

Air Drying by Adsorption on Zeolite Type Desiccants

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Abstract: This paper presents the results of an experimental study of mass transfer at air drying by adsorption on silica gel or zeolite grains, in fixed bed. Moist air at different temperatures, flow rates and relative humidity values was used. The process efficiency was established by gravimetric determination of the moisture retained by the solid material or by measuring the air humidity at the exit of the layer, respectively. The pressure loss through the fixed bed was also measured.

Keywords: adsorption, air drying, mass transfer, zeolite

1. Introduction

Gas drying by adsorption has undergone considerable development in the last few years as a consequence of achievements in the production of adsorbent materials (silica gel or activated alumina impregnated with CaCl_2 , porous host matrices and composite materials impregnated with a hygroscopic substance, usually inorganic salts- CaCl_2 , LiCl , LiBr) [1-3].

A particular structural feature of zeolites relative to other aluminosilicate materials, and other crystalline materials in general, is the existence of channels and/or cavities linked by channels. The size and shape of channels/cavities in zeolites therefore define the structural parameters of a given type of zeolite.

Zeolites are among the most important inorganic cation exchangers. The aluminosilicate structure is negatively charged and attracts cations that come to reside inside the pores and channels. Zeolites have large empty spaces, or cages, within their structures that can accommodate large cations (Na^+ , K^+ , Ca^{2+}) and even relatively large molecules and cationic groups, such as water, ammonia, carbonate ions and nitrate ions. The basic structure of zeolites is biologically neutral. The ion-exchange process is reversible [4].

2. Experimental

In the experimental measurements two types of adsorbents were used:

- spherical silica gel grains with an average diameter of 2.5 mm, apparent density 730 kg/m^3 , specific surface - $650 \text{ m}^2/\text{g}$, void fraction - 0.36 mL/g [5];
- zeolite grains of different sizes;

The experiments were performed at two temperature values of the water used for moistening the air: 24°C and 50°C respectively, and three air flow rate values: 0.8; 1 and $1.2 \text{ m}^3/\text{h}$. In all cases the height of the adsorbent layer was 180 mm.

The experimental installation includes:

- a cylindrical vertical tube with diameter $d_1=33 \text{ mm}$ and height $h_1 = 200 \text{ mm}$, provided on half of the height

with glass Raschig rings ($d_2 \times h_2 \times \delta = 8 \times 8 \times 1 \text{ mm}$), having the role of an air moistening zone. At the bottom, the tube is provided with a central tube having the diameter of 16 mm through which the moist air is moving. This air is obtained by bubbling atmospheric air in water. At the top, the tube is provided with a thermometer and, respectively, a connecting tube through which the moist air is moving to the drying zone;

- a tube with diameter $d_i = 18 \text{ mm}$ and length $l = 300 \text{ mm}$ in which the adsorbent material is placed and air drying takes place. The extremity where the air ejecting takes place (after the adsorbent layer) is provided with a tube that sucks the air and makes the connection with the psychrometer

- a R-300 Boeco type vacuum pump that ensures the air flow necessary for bubbling in water, flow measured by a rotameter;

- psychrometer;
- analytical balance;

- manometer attached to the tube where drying occurs, to measure the pressure loss through the adsorbent layer.

To determine the effectiveness of the adsorbent type used, it was proceeded as follows: the moist air flows upward through the glass tube centrally placed and crosses the Raschig rings packing. Air temperature is measured at the exit of the packing layer in order to calculate the initial absolute humidity. The air is then placed in the drying tube being forced to pass through the adsorbent layer. When leaving the adsorbent layer, the air is drawn into a psychrometer which enables the determination of vapor pressure and relative humidity. From these two quantities it was calculated the value of the absolute humidity x and the enthalpy H of the final air.

3. Results and Discussion

The characterization of the adsorbent material was made by measuring the apparent density (Table 1), as well as by establishing its grain size - sift analysis method using sieves having standard mesh size [6]. The obtained granulometric curves are shown in Figure 1.

TABLE 1. The apparent density of the adsorbent samples

| Sample | Apparent density, g/cm ³ |
|------------|-------------------------------------|
| Silica gel | 0.730 |
| Zeolite Z1 | 0.808 |
| Zeolite Z2 | 0.800 |
| Zeolite Z3 | 0.824 |
| Zeolite Z4 | 0.948 |

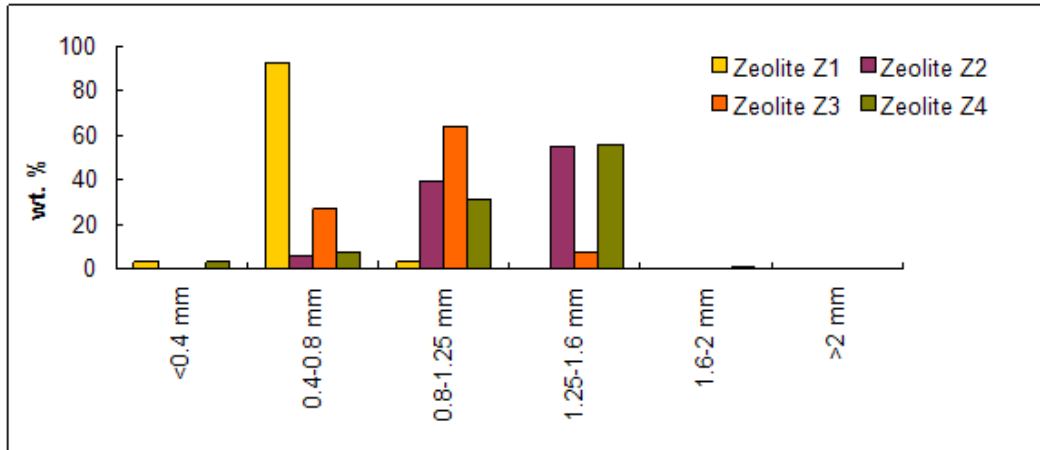


Figure 1. Granulometric curves for the zeolite samples

Absolute humidity - x - defined as the amount of vapor contained in the amount of dry air was calculated with rel. (1) [7]:

$$x = 0.622 \cdot \frac{p_{vap}}{P - p_{vap}} \quad (1)$$

Relative humidity - ϕ - defined as the ratio between the real vapor pressure (p_{vap}) and the saturation pressure (maximum, p_{sat}) at the temperature of the moist air, was calculated with rel. (2) [7]:

$$\phi = \frac{p_{vap}}{p_{sat}} \quad (2)$$

The pressure of the water vapor at different temperatures was calculated using equation (3):

$$p_{vap} = 610.78 \cdot \exp\left(\frac{17.294 \cdot t}{238.3 + t}\right) \quad (3)$$

p_{vap} is expressed in Pa when temperature is expressed in °C.

The enthalpy of moist air H (kJ/kg moist air) was calculated using equation (4):

$$H = (1.01 + 1.97 \cdot x) \cdot t + 2493 \cdot x \quad (4)$$

where x is the absolute humidity of the air and t its temperature [7].

TABLE 2. The properties of atmospheric air

| Adsorbent | t_{moist} , °C | t_{dry} , °C | p_{vap} , mmHg | p_{sat} , mmHg | x , g/kg | ϕ , % | H , kJ/kg |
|------------|------------------|----------------|------------------|------------------|------------|------------|-------------|
| Silica gel | 18.0 | 25.0 | 15.42 | 23.65 | 12.88 | 65.2 | 58.0 |
| Z4 | 18.7 | 25.6 | 16.11 | 24.5 | 13.47 | 65.7 | 60.1 |
| Z3 | 20.1 | 26.3 | 17.57 | 25.54 | 14.72 | 68.8 | 64.0 |
| Z2 | 17.7 | 24.0 | 15.13 | 22.28 | 12.63 | 67.9 | 56.3 |

At the beginning of each set of experimental measurements (before saturation with water vapor and the use of desiccant materials for dehumidification), the properties of atmospheric air were established using the psychrometer, Table 2.

The moist air obtained by bubbling atmospheric air in water, before entering into desiccant layer, is considered saturated ($\phi = 100$). At the exit of the adsorbent layer, due to the retention of water vapor, the air becomes unsaturated ($\phi < 100$).

The values of vapor/saturation pressure were calculated with rel. (3), and with these values was calculated the absolute humidity of the initial air (before the entry in the layer based on the temperature indicated by the thermometer placed at the exit of the wetting zone) and final air (after leaving the layer, depending on the temperatures indicated by the thermometers of the psychrometer), respectively.

For the case of using silica gel as adsorbent, the obtained values are presented in Tables 3a and 3b.

In Figure 2 is represented the evolution of air humidity when it is drying on silica gel, relating the amount of water retained ($\Delta x = x_i - x_f$) to 100 g adsorbent.

When using zeolite Z3 as adsorbent, the obtained values are presented in Tables 4a and 4b.

TABLE 3a. Air drying on silica gel layer ($t_{water}=24^{\circ}C$)

| Air flow, m^3/h | Initial air | | | Final air | | | |
|-------------------|----------------------------|------------|---------|-----------------------------|-----------------------------|------------|---------|
| | $p_{vap}=p_{sat}$, mmHg | ϕ , % | x, g/kg | P_{vap} | P_{sat} | ϕ , % | x, g/kg |
| | | | | mm Hg | | | |
| 0.8 | 23.15($t=24.2^{\circ}C$) | 100 | 19.54 | 17.02 ($t=19.5^{\circ}C$) | 24.95 ($t=25.5^{\circ}C$) | 68.2 | 14.25 |
| 1.0 | 22.47($t=23.7^{\circ}C$) | | 18.95 | 18.28 ($t=20.5^{\circ}C$) | 24.95 ($t=25.5^{\circ}C$) | 73.3 | 15.33 |
| 1.2 | 22.2 ($t=23.5^{\circ}C$) | | 18.71 | 18.28 ($t=20.5^{\circ}C$) | 24.95 ($t=25.5^{\circ}C$) | 73.3 | 15.33 |

TABLE 3b. Air drying on silica gel layer ($t_{water}=50^{\circ}C$)

| Air flow, m^3/h | Initial air | | | Final air | | | |
|-------------------|---------------------------|------------|---------|-----------------------------|-----------------------------|------------|---------|
| | $p_{vap}=p_{sat}$, mmHg | ϕ , % | x, g/kg | P_{vap} | P_{sat} | ϕ , % | x, g/kg |
| | | | | mm Hg | | | |
| 0.8 | 45.7($t=39^{\circ}C$) | 100 | 39.79 | 20.21 ($t=22^{\circ}C$) | 27.49 ($t=27.3^{\circ}C$) | 73.5 | 17.00 |
| 1.0 | 45.2($t=38.7^{\circ}C$) | | 39.33 | 20.61 ($t=22.3^{\circ}C$) | 28.94 ($t=28.3^{\circ}C$) | 71.2 | 17.34 |
| 1.2 | 42.4 ($t=37^{\circ}C$) | | 36.75 | 19.82 ($t=21.7^{\circ}C$) | 28.07 ($t=27.7^{\circ}C$) | 70.6 | 16.65 |

TABLE 4a. Air drying on zeolite Z3 layer ($t_{water}=24^{\circ}C$)

| Air flow, m^3/h | Initial air | | | Final air | | | |
|-------------------|-----------------------------|------------|---------|-----------------------------|-----------------------------|------------|---------|
| | $p_{vap}=p_{sat}$, mmHg | ϕ , % | x, g/kg | P_{vap} | P_{sat} | ϕ , % | x, g/kg |
| | | | | mm Hg | | | |
| 0.3 | 27.35 ($t=27.2^{\circ}C$) | 100 | 23.22 | 21.14 ($t=22.7^{\circ}C$) | 28.5($t=28^{\circ}C$) | 74.2 | 17.8 |
| 0.6 | 25.65 ($t=26^{\circ}C$) | | 21.72 | 21 ($t=22.6^{\circ}C$) | 27.92 ($t=27.6^{\circ}C$) | 75.2 | 17.67 |
| 0.8 | 25.09 ($t=25.6^{\circ}C$) | | 21.23 | 22.21 ($t=23.5^{\circ}C$) | 28.94 ($t=28.3^{\circ}C$) | 76.7 | 18.72 |

TABLE 4b. Air drying on zeolite Z3 layer($t_{water}=50^{\circ}C$)

| Air flow, m^3/h | Initial air | | | Final air | | | |
|-------------------|-----------------------------|------------|---------|-----------------------------|-----------------------------|------------|---------|
| | $p_{vap}=p_{sat}$, mmHg | ϕ , % | x, g/kg | P_{vap} | P_{sat} | ϕ , % | x, g/kg |
| | | | | mm Hg | | | |
| 0.3 | 41.1($t=36.2^{\circ}C$) | 100 | 35.56 | 21.53 ($t=23^{\circ}C$) | 28.79 ($t=28.2^{\circ}C$) | 74.8 | 18.13 |
| 0.6 | 40.45 ($t=35.8^{\circ}C$) | | 34.97 | 21.94 ($t=23.3^{\circ}C$) | 29.08 ($t=28.4^{\circ}C$) | 75.4 | 18.49 |
| 0.8 | 39.81 ($t=35.4^{\circ}C$) | | 34.38 | 22 ($t=23.3^{\circ}C$) | 28.35 ($t=27.9^{\circ}C$) | 77.6 | 18.53 |

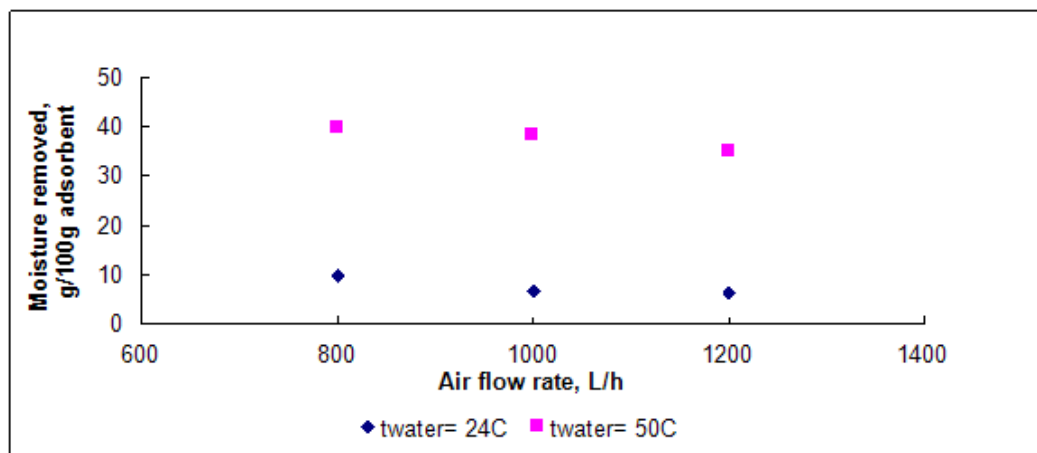
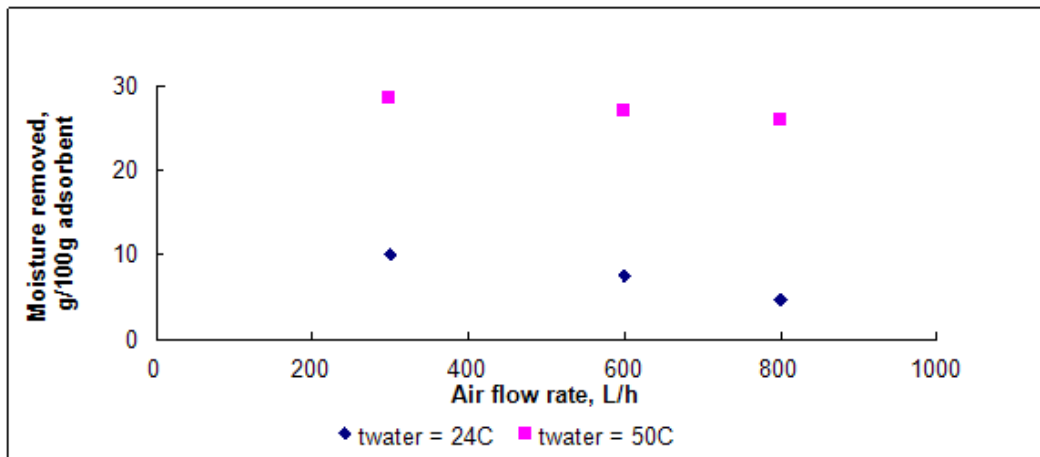
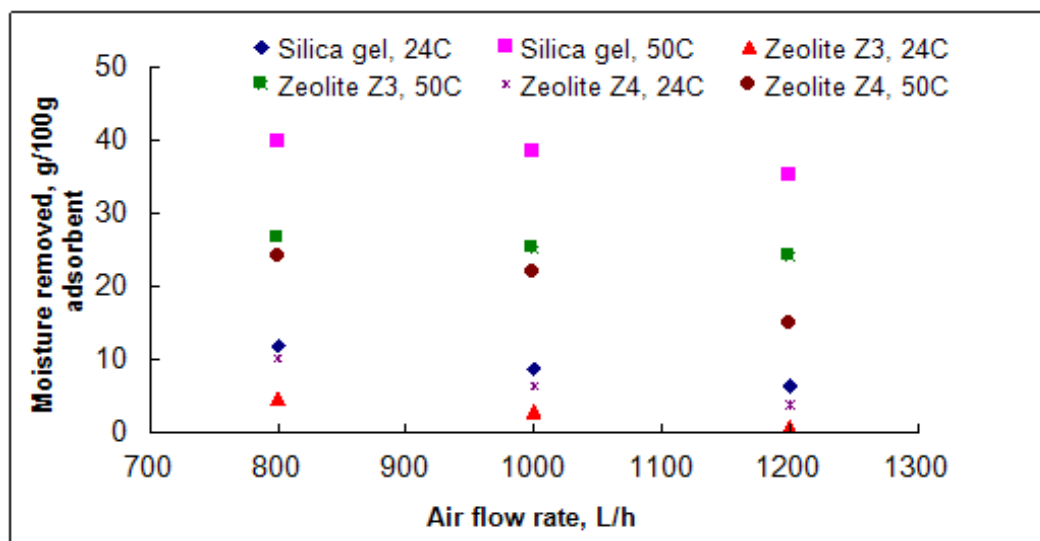


Figure 2. $\Delta x = f(V_{air})$ dependence for air drying on silicagel layer

Figure 3. . $\Delta x = f(V_{air})$ dependence for air drying on zeolite Z3 layerFigure 4. . $\Delta x = f(V_{air})$ dependence for air drying on different adsorbents

In Figure 3 is represented the evolution of air humidity when it is drying on zeolite Z3.

The degree of moisture retention, by comparison, for three types of adsorbents is shown in Figure 4.

4. Conclusions

In all cases, the amount of moisture retained by the adsorbent material decreases with the increase of air flow rate. Also, at the same rate of the air bubbled into the water, the increase of water temperature leads to a stronger air enrichment in vapor, but also to a greater retention of moisture on adsorbent material;

In the case of sample Z2 ($d_m = 0.805$ mm) the experiments could only be made at air flow rates lower than $0.8 \text{ m}^3/\text{h}$, due to the occurrence of the pneumatic conveying of the adsorbent material. For the same reason it could not be used for drying zeolite Z1 ($d_m = 0.606$ mm).

REFERENCES

- Petrescu S., Horoba L.D., Galben I.G. and Secula M.S., *Rev.Chim. (Bucharest)*, 60(3), **2009**, 308-312.
- Secula M.S., Spiridon M., Solomon I. and Petrescu S., *Rev.Chim. (Bucharest)*, 62(12), **2011**, 1175-1179.
- Spiridon M., Hauta O-R., Secula M.S. and Petrescu S., *Rev.Chim. (Bucharest)*, 63(7), **2012**, 711-714.
- Auerbach S.M., Carrado K.A. and Dutta P.K., *Handbook of Zeolite Science and Technology*, Marcel Dekker, Inc., NY, **2003**.
- Ng K.C., Chua H.T., Chung C.Y., Loke C.H., Kashiwagi T., Akisawa A. and Saha B.B., *Appl. Therm. Eng.*, 21, **2001**, 1631-1642.
- <http://cadredidactice.ub.ro/gheorghesimionescu/files/2011/03/clasarea-substantelor-minerale-analiza-granulometrica-a-nisipurilor.pdf>.
- Tamas A. and Minea R., *Uscarea-Aspecte teoretice si aplicative*, Ed. Politehnica, Timisoara, **2006**.

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