DEVELOPMENT OF A NOVEL ENERGY-EFFICIENT ADSORPTION DRYER WITH ZEOLITE FOR FOOD PRODUCT

M. Djaeni[1], AJB van Boxtel[2]

[1]Department of Chemical Engineering, Faculty of Engineering, Diponegoro University
Jl Prof H. Soedharto, SH, Tembalang, Semarang Indonesia 50276
Tel.:+6224 7460058, E-mail: m.djaeni@undip.ac.id, mzaini98@yahoo.com
[2]Systems and Control Group
[2]Dept. Agrotechnology and Food Science, Wageningen University and Research Centre
Bornsesteg 59, 6708 PD Wageningen, The Netherlands,E-mail: ton.vanboxtel@wur.nl

Abstract: The demand of high quality dry products closing to the fresh condition increases significantly. Current drying technology have shown the significant improvement on product quality, but the breakthrough respecting to energy efficiency is scarce. Air dehumidification with adsorbent such as zeolite is a potential option to enhance the drying effectiveness. With this method, the air as drying medium is contacted with zeolite. Hence, the vapor in air is drastically reduced up to 0.1 ppm or dew point -50°C. Meanwhile the air temperature increases at the same time due to the release of adsorption heat. As a result, the dryer inlet air contains more sensible heat for drying which improves the driving force for drying as well as total energy efficiency. This paper discusses the application of adsorption dryer with zeolite for drying carrageenan and corn. The results showed the positive improvement for product quality as well as shorter drying time. However, the comprehensive feasibility study is still required before commercial application.

Keywords: adsorption, carrageenan, dehumidification, energy efficiency, zeolite,

INTRODUCTION

Drying is a significant step on food and food additive processing. The position of drying becomes more and more strategic due to the change of life style of modern people who prefer to find high quality dry products closing to the fresh or natural condition. The high quality powdered products such as soup, sauces, milk, coffee, and dried yeast are preferred due to its handy, high purity, and long storage life. An example is milk powder that can be stored for a period longer than a year instead of some weeks and for which the transportation volume is 8-10 times reduced (Birchal et al, 2005; Djaeni, 2008)

In industries, a large part of energy is spent for drying. For example, in food processing and pharmaceutical, it is about 10-20% of the total energy usage. In the wood and pulp, the consumption is higher that can round 30%. Event, at postharvest treatment, the drying takes up to 70% of total energy required (Djaeni, 2008).

At present, several drying methods are used, from traditional to modern processing: e.g. direct sun, convective, microwave and infra-red, ultra sound, centrifuge, freeze, and vacuum drying. The various designs are also applied referring to the wet product characteristic, i.e.; fluidised bed dryer for grain or powder, spray dryer for getting dry powder from liquid, rotary dryer for grains, and tray dryer for higher size material such as cacoa and vegetables. The various designs are objected to get higher efficiency as well as product quality. At high temperature drying, energy efficiency can reach 60%. Whereas, at freeze dryer, the efficiency is below 30% (Djaeni, 2008).

Until now, the drying technology is often not efficient in terms of energy consumption and has a high environmental impact due to combustion of fossil fuel or wood as energy source (Kudra and Mujumdar, 2002). The sources of fossil fuel are limited, the price of energy increases, the world wide industrial energy usage rises, and increase of greenhouse gas emission becomes a global issue due to climate change; the need for a sustainable industrial development with low capital and running cost especially for energy becomes more and more important. In this context the development of efficient drying methods with low energy consumption is an important issue for research in drying technology (Djaeni, 2008).

Higher operational temperature can be an option for increasing energy efficiency and speeding up drying time. However, the product quality will degrade especially for food, and pharmacetutical. Air dehumidification is potential for improving driving force for low or medium temperature that can be suitable for heat sensitive product (Djaeni et al, 2007; Djaeni et al, 2009).

This paper discusses the potential of adsorption dryer with zeolite efficient low or medium temperature dryer. The results involving the conceptual design, and experimental work for carrageenan dan corn are evaluated.

ADSORPTION DRYER WITH ZEOLITE

Air dehumidification by adsorbents has potential to enhance the drying efficiency (Alikhan et al, 1992; Revilla et al, 2006; Ratti, 2001; Djaeni et al, 2009). With this method, the air is dehumidified by adsorbing vapor while the air temperature increases due to the release of the adsorption heat (see Fig. 1). As a result, the dryer inlet air contains more sensible heat for drying which improves the driving force for drying as well as total energy efficiency.

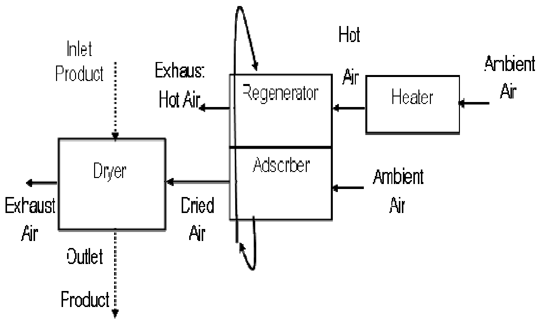


Fig. 1. A schematic diagram of an adsorption dryer with air dehumidified by an adsorbent (Djaeni, 2008)

The application of adsorption dryer has been widely investigated for many purposes (Alikhan et al, 1992; Revila et al, 2006; Ratti, 2001; Djaeni et al, 2009). Research in immersion drying of wheat with a range of adsorbing materials (synthetic zeolite, natural clay, pillared aluminum clay, and sand) showed that the zeolite has the highest moisture uptake capacity from the product (Revilla et al, 2006). By taking into account the energy for standard regeneration of adsorbents, energy savings compared to a conventional dryer are estimated to be around 10-15%. In an alternative approach, the adsorption dryer with zeolite is combined with heat recovery. The benefit of this system is that the energy in the exhaust of the regeneration unit is nearly fully recovered and can be used for other operations (Djaeni et al, 2007).

The advance modification such as multistage system is required to explore the potential of adsorption dryer with zeolite in which enhances the energy efficiency, as presented in Fig. 2 and Fig. 3 (Djaeni, 2008). The main benefit is that the energy content of the exhaust air is reused several times. Moreover, the released adsorption heat is utilized to heat the air for drying in the succeeding stages. As a consequence, product drying hardly requires heat supply. The regeneration of spent zeolite from the adsorbers requires heat supply, but with heat recovery the net energy input can be kept low (Djaeni et al, 2007).

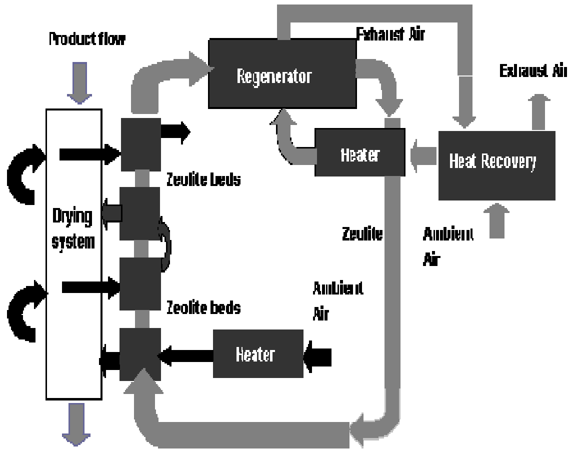


Fig. 2. Multistage adsorption dryer with zeolite (Djaeni, 2008)

Fig. 3 presents the psychometric chart analysis for single and multistage adsorption dryer with zeolite. At same evaporation duty, the single stage requires higher temperature (from point 0 until 1') or more air flow rate. The higher temperature can deal with product quality. While, the higher air capacity needs bigger size of equipment and higher power compressor. With multistage system, the product and air can contact intesively, and the evaporation duty is distributed in each stage. In addition, the exhaust heat from previous stage can be directly recovered in the next stage. Hence, lower air temperature (from 0 to 1, 2 to 3, and 4 to 5) or air flow is required

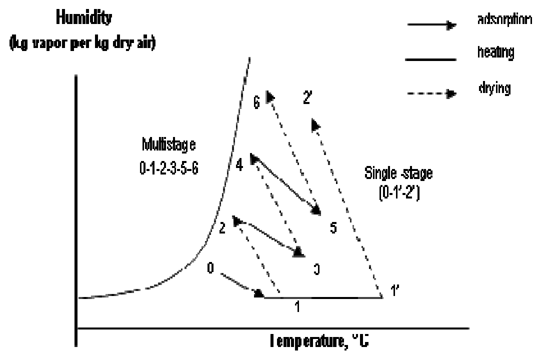


Fig.3. Psychometric analysis for single and multi stage adsorption dryer with zeolite (Djaeni, 2008)

Performance evaluation in term of energy efficiency has been done for single and multistage dryer in comparison with conventional dryer. The results indicated that the energy efficiency of adsorption dryer is higher than that of conventional dryer (see Table 1). Even one stage adsorption dryer with zeolite can compete with 4 stage conventional dryer in term of energy efficiency (Djaeni et al, 2007).

Table 1. Performance of multistage zeolite dryer with energy recovery (Djaeni et al, 2007)

Options	Number of stages	Energy efficiency (%)
Conventional dryer	1	60
	4	70
Adsorption Dryer		
Single stage	1	72[12]*
Cross-current	2	81[12]*
	3	83
	4	84
Co-current	2	78
	3	82
	4	82
Counter-current	2	80
	3	88
	4	90

*Note: the process has been proved by experimental work using imitated product

Based on Table 1, extending the number of stage increases the efficiency. However, the difference between a three and four stage system is not significant anymore. For co-current system, the input air and product streams go in the same direction through the system. The driving force decreases along the stages in which reduces energy efficiency. In contrast, for counter-current dryer, the air and product flows are in the opposite direction in which has the ability to use the air from last stage to preheat fresh product. So, the efficiency with heat recovery becomes higher close to 90% (Djaeni et al, 2007, Djaeni et al, 2008).

3. Application and Results

3.1 Case study on Drying Carrageenan

Carrageenan, a sulfated polysaccharide isolated from red seaweed, *Euchema cottoni*, is an important material in food industry and pharmaceutical. The material having high affinity of water is used as stabilizer, edible coating, and thickener for dairy, food, and pharmaceutical products (Voragen, 2002; Anonymous, 2009).

Retaining quality is important in carrageenan drying. Like in all food product a long residence time at high temperatures has a negative effect on the product quality (Thommesa et al, 2007, Falshaw et al, 2001). To reduce loss of quality it is proposed to dry with dehumidified air with zeolite (see Fig. 4).

The work was performed in a tray dryer equipped with a unit for air dehumidification with zeolite (see Fig. 4). Ambient air at flow rate 1.5 m^3/minute and relative humidity (RH) around 80% and 29-33°C passed the adsorber column (suppose A) which contains the activated natural zeolite (1.5 kg/column, particle size 2 mm). About 70-80% of water in air is removed, and the air temperature increases 5-10°C due to the adsorption heat. The dry air was heated to the drying temperature (suppose 60°C) and was fed to the dryer for evaporating water from carrageeanan with initial water content of 82%, 2 mm thickness, and 6x6 cm cross sectional size per piece. When the zeolite approaches saturation the adsorption function was switched to column B and zeolite in column A was regenerated at 200°C. Water content in carrageenan, air temperature, humidity and velocity, were measured every 15 minutes. The product quality indicators whiteness and gel strength were analyzed after drying with a brightness and color meter 68-50 (TMI, USA) and texture analyzer type TA1 (LLOYD Material Testing, UK). The process was repeated from different dryer temperature.

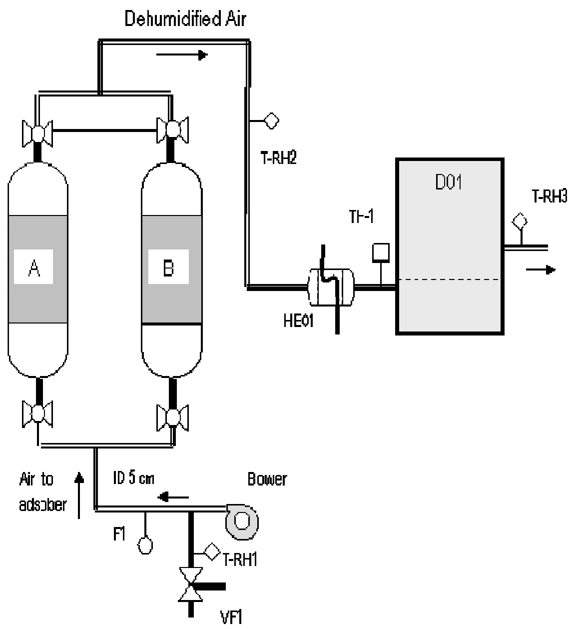
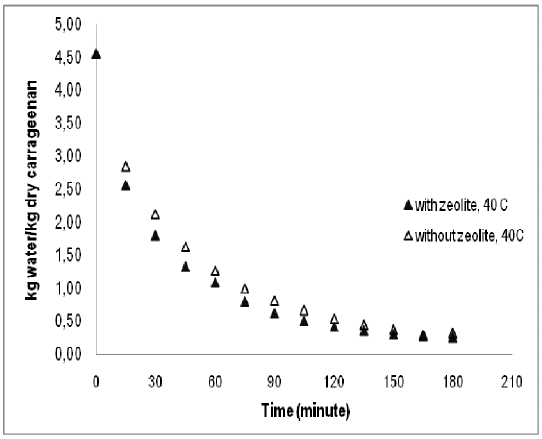


Fig. 4. Air dehumidified by zeolite for carrageenan

Experimental differences between drying with and without air dehumidification at 40 and 60°C are given in Fig. 5 (part a and b). The results show that the drying time for both temperatures is faster than that of the drying without zeolite. However, after operational time more than 120 minute, the effect is not significant anymore since the water content in carrageenan close to the equilibrium.

When the temperature higher than 100°C, the effect of dehumidified air is also not significant. This because, the equilibrium moisture in carrageenan is slighty change, only. Hence, the driving force of water transport from surface of carrageenan to the air does not improve.

a.


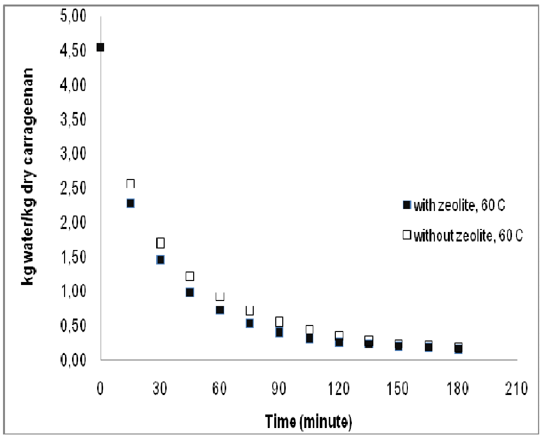
b.


Fig. 5. Comparison of drying with and without zeolite at 40 °C part a, and 60°C, part b

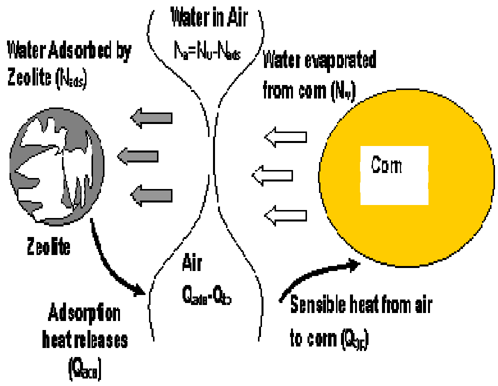
On the other hand, the carrageenan quality declines drastically at higher temperature, as indicated in product whiteness and gel strength (see Table 2). At temperature higher 80°C, polysacharide starts to decompose forming caramel. As a result, the colour becomes brown, and gel strength of product is lower. Then, this condition is not recommended.

Table 2. Quality of carrageenan at different operational temperature

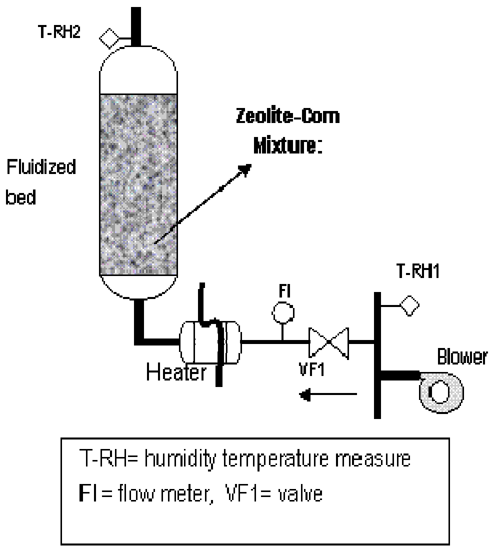
Temperature °C	Whiteness	Gel strength gr.cm^{-2}
40	53	116,0
60	50	105,1
80	44	98,8
100	40	87,5
120	36	63,0

3.2. Mixed Adsorption Drying for Corn

This design is a bit unique, since the corn as a product and zeolite was mixed in certain composition and placed in a column. The mixture was fluidized by air at different temperature. Air will evaporate water from the product, while the vapor will be adsorbed by zeolite. Hence, the de-sorption (drying) and adsorption take place simultaneously (see Fig. 6). The advantages, is the driving force for drying can be kept high until zeolite saturated by water (Djaeni, et al 2011). For initial test, the zeolite 3A from Zeochem, Switzerland and natural zeolite activated by KOH were used and compared with drying without adsorbent.



a.



b.

Fig. 6: Mixed-adsorption dryer with zeolite (a. process transport, b. operational system)

Results indicated that zeolites have given positve effect on drying time as well as corn quality. Fig. 7 presents the drying corn with and without zeolite at operational temperature 40°C. Based the figure, the driving force for drying improves significantly until water in corn reach 0,15 kg water/kg dry corn. Then, the drying time can be shorter. Here, it also indicated that the synthetic zeolite is still superior than that of natural zeolite activated by KOH.

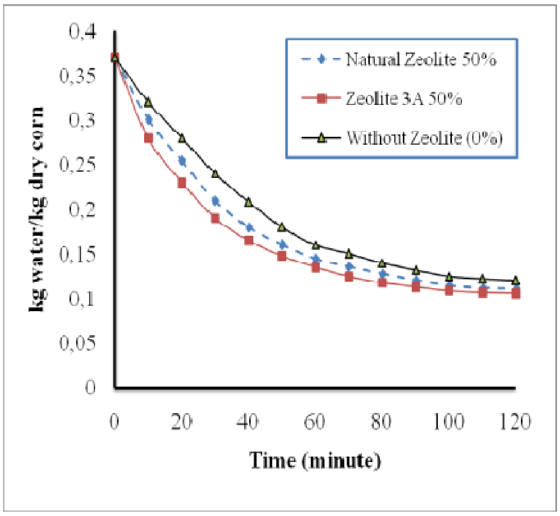


Fig. 7. Comparison of drying with and without zeolite at operational drying temperature 40°C

Meanwhile, the corn quality measured in protein content does not degrade during the process at various zeolite composition in mixture. This research can be a basic consideration for drying corn. However, further research is still required in the aspect of amino acid, corn oil, and energy efficiency

Table 3. Proximate protein at different operational drying temperature and percentage of zeolite in mixture

Zeolite	Temperature (°C)	Zeolite %	protein %
Without Zeolite	40	0	8,70
	50	0	8,60
Zeolite 3A	40	25	8,70
		50	8,80
		75	8,60
	50	25	8,40
		50	8,50
		75	8,60
Natural Zeolite	40	25	8,80
		50	8,60
		75	8,80
	50	25	8,40
		50	8,60
		75	8,60

CONCLUSIONS

The works confirm that the adsorption dryer with zeolite is potential for heat sensitive food product in term of product quality and energy efficiency. However, the high energy for regeneration still becomes a next problem to be overcome. Combining with energy recovery system makes the adsorption drying be more interesting. Until now, the realistic pilot process for more and more food products are needed to ensure the reliability of process. In addition, the comprehensive feasibility study involving important factors such as investment, total running cost, and added value of high quality product, also must be done before industrial application.

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