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Regression approach in assessing the efficiency of different types and amount of desiccants for producing dry air to be used in ambient temperature dryer

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Abstract

The present experiment was undertaken to design the ambient temperature dryer and to evaluate the efficiency with different desiccants at different quantities in the Department of Pomology and Post-Harvest Technology of UBKV, Pundibari. The proto type ambient temperature dryer is designed with compressor, desiccant bottles, drying chamber connector pipes, thermo-hygrometer and anemometer. Firstly, air is passed from air compressor to the desiccant chamber where the desiccant absorbs moisture from the air and pass dry air in to the drying chamber to absorb moisture from the commodity. To evaluate the efficiency of ambient temperature dryer with different desiccants *viz*., anhydrous $CuSO_4$, anhydrous $CaCl_2$, Silica and different weights *viz*., 250, 500 and 750 grams were taken. The experiment was conducted in Completely Randomized Factorial Design with the above two factors at equal levels and replicated thrice. It was concluded that the total capacity of outlet air to hold moisture was recorded to be 0.199, 0.209 and 0.228 kg of moist air during the entire operation of 360 minutes when silica with 250, 500 and 750 g respectively was used and the total moisture removed (68, 91 and 112 g) during the experimentation of 360 minutes was found to be best when silica with 250, 500 and 750 g was used. The data sets were analysed with the values of regression coefficient for different models and all the data sets were found to fitted best in power model for all the desiccants.

Keywords: Ambient temperature dryer, desiccant, moisture, and silica

1. Introduction

India has not only emerged as an important producer else it is the second-largest producer of fruits and vegetables. India's share in the world production of fruits and vegetables stands at 11.38% and 11.78% respectively, horticulture area is 27.23 million hectares with the production of 331 million tons (Smita *et al.*, 2022) [6]. Processed and value added products are gaining importance in the worldwide markets (Dethe *et al.*, 2022) [2]. Drying is a suitable alternative for postharvest management. There are several studies that have addressed the problems associated with conventional convective drying. One of the key issues of drying technology is to propose strategy to maximize energy savings, increase the efficiency of drying processes and thus improve final product quality in general, drying processes are determined by the combination of three variables: temperature, humidity, and duration.

The high temperature of the drying process is an important cause for loss of quality. Lowering the process temperature and suing ambient temperature for drying has great potential for improving the quality of dried products. As an alternative to all other drying methods, desiccant drying technology is feasible and economically viable (Ninganna and Vyakaranahal, 2019) [5]. Drying using desiccant material produces dry air because the desiccant material adsorbs moisture from the air. Desiccants are a potential media especially suited for drying applications. Use of heat to evaporate moisture from the food also results in a loss of fresh colour, vitamins and texture. There is need for developing gentle drying technologies to attain better product quality in shorter drying period with better retention of nutritional and sensory characteristics, with operational safety and better process control, non-polluting, economic higher capacity dryers. With this in mind and also considering constrains of conventional dryers, the current experiment was done.

2. Materials and Methods

The proto type ambient temperature dryer was designed and assembled in the Department of

Pomology and Post-Harvest Technology of UBKV, Pundibari with compressor, desiccant chamber, drying chamber, connector pipes, thermo-hygrometer and hot wire anemometer. Firstly, air is passed from oil free compressor to the desiccant chamber where the desiccant absorbs moisture from the air and pass dry air in to the drying chamber to absorb moisture from the commodity. The experiment was carried out by following Two Factorial Completely Randomized Design with two factors i.e., desiccant type *viz*., $CuSO_4$, $CaCl_2$, Silica and desiccant weight *viz*., 250, 500 and 750 grams, thereby forming nine treatment combinations (T_1 = $CuSO_4$+250 g, T_2 = $CuSO_4$+500 g, T_3 = $CuSO_4$+ 750 g, T_4 = $CaCl_2$+250 g, T_5 = $CaCl_2$+500 g, T_6 = $CaCl_2$+750 g, T_7 = Silica+250 g, T_8 = Silica+500 g and T_9 = Silica+750 g) in triplicate for each desiccant and different weights for determining the rate of drying by recording dry bulb temperature and relative humidity to resolve the psychrometric properties of air.

The psychrometric observations (dry bulb temperature and relative humidity) were recorded up to 360 minutes after 10, 20, 30, 60, 90, 120, 180, 240, 300 and 360 minutes. The temperature and relative humidity were recorded using digital thermo-hygrometer located inside the drying chamber placed near to inlet and another is placed at outlet. Over the entire period of study, the data were recorded at certain intervals of 360 minutes. Volume of air, relative humidity fraction, saturation vapour pressure, vapour pressure, humidity ratio, total volume of inlet and outlet air, specific volume of inlet and outlet air, total weight of inlet and outlet air, absolute humidity of inlet and outlet air, total moisture removed during the time interval, rate of moisture removal, enthalpy of inlet and outlet air (kJ/kg), difference in enthalpy (kJ/kg), rate of enthalpy drop (kJ/kg.h), absolute saturation humidity at outlet temperature (kg/kg), capacity of outlet air to hold more moisture (kg/kg), total capacity of outlet air to hold more moisture (kg).

3. Results and Discussions

The efforts were undertaken to study the relative capacity of different desiccants in removing moisture from the moist air to produce dry air for dehydration of fruits and vegetables. Anhydrous copper sulphate, anhydrous calcium chloride, and silica were utilized as desiccants in this experiment. Different weights of desiccants were used in the inlet line through which air was passed to the drying chamber at an air velocity of 5m/s inlet. To analyse the kinetics of moisture removal from the inlet air during the time interval, psychrometric parameters of inlet and outlet air from the desiccant chamber were recorded at different time intervals up to 360 min.

3.1 Kinetics of removal of moisture from inlet air by anhydrous copper sulphate

Anhydrous copper sulphate at different quantity i.e., 250 g, 500 g and 750 g were used in the air inlet line leading to the drying chamber. Initially, at first ten minutes, the average rate of moisture removal was 0.010 kg/h where 250 g of anhydrous copper sulphate was used as desiccant whereas the average rate of moisture removal during the first ten minutes was 0.012 kg/h for 500 g and further increased to 0.015 kg/h when the amount of desiccant was increased to 750 g. Thus, it may be concluded that initial average rate of moisture removal was proportionately increased with the amount of desiccant used in the inlet line. These initial rates were found to decrease as the time interval increased and this trend was independent of amount of desiccant used. it was concluded that the total capacity of outlet air to hold moisture was recorded to be 0.228 kg of moist air during the entire operation of 360 minutes when silica with 750 g was used and the total moisture removed (112 g) during the experimentation of 360 minutes was found to be best when silica with 750 g was used. The data sets were analysed with the values of regression coefficient for different models and all the data sets were found to fitted best in power model for all the desiccants (Dorouzi *et al.*, 2018) [3]. At the end of 360 minutes of experimentation, the average rate of moisture removal was dropped to 0.0023 kg/h when 250 g of desiccant was used, whereas 0.0043 kg/h and 0.0062 kg/h were recorded when 500 g and 750 g of desiccant were used respectively (Fig 1).

In experimentation with 250 g of anhydrous copper sulphate, the total amount of moisture removed and total enthalpy of outlet air during the entire operation of 360 minutes was found to be 26 g from 18.71 kg of moist air and 1384.93kJ/kg of moist air respectively whereas 33 g from 18.57 kg of moist air and 1466.34kJ/kg were recorded when 500 g was used. When 750 g was used, the total amount of moisture removed and total enthalpy of outlet air during the entire operation of 360 minutes was found to be 45 g from 18.53 kg of moist air and 1482.44 kJ/kg of moist air (Table 1). The total capacity of outlet air to hold moisture was recorded to be 0.167 kg of moist air during the entire operation of 360 minutes when 250 g of anhydrous copper sulphate was used, whereas 0.172 and 0.167 kg of moist air was recorded when 500 and 750 g of anhydrous copper sulphate respectively.

Table 1: Performance of anhydrous copper sulphate as desiccant in production of dry air

Quantity of anhydrous copper sulphate (g)	Total weight of inlet air in 360 min (kg)	Total moisture removed in 360 min (g)	Total enthalpy of outlet air (kJ)	Total capacity of outlet air to hold moisture (kg)
250 (T_1)	18.71±0.096	26±0.000	1384.93±57.075	0.167±0.017
500 (T_2)	18.57±0.047	33±0.003	1466.34±47.394	0.172±0.012
750 (T_3)	18.53±0.0193	45±0.002	1482.44±18.909	0.167±0.013

*data presented above are mean ± SD (n = 3)

The plot of average rate of moisture removal against time interval shown a non linear correlation and hence the regression analysis were done to find the best fitted model for the data. The average data from the three replications under different treatments were fitted into linear, exponential, logarithmic, second order polynomial, third order polynomial and power model. In experimentation with 250 g of desiccant, the average data were found to be the best to fitted in logarithmic model with R^2 value of 0.981 (Table 2). The next best fitted model for the data set was 3rd order polynomial with R^2 value of 0.963. In experimentation with 500 g of desiccant, the average data set was found to fitted in power model with R^2 value of 0.982. When the desiccant weight was increased to 750 g, the average data set fitted best with power model with R^2 value of 0.904. As most of the data were found to fitted into power model, it was decided to use power model for the data set from the experiment involving 250 g of desiccant where the R^2 value of 0.909 were in reasonable agreement with the R^2 value of logarithmic model.

Table 2: Values of regression coefficient for different models to fitted for the data set under experiment with anhydrous copper sulphate as a desiccant

	Regression coefficients					
	Linear	**Exponential**	**Logarithmic**	**2^{nd} order Polynomial**	**3rd order polynomial**	**Power**
T1R1	0.762	0.8713	0.9311	0.8448	0.932	0.8695
T1R2	0.8273	0.9442	0.9769	0.922	0.9456	0.9379
T1R3	0.8569	0.9369	0.9624	0.9131	0.9523	0.8585
Overall	0.8356	0.9403	0.9817	0.9141	0.9631	0.9093
T2R1	0.7032	0.7403	0.942	0.9576	0.9606	0.9012
T2R2	0.8377	0.9303	0.954	0.903	0.9157	0.9132
T2R3	0.6067	0.6867	0.9003	0.7955	0.9257	0.9028
Overall	0.7527	0.8555	0.9786	0.9147	0.9459	0.9822
T3R1	0.5618	0.6048	0.8544	0.7926	0.8473	0.8517
T3R2	0.501	0.6043	0.778	0.591	0.7879	0.8189
T3R3	0.4253	0.5027	0.7432	0.5808	0.7727	0.7777
Overall	0.5237	0.6297	0.8414	0.689	0.8372	0.904

3.2 Kinetics of removal of moisture from inlet air by anhydrous calcium chloride

Anhydrous calcium chloride at different quantity i.e., 250 g, 500 g and 750 g were used in the air inlet line leading to the drying chamber. Initially, at first ten minutes, the average rate of moisture removal was 0.018 kg/h where 250 g of anhydrous calcium chloride was used as desiccant whereas the average rate of moisture removal during the first ten minutes was 0.020 kg/h for 500 g and further increased to 0.021 kg/h when the amount of desiccant was increased to 750 g. Thus, it may be concluded that initial average rate of moisture removal was proportionately increased with the amount of desiccant used in the inlet line. These initial rates were found to decrease as the time interval increased and this trend was independent of amount of desiccant used. At the end of 360 minutes of experimentation, the average rate of moisture removal was dropped to 0.0036 kg/h when 250 g of desiccant was used, whereas 0.0034 kg/h and 0.0035 kg/h were recorded when 500 g and 750 g of desiccant were used respectively (Fig 2).

In experimentation with 250 g of anhydrous calcium chloride, the total amount of moisture removed and total enthalpy of outlet air during the entire operation of 360 minutes was found to be 41 g from 18.34 kg of moist air and 1637.96 kJ/kg of moist air respectively whereas 38 g from 18.52 kg of moist air and 1553.90 kJ/kg were recorded when 500 g was used. When 750 g was used, the total amount of moisture removed and total enthalpy of outlet air during the entire operation of 360 minutes was found to be 35 g from 18.51 kg of moist air and 1525.59 kJ/kg of moist air (Table 3). The total capacity of outlet air to hold moisture was recorded to be 0.176 kg of moist air during the entire operation of 360 minutes when 250 g of anhydrous calcium chloride was used, whereas 0.130 and 0.152 kg of moist air was recorded when 500 and 750 g of anhydrous calcium chloride respectively. Kokouvi *et al.*, 2015 [7] stated that calcium chloride absorb moisture from the ambient conditions at various rates depending upon the salt concentration, humidity and water vapour of the surrounding air due to its hygroscopic and deliquescent behaviour and he concluded that calcium chloride is a weak desiccant compared to the other hygroscopic salts.

Table 3: Performance of anhydrous calcium chloride as desiccant in production of dry air

Quantity of anhydrous calcium chloride (g)	**Total weight of inlet air in 360 min (kg)**	**Total moisture removed in 360 min (g)**	**Total enthalpy of outlet air (kJ)**	**Total capacity of outlet air to hold moisture (kg)**
250 (T_4)	18.34±0.059	41±0.004	1637.96±61.410	0.176±0.004
500 (T_5)	18.52±0.121	38±0.005	1553.90±84.445	0.130±0.008
750 (T_6)	18.51±0.067	35±0.008	1525.59±63.467	0.152±0.016

*data presented above are mean ± SD (n = 3)

The plot of average rate of moisture removal against time interval shown a non linear correlation and hence the regression analysis were done to find the best fitted model for the data. The average data from the three replications under different treatments were fitted into linear, exponential, logarithmic, second order polynomial, third order polynomial and power model. In experimentation with 250 g of desiccant, the average data were found to be the best to fitted in logarithmic model with R^2 value of 0.970 (Table 4). In experimentation with 500 g of desiccant, the average data set was found to fitted in power model with R^2 value of 0.961. When the desiccant weight was increased to 750 g, the average data set again found to fitted best with power model with R^2 value of 0.942.

Table 4: Values of regression coefficient for different models to fitted for the data set under experiment with anhydrous calcium chloride as a desiccant

	Regression coefficients					
	Linear	**Exponential**	**Logarithmic**	**2nd order Polynomial**	**3rd order polynomial**	**Power**
T4R1	0.754	0.8557	0.9601	0.9113	0.9763	0.9044
T4R2	0.6908	0.8005	0.9424	0.8793	0.9415	0.9426
T4R3	0.6681	0.8635	0.9015	0.7563	0.858	0.8902
Overall	0.7306	0.887	0.9702	0.8788	0.9563	0.9663
T5R1	0.567	0.7891	0.8686	0.7138	0.8682	0.9176
T5R2	0.5795	0.8315	0.865	0.7311	0.8098	0.945
T5R3	0.7013	0.866	0.9481	0.8426	0.9249	0.9632
Overall	0.6205	0.8419	0.9044	0.7694	0.8732	0.9612
T6R1	0.6506	0.8309	0.9194	0.7902	0.9212	0.9175
T6R2	0.5388	0.7254	0.8633	0.746	0.8464	0.929
T6R3	0.457	0.6738	0.7732	0.646	0.7255	0.8418
Overall	0.5556	0.7762	0.8684	0.7385	0.8428	0.9428

3.3 Kinetics of removal of moisture from inlet air by silica

Silica at different quantity i.e., 250 g, 500 g and 750 g were used in the air inlet line leading to the drying chamber. Initially, at first ten minutes, the average rate of moisture removal was 0.025 kg/h where 250 g of silica was used as desiccant whereas the average rate of moisture removal during the first ten minutes was 0.029 kg/h for 500 g and further increased to 0.032 kg/h when the amount of desiccant was increased to 750 g. Thus, it may be concluded that initial average rate of moisture removal was proportionately increased with the amount of desiccant used in the inlet line. These initial rates were found to decrease as the time interval increased and this trend was independent of amount of desiccant used. At the end of 360 minutes of experimentation, the average rate of moisture removal was dropped to 0.0085 kg/h when 250 g of desiccant was used, whereas 0.013 kg/h and 0.016 kg/h were recorded when 500 g and 750 g of desiccant were used respectively (Fig 3). The reason for removal of moisture at fast rate is that silica gel has a massive microscopic pore network that is interconnected. These microscopic pores retain the most moisture (Bhoite and Thaneshwari, 2022) [1].

In experimentation with 250 g of silica, the total amount of moisture removed and total enthalpy of outlet air during the entire operation of 360 minutes was found to be 68 g from 18.42 kg of moist air and 1504.71 kJ/kg of moist air respectively whereas 91 g from 18.36 kg of moist air and 1494.74 kJ/kg were recorded when 500 g was used. When 750 g was used, the total amount of moisture removed and total enthalpy of outlet air during the entire operation of 360 minutes was found to be 112 g from 18.40 kg of moist air and 1418.97 kJ/kg of moist air (Table 5). The total capacity of outlet air to hold moisture was recorded to be 0.199 kg of moist air during the entire operation of 360 minutes when 250 g of silica was used, whereas 0.209 and 0.228 kg of moist air was recorded when 500 and 750 g of silica respectively. Silica gel is the most known and used sorption material for physical adsorption of water vapor especially due to its hydrophilic properties (Jarimi *et al.*, 2018) [4].

Table 5: Performance of silica as desiccant in production of dry air

Quantity of silica (g)	Total weight of inlet air in 360 min (kg)	Total moisture removed in 360 min (g)	Total enthalpy of outlet air (kJ)	Total capacity of outlet air to hold moisture (kg)
250 (T_7)	18.42±0.083	68±0.004	1504.71±70.494	0.199±0.001
500 (T_8)	18.36±0.082	91±0.004	1494.74±65.867	0.209±0.004
750 (T_9)	18.40±0.196	112±0.002	1418.97±156.888	0.228±0.009

*data presented above are mean ± SD (n = 3)

The plot of average rate of moisture removal against time interval shown a non linear correlation and hence the regression analysis were done to find the best fitted model for the data. The average data from the three replications under different treatments were fitted into linear, exponential, logarithmic, second order polynomial, third order polynomial and power model. In experimentation with 250 g of desiccant, the average data were found to be the best to fitted in power model with R^2 value of 0.951 (Table 6). In experimentation with 500 g of desiccant, the average data set was found to fitted in power model with R^2 value of 0.943. When the desiccant weight was increased to 750 g, the average data set again found to fitted best with power model with R^2 value of 0.968.

Table 6: Values of regression coefficient for different models to fitted for the data set under experiment with Silica as a desiccant

	Regression coefficients					
	Linear	**Exponential**	**Logarithmic**	**2nd order Polynomial**	**3rd order polynomial**	**Power**
T7R1	0.6702	0.7897	0.919	0.7935	0.9055	0.937
T7R2	0.6377	0.7803	0.8896	0.7407	0.8646	0.9189
T7R3	0.467	0.5764	0.791	0.676	0.7561	0.8607
Overall	0.607	0.7487	0.8938	0.7538	0.8614	0.9517
T8R1	0.5091	0.5702	0.8447	0.7562	0.8997	0.8802
T8R2	0.5611	0.6072	0.8904	0.8462	0.912	0.8995
T8R3	0.549	0.6187	0.8911	0.8096	0.92	0.9228
Overall	0.5556	0.6284	0.9018	0.8272	0.9353	0.943
T9R1	0.6034	0.6573	0.9124	0.8652	0.9118	0.9289
T9R2	0.6556	0.7124	0.9336	0.8433	0.9442	0.941
T9R3	0.5691	0.6529	0.8725	0.7943	0.8755	0.8949
Overall	0.6303	0.7011	0.9384	0.8623	0.9397	0.9688

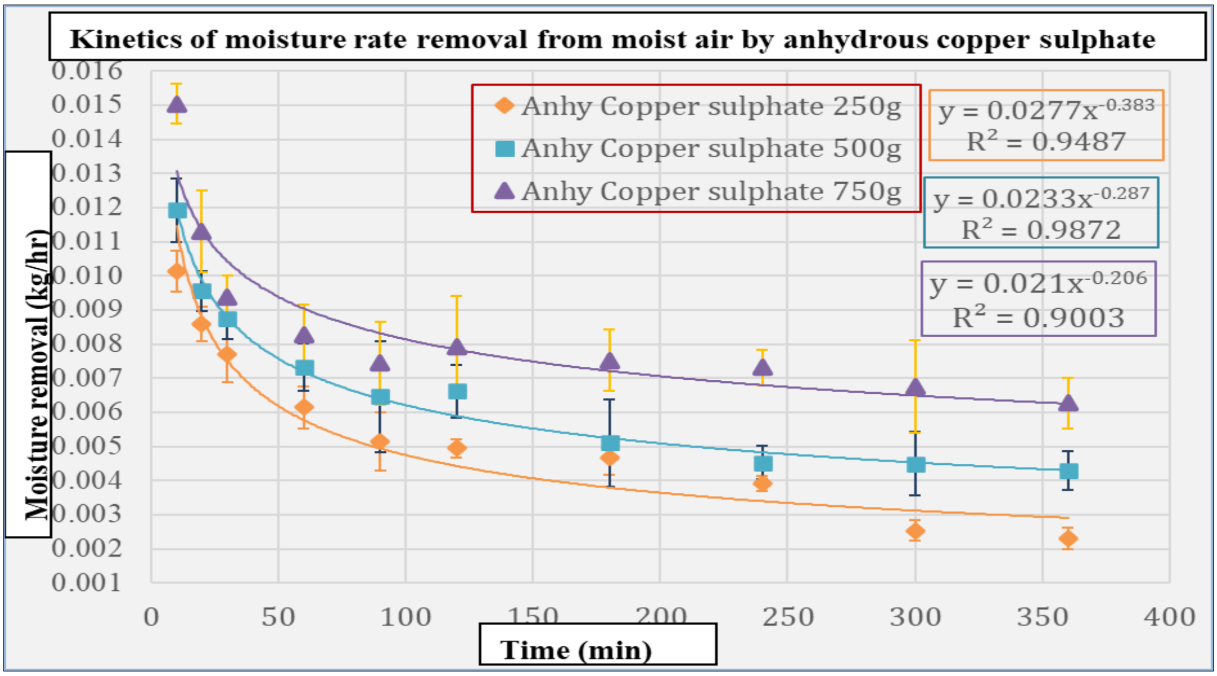

Fig 1: Kinetics of moisture removal rate from moist air by anhydrous copper sulphate

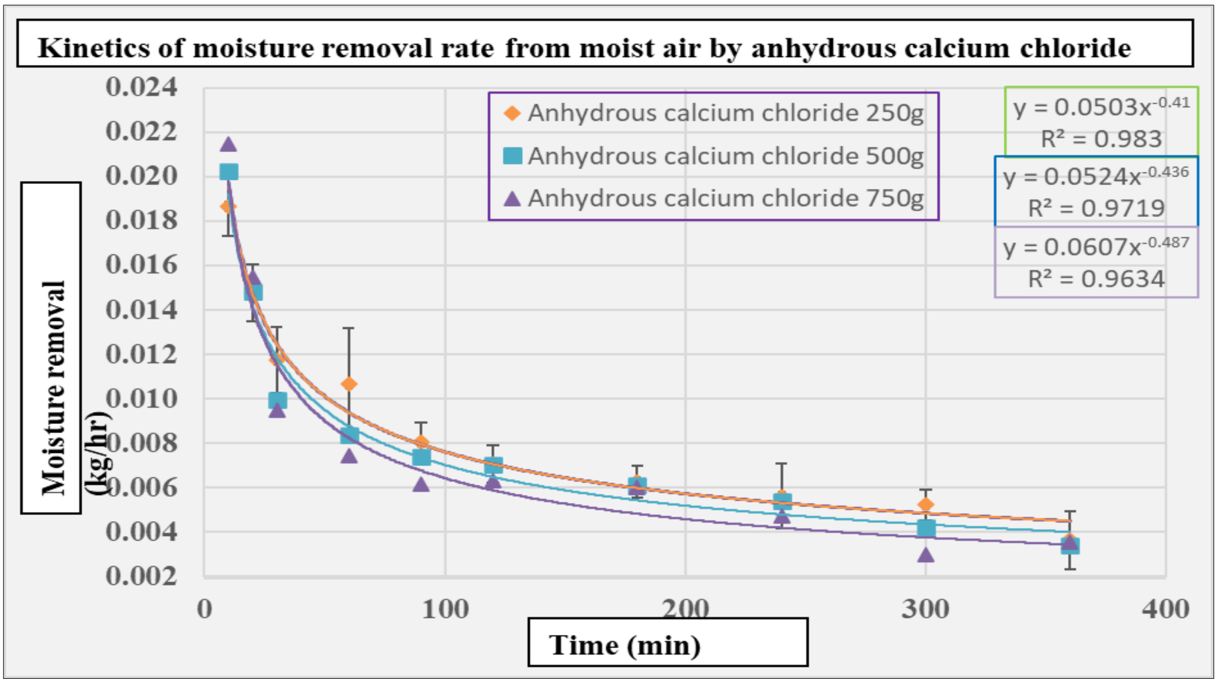

Fig 2: Kinetics of moisture removal rate from moist air by anhydrous calcium chloride

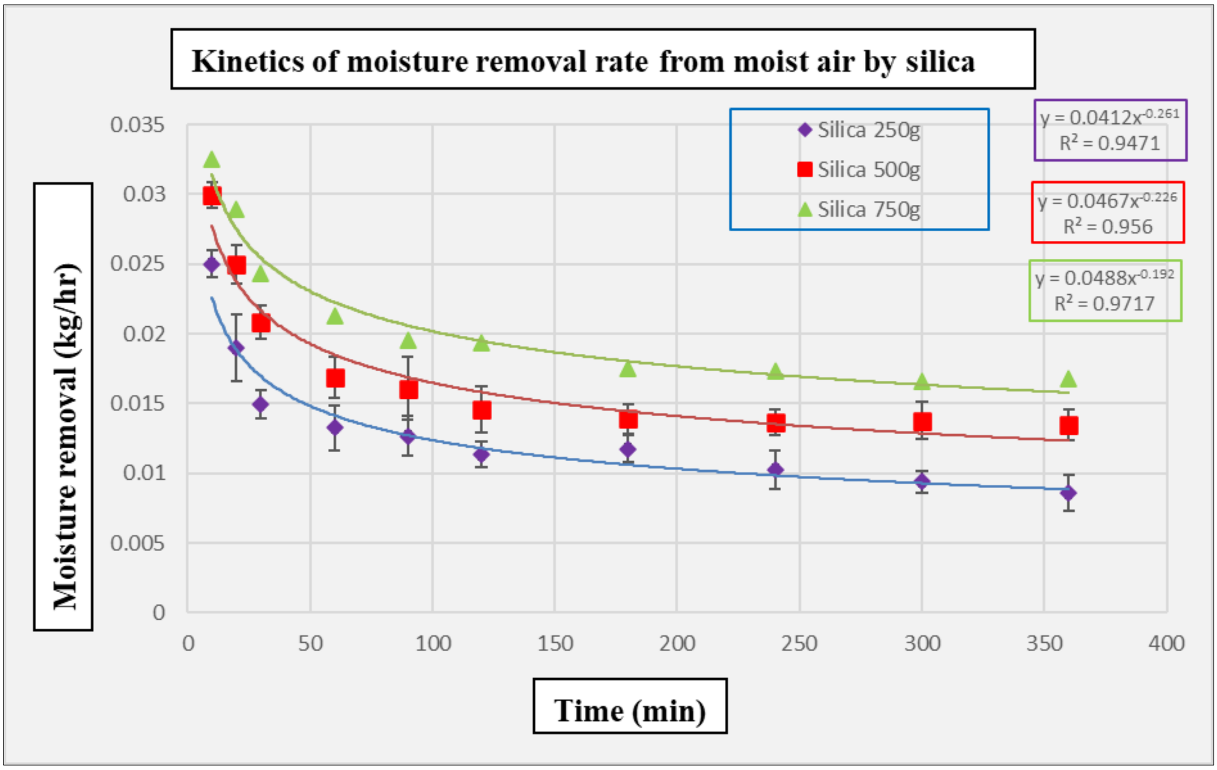

Fig 3: Kinetics of moisture removal rate from moist air by silica

4. Conclusion

Based on the results of the investigations, it was concluded that the total capacity of outlet air to hold moisture was recorded to be 0.228 kg of moist air during the entire operation of 360 minutes when silica with 750 g was used and the total moisture removed (112 g) during the experimentation of 360 minutes was found to be best when silica with 750 g was used. Among all desiccants silica was found to best in removing moisture from the air by providing dry air to hold further moisture from the commodities. Among all weights used 750 g was found to do better in absorbing moisture than all other weights used. The data sets were analysed with the values of regression coefficient for different models and all the data sets were found to fitted best in power model for all the desiccants.

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