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PERFORMANCE OF A SMALL LOCALLY MADE MOIST AIR SILICA GEL DEHUMIDIFIER

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ABSTRACT

Sorbent materials are widely used to remove water vapour from moist air, the final water vapour content of the moist air depending on its use. In this paper, a small drier to dry 1.20 kg/min (0.171 m^3/min) of saturated moist air at 600 kPa (abs) and 25°C has been designed and constructed. The sorbent used was locally available commercially dry silica gel. Experiments were carried out for a given period of time (1.5 hour) of operation of the drier under the above conditions. Calculated and experimental values of the specific humidity of the moist air and the moisture content of the silica gel per unit mass of dry silica gel have been presented both graphically and in tabular forms, for different bed thickness in the direction of the airflow. Calculated and experimental results have been found to be in close agreement with each other. Some important conclusions and recommendations are also given. The total cost involved for making the drier was about BD Tk. 4,000 (US$ 70) only.

Keywords: Dehumidifier, moist air, reactivation cycle, drying time**.**

INTRODUCTION:

Atmospheric air always contains a certain amount of water vapour. Compressed dry air (which is free of water vapour) is used for operating a vartex tube, spot cooling in precision equipment manufacturing, drugs manufacturing and in some chemical industries. Dry air can be obtained by separating the water vapour from the moist air by some sorbent material.

A sorbent material is one that reduces the vapour pressure of water contained by it to a value lower than that of saturated water at the came temperature. Actually a sorbent material has affinity for molecules of certain gases and vapour. Because of strong surface force of the sorbent material, the vapour molecules are condensed to liquid and then adhering to it. A common adsorbent material, used frequently for draying of moist air, is silica gel. Here adsorption process is strictly of physical nature where the silica gel does not change chemically. The heat liberated in the sorption process is of the same order of magnitude as the heat of condensation of the vapour. For the present work, silica gel has been used to dry moist air, although a number of other sorbent materials are in existence. This is because silica gel has a high retention capacity for the water adsorbed, chemically stable, physically rugged, capable of reactivation at reasonable temperature for reuse, and available at reasonable costs.

Commercially dry silica gel (containing about 5% of water by weight) has been used in the present work. Some characteristics of commercially dry silica gel are shown in Fig. 1 and Fig. 2.

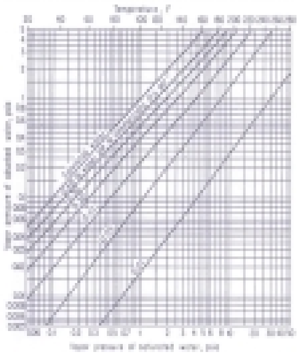

Fig. 1

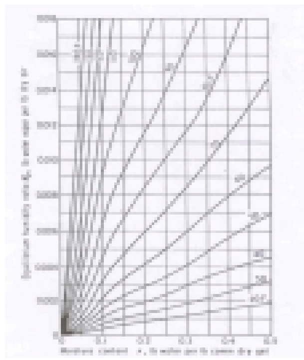

Fig. 2

THEORETICAL CONSIDERATIONS

As the sorption process progresses, the heat of condensation of the adsorbed moisture is released, and hence the temperature of both the silica gel and the moist air rises up as the air flows through the silica-gel bed. However, for silica gel this temperature rise is not large so that we shall assume the adsorbent bed is stationary and isothermal, although without internal cooling of the gel bed the system is nearer to adiabatic than isothermal. Theoretical analysis of dehumidification of moist air by an adiabatic adsorbent bed is much more complicated than when the bed is assumed isothermal. Although assumption of an isothermal adsorbent bed will introduce some error, this analysis is expected to be useful in designing a drier for satisfactory drying of moist air. The present work shows satisfactory agreement between theoretical predictions and experimental results, even when the drier is assumed as an isothermal stationary adsorbent bed. It will further be assumed in the analysis that the bed is composed of small granules of the adsorbent materials only, and that no air-filled voids between the granules exist. Taking unit area of the bed perpendicular to the direction of the airflow (Fig. 3), the following equations* can be written.

$$\frac{\partial W}{\partial x} = -\frac{h_D A_v}{G_a}(W - W_e) \quad \text{……….(1)}$$

$$\frac{\partial \alpha}{\partial \tau} = -\frac{h_D A_v}{\rho_A}(W - W_e) \quad \text{……….(2)}$$

From Fig. 2, assuming linear variation of W with α,

$$W_e = C\alpha \quad \text{……… (3)}$$

Hence (1), (2), (3) give

$$\frac{\partial W}{\partial x} = -K_1 \; (W - C_\alpha) \quad \text{..(4)}$$

$$\frac{\partial \alpha}{\partial \tau} = -K_2 \; \left(\frac{W}{C} - \alpha\right) \quad \text{...(5)}$$

where, $K_1 = \dfrac{h_D A_v}{G_A}$ … (6)

$$K_2 = \frac{h_D A_v C}{\rho_A} \quad \text{….(7)}$$

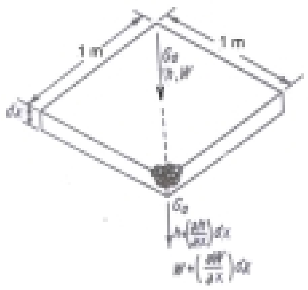

Fig. 3

In the above, C, K_1 and K_2 are constants for a particular design.

Hougen and Marshall have given solutions of Eqs (4) and (5) for the following conditions.

(i) the inlet air specific humidity (at x = 0) W_1 is constant for all τ.

(ii) α = o for all values of x for τ = 0. The solutions are

$$\frac{W}{W_1} = 1 - e^{-K_2 \tau} \int_o^{K_1 x} e^{-K_1 x} \left[J_o \left(2i \sqrt{K_1 x \; K_2 \tau}\right)\right] d\,(K_1 x) \quad \text{………. . 8}$$

$$\frac{\alpha}{\alpha_1} = e^{-K_1 x} \int_o^{K_2 \tau} e^{-K_2 \tau} \left[J_o \left(2i \sqrt{K_1 x \; K_2 \tau}\right)\right] d\,(K_2 \tau) \quad \text{……… 9}$$

* For detailed analysis, see Ref (1)

$\dfrac{W}{W_1}$ and $\dfrac{\alpha}{\alpha_1}$, both as functions of K_1 x and $K_2\tau$ have been plotted by Furnas (Ref. 5) using equations (8) and (9), and are shown in Fig. 4 and Fig. 5.

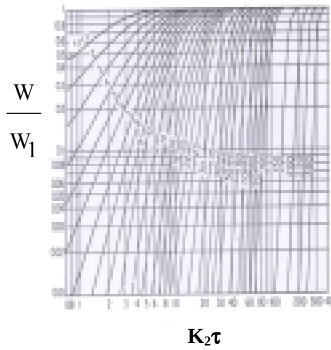

Fig. 4

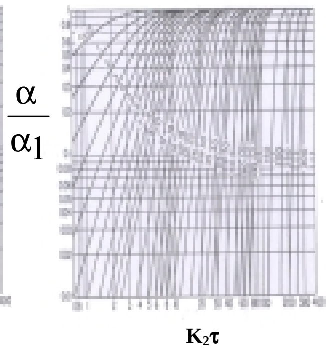

Fig. 5

Hougen and Marshall have suggested the following semi-empirical equation for adsorption of water vapour from moist air by commercially dry silica gel.

$$h_D = 0.703 \; G_a \; \left(\frac{D_p G_a}{\mu_a}\right)^{-0.51} \quad \text{…………(10)}$$

The same two authors have also given the values of D_p A_v for commercial silica gel, which are shown in the Table 1. This Table has been taken from Ref. (6).

TABLE -1

Dimensional Properties of Silica Gel Pellets (2 – 28 tyler mesh size)

Tyler Mesh Size	D_p, m	Av, m^2 / m^3
2 – 4	.00671	384
4 – 6	0.00390	663
6 – 8	0.00277	932
8 – 10	0.00193	1,335
10 – 12	0.00176	1,470
12 – 14	0.00136	1,890
14 – 20	0.00097	2,641
20 – 28	0.00069	3,740

The primary aim of the present work is to determine the psychrometric state of the moist air as it flows through the silica gel bed of the drier, for a given inlet and outlet conditions of the moist air; and to compare the calculated results with the measured values. We shall consider the following data.

Inner diameter of the drier cylinder = 10 cm.
Maximum air velocity through the drier bed: 20 m/min
Mass flow rate of the air: 1.20 kg/min (as available in the laboratory of the IUT)
Duration of operation of the drier : 1.50 hour
Pressure and temperature of air to be dried : 600 kPa (abs) and 25^{o}C (compressed air is normally available at 600 kPa and 25^{o}C in laboratories).

Final specific humidity of the air after drying = 0.0001 kg_w/kg_a

We have, P_{a1} = 600 kPa (abs), T_{a1} = 298 K.
From Fig.7, $W_1 = 0.0040\ kg_w/kg_a$.

$$\rho_{a1} = \frac{p_{a1}}{R_a\, T_{a1}} = \frac{600}{0.287 \times 298} = 7.015\ \frac{kg_a}{m^3}$$

(Assuming air as perfect gas at 600 kPa and 25 ^{0}C).

$$m_a = \frac{1.20}{60} = 0.02\ kg_a/s.$$

$$Q_{a1} = \frac{m_a}{\rho_{a,o}} = \frac{0.02}{7.015} = 0.00285\ m^3/s.$$

Maximum air velocity, $V_a = \frac{20}{60} = 0.333$ m/s.

Area of cross-section of the drier

$$A = \frac{0.00285}{0.333} = 0.00856\ m^2$$

$$\therefore\ D = \sqrt{0.00856 \times \frac{4}{\Pi}} = 0.1044 \text{ m (say 10 cm).}$$

A section of the drier with major dimensions are shown in Fig. 6. The pressure regulating valve has been installed to perform experiments at various inlet pressures.

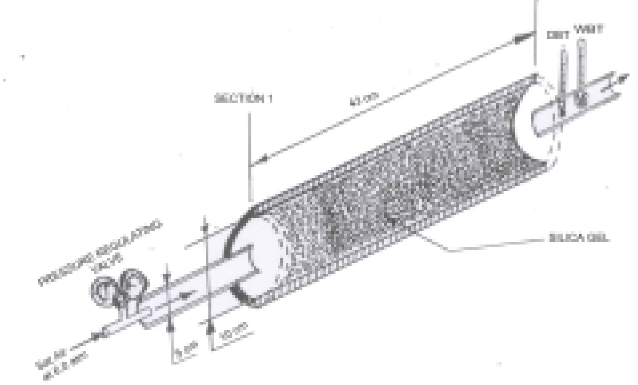

Fig. 6

We have, mass velocity, $G_{a,1} = V_{a,\,max} \times \rho_{a,1}$ = 0.333 x 7.015 = 2.336 kg_a/m^2

The silica gel pellets were 4 – 6 tyler mesh size, having equivalent spherical diameter,

D_p = 0.0039m. Then, A_v = 663.0 m^2 per m^3 (Table I)

At 25^{o}C, $\mu_a = 18.41 \times 10^{-6}\ P_a s$

Convection mass transfer coefficient

$$h_D = 0.703\ G_{a,1}\ \left(\frac{D_p\, G_{a,1}}{\mu_a}\right)^{-0.51}$$

$$= (0.703)(2.336)\ (0.0039 \times 2.336 / 18.41 \times 10^{-6})^{-0.51}$$

$$= 0.0694\ kg_w / s\ m^2\ (kg_w / kg_a)$$

$$\because\ K_1 = \frac{h_D\, A_v}{G_a} = 0.0694 \times 663.0 /2.336 = 19.69\ m^{-1}$$

We shall assume that the bed is initially dry (i.e. $\alpha = 0$)

Assuming the isothermal bed at 25^{o}C, Fig. 2 give the slope $C_1 = 0.034\ kg_A / kg_a$. For 600 kPa pressure and 25 ^{o}C, this value may be approximated as $C = \frac{0.034}{6.00} = 0.00567\ kg_A / kg_a$.

Also, from Fig. 2, $\alpha_1 = 0.125\ kg_w / kg_A$ at $W_1 = 0.004\ kg_w / kg_a$

It may be noted here that normal unsaturated atmospheric air, when compressed to 600 kPa and subsequently cooled to the original temperature, will condense out the extra water vapour and will be saturated at that temperature. Specific humidity of saturated moist air at elevated pressures for different temperatures are shown graphically in Fig. 7.

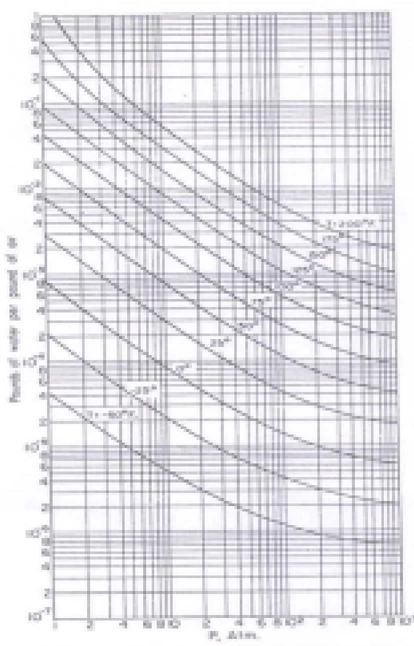

Fig. 7

$$\text{We have, } K_2 = \frac{h_D\, A_v\, C}{\rho_A} = \frac{0.0694 \times 663.0 \times 0.00567}{624.5} = 4.18 \times 10^{-4}\ S^{-1} = 1.50\ h^{-1}$$

In air case, τ = 90 min. The final specific humidity of the air leaving the drier,

$W_2 = 0.0001$ kgw/kg$_a$.

$K_2\,\theta = (1.50)(1.5) = 2.25$

$$\frac{W_2}{W_1} = \frac{0.0001}{0.0040} = 0.025$$

From Fig. 4, $K_1 x = 8.5$. Then, $x = \frac{8.5}{19.69} = 0.43$ m = 43.0 cm which is the required length of silica gel bed in the direction of air flow.

We also obtain from Fig. 5, $\frac{\alpha_2}{\alpha_1} = 0.016$

$\alpha_2 = 0.016 \times 0.125 = 0.002$ kg$_w$ / kg$_A$

We can prepare the following table for $K_2\,\tau = 2.25$

(a) Calculated values of W and α

$K_2\,\tau = 2.25$, $W_1 = 0.004$ kg$_w$ / kg$_a$, $\alpha_1 = 0.125$ kg$_w$ / kg$_A$

x, cm	0 (Section 1)	10	20	30	43
$k_1 x$	0	1.969	3.938	5.907	8.467
W, kg$_w$/ kg$_a$	0.004	0.00248	0.00128	0.00058	0.0001
W/W$_1$	1.0	0.62	0.32	0.145	0.025
α, kg$_w$ / kg$_A$	0.125	0.0575	0.0238	0.00875	0.002
α/α_1	1.0	0.460	0.190	0.070	0.016

(b) Ecperimental values of W and α

$W_1 = 0.004$ kg$_w$ / kg$_a$, $\alpha_1 = 0.125$ kg$_w$ / kg$_A$

x, cm	0 (Section 1)	10	20	30	43
W, kg$_w$ / kg$_a$	0.004	0.0028	0.00112	0.00048	0.00016
W/W$_1$	1.0	0.70	0.280	0.120	0.040
α, kg$_w$ / kg$_A$	0.125	0.050	0.030	0.014	0.0019
α/α_1	1.0	0.40	0.240	0.110	0.015

RESULTS

Calculated and experimental values of W and α are plotted for bed position x in Fig. 8 and Fig. 9 respectively.

For experimental determination of specific humidity of moist air at different sections of the gel-bed, and for subsequent comparison with calculated values, silica gel beds of length 10 cm, 20 cm and 30 cm were used, with dry-bulb and wet-bulb temperatures being measured at inlet and outlet for each location. This was done to overcome the difficulties of inserting the wet-bulb thermometer into the gel-bed at those positions. During experiments, the inlet air temperature varied slightly (between 24 to 28^{o}C). This variation was neglected in calculations. The calculated and experimental values of specific humidity are shown in Fig. 8. It is found that the two values agree satisfactorily with each other.

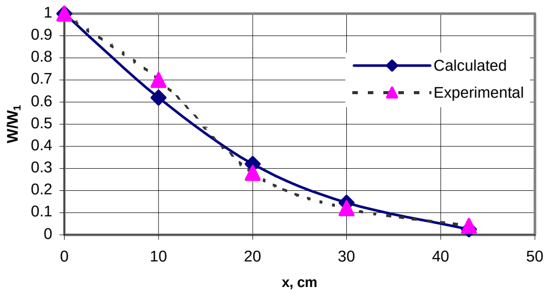

Fig. 8

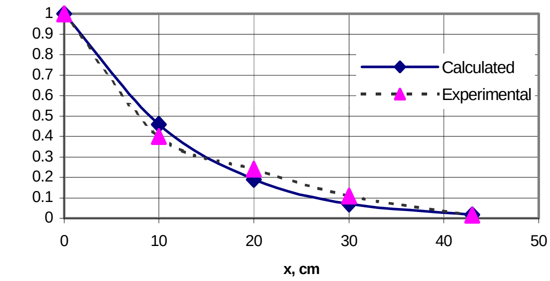

Fig. 9

For every experiment, the corresponding values of the average moisture content were found by measuring the initial gel mass (dry gel) and final gel mass (gel + water adsorbed). The calculated and experimental values of α at different bed thickness are also shown in Fig 9. Here also, it is found that the calculated and experimental values agree well.

CONCLUSIONS

The following conclusions may be drawn from the present study:

(a) A simple silica gel led of moderate thickness (bed length) can be used as a satisfactory device for drying moist air to a very low specific humidity for a reasonable period of time.

(b) Assumption of an isothermal adsorbent bed in the analysis which is easier than when the bed is assumed adiabatic seems to be satisfactory in predicting the drier performance.

(c) For continuous operation, two identical beds may be installed with one bed drying the air while the other bed reactivating the adsorbent material, thus the two beds operating alternately. The drying and reactivating period may be fixed by an automatic timer.

RECOMMENDATIONS FOR FURTHER WORK

(a) The experiment can be repeated with periods of operations other than 1.5 hours, and for saturated inlet air at other pressures.

(b) The bed may be maintained isothermal by cooling, and then the performance may be studied.

(c) Experiments during reactivation cycle may be done to determine the time for complete reactivation before the bed can be used for drying again.

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ACKNOWLEDGEMENT

The author acknowledges use of some data from Ref (7).

NOMENCLATURES

Symbols		Meanings
A	-	Gross-sectional area
A_v	-	Surface area per unit volume
C	-	Mass of dry sorbent/mass of dry air
D	-	Diameter
D_p	-	Equivalent spherical diameter of silica-gel pellets.
G_a	-	Mass velocity of air
h	-	Enthalpy of moist air
h_D	-	Convection mass transfer coefficient
i	-	$\sqrt{-1}$
J_o	-	Bessel Function of the first kind and zero order
K_1	-	$h_D A_v / G_a$
K_2	-	$h_D A_v C / P_a$
m_a	-	Mass flow rate of dry air
P_a	-	Pressure of air
Q_a	-	Volume flow rate of air
R_a	-	Gas constant for air, 0.287 kJ/kgK.
T_a	-	Temperature (Absolute) of air
V_a	-	Velocity of air
$V_{a,max}$	-	Maximum velocity of air
W	-	Humidity ratio of moist air
W_e	-	Humidity ratio of moist air in equilibrium with sorbent
W_1	-	Humidity ratio of inlet air to sorbent bed
W_2	-	Humidity ratio of out let air from sorbent bed
x	-	Depth of sorbent bed in the direction

GREEK LETTERS

Symbols		Meanings
α	-	Moisture content of sorbent material per unit mass of dry sorbent
α_1	-	Moisture content of sorbent material per unit mass of dry sorbent, at
μ_a	-	Dynamic viscosity of moist air
ρ_A	-	Density of sorbent material
τ	-	Time