Introduction to Drying:

Drying of ceramics is much more complicated than drying many other objects because unfired ceramics typically exhibit shrinkage during drying. This shrinkage can lead to cracking and loss of acceptable quality in production.

(***Drying is the process of removing water from an unfired ceramic object or raw material in the green or as-formed state or in the as received state)***.

As such, drying is accomplished by supplying energy to the ceramic in order to accomplish evaporation.

Drying is a process which is used for removing the liquid from the solid material. In standard chemical engineering practice drying of the water (compound A) from the solid (compound C) by evaporating to the flow of overheated air (compound B) is the most com-mon practical example. Drying is relatively complex process combining the heat and the mass transport. In our laboratory dryer the heat transport which is necessary for the evaporation of the water, is realized only by the heat convection from the air to the drying material.

From mass transport point of view, one must understand the drying as a diffusion process. During first period of drying, water which is contained in material evaporates from the material surface to the air flow (by external diffusion). After formation the moisture gradient inside the material second drying period begins. During this period water is transported inside material to the surface (internal diffusion). Rate of the slower process determines overall drying rate. Mass and heat transport proceed together during drying

WATER ADDED TO A DRY CERAMIC POWDER

When water is added to a completely dry ceramic powder,

• First, covers the surface of the particles. (Assuming ideal mixing to prevent agglomeration).

• Second, water fills small capillaries (minimum spaces between particles).

• Third, since most ceramic compositions also contain some large pores (generally ~50– 100 μm in size) due to imperfect particle packing or gradation, these pores are gradually filled with water.

• Fourth, additional water causes a separation of particles **called forming water** .

DRYING REMOVES

In drying, water is removed from the ceramic, and the sequence in which the various waters are removed is exactly the reverse of the theoretical sequence of water addition given above; that is, first forming water, then pore water, then capillary water, and finally surface waters are removed

• Forming water first (if present).

• Pore water next (if present).
• Capillary water (usually present).
• Surface water (always present).

Stages of drying:
The generalized rate of drying of a ceramic product is shown in Fig. 4. The rate of drying is defined as the change in the weight of moisture in the ceramic per unit time, the rate of drying is the slope of the line defined by the drying process. It is clear that the slope of the line is constant during the initial drying of the ceramic, for example, on progression from Point A to Point B in the drying process of Fig.4 . For this reason, the initial period is called the **constant rate period of drying**. As drying continues beyond Point B, the drying rate declines with the rate of decline constant. In other words, the slope of the line in (Fig 4) as drying progresses from Point B to Point C is declining at a consistent rate. This period of drying is called the **first declining rate period**. In the next period of drying (progression from Point C to Point D) the rate of drying declines at an increasing rate; this period is called the **second declining rate period**.

The progression of drying is:
• The constant rate period.
• The first declining rate period.
• The second declining rate period.
The information presented in Fig. 4 can be presented in a plot of drying rate versus time. As shown in Fig. 5, at the start of drying the rate of drying is constant on progression from Point A to Point B, beyond Point B, the rate of drying declines constantly until Point C is reached. Then, the drying rate progressively slows until drying is completed. The moisture content at Point B in Figs. 4 and 5 is called the critical moisture content (Mc) because shrinkage takes place as drying continues down to Mc, but shrinkage is negligible below Mc, this is the point at which the product can be moved without fear of warpage.

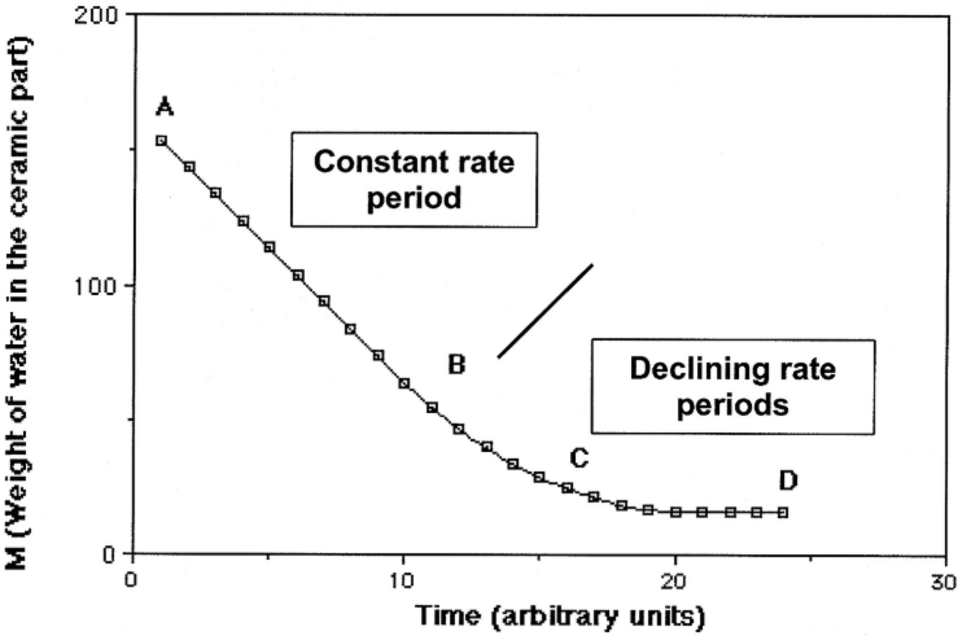

Figure 4: Change in moisture content in ceramics during drying.

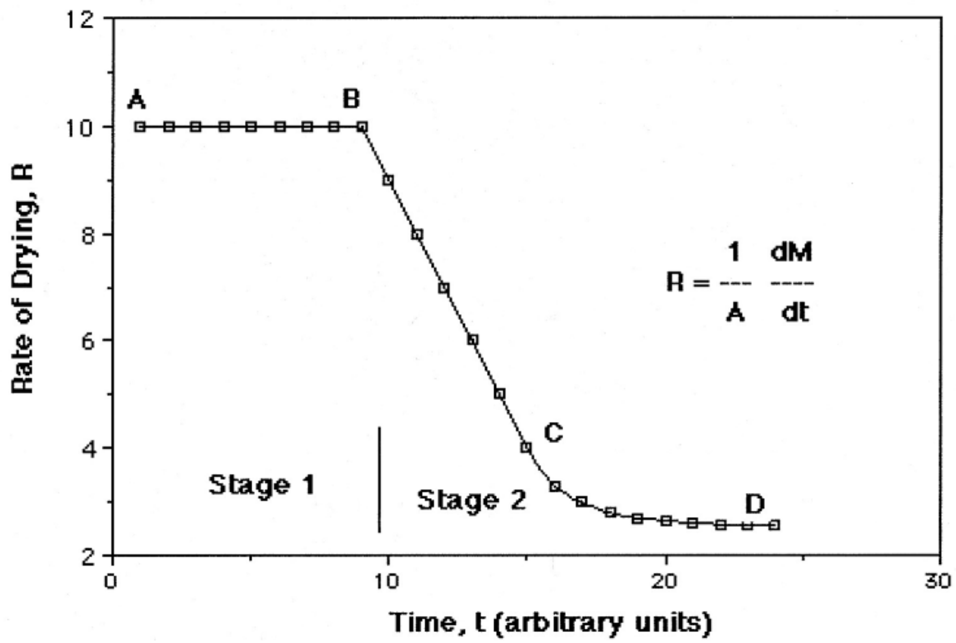

Figure 5: Drying rate plot. M = weight of water in the ceramic; A = surface area of the ceramic exposed to the drying environment.

Throughout the history of ceramic processing, it has been known that there are three primary factors in avoiding defects in drying:

- The rate of drying during Stage I must be sufficiently slow to avoid stress development, which initiates cracks.
- The moisture content of the ceramic mix affects drying shrinkage.
- The particle size distribution of the ceramic material has a significant effect on the drying shrinkage that is observed.

Drying and firing shrinkage determination:
Calculate the linear drying shrinkage as a percentage of plastic length, as follows:

$S_d = (L_p - L_d)/L_p \times 100$

where:
S_d = linear drying shrinkage, %,
L_p = plastic length of test specimen, and
L_d = dry length of test specimen.

Calculate the total linear shrinkage after drying and firing of clay shrinkage specimens as a percentage of plastic length, as follows:

$S_t = (L_p - L_f)/L_p \times 100$

where:
S_t = total linear shrinkage after drying and firing, %,
L_p = plastic length of test specimen, and
L_f = fired length of test specimen.

When desired, volume shrinkage may be calculated from linear shrinkage, as follows:

Volume shrinkage, % = $[1 - (1 - S/100)^3]\ 100$

where: S = linear shrinkage, %.

Water of plasticity: is the water necessary to bring the clay to a good working consistency and expressed as a percentage as

$T = [(W_p - W_d)/W_d] \times 100$

Where: W_p: weight of plastic piece. W_d: weight of dry piece

Shrinkage water: is that portion of the water of plasticity which is given off up to the point where shrinkage ceases

pore water: that portion of the water of plasticity which is given off from the point where shrinkage ceases until the clay piece has reached constant weight at 100C.

Shrinkage water= $t = [(V_p - V_d)/W_d] \times 100$

Where:
V_p: plastic volume.
V_d: dry volume.

Pore water = $t_2 = T - t$