

# HEAT EFFICIENCY OF MULTI-STAGE ZEOLITE SYSTEMS FOR LOW TEMPERATURE DRYING

M. Djaeni, G. van Straten, A.J.B. van Boxtel

*Systems And Control Group, Wageningen University, PO Box 17, 6700 AA Wageningen  
The Netherlands, email:mohamad.djaeni@wur.nl*

P.V. BARTELS, J.P.M. SANDERS

*Agrotechnology And Food Science Group, Wageningen University, PO Box 17, 6700 AA  
Wageningen The Netherlands,*

This work presents the evaluation of multi-stage adsorption dryers with air dehumidification by zeolite and alumina pillared clay. In a multi-stage dryer product is dried in a number of succeeding stages and for each stage the air is dehumidified by the adsorbent. The exhaust air from each stage is reused for product drying in a following stage after passing a bed with adsorbent. The heat efficiency of the drying system is evaluated and compared with a conventional drying system using air dehumidified by condensation. The evaluation concerns the effect of stage number, inlet dryer temperatures 10-50°C and inlet ambient air 10-25°C. Results show that the performance of the multi-stage adsorption dryers increases with the number of stages and a three stage system is economically most promising. For varying ambient air conditions, zeolite as adsorbent is the most favourable.

## 1. Background

Low temperature drying in the temperature range 10-50°C is favorable to limit product deterioration such as browning, shrinkage, structure deformation, the loss of valuable organic content is inhibited and product quality is retained [1]. However, the processes are expensive, need long operational time, and are complex if applied under vacuum and/or refrigerating conditions. Moreover, heat efficiency is below that for high temperature drying.

Condensation of water from air by cooling the air below dew point temperature is a common approach for air dehumidification in low temperature dryers. Air dehumidification by adsorbents as zeolites and pillared clay can also be applied to reduce the water content in air, and improves dryer efficiency [2]. A simulation study of single and multi-stage zeolite drying for the temperature range 50-90°C showed that a heat efficiency of 75-90% can be achieved, and in special configurations for heat recovery the efficiency may go up to 120% [3,4].

This paper presents the potential of low temperature dryers using zeolite and alumina pillared clay for air dehumidification compared to condensation dryers.

## 2. Methodology

The heat efficiency is evaluated for dryers operating in the temperature range 10-50°C and using ambient air conditions throughout the seasons (see table 1). Air is dehumidified by zeolite, alumina pillared clay and by a condensation dryer. The material properties, assumptions and steady state mass and heat balances has been given in previous work of Djaeni et al [3] and Yamanaka et al [5].

Table 1: Average ambient Dutch air conditions in different seasons

Temperature /Relative Humidity	10°C /80%	15°C /70%	20°C /60%	25°C /50%
Humidity kg vapor/kg dry air	0.006	0.007	0.009	0.01

### 2.1. Process Description

#### 2.1.1. Conventional condensation dryer

Figure 1 presents the configuration of the condensation dryer. Ambient air is cooled below its dew point and water condenses in the condenser. The cooled air from the condenser is used either for cooling the air in chiller (if the ambient air temperature is above the exhaust air from dryer) or for cooling the recycle air from the dryer (if the ambient air temperature is below the exhaust air from dryer). The dried air is then heated in the heater to the inlet dryer temperature conditions.

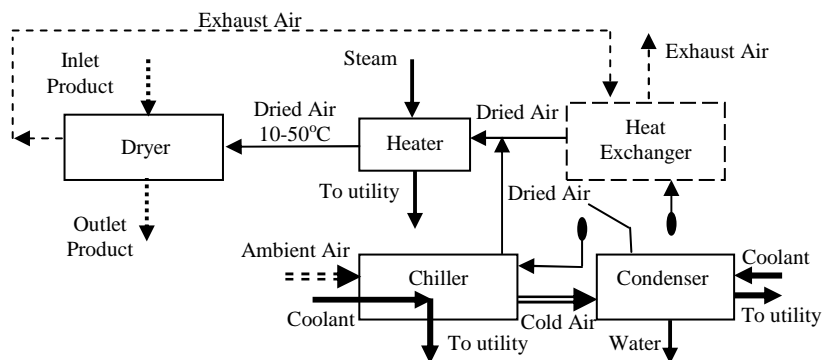


Figure 1: Low temperature condensation dryer

### 2.1.2. Multi-stage adsorbent dryer

The counter current multi-stage dryer as illustrated in figure 2 is considered [4]. Ambient air is dehumidified in the first adsorber till 90% and 70% below the input value by using zeolite and alumina pillared clay respectively. In the adsorber the air temperature increases due to the release of the adsorption heat. Depending on the drying conditions, the dried air is cooled or heated in the conditioner before using in dryer. Meanwhile, saturated adsorbent is sent to the regenerator to release water in the temperature range 120-300°C. The desorption heat is 3200 kJ/kg water for zeolite and 2600 kJ/kg water for alumina pillared clay [3,4,5]. For the next stage, air exiting dryer and regenerator is re-processed for use in the next stage. The product comes from adjacent dryer up stream and is dried further in the current stage.

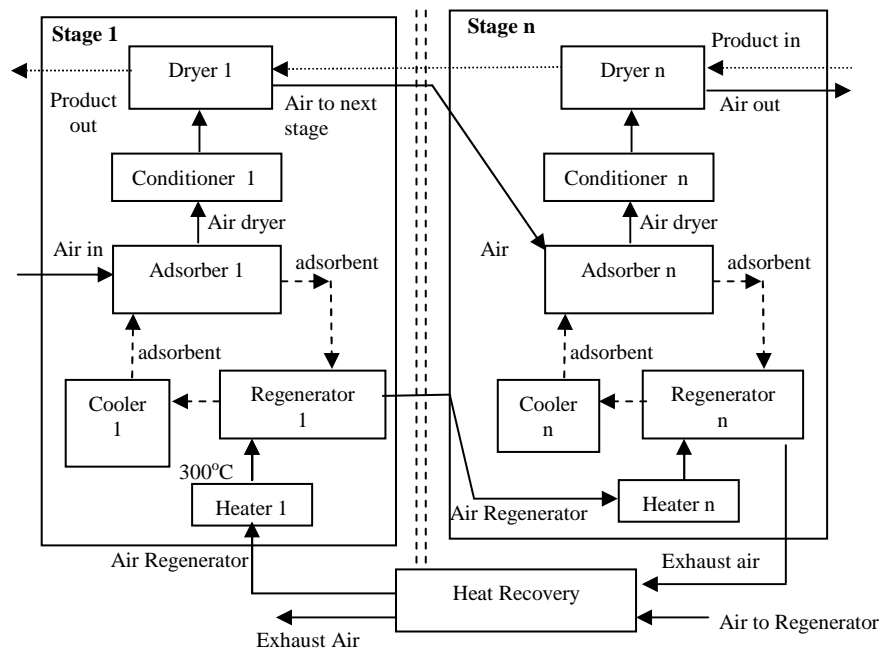


Figure 2: Multi-stage counter-current low temperature adsorbent dryer

### 2.2. Heat recovery

The heat recovery unit used for both the condensation and zeolite dryers [3,4,7] is based on the pinch concept from Linnhoff [6]. In this work, a basic pinch procedure is used to recover heat from the exhaust air leaving the last stage

regenerator and the adsorbent flow exiting each regenerator. The heat is used to heat up air before entering heater 1, and the air leaving the first stage of adsorber if its temperature is below the design condition. The heat transfer estimation used minimum temperature difference 10°C.

### 2.3. Performance evaluation

The overall efficiency is given as [3,4]:

$$\eta = \frac{Q_{evap}}{Q_{req}} 100\% \quad (1)$$

$$Q_{evap} = F_p (X_{p,in} - X_{p,out}) \Delta H_v \quad (2)$$

$$Q_{req} = \sum_{i=0}^{i=n} (Q_{he})_i - Q_{rec} \quad (3)$$

where  $F_p$  is the mass flow of dry product (kg/hr),  $X_{p,in}$  and  $X_{p,out}$  are the product water content towards and from the system (kg water/kg dry product),  $\Delta H_v$  is the latent heat of water evaporation (kJ/kg),  $Q_{evap}$ ,  $Q_{rec}$ ,  $Q_{req}$ ,  $Q_{he}$  are total heat for water evaporation, heat recovered, heat consumed, and the heat used in heat exchangers (kJ/hr),  $\eta$  is the heat efficiency (%), and subscripts of  $i$  and  $n$  refer to the stage number and the total number of stages.

## 3. Result and discussion

### 3.1. Effect of temperature and number of stages on efficiency

Figure 3 shows that the heat efficiency of the adsorbent dryer increases with increasing temperature and stage number. For temperatures below 40°C, the stage number has a significant effect on the heat efficiency. Above three stages improvement is marginal and therefore a three stage dryer is economically most promising for every temperature level.

Alumina pillared clay has a limited capacity to adsorb water from air. As a result the heat efficiency of alumina pillared clay is 5-10% below that of the dryer using zeolite. Moreover, the dryer using alumina pillared clay can not operate below 20°C.

The system recovers hot streams with higher temperature only. Therefore, the heat in the air leaving adsorber can not be recovered since all cold streams need higher temperature levels. Adsorption heat obtained in the adsorbers is in the most cases not used.

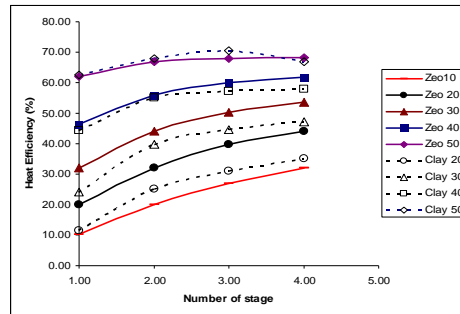


Figure 3: Heat efficiency for the multi-stage dryers as a function of the number of stages and drying temperature

### 3.2 Varying ambient conditions

Figure 4 presents the heat efficiency of the condensation dryer and the three stage adsorbent dryers. The results show that for the lower ambient temperatures, the heat efficiency of the adsorbent dryers surmounts that of the condensation dryer. This positive effect is result of the lower amount of heat released in the adsorber. The lower temperatures and the humidity values (see table 1) make that less water is adsorbed and as a result the dried air from the adsorber requires not much additional heat. In addition, the load of regenerator decreases as less water has to be removed. Thus, two advantages are obtained: less heat for zeolite regeneration and more heat can be recovered.

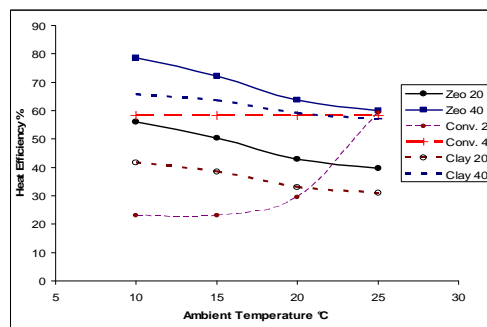


Figure 4: The effect of ambient temperature on heat efficiency

In contrast, for inlet dryer temperature below 40°C, the heat efficiency of the condensation dryer decreases as well as the decrease of inlet ambient temperature. Ambient air as hot stream source has a lower temperature level which limits the heat recovery potential. Whereas, at higher inlet dryer

temperatures, the system uses exhaust air from dryer as hot stream source that has constant temperature level. Hence, the efficiency can be kept at constant value.

#### 4. Conclusion

The heat efficiency of low temperature dryers using air dehumidified by zeolite is more profitable compared to dryers using alumina pillared clay at dryer temperatures below 40°C. At higher temperatures, the performance is similar. Compared to dryers with a condensation system for air dehumidification, dryers using adsorbents are superior at ambient temperature below 20°C. The difference in heat efficiency is the highest for low ambient temperatures. Even for ambient temperatures of 10°C, the efficiency of adsorbent dryers is 20-40% higher than that of condensation dryers.

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