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Solar Energy Zeolite Regeneration for a Milk Cooler

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Abstract: Despite the rehabilitation of Uganda's milk infrastructure, almost 50% of the milk collected by small holder farmers is wasted due to inability to store the milk and the unsafe conditions of transporting it to collection centers. To alleviate this problem, a zeolite adsorption cooler can be used but once it is fully saturated, it must be regenerated. Conventional processes of regenerating it by electrical heating have high levels of energy consumption and are not cost friendly to the rural farmers. The objective of this study therefore was to investigate the use of solar energy in regenerating the zeolite adsorbent.

In this study, solar energy regeneration of three zeolite sizes as 1/2x1/4, 4x8 and 6x14 was investigated on convective aluminum pan dryers in open solar drying. Experiments were conducted for Bear river zeolite. The constant rate period was absent from the drying curves with zeolite 6x14 size showing the fastest drying rate and recorded the highest efficiency. Moisture ratio at any drying time was compared by 14 mathematical models using the correlation coefficient (R), root mean square error (RMSE) and chi-square (χ^2) parameters. Modeling efficiency was determined for each model. The effect of drying air temperature, relative humidity and velocity on the coefficients of the best suited model was determined by multiple regression analysis. According to the results, Modified page I model best explained the open sun drying behavior of Zeolite. Moisture content of the material can be predicted more easily with the generalized model showing the effect of drying air temperature, relative humidity and velocity on the model constants and coefficients.

Key words: Zeolite, milk cooler, mathematical modeling, solar energy, regeneration

INTRODUCTION AND LITERATURE REVIEW

In most developing countries up to 30 % of food is spoilt due to lack of cooling/refrigeration systems, during transport and storage because conventional cooling systems are not affordable. Furthermore, electric power often is not available in the villages(Mubiru, 2000). Fresh milk losses at 50% in Uganda are unacceptable (Cavender et al., 2004).

Zeolite, a microporus crystalline solid is capable of adsorbing significant amounts of water vapor and other gases in their complex crystal structure. Water content of up to 25 % (kg water/kg zeolite) can be adsorbed and then desorbed by the adsorption enthalpy (Ming et al., 1993). An adsorption cooler designed for small scale dairy farmers of East Africa utilizes the highly adsorbent nature of mineral zeolite to cool a 50 liter Can of milk for approximately 12 hours using zeolite as the adsorber and water as the refrigerant (Cavender et al., 2004). Energy is absorbed from the milk container causing transient cooling of milk and the water begins to evaporate due to the latent heat of vaporization by the heat absorbed from the milk. For the cooling process to continue the water vapour has to be continuously removed from the adsorber.

Once the Zeolite is fully saturated within the cooler, it must be removed for regeneration. Zeolite regeneration processes have been mostly done by thermal heating (thermal regeneration) using mechanized equipment (Pons, 1997). However mechanized drying is expensive for the Ugandan local farmers and requires substantial quantities of fuel or electricity to operate. In Uganda, less than 9% of the population access electricity on their farms and have little means to afford mechanized drying systems (Mwebaze, 2004). Thus due to lack of electrical power to the majority of rural farmers, electrical thermal regeneration is a major set back. In areas with abundant sunshine, solar energy is the most easily accessible energy source. It is therefore, an important alternative source of energy and is preferred to other energy sources because it is abundant, inexhaustible and non-pollutant. Also, it is renewable, cheap and environment friendly. Solar energy received in Uganda ranges between 12.6 and

21 MJ/m2/day, which is quite ideal for any application (Mubiru, 2000).

The process of open sun drying is advantageous because full scale experimentation of different materials and configurations of other drying systems are time consuming and costly (Hossain and Bala, 2002). Furthermore the drying conditions, as directly related to the drying times, affect the energy demands, (Sahin and Dincer, 2005). Simultaneous heat and mass transfer takes place during open sun drying processes. Convection drying of zeolite therefore is considered to be a simultaneous heat and mass transfer process where water is transferred by diffusion from inside of the zeolite pores to the air–zeolite interface and from the interface to the air stream by convection. Heat is transferred by convection from air to the air–zeolite interface and by conduction to the interior of the solid. In air drying, the rate of removal of water depends on the conditions of the air, the properties of the material to be dried and the design of the dryer. The capacity of air for moisture removal depends on its humidity, speed and temperature.

Mathematical models like the Newton model, Page model, the Modified Page model (I and II), the Henderson and Pabis model, the logarithmic model, the two-term model and the diffusion approach model have proved to be very useful in design and analysis of heat transfer processes during drying (Midili et al., 2003). Furthermore thin layer drying equations have been used to estimate drying times of several products and also to generalize drying curves (Hossain and Bala, 2002). However, no such information was found in the literature about zeolite solar drying process under open sun with natural convection. This study was therefore conducted with the following objectives:

- To investigate the use of solar energy to regenerate zeolite as an adsorber in a milk cooler.
- To determine the Zeolite size that optimizes the regeneration process.

MATERIALS AND METHODS

The study was conducted at the Uganda Industrial Research Institute-Efficient Energy Development Centre. Zeolite samples in sizes of ½ x ¼, 4 x 8, and 6 x14 were used in the experiments which were conducted between 10 and 17 hours each day. The samples were soaked for 24hrs and drained of water by a standard inspection sieve before the commencement of each experiment. Samples weighing 0.5 Kg each were then dried as thin layers on three aluminum pan dryers at ambient temperature and were constantly stirred after every 20 minutes. Figure 1 illustrates the experiment setup as used to study the open sun regeneration of zeolite.

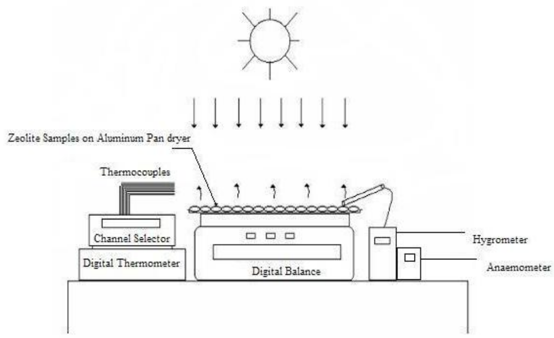

Figure 1. Experiment setup for open sun zeolite regeneration

Environmental conditions of temperature, relative humidity, air velocity and solar radiation were recorded at 20 minute intervals. In the measurements of temperature, a J type iron-constant thermocouple was used with a manually controlled channel automatic digital thermometer with reading accuracy of ±0.1 °C. An intelligent weather station hygrometer was used to measure humidity levels of the air just above the zeolite samples. A 4-89 MPH range Sky master anemometer measured the velocity of wind. A radiation meter was used to monitor the variation of solar radiation over the entire drying cycle. Moisture loss was also recorded at 20 minutes intervals during drying for determination of drying curves by a digital balance in the measurement range of 100 g - 20 kg and an accuracy of ±0.01 g.

Mathematical modeling

The drying curves obtained out of drying experiments were fitted with 14 different moisture ratio models. To normalize the drying curves, the data involving dry basis moisture content was transformed to a dimensionless parameter called moisture ratio (MR) computed as:

$$MR = \left[\frac{M_t - M_e}{M_o - M_e} \right] \quad \text{.... (1)}$$

Where:

Mt = Moisture Content at any time t

Mo= Initial moisture content at t=0

Me = Equilibrium moisture content

The thin layer drying equations were tested to select the best model that best describes the zeolite drying curve in open sun drying by carrying out a regression analysis. The analysis was carried out by SAS computer package to conduct statistical analyses for the 14 models. Modeling Efficiency (EF) was also determined for each of the 14 models.

The Correlation coefficient R, reduced chi-square, $\chi 2$ and root mean square error (RMSE) were used as the primary criterion to select the best equation to account for variation in the drying curves of the dried samples of Zeolite. Reduced chi-square was used to determine the goodness of the fit. The RMSE was used to determine the deviation between the predicted and experimental values. The effects of temperature, relative humidity and velocity on the constants and coefficients of the best model were investigated by multiple regression of the different equations as linear, logarithmic, exponential, power and arthenius type. All possible combinations of the variables were tested and included in the multiple regression analysis. The multiple combinations of the parameters that gave the highest R-values were eventually included in the final model.

RESULTS AND DISCUSSION

The weather conditions during the experiments were; solar radiation ranged from 203 to 932 W/m^2, wind speeds from 0.08 to 0.8 m/s while the ambient air temperature ranged from 27.2 to 35.9 ^{0}C. Mean relative humidity just above surface of the samples varied between 32.2% and 53.7%.

Drying curves

Drying curves for the three zeolite sizes are presented in Fig.2.

The moisture content decreased continuously with drying time and there was no constant rate period in drying for all the sizes. The moisture ratio also varied in the same way (Fig. 3).

All the drying process occurred in the falling rate period. In this period the zeolite surface was no longer saturated with water and drying rate was controlled by diffusion of moisture from the interior of the solid to the surface. The drying rate is higher at the beginning of the regeneration process and decreases continuously with increasing drying time as shown in fig 4.

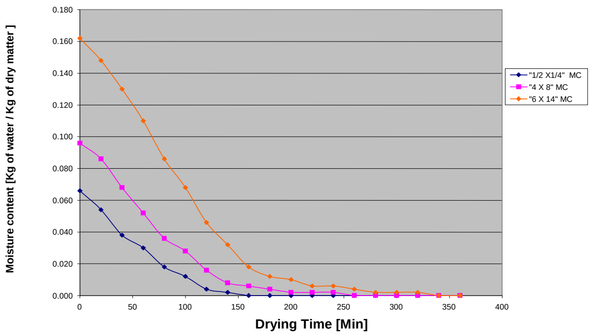

Figure 2. Variation of moisture content with zeolite drying time

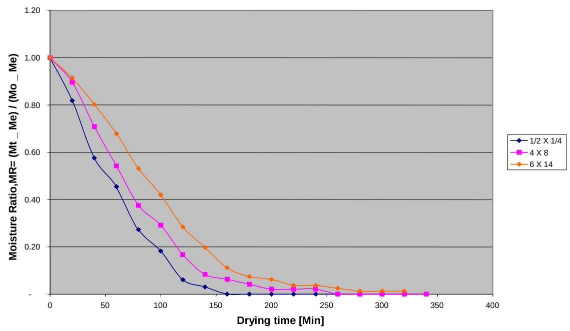

Figure 3. Variation of moisture ratio with zeolite drying time

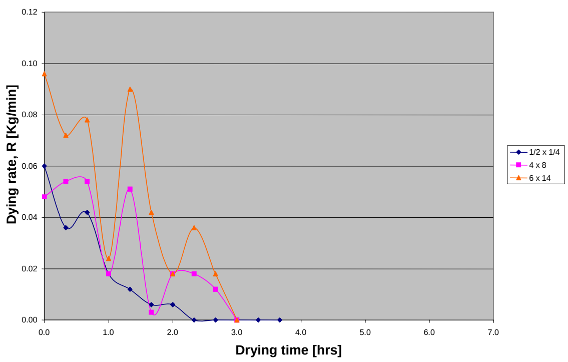

Figure 4. Variation of drying rate with zeolite drying time

As expected size 6x14 had both the highest moisture content and the fastest drying rate. This is due to the small size of the sample particles that presents a large surface area for absorption and evaporation of moisture.

Mathematical modeling of drying curves

According to the results, the Modified page I model with highest values of R (0.99628) and lowest values of $\chi 2$ (0.000018) and RMSE (0.003936) best described the drying behavior of zeolite. Through moisture ratio modeling based on the drying time, size 6x14 recorded the highest efficiency. The performance of the model is presented in Figure 5.

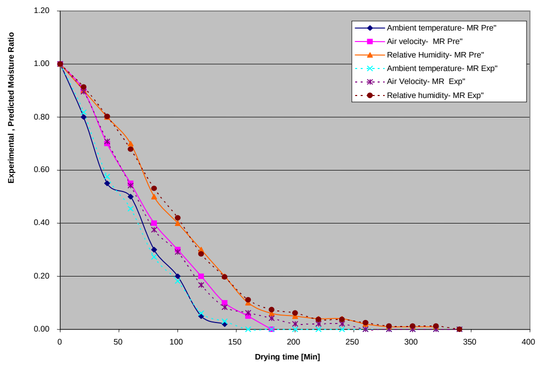

Figure 5. Variation of experimental and predicted moisture ratio with drying time at different drying conditions

It can be seen that, this model was in good agreement with the experimental results at all drying conditions. At the end of the drying period, it is evident that all the water bound by adsorption was completely removed. Furthermore, the model accuracy was evaluated by comparing the computed moisture ratio in any particular drying conditions with the observed moisture ratio. Figure 6 shows that the modified page (I) satisfactorily described zeolite drying characteristics.

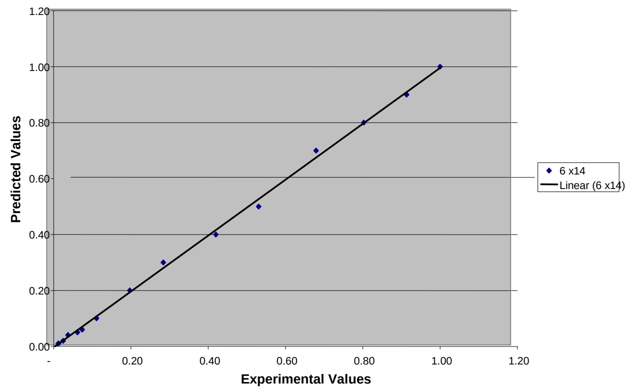

Figure 6. Comparison of Experimental and Predicted Moisture ratio values of Zeolite 6x14 for Modified Page I Model

CONCLUSIONS

In this study, regeneration of three zeolite sizes; 1/2x1/4, 4x8 and 6x14 has been successfully investigated. The drying occurred in the falling rate period showing zeolite 6x14 as the optimum size with the fastest drying rate and most efficient. Zeolite drying behavior was best described by Modified Page I model. Since zeolite size of 6 x14 proved to be the most optimum, it is the size recommended for use in a milk cooler.

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