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Progressive Review on Use of Desiccant Drying in Agricultural Applications

Jani Dilip Batukray*

Department of Mechanical Engineering, GEC-Dahod, Gujarat Technological University (GTU), Ahmedabad, India

Abstract

The review emphasizes on the use of desiccant based drying system for the storage of agricultural products. The chilling sensitivity of the tropical fruits and vegetables makes this system more promising for their optimal storage. The food preservation is very important in all over the world. Most of the food products are obtained from agricultural so it is essential that preservation of food for long time therefore the moisture removal from agricultural products is also important. The use of freely available renewable solar in natural drying process is traditional process which is used for removing the moisture from agricultural grains. The solar drying is possible only during sunshine hours. So that the time required for drying is longer. In this paper the objective is that, it can also dry the agricultural products in off sunshine hours. In off sunshine hours drying is operated by solid desiccant material which is also the adsorbent. The moisture removal rate of solid desiccant is increase by almost 25% and time required for drying is minimised. Furthermore, the drying efficiency of desiccant based dehumidification and drying system increased approximately as compare to conventional solar drying process.

Keywords

Adsorbent, Desiccant Drying, Desorption, Regeneration, Solar Drying

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1. Introduction

Many of the developing countries in the world produce large quantities of fruits and vegetables for local consumption and export. Many of these fruits and vegetables contain a large quantity of initial moisture content and are therefore highly susceptible to rapid quality degradation, even to the extent of spoilage, if not kept in thermally controlled storage facilities. Therefore, it is imperative that, besides employing reliable storage systems, post harvest methods such as drying can be implemented hand-in-hand to convert these perishable products into more stabilized products that can be kept under a minimal controlled environment for an extended period of time. Many food industries dealing with commercial products employ state-of-the-art drying equipment such as freeze dryers, spray dryers, drum dryers and steam dryers. The prices of such dryers are significantly high and only commercial companies generating substantial revenues can afford them. Therefore, because of the high initial capital costs, most of the small-scale companies dealing directly with farmers are not able to afford the price of employing such high-end drying technologies that are known to produce high quality products. Instead cheaper, easy-to-use and practical drying systems become appealing to such companies or even to the rural farmers themselves. It is also useful to note that in many remote-farming areas in Asia, a large quantity of natural building material and bio-fuel such as wood are abundant but literacy in science and technology is limited. The key element of the adsorption system is the adsorbent. Though either solid or liquid desiccant can be used as the adsorbent, solid desiccant is more popular and adsorbents like silica gel (SiO_2) and zeolite had been commonly used. The adsorbent features a very high moisture

* Corresponding author
E-mail address: dbjani@rediffmail.com

adsorption capacity due to its micro-porous structure of internal interlocking cavities which gives a large internal surface area. Note that most of the solid desiccant is porous material, which has high surface area to attract water vapor. Mostly the drying of food grains usually by application of naturally available solar energy. The moisture content in fresh agricultural products is the basic cause for spoilage. The removal of moisture prevents growth and reproduction of microorganisms and it minimizes moisture deteriorative reactions. If water is removed then the shelf life of agricultural product can be increased. It also reduces the cost of storage and transportation by reducing both weight and volume of final product. The quality of dehydrated food product is influenced by drying conditions such as temperature, relative humidity [1-3].

Now a day's various type of drying technologies is used for drying. Sun drying is traditional method of preservation of grains. The quality of sun dried product is poor with regards to its colour and flavour due to direct exposure to sun. Also, sun drying is not hygienic, does not have a control over drying and is not dependable throughout the year. In general drying is accomplished by thermal techniques and thus involves the application of heat, most commonly by convection currents of air. Throughout the convective drying of solid materials, two processes occur simultaneously namely, transfer of energy from the local environment in the dryer and transfer of moisture from within the solid. Therefore this drying may be considered as simultaneous heat and mass transfer operation. During drying of grains, medium used is atmospheric air which contains the moisture in accordance with the atmospheric humid conditions. Use of the desiccant based dryer can reduce drying time and improve product quality. However, hot air can be used for drying it rarely fails to preserve product quality, because in drying operation the product is exposed to the drying environment for a long period. Although sun drying consumes no energy, the absence of control over drying temperature was actually felt in open sun drying and the passive solar dryer, and then the later research tended to have a preference to the use of forced air circulation solar dryer. Most of the designs of forced convection solar dryers have recently been proposed for drying applications in more countriesA simple effective solar drier based on desiccant drying will use solar radiation as heat requirement for charging the desiccant material. It will be simple in use, effective in performance and eco-friendly using solar energy as heating source [4-7].

Drying equipment is classified in different ways, according to following design and operating features. It can be classified based on mode of operation such as batch or continuous, In case of batch dryer the material is loaded in the drying equipment and drying proceeds for a given period of time, whereas, in case of continuous mode the material is continuously added to the dryer and dried material continuously removed. In some cases vacuum may be used to reduce the drying temperature. Some dryers can handle almost any kind of material, whereas others are severely limited in the style of feed they can accept. Drying processes can also be categorized according to the physical state of the feed such as wet solid, liquid, and slurry. Type of heating system i.e. conduction, convection, radiation is another way of categorizing the drying process. Heat may be supplied by direct contact with hot air at atmospheric pressure, and the water vaporized is removed by the air flowing. Heat may also be supplied indirectly through the wall of the dryer from a hot gas flowing outside the wall or by radiation. Dryers exposing the solids to a hot surface with which the solid is in contact are called adiabatic or direct dryers, while when heat is transferred from an external medium it is known as non-adiabatic or indirect dryers. Dryers heated by dielectric, radiant or microwave energy are also non adiabatic. Some units combine adiabatic and non adiabatic drying; they are known as direct-indirect dryers. To reduce heat losses most of the commercial dryers are insulated and hot air is recirculate to save energy. Now many designs have energy-saving devices, which recover heat from the exhaust air or automatically control the air humidity. Computer control of dryers in sophisticated driers also results in important savings in energy. In all the above dryers, drying agent/medium is atmospheric air which contains the moisture in accordance with the atmospheric humid conditions.

Seed with lower moisture content and higher germination rate fetch higher market price. To achieve low moisture content, normally seed are dried at 55–60°C air temperature; but at these temperatures seed germination level falls (Tang and Sokhansanj [8]; Correa et al. [9]; Kumar et al. [10]). A number of studies (Gowda et al. [11]; Sarada et al. [12]; de Valentini et al. [13]; K'Opondo et al. [14]) have reported that the drying air temperature should not be above 40°C for good seed germination. However, drying air at temperature below 40°C is not able to dry seed to low moisture content due to higher relative humidity of drying air. Othmer [15] found that low moisture content of seed can be achieved at low drying air temperature by dehumidifying air. Therefore, drying of seed to low moisture content without loosing its germination requires seed drying at low temperature with dehumidified air. Different studies have been reported for seed drying at low temperature with dehumidified air using either vapour compression dehumidifier (Adapa et al. [16]) or desiccant dehumidifier (Danzieger et al. [17]; Graham et al. [18]; Sturton et al. [19]; Kundu et al. [20]; Zhangyong et al. [21]; Dhaliwal et al. [22], [23]; Ondier et al. [24]). A cabinet dryer was developed for low temperature (25–45°C) drying of alfalfa using vapour compression dehumidifier (Adapa et al. [16]). It employed recirculation of air to conserve energy and a moving tray arrangement to achieve uniform and faster drying. Chopped alfalfa was dried from 70% moisture content to 10% moisture content in 5 h and 4 h in the fixed tray drying and in the moving tray drying, respectively. The main drawback of this dryer was that there was loss of dehumidified air to the environment due to opening and closing of manual butterfly valves used to maintain the drying air temperature [47].

In the present paper, previous literatures have been reviewed on different types of dryers based on progressive development in desiccant materials for agricultural foodstuffs, and it progressive development in various applications in farming areas where raw materials and labor are readily available [25-27].

Grains should be dried to certain moisture content (MC) depending on storage period to avoid potential problems. A good maximum storage temperature is about 17°C. The following table 1 shows some of these problems and their remedy by safe storage. Figure 1 shows factors affecting the postharvest quality of the agricultural products [28].

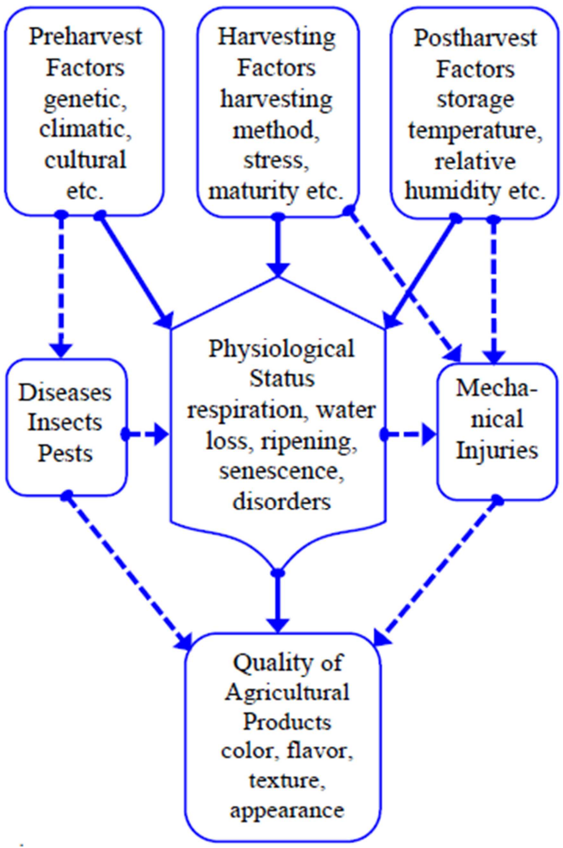

Figure 1. Factors affecting the postharvest quality of the agricultural products.

Table 1. Permissible moisture content for safe grain storage.

Storage period	Permissible moisture content for safe storage	Potential problems
1 Week – 3 months	14% or less	1. Molds 2. Discoloration 3. Insect damage 4. Respiration loss 5. Moisture adsorption
8 – 12 months	13% or less	Insect damage
Storage of seeds by farmer	12% or less	Loss of germination
> 1 year	% or less	Loss of germination

2. Working of Desiccant Drying

A desiccant Material is a material that naturally attracts moisture from both gases and liquids. There are various types of desiccant available, but all dehumidifier's uses as Silica Gel as the desiccant within the drying wheels. Silica gel is not a "gel" as the name implies, but in fact a porous granular form of silica which is made from sodium silicate. The internal structure of each silica granule is made up of a network of interconnecting microscopic pores, which by a process called physical adsorption or capillary condensation, attract and holds moisture within each granule. This trapped moisture can then, with the addition of heat, be released from the desiccant. This desiccant can then be used again and again. A desiccant wheel is basically a circular plastic or styrene disk with an extended surface that is impregnated with silica gel. Commercially available desiccants include silica gel, activated alumina, natural and synthetic zeolites, titanium silicate, lithium chloride, and synthetic polymers. Desiccant drying started off mainly in the air-conditioning industries to improve air quality for thermal comfort. However, in recent years, desiccant drying has become a popular method for the drying of herbs and flowers. Flowers dried via desiccant drying possess excellent product quality in terms of color, texture and lasting. Typical desiccants suitable for herbs and flower drying include silica gel, borax, cornmeal or alum [29].

i. The advantages of a desiccant drying system include:

ii. The moisture-laden desiccant can be re-generated by passing it through a stream of hot air which absorbs the moisture;

iii. The system is easy to design and ensures years of maintenance-free operation;

iv. Incorporating the desiccant with other drying systems such as solar and fluidized bed results in a significant reduction in energy consumption per kg of moisture removed;

v. Easy access of replacement of the desiccant media after cycles of operations.

Desiccant systems can produce low temperature drying at a controlled rate which is very important for certain agricultural products. Desiccants can remove moisture from the air which, in turn, can be used for drying purposes. The weak desiccant can be regenerated by air under certain conditions so that the desiccant can be used continuously to remove moisture from air as shown in figure 2. The desiccants absorb (or release) moisture because of the difference in vapour pressure between the surface of the desiccant and the surrounding air. Solid desiccants are impregnated in a dehumidifier bed, usually a rotary disc which slowly rotates between the process and regeneration air streams. As the hot and humid process air passes through the desiccant wheel, the moisture is removed by the desiccant, and its temperature increases. The temperature goes up so warm and dry air leaves desiccant wheel in sorption process. As wheel rotates between two sections continuously, moisture absorbed by desiccant material should be removed in desorption process so it needs to be regenerated by a desiccant heater providing hot regeneration air. Then hot air goes through wheel regeneration section and the desiccant is reactivated. Desiccant wheels remove moisture based on the difference between desiccant surface vapor pressure and air vapor pressure. Main factors affecting desiccant wheel performance which are studied in this research consist of process and regeneration inlet air temperatures, humidity ratios, and mass flow rates as well as desiccant wheel speed [30-32].

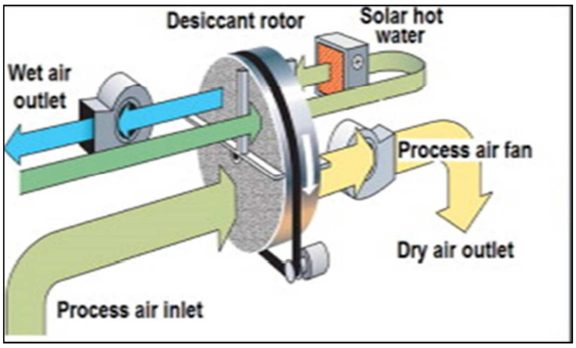

Figure 2. Working of dehumidifier drier.

The desiccant drying and dehydration are the removal of moisture from a given material. The Objective of desiccant drying is to remove water until the water activity is low enough to prevent growth of microorganisms. Drying of agricultural products is an important unit operation under post-Harvest phase. It is the process of removal of excess moisture from food products to a predetermined level. In order to reduce the amount of grain that is lost due to stress cracking, Medium temperature and slow cooling, or natural air and low temperature drying methods should be employed. The performance and development of desiccant drying systems strongly depends on the used desiccant materials. The thermo-physical properties of these materials affect the performance of the system significantly. The key parameter for the selection of a desiccant material is that it should have the ability to absorb and hold large amount of water vapor. It should be desorbed easily by providing heat input. The properties such as density, vapor pressure, etc. of different desiccant materials can be enhanced by mixing two or more materials together. The mixed desiccants are termed as composite desiccants. Many researchers have studied the properties of composite desiccant materials in order to study their effects on drying performance of the system. The excessive heat can damage cereal grain and reduce their ability to germinate; hence, maximum safe air temperatures must not be exceeded [33-35].

The limitation faced by desiccant system is availability of regenerating heat to regenerate desiccant material. But the use of solar energy as shown in figure 3 and waste heat for regeneration of desiccant material will make the system more economical. The use of desiccant drier system can solve lot of environmental problems well, as it can also minimize the high demand of electrical energy for conventional solar drying system and its poor quality for drying as well as availability during longer period [36].

Following factors as listed below are responsible for the maximum temperatures for drying cereal grain:

1. Length of storage.

2. Low temperatures should be used if the grain is to be stored for 6 months or more.

3. Moisture content.

4. The damper the grain, the longer the drying process. Low temperatures should be used.

5. Type of grain dryer.

6. Lower temperatures should be used in dryers which do not mix or circulate the grain.

7. End use of the grain - malt or seed - low temperature.

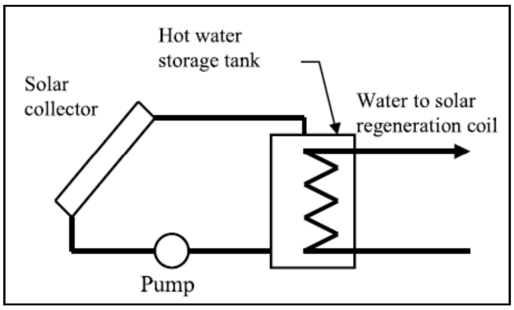

Figure 3. Use of renewable solar energy in desiccant drying.

The apparatus used for desiccant drying was based on solar dryer as shown in Figure 4. The desiccant bed was a shallow tray with a perforated bottom of solid bentonite $CaCl_2$ desiccant packed into small bags. The desiccant was formed from a mixture of bentonite, $CaCl_2$. Above the bed a double Tedler glazing panel was placed. The panel and the desiccant bed were slightly inclined to the horizontal for optimal solar energy collection and protection from the ingress of rain. The apparatus contained a grain bed but for these tests it was empty, as the aim was to assess its ability to deliver dehumidified air to an external application. During the daytime, ambient air was drawn through the entry port by a small fan, passed through the desiccant bed and then exhausted via valve A. Valve B remained closed. At night, valve A was closed and B was opened; the air that passed through the desiccant bed was exhausted by valve B to the atmosphere; in practical use, it would be delivered to the grain store. The fan used in the prototype was powered from a 12V battery, charged by a small photovoltaic panel mounted alongside; its power demand was in the range 5-10 W [37].

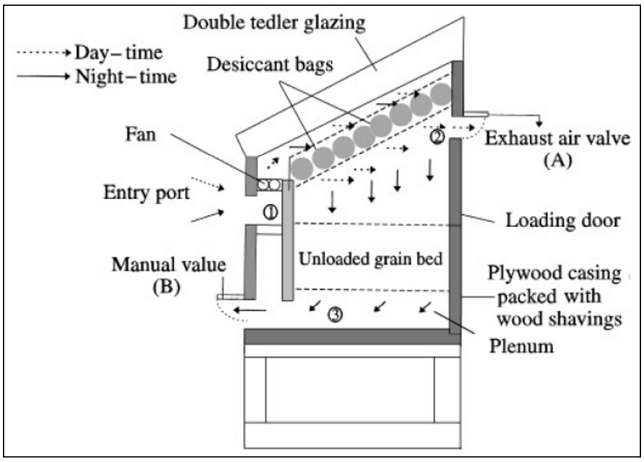

Figure 4. Solar powered desiccant integrated crop drier.

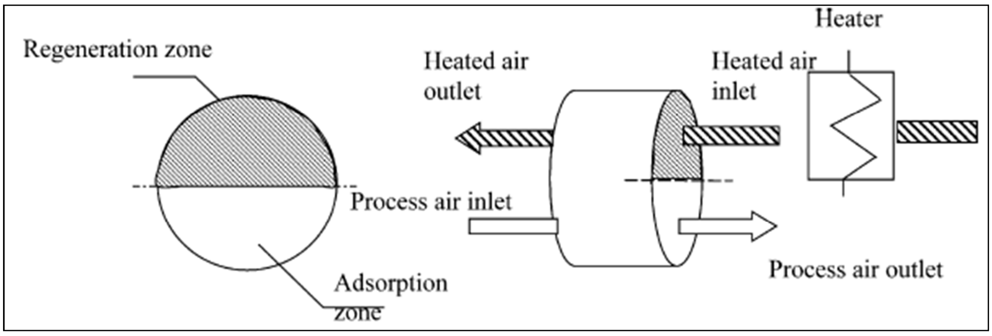

Figure 5. A desiccant wheel system for drying application.

Several researchers have recently found improved quality of dried agricultural products by integrating the desiccant system into the traditional solar drying system. One of the most promising desiccant drying systems of recent years is the desiccant wheel as shown in Figure 5. In the adsorption region, the desiccant adsorbs water vapor and the dehumidified air is then delivered through the process outlet directly into the drying chamber. Then, as the desiccant media rotates it switches the adsorption and regeneration zone, and the hot air entering into the regeneration zone inlet drives off the moisture and exhausts it into the atmosphere. After regeneration the hot, dry desiccant rotates back into the process air stream where a small portion of the process air cools the desiccant so that it can begin the adsorption process all over again. To increase dehumidification capacity, farmers can either increase the diameter of the rotating bed to hold more desiccants, or increase the number of beds stacked on top of one another. Such a rotating horizontal bed design offers low first cost and reduced operating overheads. Also, the design is simple, compact and easy to produce as well as install and maintain, which makes it suitable for application in rural farm areas [38-41].

3. Adsorbents Used in Desiccant Drying

Many attempts have been made earlier to develop adsorbents for the desiccant drying. Porous materials have been chosen as ideal adsorbent materials due to their superior textural properties, including pore size, pore volume, and surface area, as well as tunable functionality. Characteristics of the adsorbate play an important role in adsorption. Some important desiccant materials used in desiccant drying are described as follows [42-46]:

i. Silica materials

One conventional adsorbent for dehumidification is silica gel. Silica gel physically adsorbs moisture from air into its internal pores. The adsorption and desorption characteristics of different silica gels may vary based on their manufacturing procedures. The variable adsorption performance suggested that the textural properties of silica gel played a significant role in dehumidification. Silica gel has very high moisture adsorption capacity because of its micro-porous structure of internal interlocking cavities, which provide a high internal surface area. Silica gel interacts with H_2O through the significant amount of surface via hydrogen bonding interactions. The significant number of active sites makes silica gel a promising material for air dehumidification at high humidity. However, due to the mild hydrogen bonding between OH groups and H_2O, silica gel is not suitable for deep dehumidification. It should also be pointed out that the adsorption capacity of silica gel decreases with an increase in adsorption temperature due to its weak physisorptive nature. Silica gel is not susceptible to structural damage in a mild regeneration condition, but a loss of surface silanol groups for moisture adsorption occurs at a high regeneration temperature.

ii. Activated carbon

Activated carbon is one of the most important adsorbents dominating the commercial use of adsorption. Taking advantage of porous materials with very high surface areas and large pore volumes, activated carbon and carbon-based materials have been studied for adsorption dehumidification. The textural properties of activated carbon vary with the carbon sources and activation methods. The hydrophobic nature of the perfect graphene structure in some activated carbon shows a low adsorption capacity of H_2O at low relative pressures of water vapor. However, it is worth noting that the surface chemical properties of activated carbon, including surface functional group types and density, can be modified by different activation processes at variable conditions. With the modification of activated carbon with silica for a more hydrophilic surface, a significantly improved adsorption capacity was reported.

iii. Zeolites

Zeolites play an enabling role in deep dehumidification. Zeolites that are in commercial use for air dehumidification today are types A, X, and Y. Zeolites possess special adsorption properties due to their unique surface chemistry and crystalline pore structures Zeolites can achieve low dew points or deep dehumidification of air due to the strong zeolite–H_2O interaction. However, the regeneration of zeolites at low temperatures is difficult because the bond of water molecules with Al cation sites in the zeolite is quite strong. In previous study it is observed, a heat of adsorption of zeolite adsorbents up to 50% greater than the latent heat of vaporization was reported, which indirectly suggested that a high desorption energy is required for regeneration. Therefore, one of the drawbacks of using zeolites as the dehumidification adsorbent is the energy-intensive regeneration due to the required high desorption temperature.

iv. Supported Haloid-Based Adsorbents

The application of haloid-based salts, LiCl and $CaCl_2$, for dehumidification is limited by their short lifetime due to their lyolysis properties, which cause the loss of desiccant materials. In addition, haloid-based salts become mobile after absorbing moisture, which may readily corrode the metal part of the dehumidification wheel. This drawback of using haloid-based salts can be overcome by supporting or fixing the haloid-based salts over a porous substrate. Moreover, by using a porous substrate with a high surface area, the adsorption capacity of supported haloid-based salts can be improved due to the larger amount of exposed active sites of haloid-based salts to absorb moisture.

v. Metal Organic Frameworks

As a new family of adsorbent materials, porous metal organic frame works (MOFs) have attracted enormous attention. Possessing large surface area, tunable pore size and shape, and adjustable composition and functionality, MOFs have shown unique advantages and promise for adsorption and separation technologies. Recently developed, a new class of adsorbents, hierarchical porous MOFs with mesoporous cages, and demonstrated superior adsorption performance for energy-efficient dehumidification. The feasibility of practical application of MOF materials for adsorptive dehumidification will be further evaluated on a large scale. The parameters such as adsorbent packing density, material cost, etc., should be taken into account for industrial applications. Further development and obtaining a fundamental understanding of these materials will definitely be a major area of focus in the near future.

vi. Others

Other types of adsorbents studied for air dehumidification at a low RH include renewable biomass-based adsorbents; for example, dry coconut coir, starch, corn grits, etc. Cellulose and starch-containing materials have shown promising features for the removal of water, including easy availability, much less expensive than molecular sieves, mechanical stability, biodegradability, and easy disposal. However, the application was limited by its low surface area.

vii. Calcium Chloride

Calcium chloride is a typical ionic halide which serves calcium ion in aqueous solution and at room temperature it is a solid. It is generally produced by direct reaction of limestone with hydrochloric acid but in large quantities it is produced as a byproduct of solvey process. It has a boiling point temperature of 1395°C with 2.15 g/cc density.

viii. Lithium Chloride

Lithium chloride is an ionic salt that is widely used in air-conditioning systems. It has better hygroscopic properties and amazing solubility of about 83g/100 ml at 20°C in polar solvents. It has a boiling point temperature of 1382°C with

2.068 g/cc density. The crystallization line of LiCl-H_2O solution is an increasing mass fraction of Li-Cl and reducing water content

ix. Composite desiccant

Composite materials are generally formed by the impregnation of hygroscopic salts into the pores of the host, i.e., a porous desiccant material in this case. The hygroscopic salts (nitrates, sulphates and haloids etc.) possess high water adsorption characteristics but they are unstable at higher humidity ratios due to lyolysis, so porous desiccant materials with stable characteristics like silica gels, activated carbon, mesoporous silicates and natural rocks are used as host material. Previously investigated some composite desiccants for cooling applications and reported that the composite desiccants achieved high COP as well as water adsorption characteristics.

Author's name *et al.*: Article Title

4. Conclusions

A dual role of the desiccant system can be considered when storage is required for both dried and freshly harvested products. Products like cereal grains and plant seeds often require special attention after drying as they need to be stored in vast quantities and for long periods. The two factors that most influence the seed viability are temperature and moisture content. The moisture content of the seed is a function of the surrounding ambient relative humidity (RH). Therefore, to minimize fungal activity which can cause a decrease in seed viability, discoloration and possible production of harmful substances such as mycotoxins, proper storage conditions requires a RH of below 70%. The desiccant wheel system can then be utilized in storage facilities to produce the required RH to ensure optimal germinability of seeds, and longer shelf life of grains. This additional application of the desiccant systems makes it even more attractive to rural farming areas whereby drying and storage functions are often known to be inadmissible. Given a proper sized, low-cost dryer, food processing can proceed uninterrupted in rural areas. Mainly in the villages the farmers want to process their surplus crops by using the economical dryers to process it for the future market sell. Such low-cost food drying technologies can be readily introduced in rural areas to reduce spoilage, improve product quality and overall processing hygiene. The eventual objective of employing these appropriate drying technologies is to significantly improve the agricultural returns for farmers in appreciation of thehard effort they have devoted in crop cultivation.

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