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Steady-state Investigation of Desiccant Drying System for Agricultural Applications

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Present study provides the applicability of desiccant drying system (DDS) for the drying of cereals grain at low temperature and lower humidity. The performance of two drying approaches with two desiccant materials i.e. silica gel and lithium chloride (LiCl) have been analyzed by a desiccant dehumidification model available in literature. Two desiccant drying cases discussed are: Case-I, latent load control effect, Case-II both latent and sensible load control effect. Case-I approach seems more effective towards the drying of delicate and temperature sensitive agricultural product like seeds. However, results showed that Case-II gives more economical and energy saving drying solution for the commercial purpose drying. Regarding the appropriate desiccant material used, LiCl is appropriate choice for Case-I and silica gel is appropriate choice for Case-II.

Keywords: Desiccant, drying, agriculture, temperature.

Nomenclature

Cp	Specific heat capacity [kJ kg K^{-1}]
DDS	Desiccant drying system
DM	Dry matter [kg]
EMC	Equilibrium moisture content [%]
F_a	Mass flow rate [kg s^{-1}]
h	Enthalpy [kJ kg^{-1}]
MC	Moisture content [%]
Q	Energy [kJ s^{-1}]
T	Dry bulb temperature [ºC]
Y	Humidity ratio [kg/kgDA]
Φ	Performance index[kg kW^{-1}]

1. Introduction

Drying is a conventional preservation/storage technique which is under practiced from ancient time. Market of dry fruits and vegetables has achieved an earnest abode in the world market[1)]. For example Japan spent 6 billion USD on dry vegetables and seaweed in 1998, which does not include the consumption in restaurants[2)]. Agricultural products are harvested at higher moisture content then that of safe storage level of moisture in order to avoid the shattering or other losses. Consequently drying is considered an important post-harvest technique for the safe storage of agricultural product. In addition, selling of agricultural products and storage for whole year consumption also require to reduce the moisture level and low temperature storage[3)]. There are many drying techniques applied for the removal of moisture from the agricultural products. The basic principle is to create vapor pressure deficit between the product and environment to accelerate the moisture removal. Conventional drying methods include, drying by airflow, vacuum drying, and freeze-drying but these methods result in low drying rate[4,5,6)].

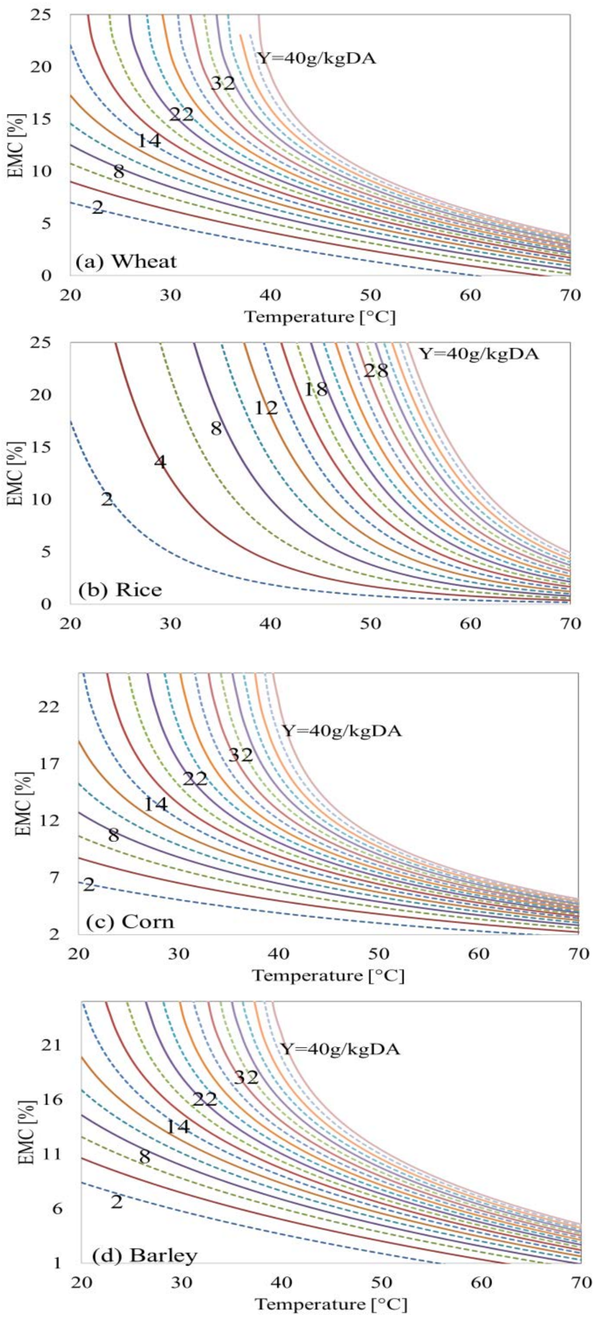

Fig. 1: Effect of temperature and humidity ratio on EMC for: (a) wheat, (b) rice, (c) barley and (d) corn.

Many researcher work on hot air flow drying of rice[7], soybeans[8], green beans[9] and canola[10] showed that it is energy intensive process. In addition, hot airflow drying take long time and has low energy efficiency as it causes shrinkage of dried product which result in reduced moisture and heat transfer. Severe shrinkage also reduces bulk density and rehydration capacity. Another method is microwave drying which also has some drawbacks including uneven heating and textural damage of product[11]. Drying of agricultural product by adsorption technology by using desiccant drying system (DDS) is identified as a means of low temperature drying as well as improve energy efficiency suitable for heat sensitive products like food[12,13]. Desiccant drying is one of the quality and energy conservation drying technique. It has been used from ancient time in alternate layer of desiccant material and drying products[14]. In addition to maintain the quality of product, the cost of production is another concern that motivates the researcher to adopt desiccant drying system. The quality of drying product is equally important as far as the drying process for the storage of agricultural products for certain period of time. As far quality is concerned, drying air conditions are very important. Temperature and humidity of the drying air influence the quality of product in term of nutrient conservation, color and surface texture[15].

High temperature drying causes loss of nutrients and vitamin C, found in agricultural products[16]. In addition to higher drying air temperature, higher humidity also affects the color of drying product[17].

Figs. 1(a)-(d) showed the equilibrium moisture contents (EMC) with relation to temperature and humidity ratio for wheat, barley, rice and corn, respectively. In drying process EMC is the indication of the effect of the water activity which can determine the biological changes in the storage. The significance of humidity control can be seen Fig. 1, thereby dehumidified air requires low drying temperature in order to achieve 14% EMC. However, in case of higher humidity ratio, higher drying air temperature is required to achieve optimum level of EMC e.g. 14% for wheat. The DDS has ability to dry the agricultural products at low temperature and low humidity ratio. Total drying time reduced by increasing the drying air temperature, flow rate and using less humid air. However, increase in temperature and flow rate is not always favorable because of quality loss and high energy consumption. Many studies have been reported on desiccant materials for moisture adsorption equilibrium[18] and adsorption rate[19]. On the other hand steady-state investigation of desiccant drying systems for agricultural applications has not been extensively studied in the literature.

From the above prospective, drying charts are developed in this study for four types of grains (i.e. wheat, barley, corn and rice). It will help to select the drying air conditions according to the different drying applications/stages. Two cases of desiccant drying are considered and optimized accordingly for the purpose of seed and commercial drying at the expense of minimum energy. DDS can also play a role to reduce the drying time by providing fast adsorption rate. Present study discusses energy consumption for two different desiccant drying approaches. It is worth mentioning that the drying rate is not considered for the simplicity of analysis.

2. Development of drying charts

Equilibrium moisture contents (EMC) is the function of temperature and relative humidity of drying air. The knowledge of EMC is important for the development of control strategies for the safe storage of agricultural products. Different types of grains require different amount of moisture level for storage. For the storage of one year, the dry-bulb MC of wheat, barley, corn and rice should be reduced up to the level of 13%, 13%, 14% and 15%, respectively[20, 21, 22]. Figs. 2(a)-(d), present various possible combination of temperature and humidity of drying air by which safe storage moisture level can be achieved. However, maximum allowable drying temperature and humidity are the factors which further limit these possible drying air combinations. As the maximum recommended drying air temperature for the purpose of seed are 60ºC, 45ºC, 45ºC and 42ºC for wheat, corn, barley and rice, respectively. Whereas for commercial usage maximum recommended drying air temperature are 65ºC , 55ºC, 60ºC[21] and 50ºC[22] for wheat, corn barley and rice, respectively.

Quality of supply air can be ensured by maintaining the temperature, humidity and flow rate which helps to remove the respiratory heat, CO_2 and O_2 level in the storage. DDS is capable of maintaining these parameters to ensure the quality of drying. In Figs. 2(a)-(d), it has been shown that many possible combinations can be formed by following the required EMC line. However possible combination includes high temperature with high humidity and low temperature with low humidity. It has been shown that if the latent load of the supply air is controlled, same EMC is achieved at lower temperature. Low temperature as well as low humidity is considering favorable drying conditions for conservation of nutrients[23]. In this way, DDS helps to achieve these conditions by lowering the humidity of drying air[24].

3. Proposed desiccant drying system

Fig. 3 represents the schematic diagrams of the proposed solid desiccant based drying system. It mainly consists of: (i) a desiccant wheel used to dehumidify the air; (ii) heater for process air heating (bio-mass/gas or electric); (iii) drying bin/structure; (iv) heater for regeneration of desiccant wheel (electric driven or preferably bio-mass/gas driven). When air passes through these components it undergoes alteration of psychrometric air conditions. Dehumidification of the air, heating of the dehumidified air, evaporation of product moisture and heating of regeneration air are represented by point 1 to 7 in Fig. 3.

Point 1 represents the ambient air condition at the inlet of desiccant wheel. Point 2 represents the dehumidified air condition at the outlet of desiccant wheel. Point 3 represents the heating of drying air at required temperature. Processed air is supplied to the inlet of the drying structure, while passing through the drying structure, its humidity increases as moisture is absorbed by the air due to vapor pressure deficit[25] and leaves the DDS at point 4.

Ambient air is heated from point 5 to 6 at required regeneration temperature and pass through the desiccant wheel. Solar or thermal waste water heat could be used

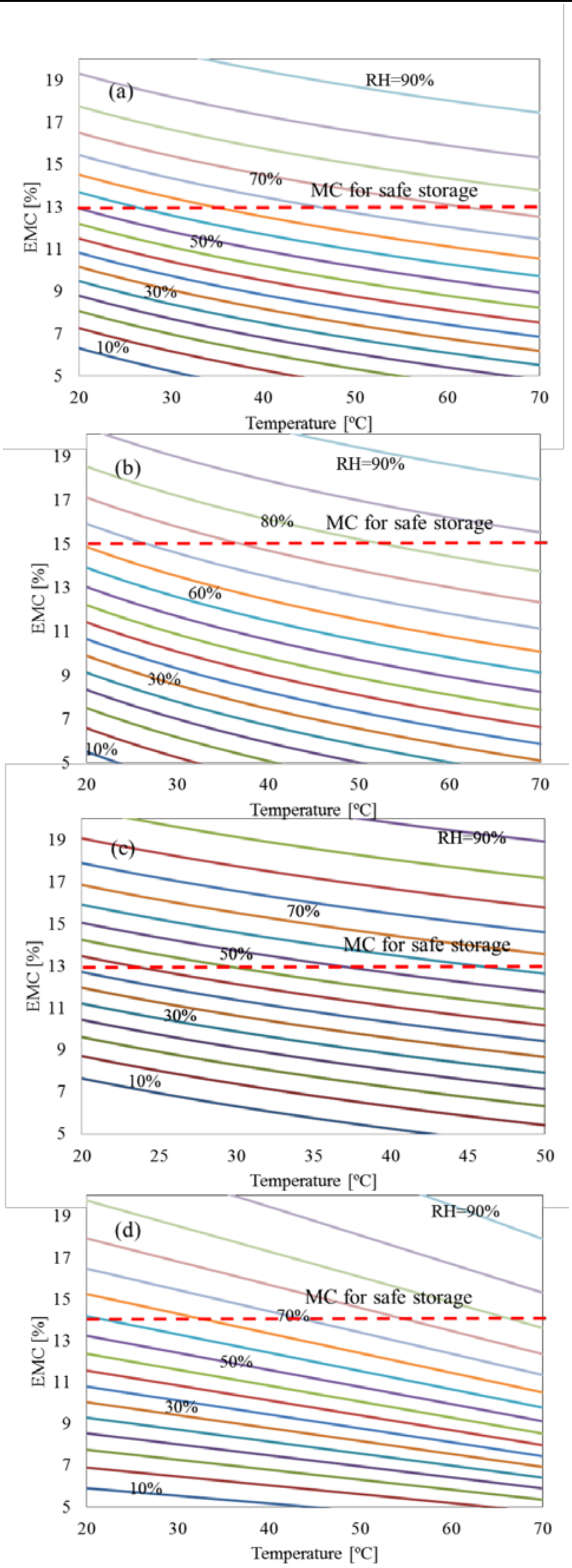

Fig. 2: Drawing chart for: (a) wheat, (b) rice, (c) barley and (d) corn.

for the regeneration of desiccant wheel[26]. Air simultaneously passes through the adsorption and regeneration sides of desiccant wheel during drying process.

4. Materials and methodology

4.1 Materials

In present study two desiccant materials used are silica gel and LiCl. Desiccant material silica gel is reported as most commonly used desiccant material used in desiccant air conditioning due to its strong affinity towards moisture[27] and can absorb 40% of its own weight[28].

Desiccant material LiCl is a hygroscopic salt and also one of the important desiccant materials used for the dehumidification. LiCl has strong affinity towards moisture and can absorb water vapor as a solid desiccant. It continues to attract moisture even turn in to liquid solution[28].

4.2 Research methodology

In present study two desiccant drying cases discussed are:

Case-I: Latent load control effect (Regeneration air temperature T_6 changes 50ºC, 55ºC, 60ºC, 65ºC, 70ºC, 75ºC and 80ºC to get different levels of humidity ratio)

Case-II: Latent and sensible load control effect

(Drying air temperature T_3 is changes 50ºC, 52ºC, 54ºC, 56ºC, 58ºC and 60ºC for humidity ratio Y_2 0.010 and 0.008 kg/kgDA).

For Case-I various levels of humidity ratio of process air are obtained at regeneration air temperature 50ºC, 55ºC, 60ºC, 65ºC, 70ºC, 75ºC and 80ºC. Fig. 4(a) is the psychrometric representation of Case-I where point 1 is the ambient air conditions T_1 25ºC and Y_1 0.014 kg/kgDA. Point 2 represents various levels of dehumidification achieved at different regeneration temperature. For desiccant material silica gel, temperature of process air is 40ºC, 43ºC, 45ºC, 47ºC, 49ºC, 51ºC and 52ºC and humidity ratio is 0.0097, 0.0089, 0.0083, 0.0077, 0.0072, 0.0068 and 0.0064 kg/kgDA at regeneration temperature 50ºC, 55ºC, 60ºC, 65ºC, 70ºC, 75ºC and 80ºC, respectively.

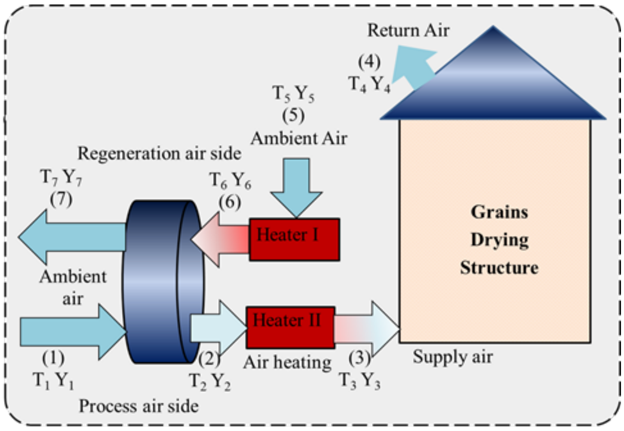

Fig. 3: Schematic diagram of desiccant drying system.

However for desiccant material LiCl temperature of process air is 41ºC, 44ºC, 46ºC, 48ºC, 50ºC, 52ºC and 54ºC and humidity ratio is 0.0104, 0.0093, 0.0087, 0.0082, 0.0077, 0.0073 and 0.007 kg/kgDA at regeneration temperature 50ºC, 55ºC, 60ºC, 65ºC, 70ºC, 75ºC and 80ºC, respectively. Point 2 and 3 are same for Case-I as process air without heating supplied to the outlet of drying structure. Point 4 represents the exhaust air from the drying structure and it is assumed that temperature of the air at point 4 is equal to the wet bulb. Point 5 is the start of regeneration stream, T_5 25ºC Y_5 0.014 kg/kgDA. Point 6 represents the heating of ambient air at 50ºC, 55ºC, 60ºC, 65ºC, 70ºC, 75ºC and 80ºC for regeneration of desiccant wheel. Point 7 represents the air conditions at the outlet of regeneration side of desiccant.

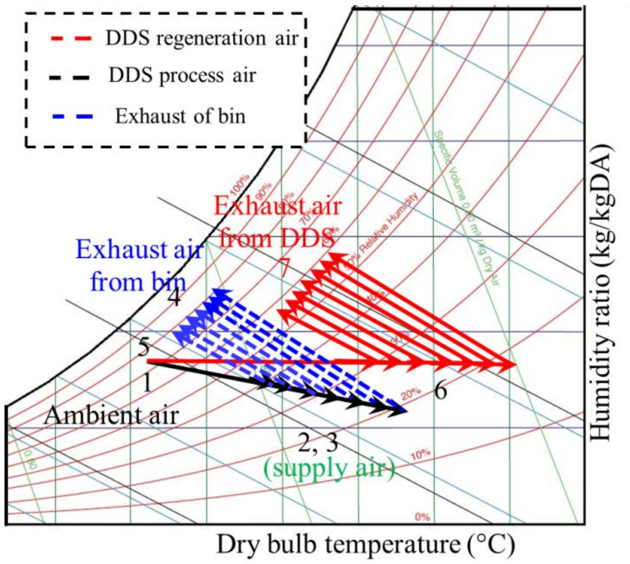

Fig. 4(a): Psychrometric representation of case-I (i.e. latent load control).

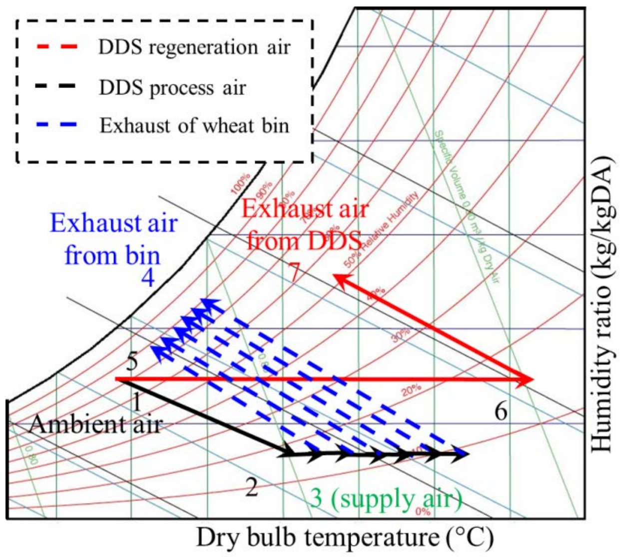

Fig. 4(b): Psychrometric representation of Case-II (i.e. latent and sensible load control).

For Case-II, process air at humidity ratio Y_2 (0.010 and 0.008) kg/kgDA are heated at various levels of drying air temperature T_3 50ºC, 52ºC, 54ºC, 56ºC, 58ºC and 60ºC. Fig. 4(b) is the psychrometric representation of the Case-II where point 1 is the ambient air conditions T_1 25ºC and Y_1 0.014 kg/kgDA. Point 2 is the process air conditions after passing through the desiccant and temperature of the air is 39ºC for desiccant material silica gel and 42ºC for desiccant material LiCl at humidity ratio 0.010 kg/kgDA. However at humidity ratio 0.008 kg/kgDA temperature of process air is 46ºC for desiccant material silica gel and 50 ºC for desiccant material LiCl. Point 3 represents sensible heating of the process air at temperature 50ºC, 52ºC, 54ºC, 56ºC, 58ºC and 60ºC and permits it to flow through the drying structure. Point 4 is the air conditions at the outlet of drying structure and temperature is assumed to be equal to wet bulb. Point 5 to 6 represents the heating of ambient air for the purpose of regeneration of desiccant and regeneration temperature is 48ºC for desiccant material silica gel and 51ºC for desiccant material LiCl at humidity ratio 0.010 kg/kgDA. However at humidity ratio 0.008 kg/kgDA temperature of regeneration air is 63ºC for desiccant material silica gel and 68ºC for desiccant material LiCl. Point 7 is the air conditions at the outlet of regeneration side of desiccant. Air conditions for point 1 to 7 are determined as follow:

- Point 1 ambient air condition T_1 25ºC and Y_1 0.014 kg/kgDA.
- At point 2 ambient air is dehumidified Y_1 to Y_2 and temperature increases from T_1 to T_2 due to heat of adsorption released by desiccant material. For determining the air conditions at point 2 Beccali et al model is used. In Case-I different levels of humidity ratio are determined for all regeneration temperatures. Whereas in Case-II sensible load effect is determined for all drying air temperature at drying air humidity ratio 0.010 and 0.008 kg/kg DA.
- Point 3 represents the sensible heating of the air by using biomass/electric air heater. In Case-I process air is not heated. However for Case-II process air is heated at different temperature levels 50ºC, 52ºC, 54ºC, 56ºC, 58ºC and 60ºC. Point 3 air conditions are also used to estimate the EMC which determined the quantity of moisture removed from the grains through its one pass.
- Point 4 represents the air conditions at the outlet of the drying structure. Air carries moisture from the grains and its temperature decreases and humidity increases.
- Point 5 is ambient air conditions and start of regeneration stream where $T_5 = T_1$, $Y_5 = Y_1$
- Point 6 represents the heating of air for the purpose of regeneration of desiccant.T_6 is determined by solving Eq. (1) or (2) (depending on the type of desiccant material used) with Eq. (4) simultaneously.

Point 7 represents the outlet air condition of the regeneration side of the desiccant wheel.

The equations 1-4 describe the Beccali et al model[28]. For the calculation of enthalpy corresponding to the type of desiccant wheel Eq. (1) and (2) are used for desiccant material silica gel and LiCl respectively.

$$h_2 = (0.1312h_6 + 0.8688h_1) \tag{1}$$

$$h_2 = (0.1861h_6 + 0.8139h_1) \tag{2}$$

Where h_1, h_2, *and* h_6 are the enthalpy of air conditions at inlet of adsorption side, outlet of adsorption side and inlet of regeneration side of desiccant wheel (kJ kg^{-1}), respectively. Enthalpy as a function of absolute humidity and temperature at particular point is calculated by Eq. (3):

$$h = \frac{(2501 + 1.805T)}{1000} + 1.006T \tag{3}$$

Relative humidity at point 2 is determined by using the relative humidity at point 1 and 6:

$$RH_2 = (0.9428RH_6 + 0.0572RH_1) \tag{4}$$

At particular point, RH is determined as a function of absolute humidity and temperature by following empirical relation[29].

$$RH = (18.6715Y + 1.7976)e^{-0.053T} \tag{5}$$

EMC is a function of drying air temperature and relative humidity. Its values are determined by using Eq. (6) and (7) for wheat, rice, barley and Corn. Modified-Chung-Pfost equation is used for wheat, barley and rice.

$$EMC = \frac{1}{-C_3}\ln\left(\frac{T_3 + C_2}{-C_1}\ln RH_3\right) \tag{6}$$

Eq. (6) uses three empirical coefficients i.e. C_1, C_2, and C_3, which are taken from the literature and suppose to best fitted against the moisture isotherm equations for selected cereals (wheat, barley and rice). In this study, the numerical values of the optimized parameters of C_1, C_2, and C_3 for desorption isotherms of wheat are 545.25, 64.047 and 0.17316, respectively[30] and for barley are 338.032, 16.581 and 0.182 respectively[31] and for rice are 227.091, 16.912 and 0.179[32]. However Modified Oswin equation is used for the determination of EMC of corn, empirical coefficient C_1, C_2, and C_3 associated with the equation are13.9005, -0.076819 and 2.96243 respectively[33].

$$EMC = \frac{C_1 + C_2 T_3}{\left(\frac{1}{RH_3} - 1\right)^{\frac{1}{C_3}}} \tag{7}$$

Energy required for the regeneration of desiccant and heating of drying air is calculated by using Eq. (7)[34]:

$$Q_{total} = F_a C_p (T_3 - T_2) + F_a C_p (T_6 - T_5) \tag{8}$$

where F_a is the air mass flow rate (kg s^{-1})during regeneration and heating; C_p is the specific heat capacity of air (kJ kg^{-1}K^{-1});T_2, T_3, T_5 and T_6 are the desiccant wheel outlet air temperature, drying air temperature, ambient air temperature and regeneration temperature (ºC), respectively.

Performance index, Φ (kg kW^{-1}) is introduced in order to evaluate the desiccant drying approaches. The Φ can be defined as amount of moisture removed per unit drying energy.

$$\Phi = \frac{DM(EMC_{initial} - EMC_{drying\ cond.})}{Q_{total}} \tag{9}$$

Where *EMC*, *DM* and Q_{total} are the equilibrium moisture content (-) at ambient condition, equilibrium moisture content (-) at particular drying air condition, dry matter (kg) and total thermal energy for heating and regeneration of the air (kJ s^{-1}), respectively.

5. Results and discussion

To determine the effect of latent load control, ambient air is dehumidified at various levels of humidity ratio by changing the regeneration air temperature from 50ºC to 80ºC.

Figs. 5(a)-(d) represent the process air conditions at different levels of regeneration air temperature for desiccant materials; silica gel and LiCl. In addition Figs. 5(a)-(d) also represent the EMC curves at different levels of RH and temperature for four types grains. EMC at particular drying condition determined the drying potential of the air. This is due to the fact that drying depends on the vapor pressure gradient[19] and DDS helps by removing the moisture from drying air by adsorption. The main tenacity of drawing the process air conditions on EMC curves are to compare the EMC values developed by particular regeneration temperature. It has been found that by increasing the regeneration temperature, EMC value decreases for both desiccant materials.

Total thermal energy required for the regeneration of desiccant and heating of drying air is calculated for Case-I. Fig. 6 represents the total thermal energy required at different regeneration temperature 50ºC, 55ºC, 60ºC, 65ºC, 70ºC, 75ºC and 80ºC. It has been found that as the regeneration temperature increases from 50 ºC to 80ºC for both desiccant materials, Q also increases from 12.66-27.85kJ s^{-1}.

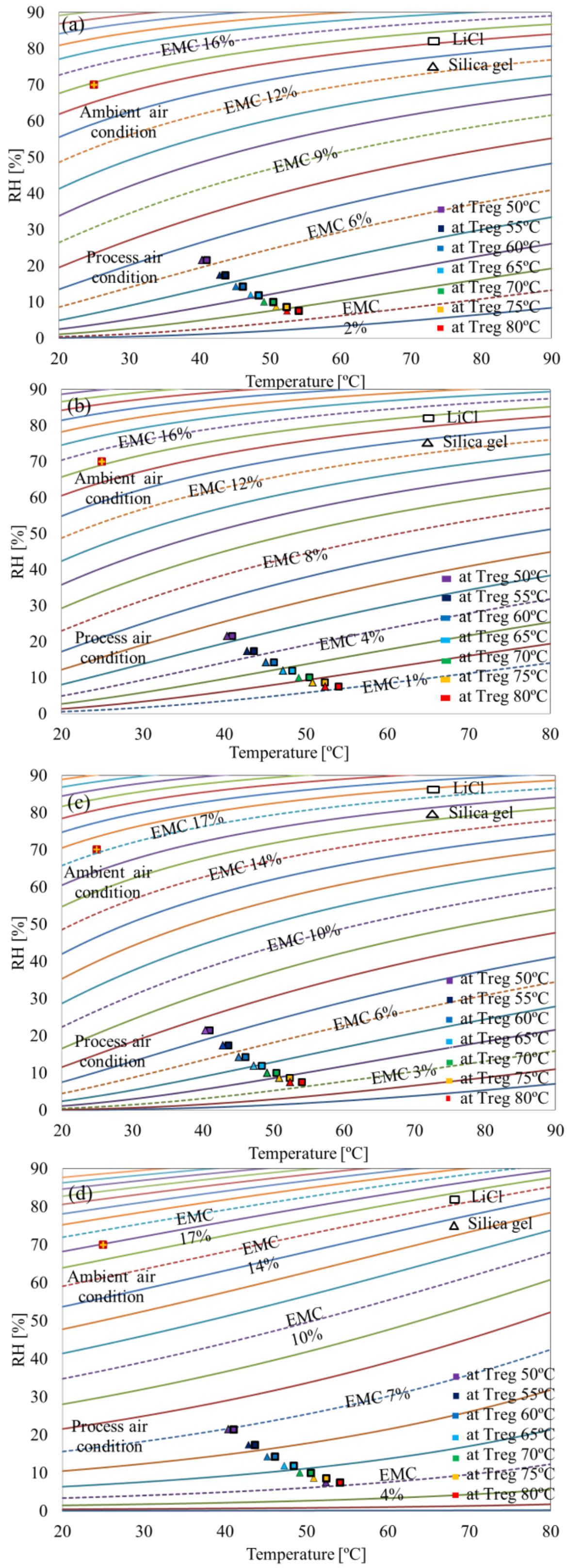

Fig. 5: Pictorial representation of process air conditions at different levels of regeneration temperature on EMC chart for Case-I for: (a) wheat, (b) rice, (c) barley and (d) corn.

Increase in thermal energy input is due to the fact that increase in regeneration temperature, provides more dehumidified process air[35]. Desiccant material silica gel produces more dehumidified air under same regeneration temperature as compared to LiCl. However temperature of processed air is lower for silica gel which shows that for the drying of temperature sensitive grains. On other hand desiccant material LiCl, process air conditions develop low EMC at same regeneration temperature which showed that LiCl is more economical to use regarding the thermal energy consumption. Fig. 7 represents the performance index for 1000 kg of grains at different levels of regeneration temperature. Higher value of Φ at low regeneration temperature represented that drying air can carry more moisture in one pass at the consumption of less energy as represented by Eq. (9). It has been shown that value of Φ decreases as the regeneration temperature increases. As increase in regeneration temperature accompanied by the increase in total input energy but on the other hand there is no significant change in the process air temperature and humidity ratio as also shown by Figs. 5(a)-(d).

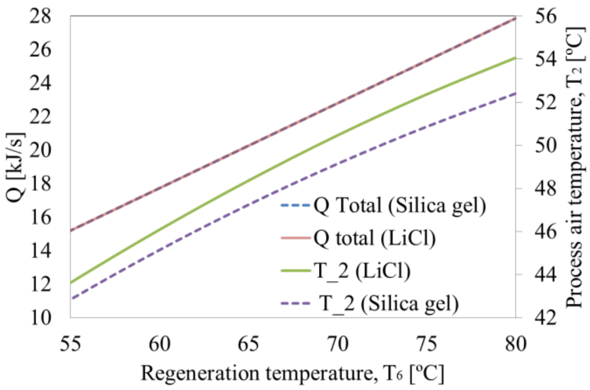

Fig. 6: Total thermal energy and process air temperature required for Case-I at regeneration temperature ranging from 50°C-80°C.

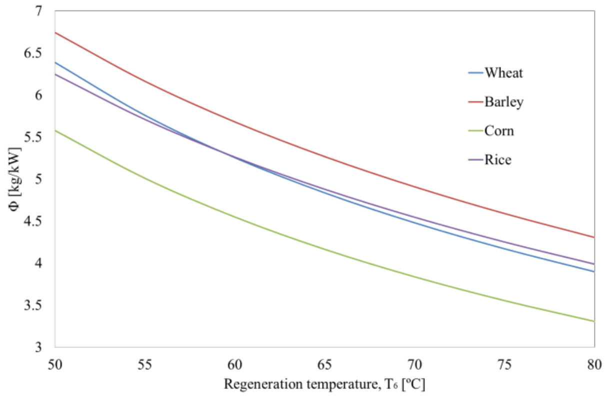

Fig. 7: Effect of regeneration temperature on performance index for Case-I.

Case-I optimum drying air conditions founded are at minimum regeneration temperature 50°C for all types of grains. It also showed that there is no significant difference between the value of Φ of desiccant material silica gel and LiCl.

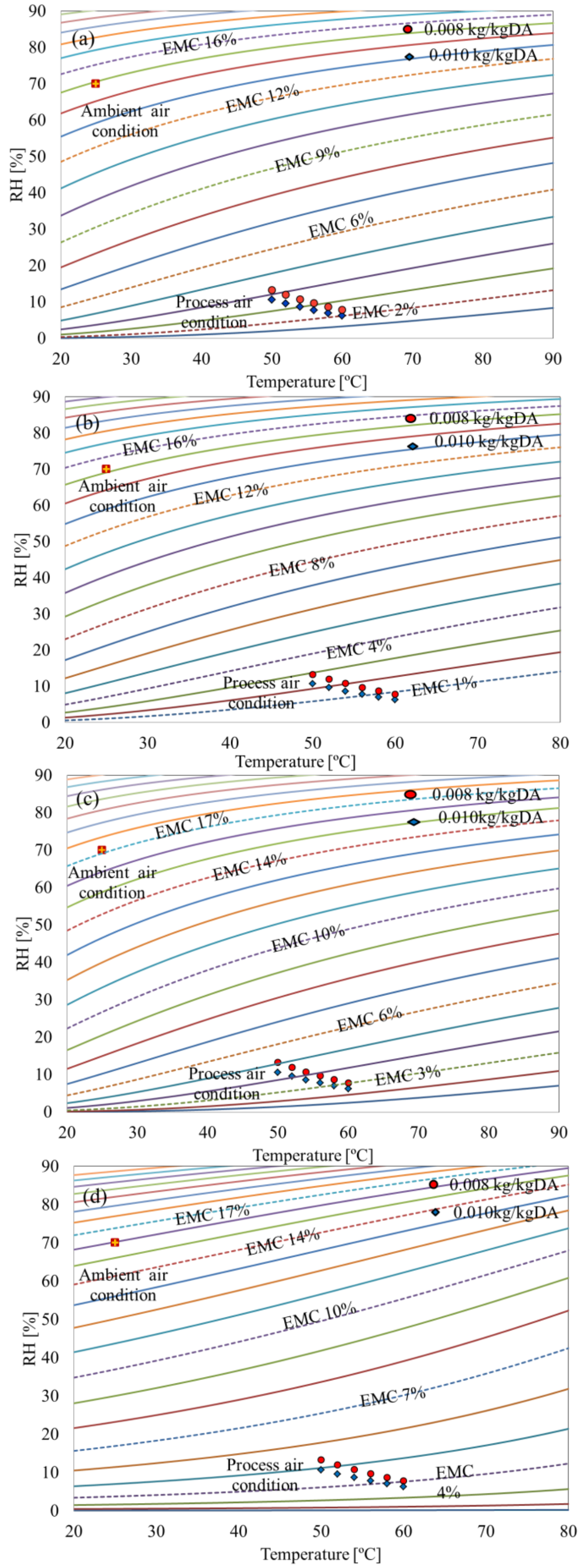

Fig. 8: Pictorial representation of process air conditions at different levels of air heating on EMC chart for Case-II for: (a) wheat, (b) rice, (c) barley and (d) corn.

However Φ varies at different regeneration temperatures from 6.4 to 3.90 kg $kW^{-1}$for wheat grains, 6.74 to 4.30 kg $kW^{-1}$for barley, 5.58 to 3.31 kg $kW^{-1}$for corn and 6.25 to 4.00 for rice in case of LiCl. However, desiccant material silica gel it varies from 6.35 to 3.87 kg $kW^{-1}$for wheat, 6.70 to 4.26 kg $kW^{-1}$for barley, 5.36 to 3.29 for corn and 6.21 to 3.95 kg $kW^{-1}$for rice.

Case-II is determined by dehumidifying the air at humidity ratio 0.010 kg/kg DA and 0.008 kg/kg DA and then heating of the dehumidified air at various temperatures 50ºC, 52ºC, 54ºC, 56ºC, 58ºC and 60ºC.

Fig. 8 represents the process air conditions of Case-II. EMC curves are determined for four types of grains and process air conditions are plotted on it for Case–II. It has been shown that for both desiccant materials at particular humidity ratio, processed air have same value of EMC as heating temperature is same. However lower value of EMC is obtained by increasing the drying air temperature. Total thermal energy required to hold the latent and sensible load control effect is also determined for Case-II. Fig 9 presents the total thermal energy required for regeneration and heating of the process air at humidity ratio of 0.010 and 0.008 kg/kg DA at different levels of temperature 50ºC, 52ºC, 54ºC, 56ºC, 58ºC and 60ºC. It has been found that for desiccant material silica gel and LiCl, Q increases by increasing the drying air temperature from 13.65-17.7 kJ s^{-1} for silica gel and 13.86-17.92 kJ $s^{-1}$for LiCl at humidity ratio 0.010kg/kgDA. Whereas for humidity ratio 0.008kg/kgDA, it varies from 16.72-20.77 kJ s^{-1} for desiccant material silica gel and 17.50-21.55 kJ s^{-1} for desiccant material LiCl. The reason of higher thermal energy at 0.008kg/kgDA is that it requires high regeneration temperature. Likewise silica gel produce more dehumidified air at as compared to LiCl that's why energy required for regeneration is less for particular humidity ratio of process air. Which showed that silica gel is more economical to use for Case-II.

In case of sensible load control, less energy is required for the regeneration of silica gel as compared to LiCl that's why for Silica gel total energy consumption is low. Regeneration energy required for silica gel is 9.3 kJ s^{-1} and LiCl is 10.5 kJ s^{-1} at humidity ratio 0.010 kg/kg DA.

Figs. 10(a)-(d) represent the performance index for 1000 kg of grains for Case-II. It has been found that by increasing the temperature of process air, Φ decreases same like Case-I. However in Case-II, its value are more as compared to Case-I. Maximum value found for desiccant material silica gel, at humidity ratio 0.010 kg/kgDA are 6.65 kg $kW^{-1}$for wheat, 7.72 kg $kW^{-1}$for barley, 6.09 kg $kW^{-1}$for corn and 7.14 kg $kW^{-1}$for rice. However at humidity ratio 0.008 kg/kgDA its values are 5.71 kg kW^{-1}, 6.60 kg kW^{-1}, 5.17 kg $kW^{-1}$and 6.11 kg $kW^{-1}$for wheat, barley, corn and rice, respectively.

In Case-II, higher value of Φ at humidity ratio 0.010kg/kg DA, prove that it is more feasible approach as compared to drying at 0.008kg/kgDA. However it also showed that Case-II drying at 50ºC and humidity ratio 0.010kg/kgDA at regeneration temperature 63ºC have the highest potential to carry the moisture at the expense of less energy. Whereas these conditions only suitable for commercial drying as drying air temperature is higher than the seed drying limit.

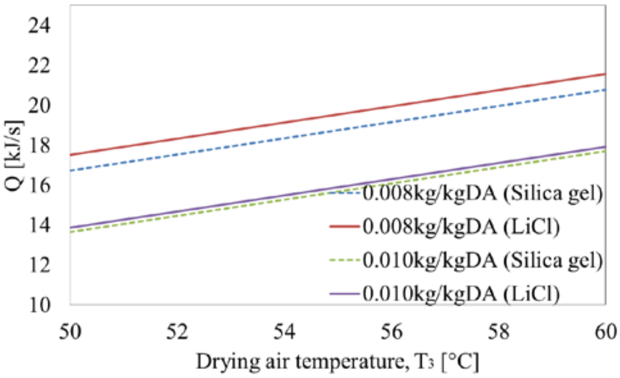

Fig. 9: Total thermal energy required for Case-II at humidity ratio 0.008 and 0.010 kg/kgDA and drying air temperature ranging from 50ºC-60ºC.

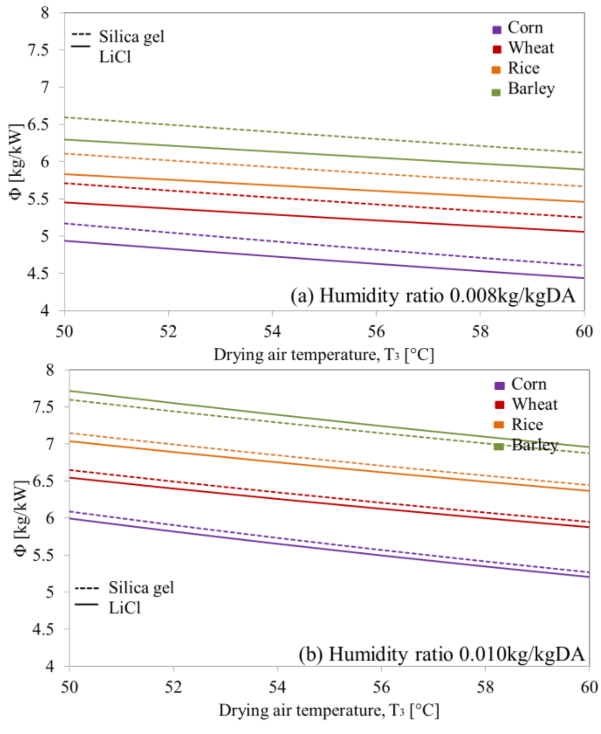

Fig. 10: Effect of drying air temperature on performance index for Case-II for humidity ratio: (a) 0.008kg/kg DA (b) 0.010kg/kg DA.

It is concluded that Case-I at minimum possible regeneration temperature 50ºC consequently drying air temperature 41ºC is optimum condition for seed drying whereas for Case-II, drying at humidity ratio 0.010kg/kg DA at drying air temperature 50ºC is not in the range of seed drying. However these conditions are found quite reasonable for commercial purpose drying as the expense of minimum energy.

6. Conclusions

This study investigated steady state solid desiccant drying technique for the drying of four types of grains wheat, barley, corn and rice. Two desiccant drying approaches discussed are; latent load control and both latent & sensible load control effect. Beccali et al. model, Modified Chung-Pfost and Modified Oswin EMC equations are used to evaluate the both cases. Case-I deals with the drying of cereals grain without heating at various levels of humidity ratio of processed air. Whereas Case-II deals with the dehumidification of the ambient air at certain level and then heating the process air up to safe temperature limit. Case I results showed that by increasing the regeneration temperature moisture carrying capacity of the air increases however at the expense of more energy. Case I drying air conditions found effective for seed drying as drying air temperature not exceed the recommended seed drying temperature limit. Whereas, optimum drying conditions devising maximum potential to carry the moisture at the expense of minimum energy is at regeneration temperature 50ºC. Case-II results showed that it is more suitable for commercial drying as drying air temperature is higher as compared to Case-I. Whereas, optimum drying conditions for Case-II are drying air temperature 50ºC and humidity ratio 0.010kg/kgDA.

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