

Lecture 7

Thermal processes

1. Drying:

The drying process of ceramic products is a crucial step preceding sintering. Its primary purpose is to remove water added during molding to prevent defects such as cracking or warping when the pieces are exposed to high firing temperatures.

After the ceramic parts are formed, they are transferred to the drying stage. During this process, the particles, surrounded by varying amounts of water depending on the forming techniques, converge, and the raw material shrinks in volume, a process known as shrinkage (Figure 1). Shrinkage ceases once the powder particles come into contact. The remaining water must then exit the system through the pores or microchannels. The water content decreases at the beginning of the drying process, causing the part to shrink. After approximately 72 hours, water remains only in the pores. The water content continues to decrease, but the shrinkage remains constant. Consequently, the particles can be handled and placed, for example, on conveyor belts, either mechanically or manually.

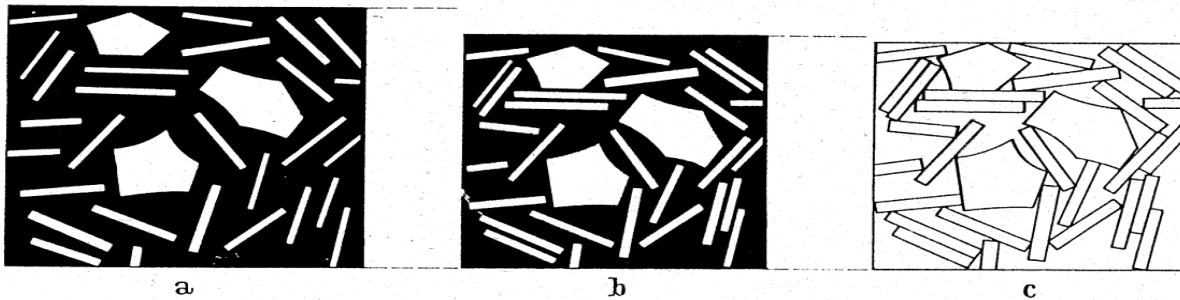


Fig.1. Illustration of the drying stages in ceramic compounds

The drying rate can be increased by raising the drying air velocity and temperature. The drying rate is also affected by the sample geometry and the density of its components. If the overall porosity is high (meaning low density), water can evaporate from the system relatively quickly.

Transitions in a furnace aggregate are more sliding (Fig. 2). In the tunnel dryer, the ware is brought in from the side. Temperature is relatively low at the beginning while humidity is high. In the course through the furnace, temperature increases and humidity decreases. Therefore, an almost constant drying speed can be adjusted for the complete drying process. Then it comes out the other side

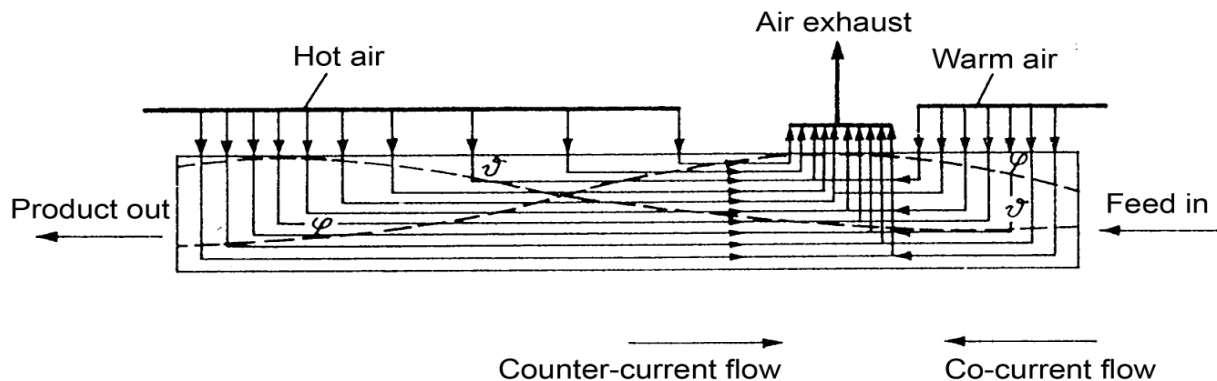


Fig.2 Drying stages (

Factors Affecting Drying Quality

1. **Air Distribution:** The airflow must be even across all product surfaces to avoid mechanical stress.
2. **Product Shape:** Thin pieces and simple shapes dry faster than thicker or more complex pieces, which may require longer drying cycles, sometimes up to 48 hours.
3. **Moisture Gradation:** A sudden increase in temperature or a rapid decrease in humidity can lead to microscopic cracks that may later cause product failure.

Drying ovens are divided into two main categories:

1. **Tunnel Ovens:** Used for mass production, where products move on conveyor belts or trolleys through a tunnel divided into different heating zones. They are characterized by high energy efficiency per unit of production.

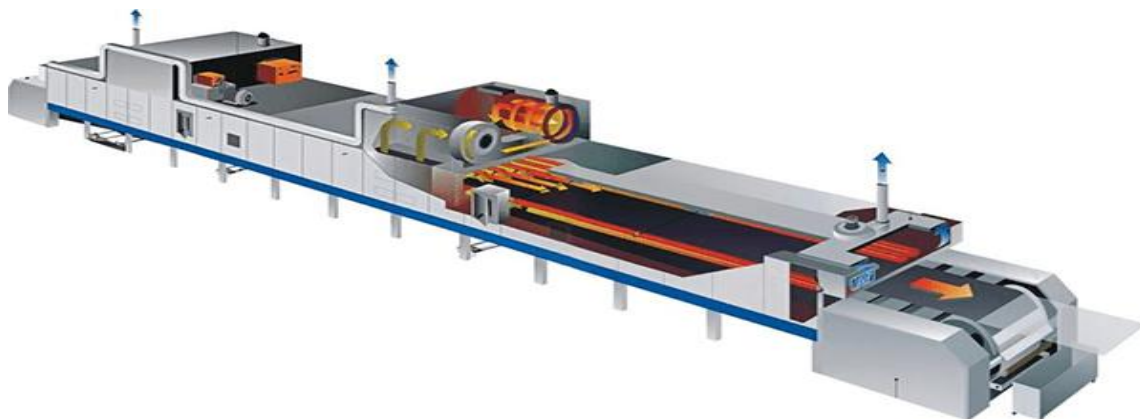


Fig.3. Tunnel Oven

2. **Batch Ovens:** Used for limited quantities or pieces of varying sizes. The oven is fully loaded, the product undergoes a specific

drying cycle, and then it is unloaded manually or automatically.fig.4.



Fig.4.oven

3.Rotary Dryer/Kiln

Movement: Consists of a large, inclined metal drum that rotates on its axis, continuously agitating the material as it moves by gravity towards the lower end.

Product Type: Designed for bulk and granular materials (such as cement, sand, minerals, and chemicals) that are not affected by agitation.

Temperature: Features high heat transfer efficiency due to the direct and continuous contact between the hot air and the particles of the agitated material.fig.5.

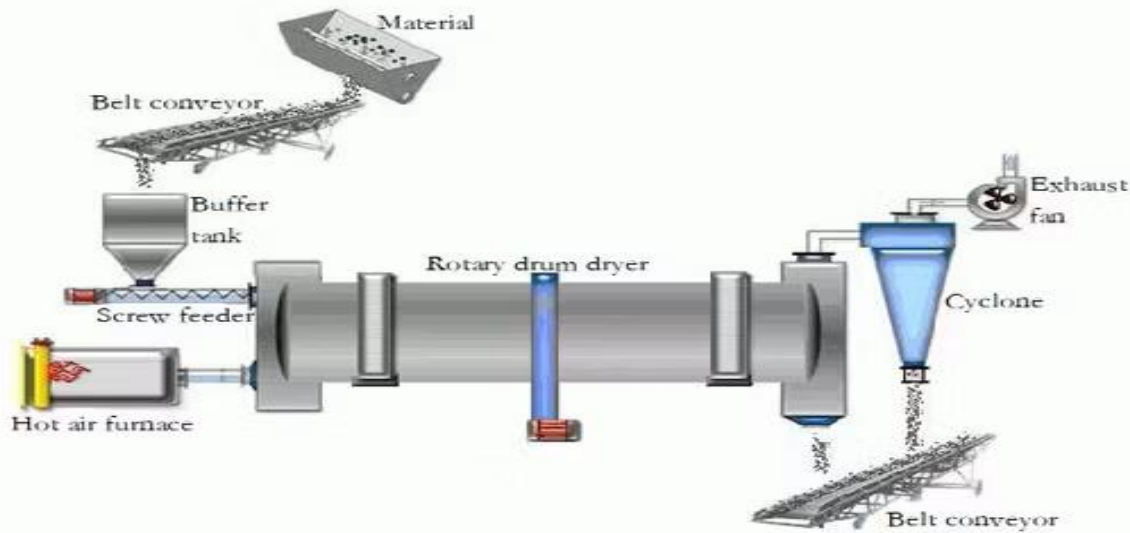


Fig.5. Rotary Dryer

2. Firing:

Drying is followed by a further thermal treatment, considerably below melting point of the ceramics, the so-called **sintering**. Sintering promotes consolidation combined with further shrinkage. Now the ceramic products get their typical structure and their characteristics.

variety of things are accomplished in the presintering reaction.

1. Decomposition. The decomposition of the raw materials (i.e., carbonates, organometallic salts, higher oxides, etc.) results in the removal of the gaseous by-products. The evolution of these gases during the sintering cycle would cause internal pressure, stresses, and cracking.

2. Reaction. The reaction of a multiphase mixture to form the desired compound. Additional milling after calcining and prior to pressing and sintering stage increases the homogeneity of the ceramic.

3. Particle Size. The presintering reaction can be closely controlled and the particle size and/or surface area of the presintered product adjusted so that close shrinkage control is maintained in the sintering operation. This is especially important in technical products which may have a rather complicated sintered shape and require close tolerances and dimensional control.

2.1. Sintering:

The sintering process is composed of three different steps:

(1) binder removal,

(2) densification,

(3) grain growth. Before densification begins the organic binders and residual moisture contained in the pressed ceramic must be removed slowly from the compact. Rapid heating at this point will result in the creation of pressure at internal voids in the material.

This pressure will lead to internal cracks and holes within the material. For very simple shapes such as toroids and disks or other small parts relatively high heating rates ($< 500^{\circ}\text{C/hr}$) can be tolerated without much structural difficulty.

The most critical region during heat up is in the range from approximately 60° to 350°C. Within this region most of the moisture and organics are volatilized and burned out. An adequate amount of oxygen or air should be supplied over the ceramic parts to cause complete binder burnout, or the

possibility occurs that the binder will be incompletely removed and residual carbon may burn out at higher temperatures with the possibility of warpage or cracking.

2.2. Kilns:

Kilns are the backbone of the ceramics industry, where brittle clay is transformed into a solid and durable material through high temperatures that reach the required firing point.

2.2.1.Types of Ceramic Kilns

Kilns vary based on their design and the type of fuel used:

1.Tunnel Kilns: Large, continuous industrial kilns where the products move slowly on trolleys through different heating zones (heating, firing, and cooling).

A tunnel kiln is a continuous heating system widely used in industries such as ceramics and bricks.

The basic components of a tunnel kiln are as follows:

1. Kiln Body

Structure and Lining: Consists of walls and a roof constructed of refractory materials (such as firebricks or ceramic fibers) to

withstand high temperatures, and insulating materials (such as rock wool) to minimize heat loss.

Heating Zones: The kiln body is divided longitudinally into three main zones to ensure gradual curing:

Preheating Zone: The product temperature is gradually raised to minimize thermal shock.

Firing Zone: The central zone where the temperature reaches its peak to complete chemical or physical reactions.

Cooling Zone: The temperature is slowly reduced to prevent structural defects in the product.

2. Conveying System

Kiln Cars: Thermally insulated platforms that move on rails, transporting the material through the tunnel. **Drive System:** A mechanical or hydraulic mechanism that propels the carriages continuously or intermittently at a specific speed.

3. Heating System

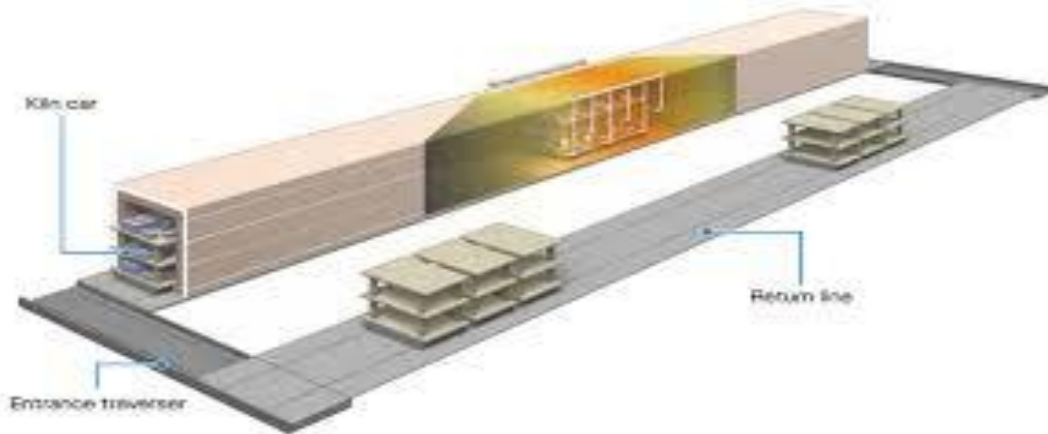
Burners: Located on either side of the furnace and powered by natural gas, oil, or pulverized coal to produce the required heat.

Electric Heating Elements: Used in electric furnaces instead of burners to ensure a cleaner environment and more precise control.

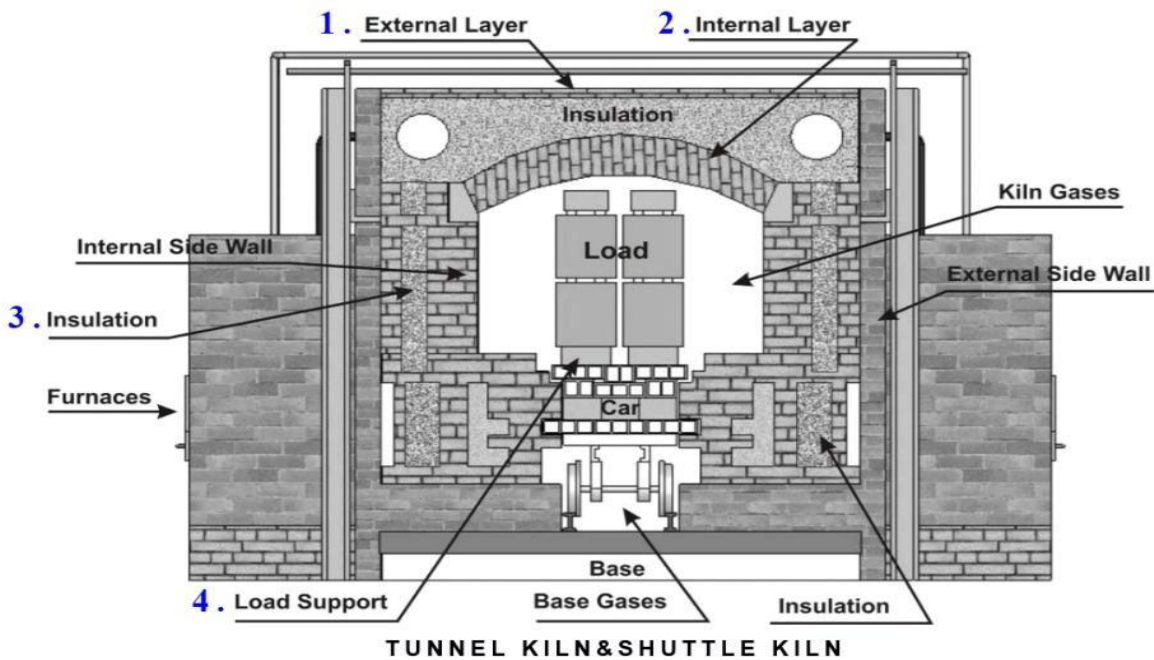
4. Ventilation and Air Circulation System

Exhaust System: To draw combustion products and hot gases from the combustion zone towards the preheating zone (counter flow).

Cooling Fans: To push cool air from the end of the furnace to cool the exiting products and heat the incoming air for use in combustion.

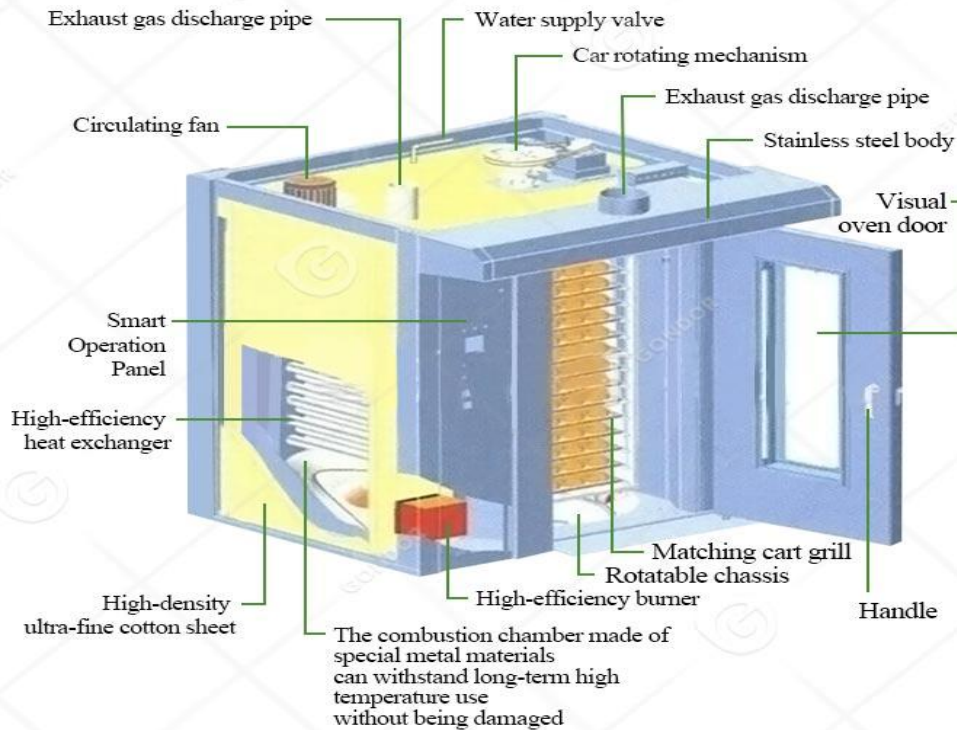


3. **Shuttle Kilns:** Cyclical kilns that are loaded with products and then closed to allow for complete firing and cooling before being unloaded. They offer high flexibility in changing firing cycles.



Shuttle Kiln

4. **Roller Kilns:** Used specifically for ceramic tiles, where the tiles move over rotating cylinders, allowing for rapid and uniform firing.



Roller Kiln

Kilns operate using either electricity or fuel (gas, liquid, or wood).

3. Stages of the Firing Process

Inside the kiln, the products undergo a precise heating cycle comprising three essential stages:

1. Pre-heating: Removal of moisture, organic matter, and carbon.
2. Firing/Soaking: Reaching the maximum temperature where sintering occurs and the material acquires its final density.

3. Cooling: Gradually reducing the temperature to prevent cracking of the pieces due to thermal shock.

Firing Techniques

1. Single Firing: The glaze is applied to the raw material and fired directly to achieve its final state.
2. Double Firing: This involves first biscuit firing to transform the clay into a durable, porous state, followed by firing the glaze after the piece has been decorated.

The firing cycle takes between 8 hours in small kilns and 24 hours in large kilns to ensure complete curing of the material.