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DRYING OF COTTON SPINNING

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ABSTRACT,

This work is concerned with thermal drying , by passing a hot air stream across different equivalent diamters of spinning samples of cotton as hygroscopic porous material to investigate the relations between the rate of drying and different conditions of air stream (dry bulb temperature , velocity and humidity).

The experimental results show that , the rate of drying increases with increasing either the dry bulb temperature or the velocity of air stream . Also, the rate of drying increases with decreasing the equivalent diamter of spinning . Increasing of the humidity of air decreases the rate of drying . The effect of dry bulb temperature on the drying operation is greater than the effect of velocity .

A comparison between the results of experimental work and theoretical concepts is made and it is found that the theoretical results of the present work are in good agreement with experimental results .

I- NOMENCLATURE.

a : Slope of drying rate curve.
b : Width of wind tunnel..............................m.
B : Width of sample.................................m.
C : Correction factor for time of drying.
d_{eq} : Equivalant diamter of spinning.................. m.
h : Pressure head.................................. m.
h_y : Heat-transfer coefficient from air to surface of spinning. ....watt/m^2.C .
L : Length of the sample.......................... m.
k_y : Mass-transfer coefficient from surface of spinning to air ....kg./$(m)^2$(hr).
K : Heat-transfer coefficient by conduction for air .watt/(m).$(C)^o$.
N : Rate of drying from wetted spinning .... gm./min.
Nu. : Nusselt number= $h_y . d_{eq}/k$.
p : Pressure ....N/m^2.
Q : Rate of air stream flow ....m^3/sec;
R : Rate of drying ..gm./m^2.min.; R_c for critical point; R_1 for start of drying ; R_2 for end of drying.
Re. : Reynolds number = ${}^{2}u . d_{eq}/\nu$
S : Outer area of spinning .... m_o^2.
T : Temperature ....C° .
u : Velocity of air stream..........................m/sec.
V : Volume of spinning ....m^3.

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X : Average moisture content, gm.water/gm. bone-dry spinning . X_c free moisture at critical point , X_1 free moisture at start of drying , X_2 free moisture at end of drying.
Y : Humidity of air..................gm.water /Kg. dry air.

LATIN LETTERS:

θ : Time of drying ..min. , θ_c time in constant rate period. θ_f time in falling rate period, θ_t total time in both period.
λ : Latent heat of vaporization of water........joule/kg.
ρ : Density of dry spinning .... gm./m ^{3}.
ν : Kinematic viscocity of air..................m^2/sec.
ψ : The rate of drying as a function of variable conditions of air stream.

SUBSCRIPTS:

d : Refers to dry bulb.
f : Refer to falling-period.
i : Refers to liquid- air interface.
s : Refers to spinning.
T : Refers to total.
w : Refers to wet-bulb.

II- INTRODUCTION.

In general , drying means the removal of relatively small amounts of water from solids,liquids or gases. Water may be removed from solids mechanically or thermally, but for certain material the mechanical method is not suitable and one must use the thermal drying in order to keep the shape and structure strength out from deformation.

Many investigators studied the rate of drying of various materials theoretically as well as experimentally[1,2,3,4], they stated that the rate of drying is divided into two main stages - The first is defined as the constant rate period and the second is the falling rate period. During the first stage period , it is assumed that drying takes place from a saturated surface of the material by diffusion of the water vapour through a stationary air film into the air stream. The main factors of influence in this stage are the material surface dimensions, the velocity of air stream , wet-bulb temperature and material temperature [5]. The second stage depends mainly on the mechanism by which the moistre from inside the material is transferred to the surface .

Capillarity, gravity force , porous and material thickness are effective factors in this period [6,7].

But all the previous work are not directed to study the drying of cotton spinning as an important subject in the industrial operations. This work is restricted to dry 100% cotton spinning by thermal drying using heated air. The solar air heater is a most convenient way to dry the cotton spinning. A number of electric heaters was used to heat the air stream in a wind tunnel to substitute the solar air heater which was designed in the solar energy laboratory of the National Research Center in Cairo.

III- THEORETICAL CONCEPTS.

In the design of dryers , an important parameter is the time required for drying the material under the conditions existing in the dryer, as this fixes the size of the equipement needed for a given capacity. For drying under constant drying conditions , the time of drying may be determined from the rate of drying curve if this can be constructed. For this problem , consider the drying of spinning surface area (s), equivalent diameter (d_{eq}) ,length (l) and mass (m) with moisture content (X) . The direction of air stream flow is perpendicular to the center line of spinning with flow velocity (u) Fig.(1). Neglecting the spinning shrinkage and assuming spinning the density ρ_s to be constant,

then , the change of spinning mass;

$$dm. = V_s . \rho_s . dX \quad . \qquad (1$$

The rate of drying

$$R = - dm. /S. d\theta .$$

$$= - \frac{V_s . \rho_s . dX}{S. d\theta} \quad . \qquad (2$$

Since , the rate of drying curve provides a relation between (R) and (X) (Fig.2) , equation (2) may be integrated and written in the following form;

$$\theta = - \frac{V_s . \rho_s}{S} \int_{X_1}^{X} \frac{dX}{R} . \qquad (3$$

or

$$\theta = - \frac{d_{eq} . \rho_s}{4} \int_{X_1}^{X} \frac{dX}{R} . \qquad (4$$

Where θ is the time of drying during the constant rate period ,(R) is constant and may be denoted by (R_c) , then equations (3,4) become

$$\theta = - \frac{V_s . \rho_s}{S_s . R_c} (X_1 - X_2) \text{........ for ....} X_1 > X_2 \geq X_c \text{...} (5$$

or

$$\theta_c = \frac{d_{eq} . \rho_s}{4R_c} (X_1 - X_2) \quad . \qquad (6$$

Assuming a linear relation between the drying rate and moisture content during the falling rate period according to the following equation;

$$R = aX + b \quad . \qquad (7$$

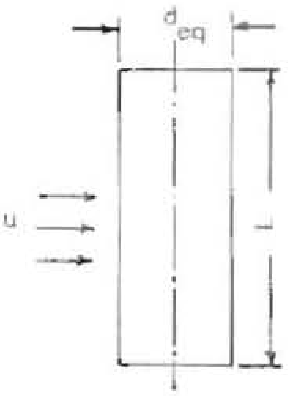


Fig. (1).

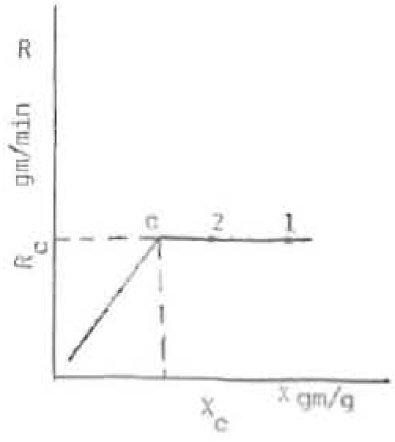


Fig. (2).

Equation (3) can be rewritten in the following form ;

$$\theta_f = - \frac{V_s \cdot \rho_s}{S_s \cdot a} \ln (R_{\gamma} / R_s) \quad , \qquad \text{(8}$$

where R_1, R_2 are the ordinates for the initial and final moisture contents respectively, a &b are constants .

The constant a is the slope and equals to ;

$$a = \frac{R_c - R}{X_c - X} \quad . \qquad \text{(9}$$

Substituting eqs.(7,9) into eq.(8) one gets ;

$$\theta_f = - \frac{V_s \cdot \rho_s}{S_s} \left[\left(\frac{X_c - X}{R_c - R} \right) \ln . \left(\frac{aX_1 + b}{aX_2 + b} \right) \right] \qquad \text{(10}$$

The total drying time (θ_T) becomes;

$$\theta_T = \theta_c + \theta_f$$

$$\therefore \theta_T = \frac{V_s \cdot \rho_s}{S_s \cdot R_c} \left[(X_1 - X_c) + \frac{X_c - \bar{X}}{(R_c - \bar{R})} \ln . \frac{a X_c + b}{a X_2 + b} \right] \qquad \text{(11}$$

In some situations , a single straight line passing through the origin adequately represents the entire falling rate period , i.e. b=0 . In this case , and considering the rate of drying at the critical point

$$R_c = - \frac{dm}{S_s . d\theta} = \frac{N}{S} = \frac{h_y (t - t_i)}{\lambda_i} = k_y (y_i - y) \quad , \qquad \text{(12}$$

equation (11) can be written in the following form;

$$\theta_T = \frac{V_s \cdot \rho_s \lambda_i}{S_s h_y (t - t_i)} \left[(X_1 - X_c) + \left(X_c \ln . \frac{X_c}{X_2} \right) \right] \quad , \qquad \text{(13}$$

or

$$\theta_T = \frac{d_{eq} \cdot \rho_s \cdot \lambda_i}{4 h_y (t - t_i)} \left[(X_1 - X_c) + X_c \ln . \frac{X_c}{X_2} \right] \quad , \qquad \text{(14}$$

where X_2 is the moisture content at the end of entire process.

The avorage forced convective heat transfer coefficient($\bar{h}_y$) can be determined as [6],

$$\frac{\bar{h}_y \cdot d_{eq}}{K_{air}} = 0.0208 \left(\frac{V . d_{eq}}{\nu} \right)^{0.814} \quad . \qquad \text{(15}$$

Substituting eq.(15) into eq. (14) the total drying time becomes,

$$\theta_T = \frac{d_{eq}^{1.186} \cdot \rho_s \cdot \lambda_i}{0.0832 \left(\frac{V}{\nu_{air}} \right)^{0.814} . K_{air} . (t - t_i)} \left[(X_1 - X_c) + X_c \ln . \frac{X_c}{X_2} \right] \cdot \qquad \text{(16}$$

Equation (16) gives an estimation for the time of drying as a function of the air stream parameters and the initial and final parameters of the spinning material.

IV- EXPERIMENTAL TECHNIQUE.

The experimental set up comprises a wind tunnel , pitot tube , inclined water manometer, hot wire anemometer ,thermometers , boiler , heaters , stop-watch and sensetive digital balance. Schematic diagram of the experimental set-up is shown in fig.(3).

The wind tunnel is an open low speed one with cross sectional area 30 x30 Cm. of test section, the wind tunnel is provided with a damper which is operated by hand . The maximum air velocity is 15 m/sec.

The experiments were carried out at three values of air velocity (7.8, 3.5 and 2.8 m/sec.) .

The measured velocities by pitot-tube are checked by using a hot wire anemometer. Thermometers are used to measure dry bulb and wet bulb temperatures, then the humidity of air stream through the wind tunnel can be measured by using psychrometic charts.

Twelve electric heaters were used to control the air temperature in a range of 50C°. Electric boiler was used to control air humidities by injection a suitable amount of steam from the boiler.

The rate of drying could be determined for a sample of spinning of cotton material, by suspending it from the digital balance by using small chain in the test-section of wind tunnel. The wieght of the spinning sample at different time intervals was obtained by the balance. The diameter of the cotton spinning is not smooth running but if it is round spinning, then its equivalent diameter can be measured by using projector and known standard diamter .

V- EXPERIMENTAL RESULTS AND DISCUSSION.

The experiments were carried to obtain the relations for the following conditions,

1- The first set of experiments was carried out to get the rate of drying against moisture content under different dry bulb temperatures of the air stream , keeping the other air stream parameters the same . The different dry bulb temperatures were (t_1=18 °c , t_2=24 °c , t_3=27 °c and t_4= 32°c) . The results in this case are plotted in fig.(4) . It is shown that ,when the dry bulb temperature of air stream increases the rate of drying also increases . This is due to the increase of the vapour-density difference at the spinning-sample surface and in the air stream .

2- The second set of experiments was carried out to get the rate of drying against moisture content under different velocities of air stream, and keeping the other air stream parameters the same . The different velocities were (u_1=7.8 , u_2= 3.5 and u_3= 2.8 m/sec.) . The results in this case are plotted in fig.(5). It is shown that ,when the velocity of air stream increases,the rate of drying also increases . This is due to the increase of the convective mass transfer coefficient .

3- The third set of experiments was carried out to get the rate of drying against moisture content under different humidities of air stream, and keeping the other air stream parameters the same . The different humidities were ($Y_1 = 7.2$, $Y_2 = 8$, $Y_3 = 9.2$ gm/kg). The results in this case are plotted in fig. (6) . It is shown that , when humidity increases the rate of drying decreases . This is due to the decrease of the vapour-density difference at the spinning-sample surface and in the air stream.

4- The fourth set of experiments was carried out to get the rate of drying against moisture content under different sizes of spinning, and keeping the other air stream parameters to be the same . The different sizes were ($d_{eq} = 0.014$, 0.02 , and 0.025 m.), The results in this case are plotted in fig.(7) . It is shown that the rate of drying increases with small equivalent diameter of spinning rather than the large spinning, this means that when the outer surface decreases the rate of drying increases. This is due to the increase of the convective mass transfer coefficient.

The falling rate period is divided into two zones(I and II). In the frist zone (I) the surface of the wet sample is capable of supplying the air stream with moisture until it is dried, then the moisture is brought out from the interior of sample in which the second zone (II) is beginning to appear . The rate of drying in the first zone is falling slowly, but in the second zone the rate of drying is falling rapidly.

Finally from experimental curves under various conditions it is possible to obtain important relations showing the effect of all variables conditions on the rate of drying .

i) The stream velocity at high moisture content is more effective on the rate of drying than that at low moisture content .

ii) The effect of temperature at high moisture content is greater than that at low moisture content .

iii) The rate of drying increases by increasing temperature and velocity of air stream .

iv) The effect of humidity at low moisture content is greater than that at high moisture content .

v) The effect of d_{eq} at low moisture content is greater than that at high moisture content .

From the experimental results, the rate of drying can be obtained as function of velocity, dry bulb-temperature, humidity and equivalent diameter . Fig.(8) shows the relation of the rate of drying against moisture content, this figure, is constructed from the experimental results in first zone . While figure (9) shows the relation of the rate of drying for the second zone against moisture content . From figs.(8,9) an empirical formula can be obtained in the following forms;

a) For

$$0.0529\,u + 0.337 \leq X \leq 1.2$$
$$0.02\,T_d - 0.01 \leq X \leq 1.2$$

and

$$0.70 \leq X \leq 1.2$$

$$N = -0.04 + \left[1.25 \ast 10^{6} + 7.4 \ast 10^{-7}\,X\right] u^{0.35} \ast T_d^{4} \ast Y^{-1.2} \ast d_{eq}^{0.21}$$

b) For

$$0.0529\,u + 0.337 \geq X \geq 0.1$$
$$0.02\,T_d - 0.01 \geq X \geq 0.1$$
$$0.7 \geq X \geq 0.1$$

$$N = -0.03 + \left[3.32 \ast 10^{-5} + 9 \ast 10^{-4}\,X\right] u^{0.13} \ast T_d^{2.3} \ast Y^{-1.08} \ast d_{eq}^{-0.17} \quad -(17$$

Comparison was made between the time of drying recorded experimentally during each test condition and that theoretically estimated by eq.no.(13). The following remarks are observed;

1- The first comparison made for the first stage set of experiments (different dry bulb temperatures) and two curves for θ_{th} and θ_{exp} are plotted in fig.(10)and correction factor is obtained;

$$C_T = \left(\frac{\theta_{exp}}{\theta_{th}}\right) = 0.88 \quad .$$

2- The second comparison made for the second set of experiments (different velocities of air stream) and two curves for θ_{th} and θ_{exp} are plotted in fig.(10), and correction factor is obtained,

$$C_u = \left(\frac{\theta_{exp}}{\theta_{th}}\right) = 0.86 \quad .$$

3- The third set of experiment (different humidities of air stream) and two curves for θ_{th} and θ_{exp} are plotted in fig.(10), and a correction factor is obtained;

$$C_y = \left(\frac{\theta_{exp}}{\theta_{th}}\right) = 0.85 \quad .$$

4- For the fourth set of experiments (different equivalant diamters of spinning) and two curves for θ_{th} and θ_{exp} are plotted in fig.(10) and a correction factor is obtained,

$$C_d = \frac{\theta_{exp}}{\theta_{th}} = 0.86 \quad .$$

VI- CONCLUSIONS .

From the present work , it can be concluded that;

1- The theoritical formulation predicted based on dividing the period of drying into two periods, the first is called constant rate period and the second is called falling-rate period, but all experimental plotted curves are divided into two falling rate periods.

2- A new approximate correlation for drying rate (N) as a function of temperature, velocity and humidity of air, moisture content and equivalent diameter for different spinning sample has been developed (equation no. 17) .

3- A correction factor was obtained $C = \frac{\theta_{exp}}{\theta_{th}} = (0.85 \div 0.88)$ which permits the use the theoretical expression for estimating the drying time of cotton spinning in practice.

VII- REFRENCENES.

1. J.M. Coulson and J. F. Richarson, Chemical Engineering, Vol.II, 3/e, McGraw-Hill (1978).
2. W.L. McCabe and J.C. Smith, Unit Operation of Chemical Engineering, McGraw- Hill(1956).

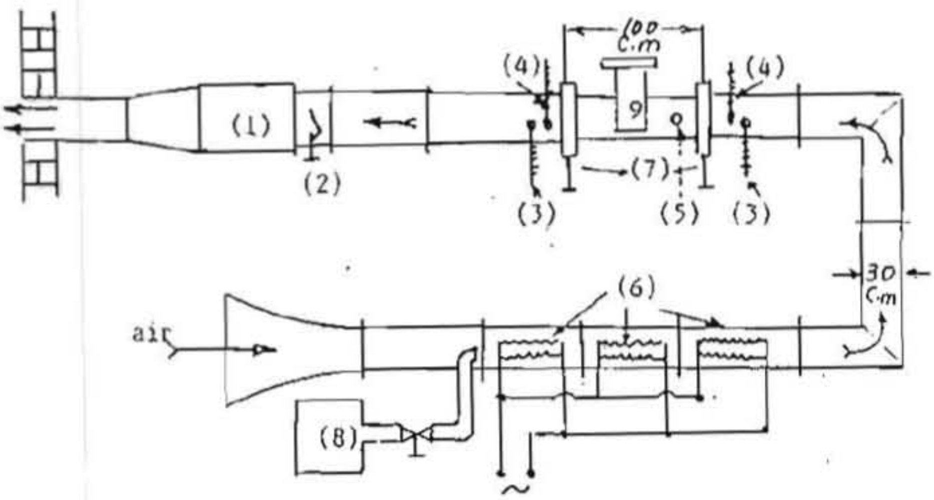
3. Robert C. Treybal, Mass Transfer Operation, 3/e. McGraw-Hill(1980).

4. Bennett and Myers, Mass,Momentum and Heat Transfer,2/e, (1975).

5. Powell R.W. and Griffiths E., The evaporation of water from plane and cylinderical surface,Trans. Inst. Eng.13,(1935).

6. McCready D. W.and McCabe W.L., Trans. AICHE,29,(1933) 131.

7. Huang T.L.D.et-al,Heat and mass transfer,Int.J.,Vol.22,(1978),257.



1- Motor&Blower. 2- Damper . 3- Wet-bulb thermometer 4- Dry-bulb thermometer 5- Pitot tube 6- Electrical heater 7- Gates 8- Boiler 9- Digital Balance.

Fig.(3) Schematic diagram of experimental set-up.

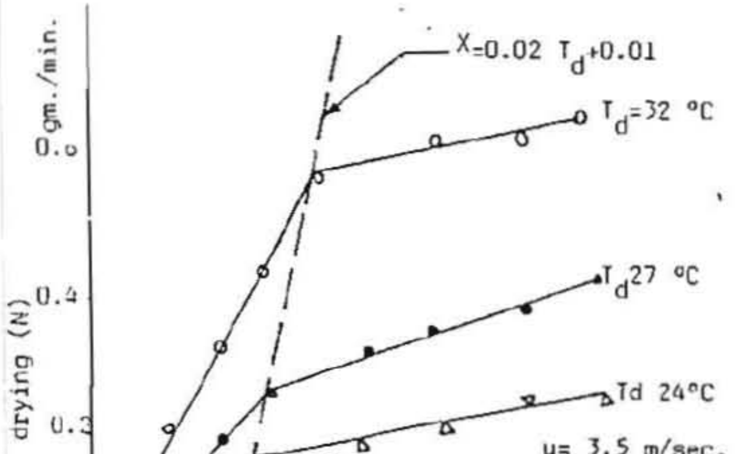


Fig. (4) Rate of drying for cotton spinning with variable dry bulb temperature.

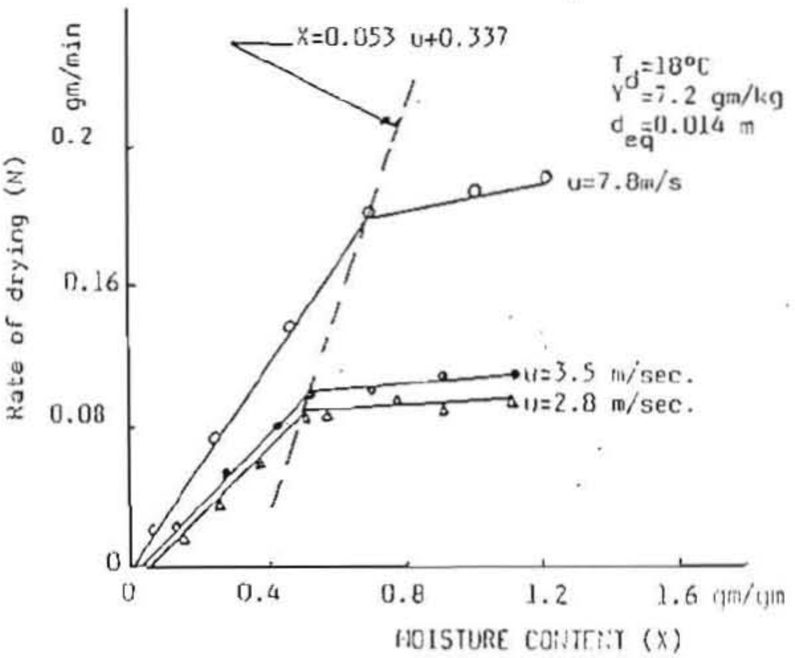


Fig. (5) Rate of drying of cotton spinning with variable velocity.

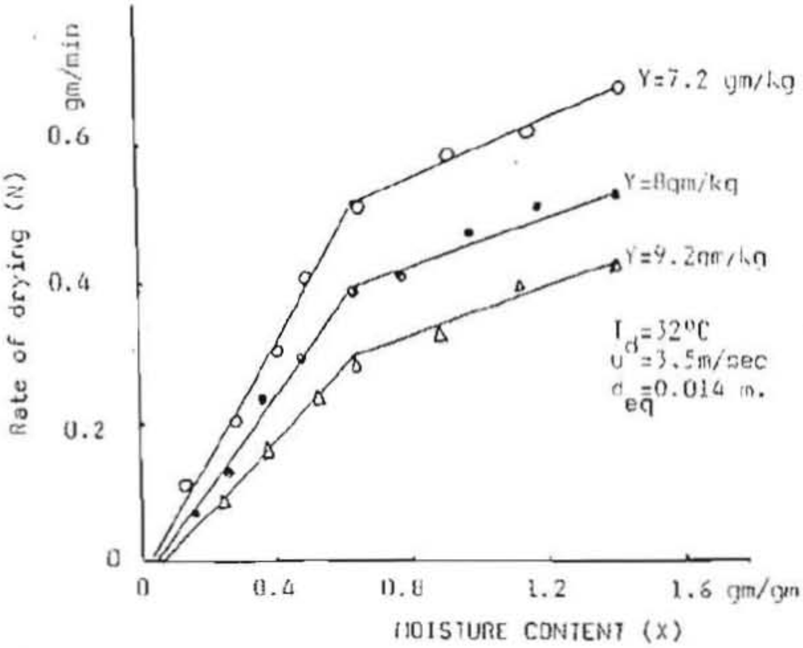


Fig. (6) Rate of drying of cotton spinning with variable humidity.

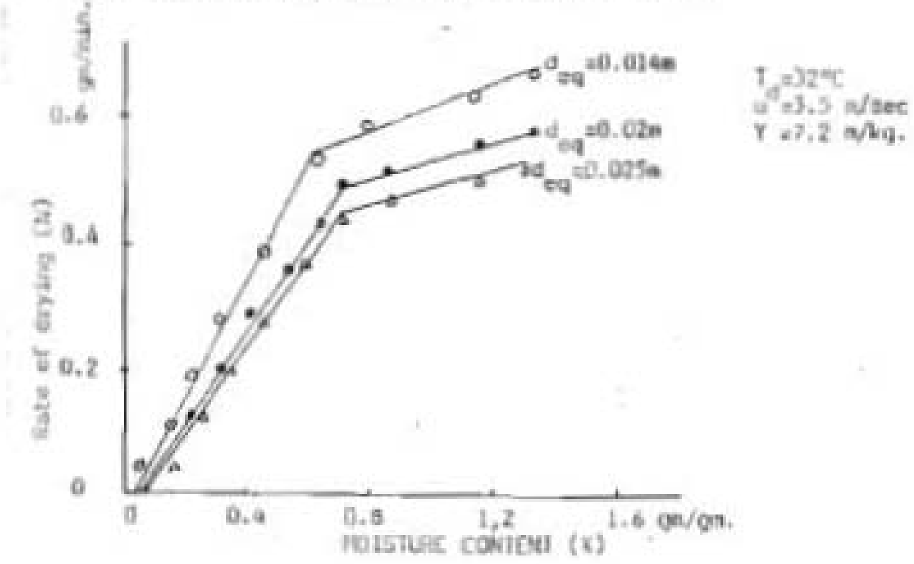


Fig. (7) Rate of drying of cotton spinning for variable size.

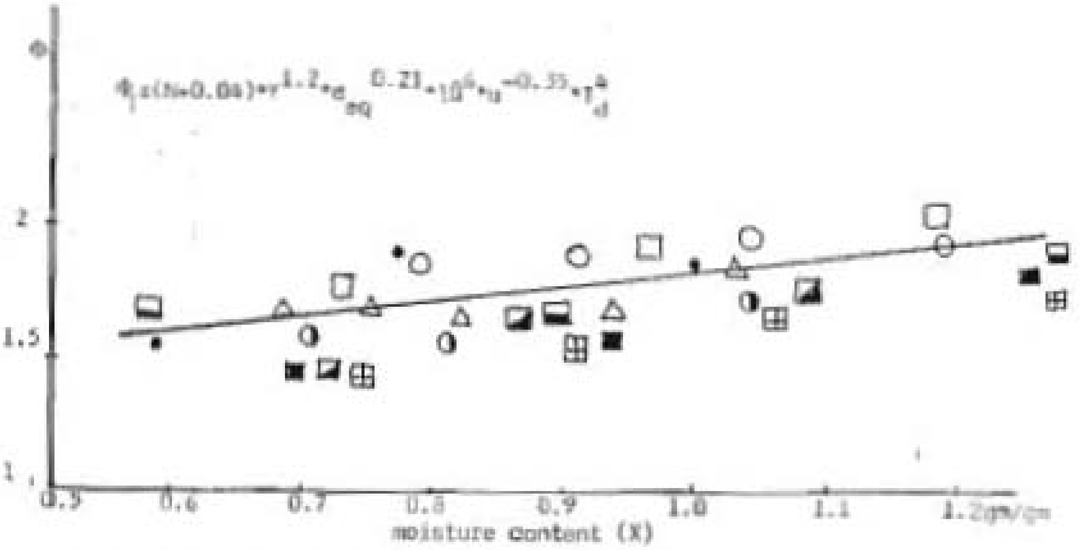


Fig.(8) The relation between Φ_I and moisture content in the first zone.

	○	▭	◒	△	•	▤	◪	◐	■	⊞
T_d °C	24	27	18	18	18	32	32	32	32	32
u m/sec	3.5	3.5	2.8	3.5	7.8	3.5	3.5	3.5	3.5	3.5
Y gm/kg	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	8	9.2
d_{eq} mm	14	14	14	14	14	14	20	25	14	14

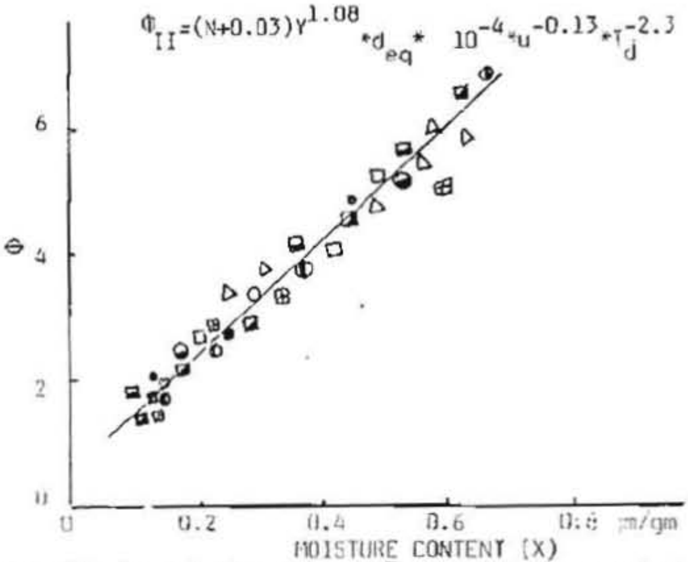
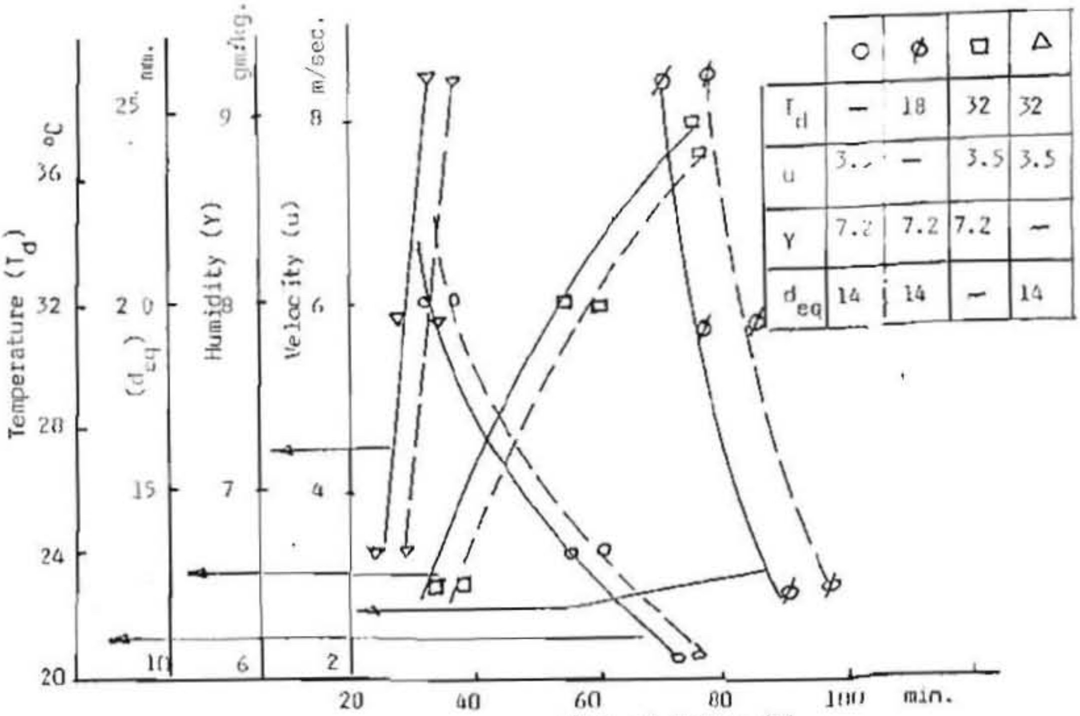


Fig.(9) The relation between Φ_{II} and moisture content in second zone.
(all symbols are the same as in fig.8)



	○	⌀	□	△
T_d	—	18	32	32
u	3.[illegible]	—	3.5	3.5
Y	7.2	7.2	7.2	—
d_{eq}	14	14	—	14

Fig.(10) Comparison between experimental (—solid line) and
theoritical form(---dashed line).