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THEORETICAL AND EXPERIMENTAL STUDY ON THE PERFORMANCE OF COTTON KNITTED FABRIC AS DESICCANT HOLDER

دراسة تجريبية على أداء قماش تريكو قطني كحامل للماص [illegible]

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[illegible]

[illegible] دراسة نظرية و تجريبية لتأثير عوامل تصميم المهد و خواص الهواء الجوي على عملية امتصاص الرطوبة من الجو. المهد [illegible] عن إطار قفصي مزود بطبقات من قماش تريكو قطني مشبع بمحلول مائي من كلوريد الكالسيوم (الماص). يصف النموذج [illegible] الحرارة و رطوبة الهواء و تركيز الماص و كمية الملح المحتواة في المهد على عملية الامتصاص. تم استنتاج صيغة عامة تصف التغير [illegible] الزمن في صورة لا بعدية. تم تصميم و تصنيع طاولة اختبار تعطي إمكانية التحكم في رطوبة الهواء ودرجة حرارته و سرعته [illegible] أتاحت نتائج التجارب العملية عمل تقييم كمي لتأثير عوامل الهواء و الماص على معدل الامتصاص و تغير كمية الماء الممتص [illegible] مقارنة النتائج العمليه مع نتائج حل النموذج النظري و آلتي أوضحت توافقا جيدا بينهما.

Abstract

In this work, theoretical and experimental studies of the influence of bed design parameters and ambient air properties on the absorption of moisture from ambient air are presented. The desiccant bed under investigation is a cage frame with cotton cloth layers impregnated with Calcium Chloride solution, which forms the walls of the cage. The theoretical model describes the effect of air temperature, humidity and desiccant properties (mass of salt and concentration) on the absorption process. A general expression describing the variation of desiccant concentration with time, in dimensionless form is obtained. In the experimental part, the set-up is prepared such that air humidity, temperature and flow rate can be varied and controlled during the experiments. Quantitative evaluation of the effect of air properties and desiccant parameters on the absorption rate and instantaneous values of the weight of absorbed water is presented and discussed. Also, the comparison between the results of the theoretical model and experimental data shows good agreement

Nomenclature

A	absorption area, m^2
b	barometric pressure, mm Hg
B(T)	temperature dependent constant [Eq. 24]
C	integration constant [Eq. 10]
C(T)	temperature dependent constant [Eq. 25]
h	heat transfer coefficient, W/m^2
I	total enthalpy of absorbent, J
K_G	mass transfer coefficient, kg/m^{2}s
M	mass, kg
pv	vapor pressure, mm Hg
T	temperature, K
t	time, s
U	Velocity, m/s
V	volume, m^3
X	dimensionless concentration ratio
x	solution concentration, kg/kg
y	water concentration, kg/kg

Greek symbols

ΔM	Mass difference, kg
τ	dimensionless time
ε	Porosity
ω	air moisture content, kg water/kg air

Subscripts

a	air or at equilibrium with air
c	cloth material
i	initial
s	Solution
st	salt
t	instantaneous
w	water
Δt	time interval

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Keywords: air moisture absorption, , cotton knitted fabfic and calcium chloride bed.

INTRODUCTION

Fresh water supply is the limiting condition for the need of population growth and development in many areas of the world. Water can be provided by transportation from other locations, desalination of saline water and by extraction of water from atmospheric air. Extraction of water from atmospheric air, however, has several advantages compared with other methods, where air as a source of water is renewable and clean and has great amount of water compared to fresh water in earth's surface [1]. Moreover, it is preferred to solve water problem in many areas using the natural resources and the renewable energy sources like solar energy where the available area to collect solar radiation and volumes of air are infinite.

Water can be extracted from moist air by cooling to a temperature lower than its dew point, where the moisture is condensed. Several investigators [2-5] have studied this method. Generally, it is reported that the energy consumption is high especially when solar energy is used, to power the cooling system [6], due to low conversion efficiency.

Another approach for water extraction from atmospheric air is by absorption of moisture from moist air into solid or liquid desiccants with subsequent evaporation of water from desiccant by heating and condensation of vapor [7,8]. Solar energy can be used to power the absorption regeneration systems, producing water from atmospheric air [9-13]. In addition, it is observed that the design and operation of the absorption-regeneration system is simpler than that of the cooling system.

Absorption of moisture from ambient air can be enhanced by increasing the potential of vapor pressure between air and desiccant or by increasing the mass transfer area. The potential of mass transfer is dependent on vapor pressure in air and on the desiccant surface. Ambient air-dry bulb temperature and its humidity ratio limit the vapor pressure in air stream, whereas the vapor pressure on the desiccant surface can be lowered by decreasing the liquid temperature for a given concentration or by increasing concentration for constant liquid temperature. Decreasing liquid temperature can be carried out through the heat transfer between the cooled air stream and the desiccant surface.

Using solid desiccants can enhance mass transfer area. However, higher regeneration temperature is needed in such cases. Also higher-pressure drop (power) of the air stream passing through the bed is required. On the other hand, liquid desiccant such as Calcium Chloride requires lower temperature for regeneration and a comparatively lower pressure drop for air stream passing through the absorption and regeneration towers.

When liquid desiccants are applied, recirculation of it trough the mass transfer equipment consumes pumping power and the rate of absorption is limited by the contact area between liquid desiccant and air streams. Application of solid beds, impregnated with liquid desiccant can increase the area of mass transfer and consequently the mass transfer rate [14].

The objective of the present study is to provide additional analytical and experimental data for desiccant absorption to aid in the design of solar-based desiccant systems. Therefore, experimental and theoretical analyses are carried out exploring the influence of air flow rate, air inlet temperature and desiccant initial concentration (initial mass of salt). Also, a new desiccant carrier is proposed in this study.

ABSORPTION MODEL

The kinetics of absorption depends on the rate of mass transfer between the air stream and absorbent and can be expressed as:

$$dM_w / dt = K_G A (y_a - y_s) \quad (1)$$

Applying heat balance for the absorption process, the enthalpy of absorbent can be evaluated from the following equation.

$$dI/dt = h A (T_a - T_s) + K_G A q (y_a - y_s) \quad (2)$$

Where t is the absorption time, M_w is the mass of absorbent, A is the absorption area, K_G is the mass transfer coefficient, I is the enthalpy of absorbent, h is the heat transfer coefficient between air and desiccant, T_a and T_s are the temperatures of air and desiccant respectively and q is the heat of absorption.

Absorption operations are usually exothermic, and when large quantities of solute gas are absorbed to form concentrated solutions, the temperature effects can not be ignored. However, in case of dilute gas mixture (ex. Water vapour in atmospheric air) it is frequently satisfactory in these cases to assume that the operation is isothermal[15] The water concentration at equilibrium with ambient air y_a and the water concentration in the bed y_s can be respectively defined by the following relations,

$$y_a = 1 - x_a \quad (3)$$
$$y_s = 1 - x_s \quad (4)$$

Where x_s and x_a are solution concentration in the bed and solution concentration at equilibrium with ambient air respectively.

Substituting from equations 3 and 4 in equation 1we get,

$$dM_w / dt = K_G A (x_s - x_a) \quad (5)$$

The solution concentration x_s is defined as the ratio of the mass of salt in the solution to the total mass of solution as follows,

$$x_s = M_{st} / (M_{st} + M_w) \quad (6)$$

Where M_{st} is the mass of salt and M_w is the mass of water in the solution

Rearranging eqn. 6 yields,

$$M_w = M_{st}(1 - x_s)/ x_s \quad (7)$$

Differentiating the above equation with respect to time t,

$$dM_w/ dt = - (M_{st} / x_s^2) dx_s / dt \quad (8)$$

From Eqn. 5 and 8 we get,

$$dx_s / [x_s^2 (x_s - x_a)] = -(A K_G / M_{st}) dt \quad (9)$$

Integrating Eqn. 9 we get [16],

$$[1/(x_s x_a)] + (1/ x_a^2) \ln (1 - x_a/x_s) = -(A K_G / M_{st}) t + C \quad (10)$$

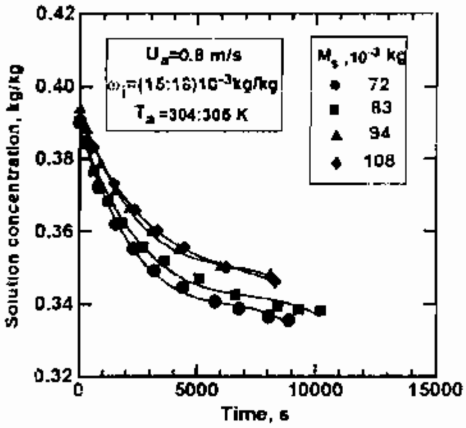

Fig (9) Variation of solution concentration with time for different masses of salt.

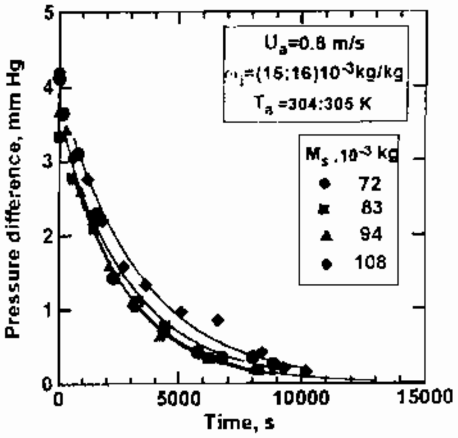

Fig (10) Variation of pressure difference with time for different masses of salt.

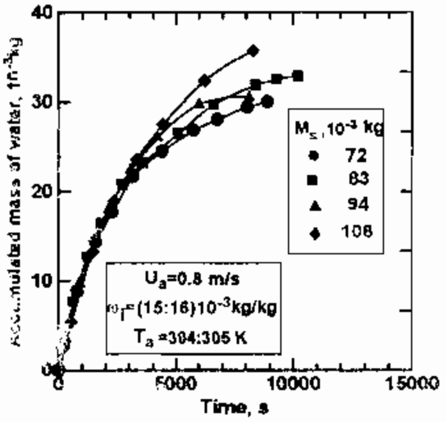

Fig (11) Variation of accumulated mass of water with time for different masses of salt.

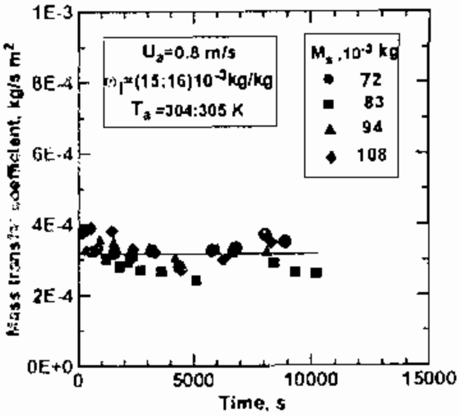

Fig (12) Variation of mass transfer coefficient with time for different masses of salt.

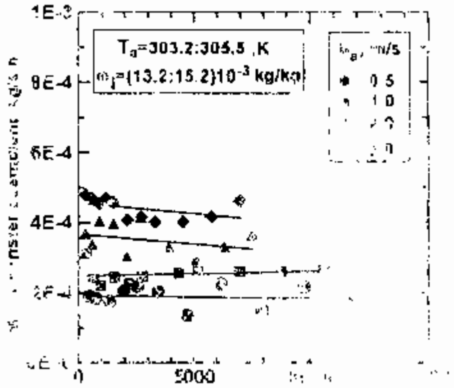

Fig (13) Variation of [illegible] for different [illegible]

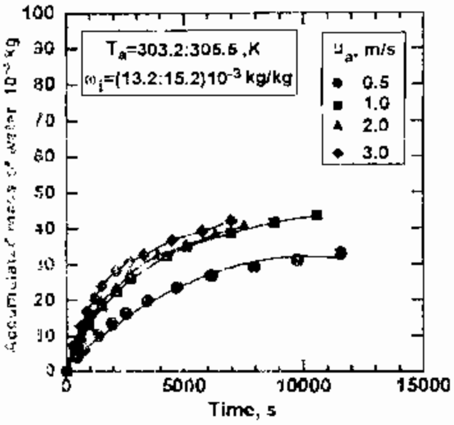

Fig (14) Variation of accumulated mass of water with time for different air velocities

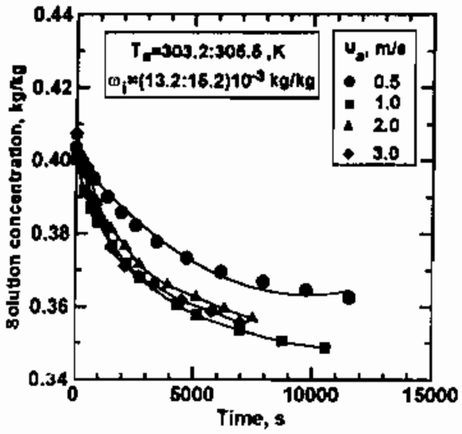

Fig (15) Variation of solution concentration with time for different air velocities.

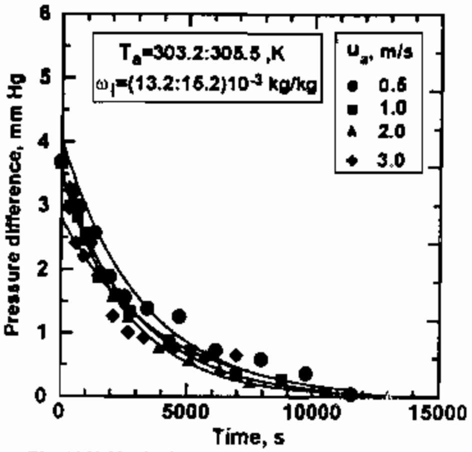

Fig (16) Variation of pressure difference with time for different air velocities.

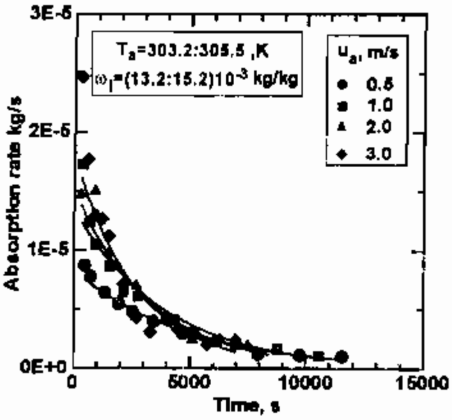

Fig (17) Variation of absorption rate with time for different air velocities.

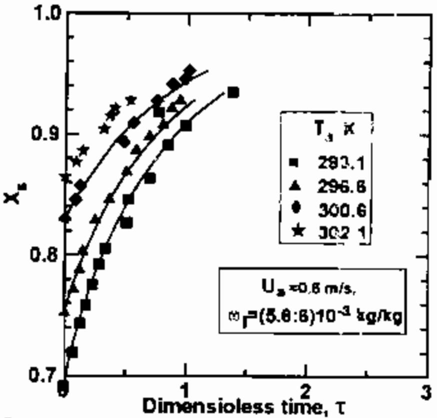

Fig (18a) Comparison between experimental and theoretical results for different air tepmeratures.

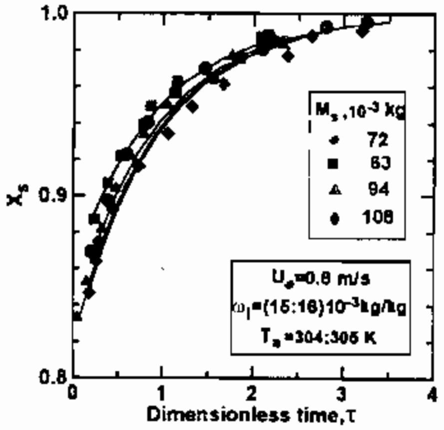

Fig (18b) Comparison between experimental and theoretical results for different masses of salt.

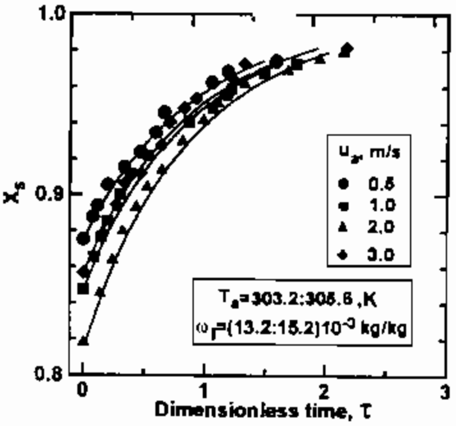

Fig (18c) Comparison between experimental and theoretical results for different air velocities.