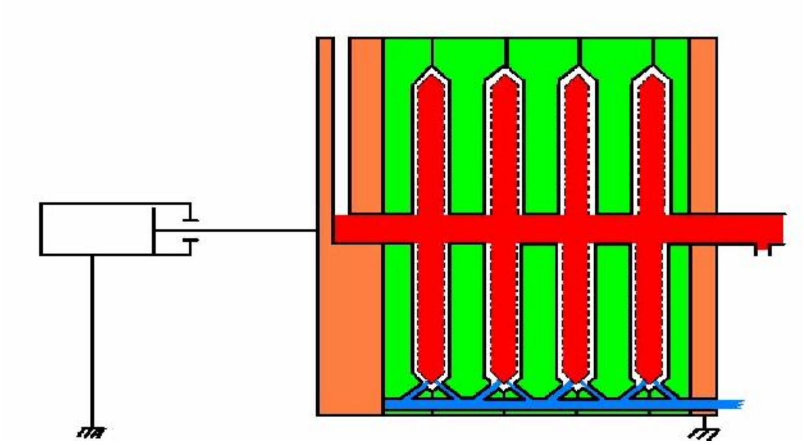

Figure 2.8: Filter press in filtration process

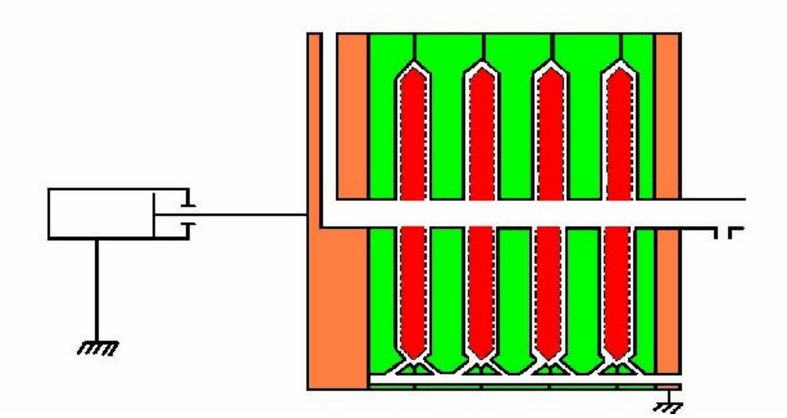

Figure 2.9: Core chase by means of compressed air

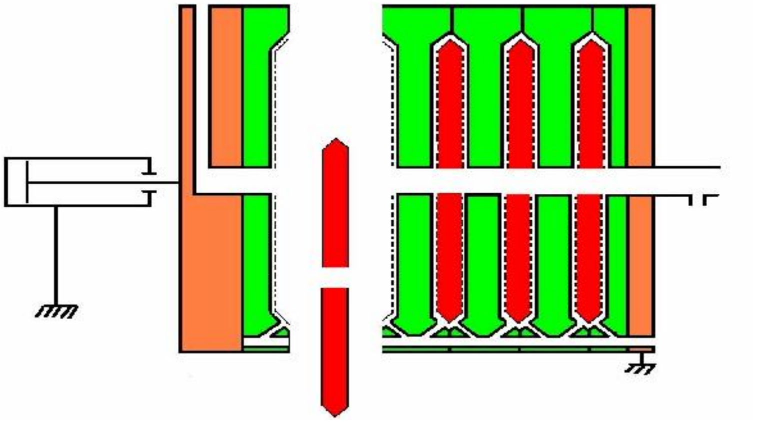

Figure 2.10: Cakes discharge

2.4 Mixing:

The purpose of mixing or blunging is to combine the constituents of a ceramic powder to produce a more chemically and physically homogenous material for forming. Pug mills often are used for mixing ceramic materials. Several processing aids may be added to the ceramic mix during the mixing stage. Binders and plasticizers are used in dry powder and plastic forming; in slurry processing, deflocculants, surfactants, and antifoaming agents are added to improve processing[17].

Liquids also are added in plastic and slurry processing. Binders are polymers or colloids that are used to impart strength to green or unfired ceramic bodies. For dry forming and extrusion, binders amount to 3% by weight of the ceramic mixture. Some examples of binders are polyvinyl alcohol and polyethylene glycol [18].

Plasticizers and lubricants are used with some types of binders. Plasticizers increase the flexibility of the ceramic mix. Examples include adsorbed water, ethylene glycol, stearic acid, oleic acid, and glycerine. Lubricants, such as stearic acid and oleic acid, lower frictional forces between particles and reduce wear on equipment [10].

Water is the most commonly used liquid in plastic and slurry processing. Organic liquids such as alcohols may also be used in some cases. Deflocculants also are used in slurry processing to improve dispersion and dispersion stability. Some examples of deflocculants are monovalent cations for clay-water slurries or slips, ammonium salts for polar liquids, acids and bases to control pH, and oleic acid, tartaric acid, benzoic acid, stearic acid, and trichloroacetic acid for oxide powders in nonpolar liquids. Surfactants are used in slurry processing to aid dispersion, and antifoams are used to remove trapped gas bubbles from the slurry[10].

2.4.1 Pug Mill:

A pug mill or pug mill is a machine in which materials are simultaneously ground and mixed with a liquid. Industrial applications are found in pottery, bricks, cement and some parts of the concrete and asphalt mixing processes. A pug mill is a fast continuous mixer. A continuous pug mill can achieve a thoroughly mixed, homogeneous mixture in a few seconds. Mixing materials at optimum moisture content requires the forced mixing action of the pug mill paddles, while soupy materials might be mixed in a drum mixer. A typical pug mill consists of a horizontal boxlike chamber with a top inlet and a bottom discharge at the other end, 2 shafts with opposing paddles, and a drive assembly. Some of the factors affecting mixing and residence time are the number and the size of the paddles, paddle swing arc, overlap of left and right swing arc, size of mixing chamber, length of pug mill floor, and material being mixed[17,18].

Figure 2.11: Pug Mill[18]

2.5 Forming:

In the forming step, the ceramic mix is consolidated and molded to produce a cohesive body of the desired shape and size. Forming methods can be classified as either dry forming, plastic molding, or wet forming. Dry forming consists of the simultaneous compacting and shaping of dry ceramic powders in a rigid die or flexible mold. The most commonly used dry forming method is pressing, which is used for forming relatively simple shapes. Ceramic tile typically are formed by dry pressing. Prior to pressing, many facilities granulate the ceramic mix to form a free-flowing powder, thereby improving handling and compaction. The most commonly used method of granulation is spray-drying. In this step, the ceramic mix is combined with water to form a slurry. The slurry is injected into a drying chamber with hot gases. As the hot gases contact the slurry, a powder is formed and collected in a cyclone or fabric filter. Spray dryers generally are gas-fired and operate at temperatures of 70° to 570°C (160° to 1050°F)[19].

For more complex shapes, isostatic pressing and vibratory compaction can be used. In isostatic pressing, the ceramic mix is placed inside a flexible mold, which is then deaired, sealed, and placed in a pressurized chamber. Vibratory compaction is used for producing irregular shapes from ungranulated powders[10].

Plastic molding is accomplished by jiggering, or injection molding. Jiggering is used to form circular or axially symmetrical shapes by shaping a plastic material on a spinning platform. Jiggering is widely used in the production of dinnerware. In injection molding, a ceramic mixture, which typically is heated, is injected into a die. This method generally is used for making small, complex shapes. Wet forming methods involve the use of a ceramic slurry. The most commonly used wet forming method is slip casting. Other wet forming methods include gelcasting and tape casting. In slip casting, a ceramic slurry with a moisture content of 20 to 35 percent is poured into a porous mold. Capillary suction of the mold draws the liquid from the mold, thereby consolidating the cast ceramic material. After a fixed time, the excess slurry is drained, and the cast shape is dried. Slip casting is widely used in the manufacture of sinks and other sanitary ware and structural ceramics with complex shapes[20].

2.6 Glazing:

Glazes resemble glass in structure and texture. The purpose of glazing is to provide a smooth, shiny surface that seals the ceramic body. Not all ceramics are glazed. Those that are glazed can be glazed prior to firing, or can be glazed after firing, followed by refiring to set the glaze. Many facilities prepare glazes onsite by grinding and mixing a combination of raw materials; other facilities purchase glazes that require no additional processing. In most cases, the primary materials in the glaze mix are the same materials that form the ceramic body. Metal oxides, such as chromium oxide, cobalt oxide, and manganese oxide often are used to color glazes. Glazes generally are applied by spraying, but dipping or flooding also are used for glaze application. Depending on their constituents, glazes mature at temperatures of 600° to 1500°C (1110° to 2730°F)[10,21].

2.7 Drying:

The drying process in the ceramic industry is the greatest energy consumer second to the firing process. Drying means loss of moisture from the surface of the substance by evaporation, and the drying speed depends on the temperature and humidity. When the substance is dried and moisture is lost, particles are put close to each other, resulting in shrinkage[10].

After glazing, ceramics must be dried. Drying must be carefully controlled to strike a balance between minimizing drying time and avoiding differential shrinkage, warping, and distortion. The most commonly used method of drying ceramics is by convection, in which heated air is circulated around the ceramics. Air drying often is performed in tunnel kilns, which are long furnaces with drying, firing, and cooling zones. In tunnel kilns, the drying zone typically uses heat recovered from the cooling zone. Periodic kilns or dryers operating in batch mode also are used. Convection drying also is carried out in divided tunnel dryers, which include separate sections with independent temperature and humidity controls. An alternative to air drying is radiation drying in which microwave or infrared radiation is used to enhance drying[23].

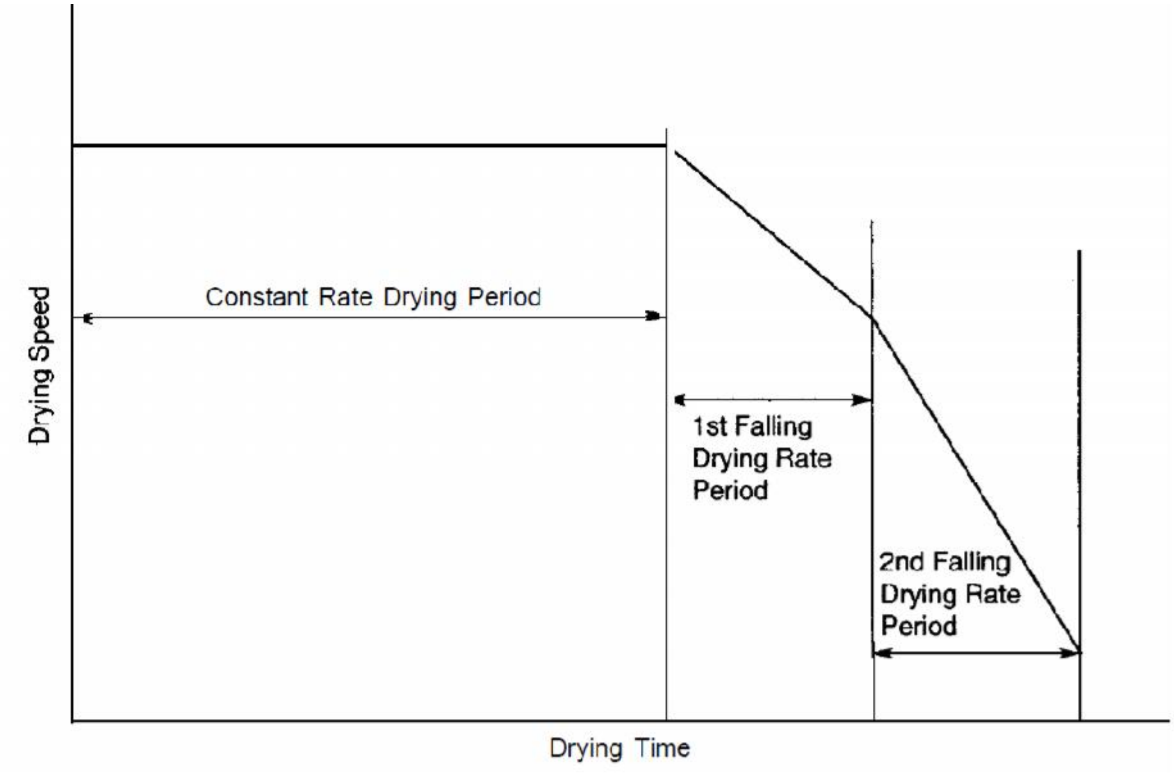

Figure 2.12: Drying time and speed[23]

Fig.2.11 shows the relationship between the drying time and speed. The constant rate drying period is the period when balance is kept between moisture shifting from inside the substance to the surface and moisture evaporation from the surface. The first falling drying rate period is the period when moisture shifts from inside the substance to the surface with reduced moisture evaporating from the surface. The second falling drying rate period is the period when evaporation takes place inside and vapor diffuses to the surface, without moisture shifting from inside the substance. Cracks due to drying is caused during the period when the green body shrinks that is, when the temperature gradient is steep under drying conditions between the constant rate drying period and first falling drying rate period, or when the temperature is excessively low. It is essential to have a correct understanding on these conditions before starting the drying process[24].

2.8 Firing:

Firing is the process by which ceramics are thermally consolidated into a dense, cohesive body composed of fine, uniform grains. This process also is referred to as sintering or densification. The characteristics of unfired ceramics that most affect firing are particle size, density, and particle shape[10]. In general[24]:

1. ceramics with fine particle size fire quickly and require lower firing temperatures;
2. dense unfired ceramics fire quickly and remain dense after firing with lower shrinkage; and
3. irregular shaped ceramics fire quickly.

Other material properties that affect firing include materialsurface energy, diffusion coefficients, fluid viscosity, and bond strength.

Parameters that affect firing include firing temperature, time, pressure, and atmosphere.

Ceramics generally are fired at 50-75% of the absolute melting temperature of the material. Firing occurs faster at higher temperatures, but so does coarsening. A short firing time results in a product that is porous and has a low density; short to intermediate firing time results in fine-grained (i.e., having particles not larger than 0.2 millimeters), high-strength products; and long firing times result in a coarse-grained products that are more creep resistant[24]. Applying pressure decreases firing time and makes it possible to fire materials that are difficult to fire using conventional methods. Oxidizing or inert atmospheres are used to fire oxide ceramics to avoid reducing transition metals and degrading the finish of the product[10].

In addition to conventional firing, other methods used include pressure firing, hot forging, plasma firing, microwave firing, and infrared firing. The following paragraphs describe conventional and pressure firing, which are the methods used most often[25].

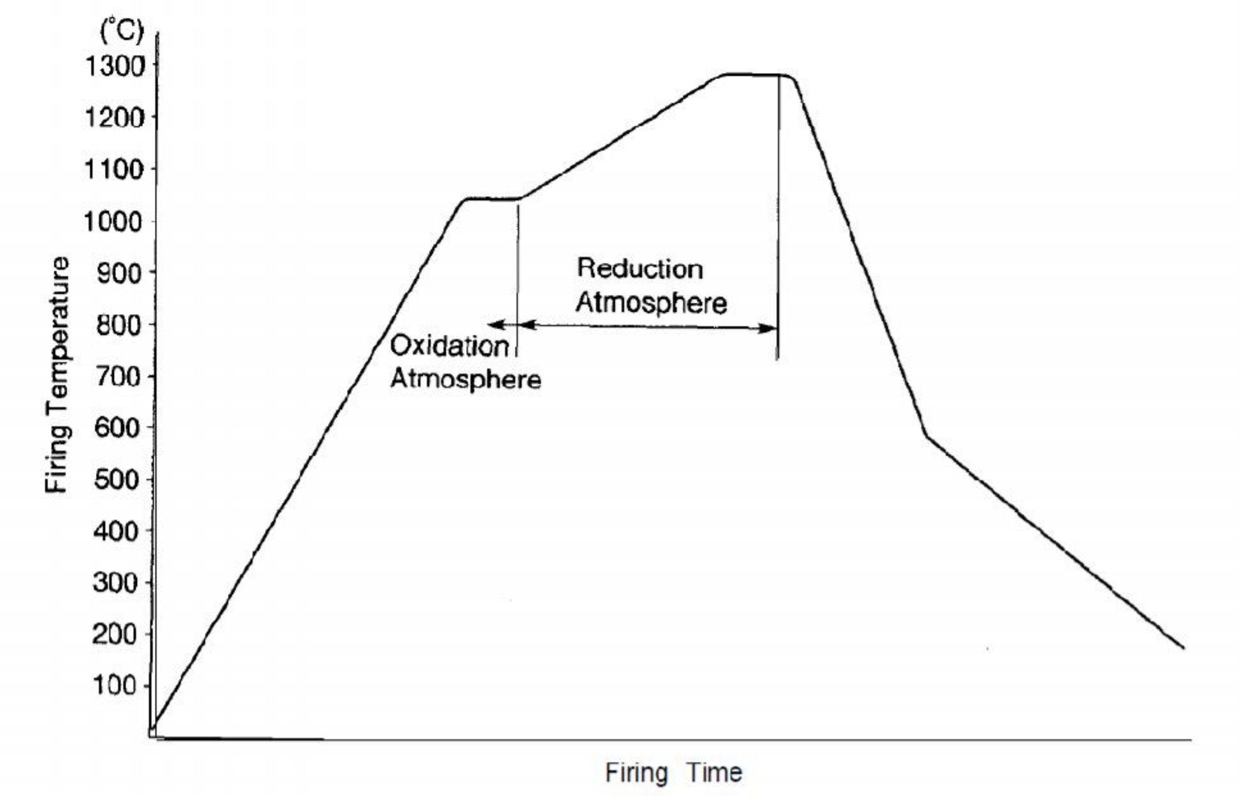

Figure 2.13: Porcelain heat curve[25]

Conventional firing is accomplished by heating the green ceramic to approximately two-thirds of the melting point of the material at ambient pressure and holding it for a specified time in a kiln. Kilns can be classified as periodic (intermittent) or tunnel (continuous). Periodic kilns are heated and cooled according to prescribed schedules. The heat for periodic kilns generally is provided by electrical element or by firing with gas or oil[10]. Periodic kilns can be classified as shuttle kilns, in which the kiln is fixed and the ceramics loaded on rails are run into the kiln for firing, and elevator kilns, in which the kiln is lowered onto the kiln car or the kiln car is lowered into the kiln for firing.

Tunnel kilns are long refractory chambers with constant temperature zones through which kiln cars are passed to provide the specified time-temperature cycle. Tunnel kilns generally have separate zones for cooling, firing, and preheating or drying[10]. The kilns may be designed so that (1) the air heated in the cooling zone moves into the firing zone and the combustion gases in the firing zone are conveyed to the preheat/drying zone then exhausted, or (2) the air heated in the cooling zone is conveyed to the preheat/drying zone and the firing zone gases are exhausted separately. The most commonly used tunnel kiln design is the roller hearth (roller) kiln. In conventional firing, tunnel kilns generally are fired with gas, oil, coal, or wood[25].

Ceramic products also are manufactured by pressure firing, which is similar to the forming process of dry pressing except that the pressing is conducted at the firing temperature. The application of pressure enhances the densification of the ceramic during firing. Because of its higher costs, pressure firing is usually reserved for manufacturing ceramics that are difficult to fire to high density by conventional firing. In hot pressing, hydraulic presses and graphite dies commonly are used. In hot isostatic pressing, the pressing medium typically is a gas, such as argon or nitrogen[24].

There are several type of kilns used in the ceramic processes, some of these are explained as[26]:

2.8.1 Shuttle Kilns:

Where smaller volumes or maximum flexibility are required then shuttle kilns are often the best solution. Suitable for Potter, Tableware, Sanitaryware, Refractories, Technical Ceramics, Laboratory and Test Firings. In sizes ranging from 1m^3 to 200m^3 we can offer a kiln to suit any of your requirements[24,26].

The use of computer control systems and multiple control zones has meant that larger and larger production capacities can be fired effectively using shuttle kilns[26].

Figure 2.14: Shuttle Kiln for Sanitary ware

2.8.2 Carbell Kiln:

In this type of kiln the car and the kiln hood is movable. The advantage is that there will be perfect sealing between the kiln hood (which moves up and down through hydraulic cylinders) & the kiln car. The range of kiln temperature is between 700ºC to 1800ºC. All type of fuels like furnace oil, diesel, kerosene, LPG, natural gas, producer gas can be used for firing. Uniformly of ± 7.5ºC can be achieved in these types of kilns. This type of kiln is down draft kiln and the kiln pressure can be maintained accurately. This type of kiln is used for batch type production[25,26].

For car movement gear motor –winch arrangement is used & for hood movement hydraulic cylinder is used[10].

Range Of Parameters[25]:

Temperature : 700 to 1800 deg c

Capacity : 0.5 to 20 cu m

Fuel : Diesel / Kerosene / LPG / Natural gas / Producer gas

Control : Automatic / Semi - Automatic / Manual

Kiln movement : Hydraulic / Manual

Product to be fired : As per required.

Figure 2.15: Carbell kiln

2.8.3 Tunnel kiln:

The Tunnel kiln is designed for continuous process with minimum losses at low levels of energy consumption. The desigh low maintenance & with stability, day after day through many years of production. This is a continuous tybe kiln. Perfect air balancing is maintained to get a good efficiency in the kiln with the quality product[26].

The performance of the kiln will improve by having following heat recovery systems[10]

- Preheating the product by flue gas
- Waste heat recovery from cooling zone

The systems provided in the tunnel kiln is[10]:

- Exhaust system
- Combustion air system
- Fuel system
- Recuperator system
- Waste heat recovery system
- Burner system

Figure 2.16: Tunnel kiln

2.9 Cooling:

When cooling has started after the maximum temperature is exceeded, the gray body is vitrified to the maximum density, and the glaze is molten to be vitreous. The key point in the cooling process is to cool glass inversion point of the cristobalite at about 573°C and about 250°C gradually when quartz (SiO_2) is included in the gray body. At other temperature ranges it is not affected by the cooling speed, so the speed should be increased maximally to reduce the firing period[23,25].

2.10 Final Processing:

Following firing, some ceramic products are processed further to enhance their characteristics or to meet dimensional tolerances. Ceramics can be machined by abrasive grinding, chemical polishing, electrical discharge machining, or laser machining. Annealing at high temperature, followed by gradual cooling can relieve internal stresses within the ceramic and surface stresses due to machining. Ceramics that are oxygen sensitive often are annealed in a controlled atmosphere to achieve the stoichiometry that optimizes properties. Oxidation can increase the strength of certain hotpressed ceramics. Flame polishing is sometimes used to reduce surface flaws. In addition, surface coatings are applied to many fired ceramics. Surface coatings are applied to traditional clay ceramics to create a stronger, impermeable surface and for decoration. Coatings also may be applied to improve strength and resistance to abrasion and corrosion. Coatings can be applied dry, as slurries, by spraying, or by vapor deposition[10].

CHAPTER 3

Energy Efficiency in Ceramic Industry

Energy consumed in ceramic processes depend upon the payload of ceramic products and the effectiveness and the efficiency of the machines used. Energy consumed in ceramic industries and the chances of energy saving in that is describe processes vise as follows:

- Milling or Grinding processes
- Mixing/Forming
- Kiln
- Lighting

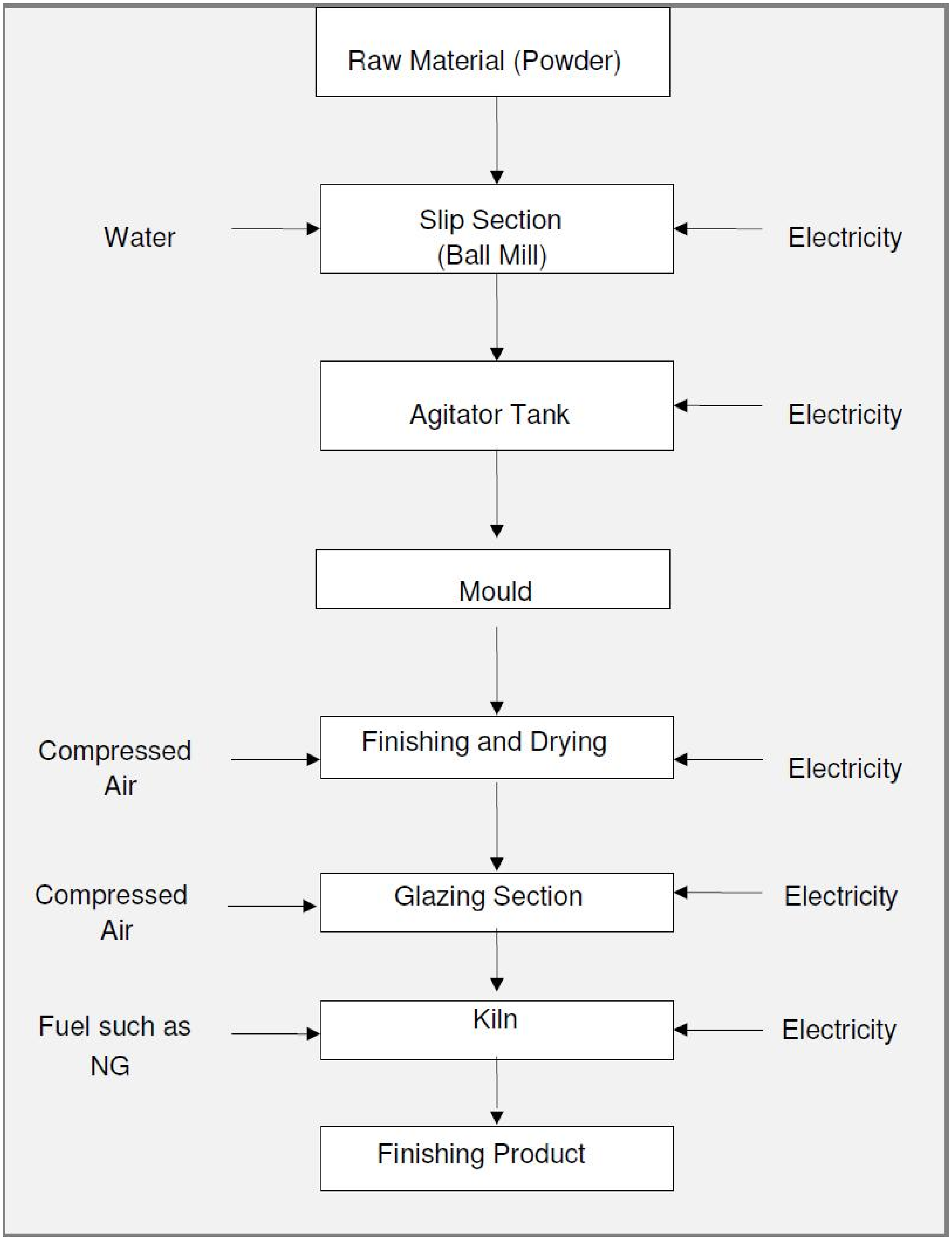

Figure 3.1: Process flow diagram of Ceramics[27]

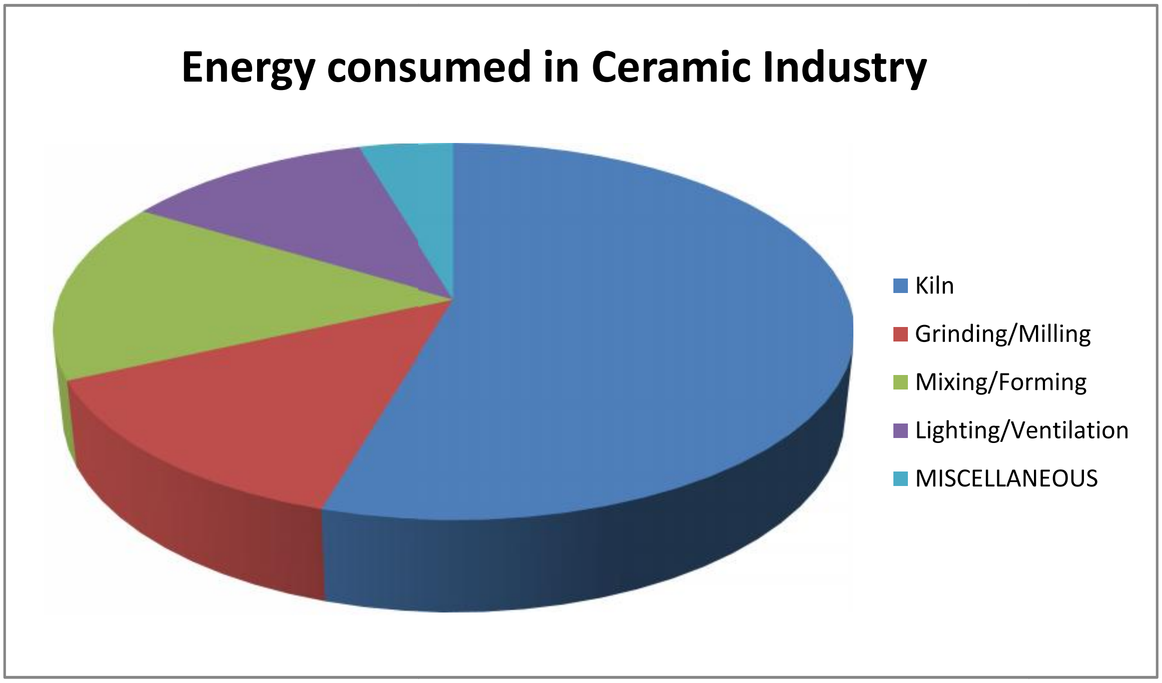

Figure3.2: Energy uses in ceramics processing

3.1 Milling or Grinding processes:

In almost all the metallurgical processes, crushing/grinding is considered to be an inseparable unit operation which is adopted at the very first stage of a series of other unit operations and/or unit processes. Size reduction of solids is done almost invariably. Ball mill finds its application in many industries like abrasives, animal products, brewing industry, chemical, confectionery, food processing, fuel preparation, metal powder, mineral preparation, paint preparation, paper, pigments for color industry, abrasives for grinding, plastics, printing ink, rubber, textiles, sintering, cement and limestone, powders for the detergent industry, pulverized coal for power generation, refractory materials for investment casting, dry powder opacifiers for ceramics industry, pharmaceuticals, mineral preparation, refractory materials for investment casting, tungsten powder and dry lubricants, carbon black for rubber, charcoal for briquetting and others[28].

3.1.1 Terms Associated with Ball Mill Operation:

a) Grindability (G):

Grindability is the number of net grams of screen undersized product per revolution. The chief purpose of study of the grindability is to evaluate the size and type of mill needed to produce a specified tonnage and the power requirement for grinding. Detailed prediction of grinding rate and product size distribution from mills await the development of a simulation based on physics of fracture[29].

T. Yalcin et al.[30] investigated the effect of various parameters on the grindability of pure Sulfur and used the obtained grinding data to establish mathematical models and set up a computer simulation program. The established mathematical model is as shown below[30].

$$y = \frac{100}{k}\left[1 - e^{-(\ln 2)\left(\frac{d}{d_{50}}\right)^{n}}\right]$$

Where:

y is cumulative percent,

passing size d,

d_{50} is the 50% passing size,

n is distribution constant,

k is a correction factor.

The n values ranged from 0.84 to 1.84, and

k values from 0.95 to 1.00.

b) Critical Speed:

If the peripheral speed of the mill is very high, it begins to act like a centrifuge and the balls do not fall back, but stay on the perimeter of the mill and that point is called the "Critical Speed" (nc).This phenomenon is called centrifuging. Ball mills usually operate at 65% to 75% of the critical speed. The critical speed is calculated as under[10].

It is generally accepted that a speed that creates a cascading action of the media is most desirable. Cascading usually occurs when the mill speed is such that the media charge breaks away from the mill wall at an angle of 45 to 60 degrees above the horizontal. Cascading is the case where grinding media from the outer edge falls and rolls in a coherent, mobile mass as suggested be a waterfall. The impact fractures the grains or the charge[31]. Moreover, there are secondary actions as the media not on the periphery cataract downward and cause further attrition through their own rotational and rubbing action. These secondary effects occur between the media, the cylinder wall and the material being ground. Such actions lead to intensive disintegrations, better dispersion, and in wet milling, more complete particle wetting, due to the high rate of shear from the spinning of the grinding media[10]. When mills are rotating at too fast a rate, centrifuging will occur. Individual media are thrown clear of the media mass and move independently until they rejoin the charge at the bottom of the mill. Un-ground material is held with the centrifuging balls and result in uneven disintegration or dispersion. When too slow speeds slipping of the media occurs[30].

$$n_c = \frac{1}{2\pi}\sqrt{\frac{g}{R - r}}$$

Where:

g is gravitational force

R is radius of ball mill

R is radius of balls

c) Work Index:

Work index is defined as the gross energy required in kilowatt-hours per ton of feed needed to reduce a very large feed to such a size that 80% of the undersize passes through 100-µm screen. The expression for this is as given below[30]

$$W = 0.3162 \times W_i \left(\frac{1}{d_P^{\ 0.5}} - \frac{1}{d_F^{\ 0.5}} \right)$$

Deniz and Ozdag have investigated the effect of elastic parameters on grinding and examined the relationship between them. The most widely known measure of grindability is Bond's work index which is defined as the resistance of the material to grinding. The standard equation used by them for the ball mill work index (Bond work index) is as follows[32].

$$W_i = 1.1 \times \frac{44.5}{P_i^{0.23} G_{bg}^{0.82} \left[\left(10 / \sqrt{P_{80}} \right) - \left(10 / \sqrt{F_{80}} \right) \right]}$$

In designing and optimizing a milling circuit using Bond Ball Mill Work Index, the following equations are used (Bond 1961).

$$W = 10 W_i \left(\frac{1}{\sqrt{P_{80}}} - \frac{1}{\sqrt{F_{80}}} \right)$$

And

$$P = T * W$$

Based on this equation it is possible to calculate, for example, the specific energy requirement for a given grinding duty, BBMWI, feed size and required product size. It is then possible to determine the size of mill required based on throughput and therefore the motor power[32].

3.1.2 ball mill size and motor power requirements:

To match a ball mill size and its motor size, some math is required. The power requirement calculated above is the motor power that must be applied at the mill drive in order to grind the tonnage of feed from one size distribution. The following shows how the size of mill required to draw this power is calculated[10].

The represents a section of a mill in operation. The power input required to maintain this condition is theoretically[28]:

$HP = (W)\ (C)\ (\sin a)\ (2\pi)\ (N)$

where:

W = weight of charge

C = distance of center of gravity or charge from center of mill in feet

a = dynamic angle of repose of the charge

N = mill speed in rpm

The value of the angle a varies with the type of discharge, percent of critical speed, and grinding condition.

In order to use the preceding equation, it is necessary to have considerable data on existing installations. Therefore, this approach has been simplified as follows[10]:

Five basics conditions determine the horsepower drawn by a mill:

1. Diameter 2. Length 3. % Loading 4. Speed 5. Mill type

These conditions have been built into factors which are given in Figure 6.

The approximate horsepower of a mill can be calculated from the following equation[30]:

HP = A x B x C x L

Where A = factor for diameter inside shell lining

B = factor which includes effect of % loading and mill type

C = factor for speed of mill

L = length in feet of grinding chamber measured between head liners at shell- to-head junction

3.1.3 TRANSITION FROM LAB TO PRODUCTION:

The transition from grinding in laboratory mill jars to grinding in production sized mills is a fairly straight forward one. There is scarcely any difference in particle reduction, providing comparable grinding media action exercised. Output will, of course, vary with longitudinal or diametric variations, and selection for production output should be on a volumetric basic[10].

The volume of a mill varies as the square of the diameter, while the horsepower necessary for the mill rotation varies as the 2.6 power of the diameter. A mill 8 feet in diameter requires 40 to 80 times more horsepower than a mill 2 feet in diameter. However, the 8 foot unit will produce a batch in approximately ¼ the time, other conditions being equal[32].

3.1.4 Amount of Grinding Media:

Good practice calls for mills to be filled from 45-55% of the total volume. With high-density ceramic media a 45-50% charge is typical, while a 50-55% charge is typical with flint pebbles or standard porcelain. For wet milling porcelain enamel frit, the Porcelain Enamel Institute recommends a 50-55% charge from both standard and high-density media. They also ecommend that the frit charge (slip), expressed in pounds, equal three to four the total volume of the mill, expressed in gallons[31]. If standard porcelain is used, the ratio should be about 3 to 1. if high density alumina media is used, the ratio should be between 3.5 to 4.5 to 1. When steel balls are used, 33% and 45-50% ball charges are common, depending upon the desired mill output. With 33% ball charges, lifter bars are usually recommended[32].

To minimize excessive ball and shell wear, full charges (50-55%) or charges no less than 45% are recommended. At values lower than 45% media tends to slip on the shell unless lifter bars are used[31].

3.1.5 Ball Mill Power-saver DLT-Q1:

Figure 3.3: Ball Mill Power-saver DLT-Q1[33]

a) Principle of electricity saving:

Wet ball mill machine (ceramic enterprise) is selected and configured according to roller diameter, technological requirements and production quantity. It includes motor (motive power) reducer, hydraulic coupler, auxiliary motor, brake coil (winding), belt, belt pulley, roller etc. In the previous control system, it operates at a constant speed and the production time could only be estimated by the experience & experiment, what is more, the start torque is too large to drive easily[10]. However, based on the summary of massive experiment and data, we research and develop ACI Ball Mill energy saver.

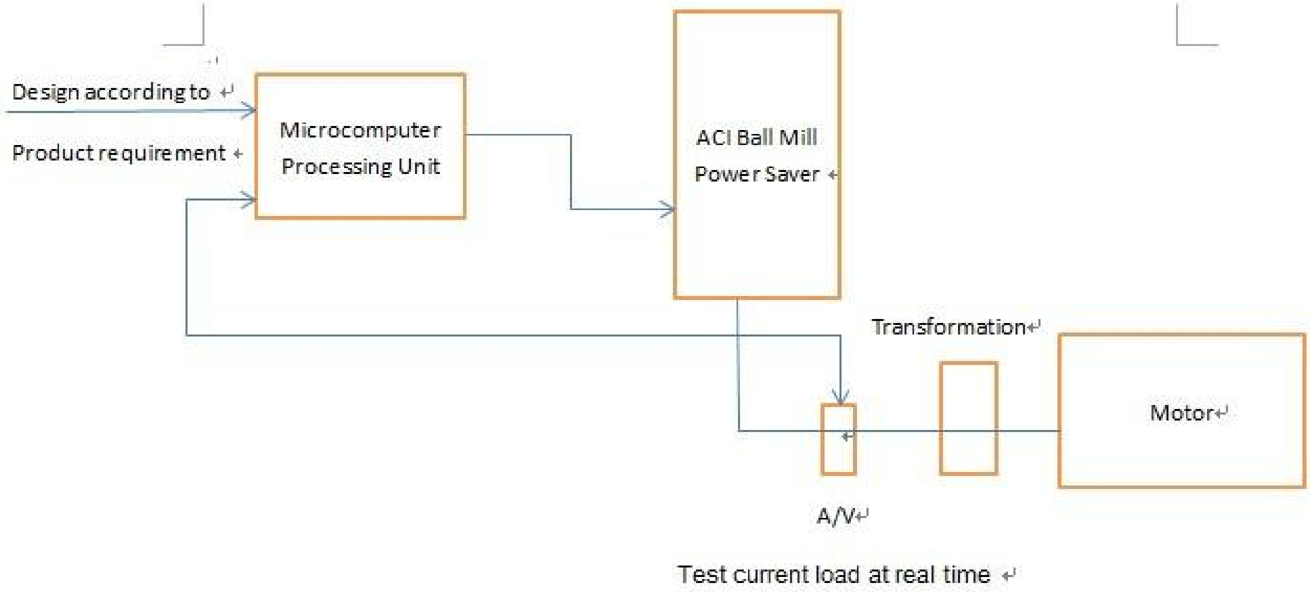

Figure 3.4: Principle of electricity saving of Power-saver DLT-Q1[33]

b) Working process:

Ball mill is on the basis of medium motion. Grinding process of the material pellets occurs among the mediums and medium with lining board. Medium motion is divided into cascading (applied in coarse grinding), down-pouring (applied in fine grinding), centrifugal (to lose grinding function)[10].

c) Through the four aspects of energy-saving[33]:

(1) Power saver adopts soft start function can reduce the starting current of 4-7 times.

(2) Power saver of the power factor can reach above 99%, the original motor power factor is below 80%.

(3) Because of the different products that are required at different speeds, again because of power and is proportional to the square of speed, we can set in different periods and different products for the speed, customers are free to set or choose (through the microcomputer processor to implement).

(4) We have automatic real-time track motor optimum operating current, thus adjusting the output voltage and current, achieve optimal economic operation point.

According to the above four points, the power saving effect can reach above 10%, the average is about 15%, the effect is very significant.
It differs from the general inverter, soft starter, power factor compensator, which is the organic combination of the three, and in overcoming the difficult start of factors such as the perfect combination of modern ceramics enterprises, is the preferred energy conservation products.

d) Function and features:

(1) Unique dynamic energy-saving function， electricity saving range ： 10%~35%

(2) After installation, it becomes an actual soft-starter to reduce the current and avoid the strong & sudden current impact over the machine to prolong its service life

(3) With the perfect protecting function in the condition of overload, overcurrent, short circuit, earthing, etc.

(4) Set the start, stop and running time conveniently

(5) Low investment and high return within 5-12 months by saving electricity

Table 3.1: Energy-saving grate ball mill — Technology parameter[31]

Cylinder Dia. (mm)	Cylinder length (mm)	Power (kw)	Length (mm)	Width (mm)	height (mm)	Processing capacity (t/h)	Max. Ball volume (t)	weight (kg)
1200	1200	22	3512	2076	1620	0.17～4.1	2.4	9610
1200	2400	45	5745	2104	1690	0.2～6.25	4.8	11615
1200	4000	80	7990	2210	2262	0.34～8.3	7.8	15932
1500	1500	45	5740	3075	2280	1.4～4.5	5.5	17125
1500	3000	80	7253	3075	2280	2.8～9	10	21425
1500	4500	130	8389	3075	2280	3.5～12.5	12	27346
2100	2200	132	7420	4225	3083	5～29	16	39350
2100	3000	180	8220	4225	3083	6.5～36	20	43100
2100	3600	210	8820	4225	3083	7.5～42	22	45191
2100	4500	280	10350	3764	3083	10～45	25	52416
2200	3000	210	8220	3864	3183	7.5～45	23.5	44600
2400	3000	245	8420	4064	3383	7.2～92	22.5	63600
2700	2100	245	8300	4786.4	3495	7.2～84	23	75440
2700	2700	280	8901	4786.4	3495	7～110	29	80092
2700	3200	320	10509	5150	3620	8～120	32	92071
2700	3600	380	10764	5150	3620	12～145	39	95271
2700	4000	380	10870	5150	3620	12.5～152	41	98271
2700	4700	380	11859	5150	3620	13～170	45	104372

3.1.6 Six Methods Which Can Improve The Efficiency of Ball Mill:

Ball mill efficiency factors, including water, stone balls, raw materials, formulations, current, dispersants, deceleration devices, and the combined effects of these factors ultimately determines the efficiency of the ball mill. The efficiency of ball mill work is from the six aspects for improvement[10].

1. ball mill and water. The mill processed ore moisture content will affect how much to the work efficiency of the mill, therefore appropriate to add the processing of ore to the mill by water, to avoid too dry mill processing ore raw materials, can also play a considerable role in the improvement of the ball mill efficiency.
2. ball mill, ball stone. The ball mill used in the diameter of the ball stone is one of the factors that affect the efficiency of ball mill work, ball stone ball size varies more favorable ore handled by the ball mill grinding, can realize more fully the grinding of large and small ore, which improve the work efficiency of the mill.
3. ball mill, raw material formulations. The mill's raw material formula and not a certain standard, or that the sole criterion of the ball mill raw material recipe is suitable for the actual working conditions, such a ball mill, ball strength can be improved, but also improve their weight, increase inertia, to help the ball mill to a certain extent improve the work efficiency.
4. the current of the mill. The current size of the ball mill is equivalent to the ball mill energy input current of the mill increase will drive the speed increase will directly improve the work efficiency of the mill. The ball mill current increase is a certain range, the current increases, the upper limit of the mill's power to reach the rated power range, more than will burn mill.

5. ball mill, dispersing agent. Ball mill at work appropriate to add a dispersing agent is also beneficial to the work efficiency. In fact, in the normal production process, the operator is able to find problems and solve the problem. Moreover, the operator based on actual personal experience, on the basis of the original can also re-innovation and upgrading.
6. ball mill, deceleration devices. The speed of the ball mill is to directly determine the factors of the ball mill work efficiency, improve the speed of the ball mill will be able to directly improve the work efficiency of the mill, so to install speed adjustment device appropriate to improve the speed of the ball mill, to a certain extent, improve the work efficiency of the mill, and to install The inverter also has a similar effect.

3.2 Mixing / Forming:

It is the process where homogeneous mixture of clay and water are formed. The energy consumed in this process is very less as compare to the overall energy consumed in the plant, so the energy conservation in mixing and forming is totally depend on the motor used in this process.

The motor selection depends on the load on the machine and the condition of the process. The table given below gives some small pug mill specifications along with the model name:

Table 3.2: Pug Mill Model List[34]

Model No.	Size of motor required(HP)	Nozzle Dia.(Inch.)	Hopper Size(inch)	Extrusion rate (kg/hr)
SHIMPO PM-071	1	3	4.75x4.75	360
SHIMPO NRA-04	0.25	3	3.5x3.5	396
SHIMPO PMX-060	2	3	8x8	55

3.2.1 Power Wedger save time and money:

The Power Wedger does the work of both a clay mixer and a pugmill but takes the space of only one machine. Buckets for storing and soaking scrap can be eliminated if scrap is stored directly in the hopper of the Pugger-Mixer. The biggest savings will be your most valuable resource, time[18]. The Power Wedger is like having a tireless studio assistant. The increased ability and ease of recycling clay will help save money on your clay bill. Buying only one machine that can both mix and pug for little more than the cost of either is also a money savings and a space saver. Proven high quality and low maintenance over the long run and a solid guarantee will produce even more savings[35].

There is no need to use your time continually force feeding clay into a pugmill. Simply load the hopper and let it mix. The Power Wedger will safely mix and deair the clay without constant attention. The reduction of physical exertion for clay preparation and processing will be an added benefit, saving your talents for more creative endeavors.

3.2.2 Capabilities:

The Power Wedger is the most versatile studio clay processing machine on the market today. It can perform a variety of functions efficiently, transforming clay in any form to a usable product.

Some examples:

- Mix moist clay from powder and water.
- Reclaim scrap - wet or dry.
- Blend two or more different bodies.
- Add materials (wet or dry) to an already moist body.
- Adjust moisture of an already wet body.

When the clay is adequately mixed, it can be deaired with vacuum and pugged out in the form of logs ready for use.

Table 3.3: Peter Pugger Model List[35]

Model No	Nozzle Dia. (inch)	Motor power (HP)	Vacuum Pump (HP)	Output (kg/hr)	Ship wt. (Kg)
VPM-9	3	½	¼	180	90
VPM-20	3	1	½	270	105
VPM-30	3	1.5	½	360	186
PM-50	3,5	2		545	180
PM-100	4	3		900	270

3.3 Kilns:

Energy consumed in the kiln is near about 60-70% of the total energy of the industry, so it is very important to improve the kiln with new technologies. If we can improve the kiln efficiency, we can save lots of energy and money. There are several methods to improve the kiln effectiveness and the efficiency. Some of them are explained as:

3.3.1 Use of Hot Air Directly as a Combustion Air in Tunnel Kiln:

Tunnel kiln is used for final baking of Ceramic wares in the unit. Natural Gas or Diesel are used as a fuel in tunnel kiln. Exhaust heat released from tunnel kiln by two ways first one is flue gas released at a temperature of around 200-220ºC and second one is hot air from final cooling zone at a temperature of around 120ºC. At present, exhaust heat from tunnel kiln sent to atmosphere and combustion air use at an ambient temperature. By the use of this hot air from final cooling zone as a combustion air in tunnel kiln, will leads to decrease in fuel consumption.

a) Description of technology:

The proposed technology will utilized hot air which is exhausted from the final cooling zone of tunnel kiln at a temperature of around 120ºC, directly as a combustion air in tunnel kiln. Implementation of this new energy efficiency technology requires following

- Design of piping duct system
- Provide the suction of the combustion blower from the final cooling zone.
- Instrumentation system for proper monitoring

b) Equipment specification:

Implementation of this system on tunnel kiln requires suitable design of duct system which sucks the hot air from final cooling zone and sends it to tunnel kiln as a combustion air. Proper insulation of the duct is very important because poor insulation results in heat loss from its surface thereby resulting in decrease in temperature of hot air.

Design of the ducting system is based on the operating parameters and length of the tunnel kiln. It varies from unit to unit.

c) Suitability over existing equipment:

Implementation of this technology on a tunnel kiln requires the arrangement to provide the suction of hot air from final cooling zone. At present, combustion air used in tunnel kiln at an ambient temperature and hot air from tunnel kiln released to atmosphere at a temperature of about 120ºC[36].

This technology has been selected for the following reasons[10,25,36,37]:

- In sanitary ware unit, major energy cost of unit is consumed in tunnel kiln only.
- Exhaust heat released to atmosphere
- It reduces the fuel consumption in tunnel kiln.
- It significantly increases efficiency of the tunnel kiln.
- Resulting in reduction in GHG emissions.
- Technology is easily available.

d) Economic Benefits From Proposed Technology:

- Use of hot air from final cooling zone of tunnel kiln at a temperature of about 120ºC as a combustion air leads to savings of about 2.25% on total Diesel consumption in tunnel kiln[10,38].
- This project will reduce the heat loss from cooling zone of tunnel kiln.
- Product quality achieved would be same as the present quality. It does not have any impact in improving the quality of the product.
- Annual monetary savings due to implementation of new technology is 1.83 lakh per year. Energy & monetary benefit analysis of new technology after implementation in tunnel kiln are shown in Table 3.4 below[10].
- Implementation of this technology will results in reduction in CO_2 emissions due to reduction in overall fuel consumption. Implementation of this project will result in saving of 4460 liters per year which leads to 11.82 tonne CO_2 emission reduction per year from one unit. Similarly, there are 500 Ceramic units in Khurja(UP), if all units will implement this project then total CO_2 emission reduction will be approximately 5910 tonne CO_2 per year. This will also help in getting the carbon credit benefit through Clean Development Mechanism (CDM) project[10,39].

Table 3.4: Energy & monetary benefit analysis of new technology after implementation in tunnel kiln

S.No.	Parameter	Unit	Value
1	Present Diesel consumption	Liters/day	600
2	Operational days	Days/year	330
3	Present Total Diesel consumption	Liters/year	198000
4	Diesel consumption after implementation of recuperator	Liters/year	193540
5	Saving of Diesel	Liters/year	4460
6	Cost of Diesel	Rs/Liter	41
7	Monetary saving	Rs.	182860

e) Cost of technology implementation:

Material required for fabrication of new technology would cost about Rs 1 lakh which includes the design and fabrication.

Table 3.5: Cost of technology implementation

S.No	Particular	Unit	Cost
1	Material cost	Rs (in Lakh)	1
2	Erection & Commissioning cost	Rs (in Lakh)	0.3
3	Interest during implementation	Rs (in Lakh)	0.1
4	Other misc. cost	Rs (in Lakh)	0.4
5	Total Cost	Rs (in Lakh)	1.8

f) Simple payback period:

The total project cost of the proposed technology is Rs 1.8 lakh and monetary savings due to reduction in Diesel consumption is Rs 1.82 lakh hence, the simple payback period works out to be one years[10].

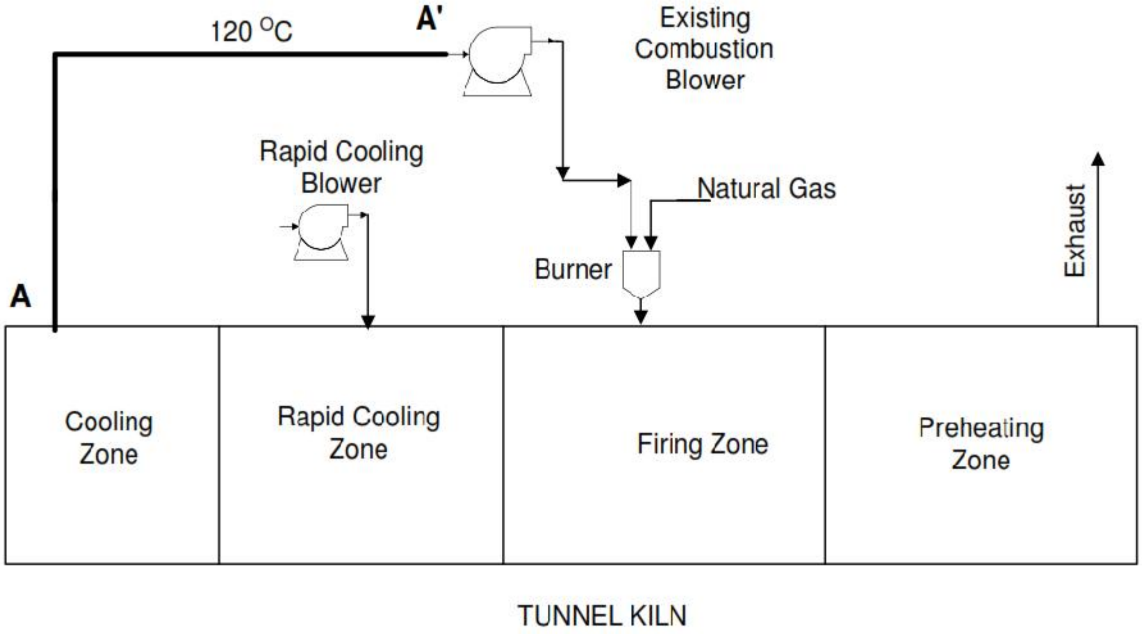

Figure 3.5: Drawings for proposed electrical & civil works

3.3.2 Use of Low Thermal Mass Carin Tunnel Kiln Cars:

The weight reduction of the kiln cars gives the significant amount of energy savings in tunnel kiln. Low thermal mass materials (LTM) are now being used for kiln car construction, which reduces the weight of the kiln car considerably[40].

Weight of car furniture was reduced from 750 kg per car to 600 kg per car (20 percent weight reduction)[10].

The following modifications were made to reduce the weight of the kiln cars:

- Replacement of refractory bricks with the hollow ceramic coated pipes at the supporting pillars for holding the racks
- Introduction of ceramic fiber blankets at the base of the car instead of refractory brick Base
- Use of cordierite (hollow) blocks to hold the raw wares instead of solid refractory mass

Heat loss by kiln car is given by[41]:

$Q=m \times C_p \times \Delta t$

Where[10]:

Q= Heat loss,

m= mass of the kiln car,

C_p= specific heat of kiln car=0.85 kJ/kg-K,

Δt= change in temperature of kiln car=1150-25=1125ºC

Now change in mass of kiln car m=750-600=150kg

Heat Loss saving (Q) = 150 x 0.85 x 1125 = 143437 kJ/kiln car

No of kiln car passes through the kiln in one day(n) = 24

Total Heat loss saving in one day = n x Q = 3442488 kJ

Calorific value of Diesel = 39000kJ/liter

Amount of Diesel Fuel saved in one day = 3442488/39000 = 88 liters

Total amount saved in one year = 88 x 330 x 41 = Rs. 1190640

Replacement of heavy refractory material of the kiln car by low thermal mass material leads to a saving of about 15% on total fuel consumption in tunnel kiln. Hence implementation of this project will give a saving of 29040 liters/year in Diesel fuel consumption in tunnel kiln which will save Rs 11.9 lakh per annum. The proposed technology leads to the increase in production due to increase in car product holding capacity and energy saving due to reduction in car weight[10].

a) Installation of Proposed Equipment:

Material required for fabrication of proposed technology would cost about Rs 15 lakh which includes the design and fabrication.

Erection & commissioning cost is Rs 1.00 lakh which includes the piping, instrumentation, labour work etc and Rs 0.43 lakh for misc. cost.

Table 3.6: Cost of technology implementation

S.No.	Particular	Unit	Cost
1	Material cost	Rs (in Lakh)	15
2	Erection & Commissioning cost	Rs (in Lakh)	1
3	Interest during implementation	Rs (in Lakh)	0.5
4	Other misc. cost	Rs (in Lakh)	0.5
5	Total Cost	Rs (in Lakh)	17

b) Simple payback period:

The total project cost of the proposed technology is Rs 17 lakh and monetary savings due to reduction in Natural Gas consumption is Rs 11.9 lakh hence, the simple payback period works out to be 1.42 years[10].

3.3.3 Pushing speed of kiln car:

Although not widely known, the faster the kiln car pushing speed (shorter the firing cycle), the less fuel will be consumed in the tunnel kiln; this will contribute to energy conservation.

The following examples will explain this:

Table 3.7: Conditions of kiln

Current car speed	24 cars/day
Fuel consumption	600 liter/day
Thermal efficiency	40%

The fuel required to fire the products of daily 30 cars under these conditions is given by[10]:

600 liiter/day x 0.4 = 240 liter/day

Fuel required to maintain the kiln temperature is:

600 liiter/day x 0.6 = 360 liter/day

Let us assume that the thermal efficiency and the fuel required to maintain the kiln temperature remain unchanged, despite possible change of the car speed. If the car speed is increased to 30 cars per day, then the fuel requirement can be expressed in the following equation[10]:

Fuel required to maintain the kiln temperature = 360 liter/day

Fuel required to fire the products:

240 liter/day x 30 cars/day / 24cars/day = 300 liter/day

Total = 300 liter + 360 liter = 660 liter/day

On the other hand,

the fuel consumption per car is given by the following:

24 cars/day: 600 liter/ 24 cars = 25 liter/car

40 cars/day: 660 liter / 30 cars = 20 liter/car

Thus, an increase of the car speed from 24 to 30 cars per day will increase fuel consumption per hor by 20% from 600 liter/day to 660 liter/day. In terms of per-car value change from 25 liter/car to 20 liter/car, showing that as much as 20% energy conservation can be achieved. Thus, less fuel consumption will result in less cost[10].

3.3.4 Air ratio in kiln:

When the fuel is combusted at the outlet of the firing kiln, it would not be an effective combustion if smoke is produced from the kiln and the smoke of offensive smell is led through the factory, or combustion is intermittent. The air ratio in the combustion chamber (excess air ratio) may be used to check if the burner combustion is effective or not Generally, complete combustion of the fuel requires excess air[40].

The relationship between the volume of actual combustion air “A” and volume of theoretical combustion air “A”, can be expressed in the following equation[39]:

$$\mathbf{A = mA_o}$$

The ratio “m” of the volume of actual air to the volume of theoretical air is called air ratio or excess air ratio.

When this ratio “m” is over 1, complete combustion takes place to create oxidizing atmosphere; in contrast when this ratio “m” is below 1, incomplete combustion takes place to create reducing atmosphere[39].

Generally, for pottery firing in oxidizing atmosphere, “m” should preferably be within the range from 1.2 to 1.5; below 1.2, the amount of combustion gas becomes insufficient resulting in larger difference in temperature in the kiln, while over 1.5, the amount of combustion gas becomes excessive resulting in smaller difference in temperature in the kiln, but requires fuel more than necessary[40].

On the other hand, in reducing atmosphere there is no need to increase the value more than necessary (m = below 0.8). To check the air ratio in the combustion chamber in practice, it is possible to calculate it by gas analysis for the combustion chamber[39].

Liquid fuel

$$m = \frac{21\,(N_2)}{21(N_2) - 79\{(O_2) - 0.5(CO)\}}$$

Gas fuel

$$m = \frac{(O_2) - 0.5(CO)}{5 \cdot C_3H_8 + 6.5\,C_4H_{10} \times \dfrac{(CO_2) + (CO)}{3\,C_3H_8 + 4\,C_4H_{10}}}$$

where symbols in parentheses indicate the composition of the combustion gas (%), and C_3H_8 and C_4H_{10} show the percentage of propane and butane contained in the fuel gas.

Thus, it is important always to analyze the combustion gas to ensure appropriate combustion. In other words, the easiest way of energy conservation for using fuel without investment is to reduce the air ratio. The volume of exhaust gas depends on the m-value of that gas. Thus, it is important to minimize the percentage of O_2 in the exhaust gas.

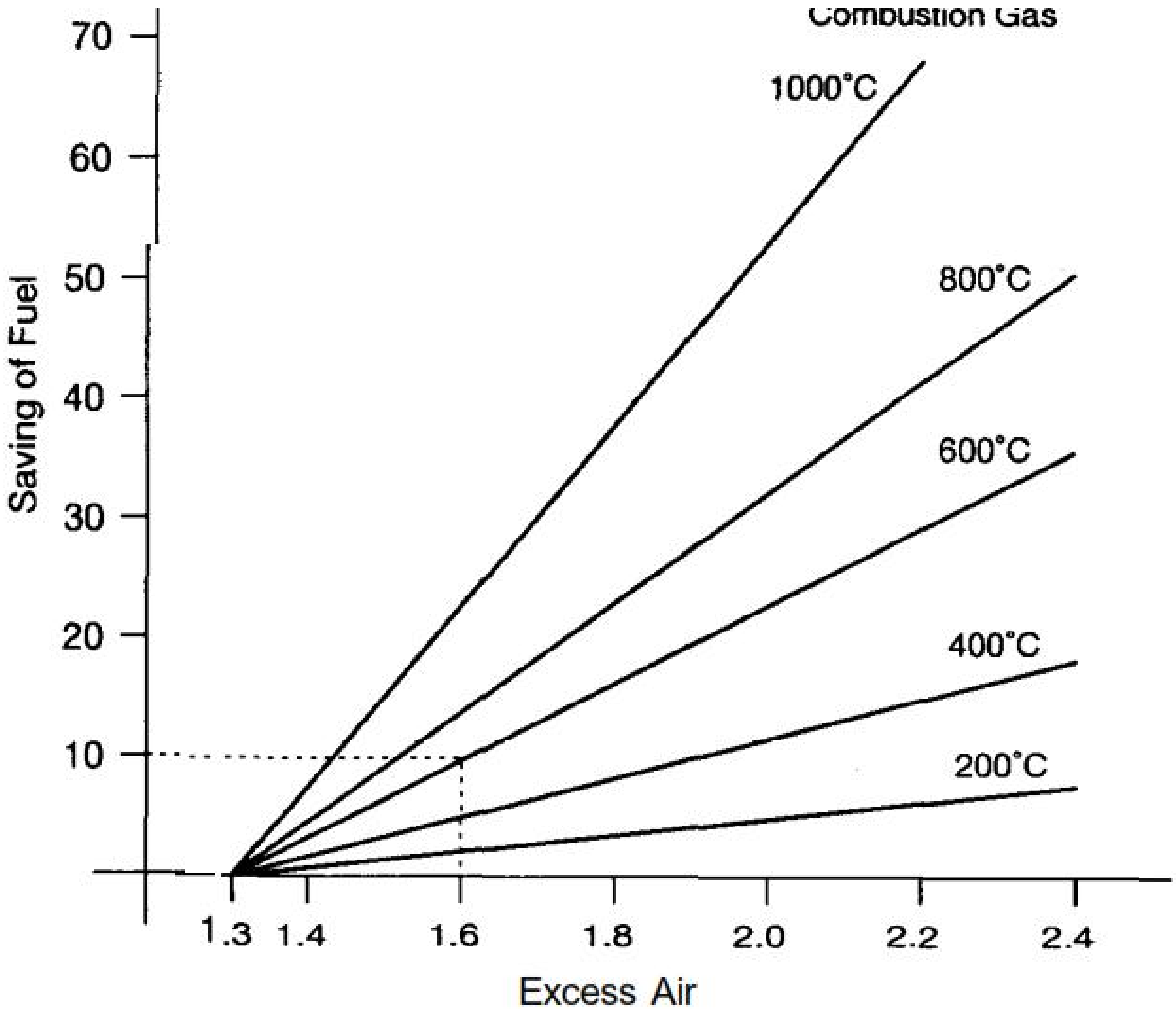

Table 3.6: Excess air - saving of fuel[39]

3.3.5 Vapour Absorption system:

The main advantage of absorption chillers is their ability to utilize waste heat streams that would be otherwise discarded. In terms of energy performance, motor-driven vapor compression chillers will beat absorption chillers every time. Still there are specific applications where absorption chillers have a substantial advantage over motor-driven vapor compression chillers[42,43].

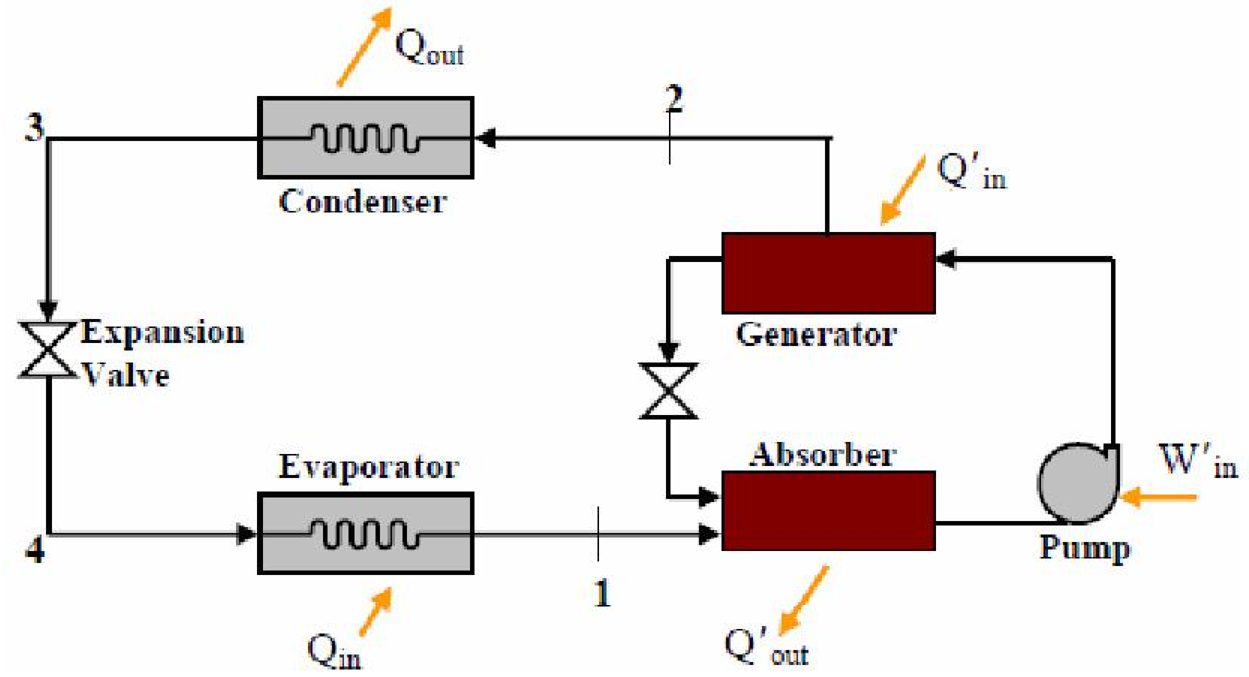

Figure 3.7: Vapor Absorption Cycle

a) Comparison between VC cycle and VA cycle:

Table 3.8: Comparison between VC cycle and VA cycle[10,42]

Parameters	VC cycle	VA cycle
Operating hours/day	12	12
Operating days/year	330	330
Operating hours/year	3960	3960
Total energy consumed kW-h/year	93555	3100
Cost of energy Rs/kW-h	5.5	5.5
Total cost of operation Rs/Year	514500	17000
Saving Rs/year	0	497500

From above table we find out that the total saving by VA cycle is nearly Rs. 497500.

b) Installation of Proposed Equipment:

We need a 15 ton VA air conditioning system to install in the industry for offices for this the cost of this installation is calculated as, Material required for fabrication of proposed technology would cost about Rs 7.5 lakh which includes the design and fabrication. Erection & commissioning cost is Rs 2 lakh which includes the piping, instrumentation, labour work etc and Rs 1 lakh for misc. cost[10].

Table 3.9: Installation of Proposed Equipment

S.No.	Particular	Unit	Cost
1	Material cost	Rs (in Lakh)	12
2	Erection & Commissioning cost	Rs (in Lakh)	2
3	Interest during implementation	Rs (in Lakh)	0.75
4	Other misc. cost	Rs (in Lakh)	1
5	Total Cost	Rs (in Lakh)	15.75

c) Simple payback period:

The total project cost of the proposed technology is Rs 15.75 lakh and monetary savings due to reduction in energy consumption is Rs 497500 hence, the simple payback period works out to be 3 years.

3.4 Lighting:

3.4.1 Light Emitting Diode (LED):

Energy efficiency of LED lamps can be very high (50 lumens/W) and life is much longer (up to 100,000 hr) than other light systems. If the technology can be adapted for barn environments, it is expected that LED lighting systems will provide large on-farm energy savings in the future.[44]

LEDs come in various forms — spot, linear or strip and monochromatic colours. They can be dimmed.

The advantages of LEDs include[44]:

•environmental friendly–energy efficient with 1/5th of the power consumption of incandescent lamps. LEDs contain no mercury and since they last longer there is less waste

- long life - LEDs lasts up to 100,000 hr compared to the typical incandescent bulbs at 1,000 hr or 20,000 hr fluorescent lamps
- low maintenance cost
- miniaturization - small size allows them to be used in areas not easily accessible
- high reliability - LEDs are solid-state devices, without moving parts, glass or filament to break. They are robust and vibration proof
- directed light for increased system efficiency
- fully dimmable
- multicolour - available in all colours
- high speed response - immediate response, no preheat or starting time required.

a) Experimental Work:

Energy usage with LED provided an 82.4% savings in kWh vs. incandescent. The following chart shows the results from R.K. Ceramics. It compares the specific energy usage between two different types of lights in two of the Ceramic industries. One was fitted with 200- 60 watt incandescent lamps, a second with 200 LED 10 watt dimmable bulbs. The lighting are on nearly 18 hours in a day, so the total energy saving after this is calculated as[10]:

Table 3.10: lighting energy usage data.

R.K. Ceramics	kWh/day	Lighting Energy Cost @Rs 6/kWh	Savings of LED vs Incandescent Daily	Projected Savings of LED vs. Incandescent Annually
Incandescent (200 lights)	216	1296	0	0
LED (200lights)	36	216	1080	356400

b) Installation of Proposed Equipment:

Material required for fabrication of proposed technology would cost about Rs 45 thousands which includes the design and fabrication.

Erection & commissioning cost is Rs 10000 which includes the piping, instrumentation, labour work etc and Rs 15000 for misc. cost[10,44].

Table 3.12: Installation of Proposed Equipment

S.No.	Particular	Unit	Cost
1	Material cost	Rs (in Thousands)	45
2	Erection & Commissioning cost	Rs (in Thousands)	10
3	Interest during implementation	Rs (in Thousands)	5
4	Other misc. cost	Rs (in Thousands)	15
5	Total Cost	Rs (in Thousands)	75

c) Simple payback period:

The total project cost of the proposed technology is Rs 75 thousands and monetary savings due to reduction in electricity consumption is Rs 3.5 lakh hence, the simple payback period works out to be 0.2 years.

CHAPTER 4

Conclusions

From the analysis of the energy audit data, it can be concluded that:

- Running the Ball Mill on 70-80% of critical speed, decreases the energy consumption by Ball mill to 85-90%.
- Using the motor as per the Ball Mill requirement will decrease the energy losses.
- Using the specified amount of grinding media increases the Ball Mill effectiveness.
- Using Ball Mill Power-saver leads to increase in power saving up to 30%.
- By using motor size as per the design of pug mill will decrease power losses.
- Use of hot air directly as a combustion air in Tunnel Kiln leads to increase in efficiency of kiln by 2-5%.
- Use of low thermal mass carin tunnel kiln will increase the efficiency of kiln by 5-17%.
- Increasing the pushing speed of kiln car by some extent will increase the efficiency of the kiln.
- Use of required amount of air ratio in kiln increases the effectiveness of kiln.
- To minimize the exhaust gas losses we can use Vapor Absorption system for cooling the cabins in the industry.
- Using latest technologies in lighting we can decrease the energy consumption in lighting by large amount.

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