Chemoreaction drying technology: principle, application and roles

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Abstract. The potential of chemoreaction drying technology application in Indonesia is upright due to the abundant availability of natural lime. Traditionally, the lime is burnt and CaO, traditionally called burnt lime or fire lime is produced. Burnt lime is used as raw materials for construction and chemical industry. Adding water to CaO changes the burnt lime to become Ca(OH)₂, which has higher price than the burnt lime, and produces heat that can be used as chemoreaction reactant for drying process. The special drying natures of CaO will be synergized during the chemoreaction drying process in the closed containers containing the burnt lime reactant and materials to be dried. The drying process in chemoreaction become special because the drying is held at slightly above room temperature, which is about 35°C. The resulting dry product can reach the water level 2 - 4 %; hence the product will be durable with very high quality. The weakness in the conduction of the chemoreaction drying process can be resolved by the use of burnt lime doubled in quantity and the drying process is compensated with longer time without depending on availability of electrical energy. Chemoreaction drying involves the process of evaporation of water in the material to be dried and heat production by the burnt lime used. The advantages of chemoreaction drying technology can be applied to produce many types of dried high quality products, without losing the expensive essential oil. Chemoreaction drying has been used to drying up seeds (corn, soybean, peanut, red chili) to produce quality seeds with very high growing power. Chemoreaction drying was also used to dry brem, a traditional fermented cake, that become highly hygroscopic sheets with 10 - 15 % water content with very good quality. The drying experiment was also be done on yeast (Saccharomyces cerevisiae) suspension to obtain dried form for storage culture. with cell viability of 10⁵/ml and in form of fine flour yeast culture. The experiments on pepper at drying temperature 29 -30°C produce dry pepper with 4 - 8% moisture. The most important role of the chemoreaction drying process is able to maintain the essential oil with the loss only 1.4 %. The quality of nutmeg by chemoreaction drying was much higher, than the sun dried.

1. Background
Chemoreaction drying technology development in Indonesia is based on the availability of natural resources, namely lime stones containing lime that is spread in some areas. In the area of lime stones, usually stand many lime stone miners that burn the lime, Ca(CO₃)₂, in the furnaces and produce CaO, traditionally called burnt lime, or fire lime, by the community.

The production of burnt lime produces raw materials used for building industries (cement industry) and chemical industry (paint industry). In industrial company, burnt lime is not directly used but
passes introduction process by adding water to change CaO to become Ca(OH)$_2$, which price is higher than the burntlime. This process produces heat that is wasted [1].

In the drying chemoreaction technology, burnt lime is used as the main reactant materials. Burnt lime has 3 distinctive attributes that can be used as chemoreaction reactant compounds for drying process [2]. The benefits are in the process of drying and on the results. The three special nature of burnt lime: (1) quickly react with water molecules, (2) exothermic reaction nature that quickly produce heat energy, (3) the process of reaction can produce very low relative humidity (RH) in the air space around it. The three special natures will be synergized during the chemo reaction drying process in the closed containers containing the burnt lime reactant and materials to be dried.

The drying process chemoreaction become special because the drying is held at low temperature, slightly above room temperature, which is about 35°C. The resulting dry product can reach the water level 2 - 4 %; with the level of water so low the product will be durable and the product quality is very high.

The weakness in the conduction of the chemoreaction drying process namely it requires careful calculation of the need of burnt lime against the amount of water and the commodity that will be dried. The process is slow drying because held on room temperature. Both weaknesses can be resolved by the use of burnt lime doubled in quantity and the drying process can are compensated with the overnight operation, secure without depending on availability of electrical energy [2].

2. The scientific principles of the drying process

Scientifically, the drying process is the process of evaporation of water from materials to be dried in enclosed space with low moisture air to produce dried products. The process of evaporation of water is the escaping the water molecules on the surface of the material facing (exposed) directly into the air space that has low RH [3]. The evaporation process will continue when the RH of space air is lower than water activity (aw) of the materials and will stop when the air RH balanced with that of the dried material [4].

The rate of drying process or evaporation of water closely related to the condition of the air and materials to be dried. The drying condition covers 3 main things namely (1) structure and construction, (2) the temperature and RH, (3) the flow or air balancing. The chemoreaction drying process covers 4 main things: (1) the level of initial water and the temperature of the materials, (2) the form of the material and the condition of the surface of the materials, (3) histology density of the materials and (4) the size of the materials. The condition of the material and the air in the dryer strongly determine the failure or the success of the chemoreaction drying process [5].

Materials with very high water level above the 80 %, like fruit, leaves, flowers, fresh milk, requires depth and accuracy in calculation including (1) designing drying space, (2) quantity of burnt lime needed and (3) the order of the materials in space to perform the drying process.

The form of the material including sheets, bullets or large slabs and the size and the condition of the surface of the materials will be very critical on the flow of the process of evaporation of water. The sheets form of the material to be dried like a leaf (also some types of flowers, thin slices materials) if arranged tend to attach to each other surface and will be very inhibiting to the rate of the drying process. The size of the material is related to the ratio of the surface area and the unit weight of the materials; material order is related to how to arrange the materials in the dryer, the thickness of the layers of the materials and the existence of the initial treatment on the materials. Many conditions influence very strongly on the chemoreaction process and drying rate.

3. The chemoreaction drying principles and applications

The principle of chemoreaction drying is based on exothermic chemical reactions between the burnt lime with water vapor from the materials to be dried in the covered space, and produce heat energy and low RH.

$$\text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2 + \Delta \text{H} (-64,8 \text{ KJ/mol.})$$

......... (1)
The result of the heat energy is used for evaporation of water from the material and low RH works to absorb and evenly distributes water vapor in the closed dryer space.

The exothermic reaction in burnt lime produces heat energy that spread in the dryer. The heat energy absorbed by the material being dried and used for the process of evaporation of endothermic water from the material. The process of evaporation of endothermic water from the material causes the temperature of the material always low and continuing low until the products wholly dried and remains low temperature. Because RH of the dryer space can be kept very low, then the drying process can produce chemoreactions products that are highly dry and can achieve 2 - 4 % level of water [6].

The chemoreaction drying process held at low temperature produces highly dry products with very low water level and is very durable. The drying process at low temperature also produces very high quality dry products. Chemoreaction drying process on food materials can produce high quality food products that nutritional contents are intact with high nutritional value [7].

4. Design of the appliance and the chemoreaction drying process

Chemoreaction drying technology involving 3 types of the design process namely design: (1) the drying appliances especially the drying space, (2) order of reactants in the dryer, (3) the needs of burnt lime. Design principles appliance of the chemoreaction dryer focus especially on the wall and the dryer opening that does not permit simultaneous air flow. Dryer space is kept to prevent air flow (mass transfer) out of the dryer and the entrance of air from the outside [8]. The dryer space is provided with the construction of the dryer that is strong and free of leaks, especially in a corner of the space and the construction of the system and the closure of the door [9]. To prevent heat leakage (the heat transfer) the wall and the door is built from the materials of effective isolator. Construction of the chemoreaction dryer design is presented in Figure 1.

In the dryer appliance, racks for the placement of burnt lime and dried materials are arranged separately, but as close as possible to reduce the distance by maintaining the freedom of the air flow in the entire space of the dryer [10]. The contents and order of the racks in the chemoreaction dryer is presented in figure 1. Dryer space contains the order of reactants burnt lime mounted to the bottom rack or added at the top rack. The order of the materials to be dried is installed in the racks in the middle. Absorbent in 2 top and bottom racks can speed up the chemoreaction drying process.

Main chemoreaction process drying involves the process of evaporation of water in the material to be dried and heat production in burnt lime used. In addition, it also involves the flex or the flow or mass transfer of steam (RH) and the transfer of heat energy in the space of the dryer. The two activities of heat production and the transfer of the hot steam are held simultaneously and repeatedly or cycled.
Figure 1. The structure of the chemoreaction dryer and order of the materials to be dried against the lime absorbent reactants.

The chemoreaction drying process cycle include: (1) burnt lime absorb water vapor from the air and space of the dryer and used for chemoreaction that produce heat, (2) the heat energy is transmitted into the air in the dryer space, (3) the heat energy absorbed from the air of the dryer space by the material being dried and used for the evaporation of water from the materials, (4) water vapor produced from the material is channeled into the air of the dryer space (5) water vapor in the dryer space that comes from the materials are absorbed by the limeburnt for chemoreaction process and produce heat energy that is channeled into the air of the dryer space. So the process is repeated simultaneously (figure 2) until every materials is dry with the desired moisture content [11].
Figure 2. The cycle and the continuity of hot water mass and hot air in chemoreaction drying space.

5. The needs of burnt lime

The needs of burnt lime are calculated based on the formula of the reaction of the CaO and H₂O (1) which is held in stoichiometry. From the chemoreaction formula (1) occurs molarity equality between reagents CaO and H₂O. To calculate molarity of each reagent, need to involve the molecular weight data. Molecular weight of the CaO rounded 56 grams permol and the weight of the water molecules of 18 grams permol. Molarity equality between CaO and H₂O is specified with the formula (2):

$$\frac{\text{the weight of the CaO}}{56} = \frac{\text{the weight of water evaporated}}{18}$$

(2)

So the ratio of CaO molarity weight and the water evaporated is to 3 : 1. The amount of burnt lime and the CaO content determine the effectiveness and the chemoreaction drying process rate [12]. In the drying process, not all the water in the material is evaporated, only up to a certain level of moisture content for each dry product. Related to the CaO content in the lime burnt and the target of moisture content in the end products, then the calculation of equal weight of burnt lime and the materials to be dried is modified into the formula (3):

$$\frac{\% \text{ of the CaO burnt time}}{56} = \frac{\% (M_o - M_k) \times \text{materials to be dried}}{18}$$

(3)

The value of the calculation ratio is not enough; to speed up the process of drying it is necessary to consider the resistance factors of drying rate namely: the level of moisture content in the materials, product type that easily grows microbes, size and shape of the pieces of the materials and the order of the materials [13]. From the formula (3) it can be seen that the amount of water that is dried from the material is equal with the moisture content in the materials (Mo) reduced by the level of water in dry products (Mk) based on the dry basis. In practice for more speed up of the drying process the use of burnt lime is multiplied several times from the results of calculation.
6. Applications and roles of chemoreaction drying

The advantages of chemoreaction drying technology can be applied to produce many types of dried high quality products, without losing the expensive essential oil.

6.1. Chemoreaction drying of seeds

Chemoreaction drying has been used to drying up seeds (corn, soybean, peanut) to produce quality seeds with very high growing power [14]. The results of chemoreaction drying of three type seeds reached the level of water 5 - 7 %, dry quality standard seed : corn 12 %, soybean 8 % and ground nuts 5 %. The quality of the seeds by the shelf life of the seed (based on seed viabilities 80%) from the drying resulting in the level of water 7.6 % provide seeds with very long shelf life : corn 73 months, soybean 68 months and ground nuts 68 months.

Chemoreaction drying was applied on the seed of red chili with the level of water from 3.1 % to 21.1% with viabilities (%) during storage such as in table 1 [15]. Analysis of the age of store from data viabilities seed red chili highly bioavailable water 7 % stored up to 6 months produced the value of age repository 26 months; means age save the seed of both hard and soft water 3.1 and 5.5 % age repository much longer above 26 months.

6.2. Solid wine brem chemoreaction drying

Brem is known in Bali as a traditional fermented drink called Bali brem, and in East Java as a solid fermentation product called solid brem; both are made from fermented glutinous rice [16]. Solid whine bremis made from fermented white glutinous rice, pressed to produce pulp, then cooked until the pulp reach 70 percent total solid, continued to process to produce thick mixture paste and mold to 2 cm thickness, then ready to be dried. Traditionally, the drying is done in the open space in the room temperature during 17 - 20 hours in the work room of the house [17]. The product is completed in the form of highly hygroscopic sheets with 10 - 15 % water content, cut into chunks of the size of 4 x 2 cm, after that it is packed as solid wine brem.

Table 1. The influence of the level of water in the seed of red chili during storage on viabilities.

| Moisture, % | Storage | Months | Viability | Shelf Life |
|------------|---------|--------|-----------|------------|
| 3.1        | 100     | 100    | 100       | >26 mo     |
| 5.5        | 100     | 100    | 100       | >26 mo     |
| 8.2        | 100     | 97     | 96        | 23 mo      |
| 9.9        | 100     | 98     | 96        | 12 mo      |
| 16.7       | 89      | 59     | 0         | 1 mo       |
| 21.1       | 75      | 40     | 0         | 0.4 mo     |

The traditional way of drying at room temperature in a workroom can only take place in the area where the RH of outside air around 40 %. With that RH air condition, not many areas in East Java is able to result in solid wine brem; moreover in Bogor with RH outside air 70 % the drying always failed to dried, but form soft pastenotfoamythat melts [18]. Experiment of drying the soft brem paste with chemoreaction drying was done at the temperature of 29°C for 12 hours and successfully become that solid wine brem with water content of 12 %.

Experiment with the addition of dextrin on the soft brem paste can improve the quality of the results such as presented in Figure 3 and the data in table 2.
Figure 3. *Brem* product from the market and the results of chemoreaction drying with the addition of dextrin.

| Dextrin addition, % | Rendemen, % | Water content, % | Total solid |
|---------------------|-------------|------------------|-------------|
|                     |             |                  | Soluble     | Insoluble   |
| Ready product       | 44,5        | 15,3             | 67,5        | 17,3        |
| 0                   | 38,5        | 18,3             | 70,0        | 11,7        |
| 5                   | 39,0        | 16,9             | 72,0        | 11,1        |
| 10                  | 42,0        | 16,1             | 73,5        | 10,4        |
| 15                  | 45,0        | 14,6             | 76,0        | 9,4         |
| 20                  | 49,0        | 14,7             | 78,5        | 6,8         |

Compared with that of the ready product from the market, solid wine *brem* products with chemoreaction drying have higher soluble solid, which means easy melting in the mouth. The characteristic quality of solid wine *bremis* easy melting in the mouth at the eating time. The treatment of adding dextrin also raises rendemen and product quality.

6.3. Chemoreaction drying of microbe culture

The chemoreaction drying experiment can also be done on microbe culture materials to obtain the dried form or for storage culture. Experiments were done on the yeast (Saccharomyces cerevisiae) suspension in form of liquid cream, normally requires a very long time drying process [20]. To speed up the drying rate, thin layers of cream yeast (around 1.5 mm) and quantity of burnt lime with greater weight ratio was used. The quality of the results of dry yeast culture based on the living population on
the dry yeast products is presented in table 2. Yeast cells viability factor data was expressed as a comparison against the number of living yeast cells of before it was dried.

**Table 3.** The influence of the ratio of the weight of burnt lime/weight of the culture on the population of yeast cell alive and % viability from before drying.

| Lime/cultureweight ratio | Moisture, % dry product | Living yeast/ml | Viability, % |
|--------------------------|-------------------------|-----------------|--------------|
| 5 : 1                    | 12.06                   | 0.9 x10⁹        | 54           |
| 10 : 1                   | 4.41                    | 1.1 x10⁹        | 60           |
| 15 : 1                   | 4.33                    | 1.1 x10⁹        | 61           |
| 20 : 1                   | 4.30                    | 1.3 x10⁹        | 72           |
| 25 : 1                   | 4.26                    | 1.2 x10⁹        | 70           |

The yeastload in the resulting dry yeast culture is still high enough with yeast cell alive $10^9$/ml and in form of fine flour yeast culture.

6.4. Chemoreaction drying of pepper, nutmeg and other essential oil-rich materials

The chemoreactiondrying experiments were carried out on the fruit materials of pepper crop of high enough of 65% [21]. The drying temperature was held at 29-30°C. The content of water in the dry pepper dried under chemoreaction drying reached as low as 4-8%. The most important role of the chemoreaction drying process is able to maintain the essential oil. From the drying experiment using sunlight, the loss of the essential oil was up 10.52% while by chemoreaction drying only 1.4% [22].

The chemoreaction drying experiment was also done on nutmeg. The results of dry nutmeg by chemoreaction drying and sun drying are presented in figure 4 [23]. The quality of nutmeg by chemoreaction drying was far higher, the skin was more even with brighter colors, while nutmeg from sun drying has wrinkled skin and the color is browner.

![Picture 4. The appearance of dry nutmeg by chemoreaction drying and sun drying.](image)

The chemoreactiondrying technology can also be applied to dry the other materials that are rich in content of oil compounds (volatile oils) as the spices (Clove, chili, onion) [24] and fragrance materials (vanilla, jasmine flowers). With low temperature chemoreaction drying in closed spaces, the essential oils is not evaporated, thus the quality of the whole dried material remains high. The technology can also be applied to the drying up of materials that contain regulated bioactive compounds such as drugs, herbs, cosmetics, etc.
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