

Studies on Moisture Sorption in Coir Fibers (*Cocos Nucifera L*)

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Synopsis

Moisture desorption characteristics in coir fibers have been studied at several temperatures (53°C, 68°C, 86°C, and 105°C) as a function of time. Moisture absorption at room temperature after heating to 53°C, 68°C, 86°C, and 105°C are also reported. The results indicate that the relation between percentage moisture loss (A) (moisture loss is the ratio of the difference between initial moisture and final moisture to initial moisture) and temperature ($T^{\circ}\text{K}$) is of the type $A = A_0e^{-B/T}$ in the range of intervals studied. The constants A_0 and B are dependent on time, and they decrease with time. The fraction moisture loss/gain (w) is related to time (t) by the equation $w = m/t + b_0$ at all temperatures investigated. The constant m decreases with temperature while b_0 increases with temperature. The equilibrium moisture content (the condition reached by the sample when it no longer takes up moisture from or gives up moisture to the surrounding atmosphere) increases with increase in relative pressure and decrease in temperatures. As the moisture content in the fiber increases, the tensile strength (tenacity) decreases and the % elongation increases. The observed results are explained on the basis of structural rearrangement on heating/cooling of lignocellulosic material.

INTRODUCTION

Moisture plays an important role in the use of fibers in textile and other industries. It has been reported¹ that in the case of polymers moisture tends to reduce modulus, yield point, and strength but increases ductility and ultimate elongation. It has been shown²⁻⁶ that for some plant fibers (like jute and mesta) the degree of crystallinity diminishes with the increase of moisture absorption, while crystallite orientation improves. The moisture content is also known⁷ to affect the tensile strength, the swelling behavior, and comparable porosity of some vegetable textile fibers. However, hardly any information is available about moisture absorption and desorption characteristics in coir fibers except for some studies⁸ on porosity and pore-size distribution in coir fibers. Earlier reports⁹⁻¹¹ include the estimation of moisture content of coir fibers as percentage of dry weight fibres, which was found to be 10%. The present study reports the relationship between moisture content and other parameters like strength, time, and temperature.

EXPERIMENTAL

Samples of retted coir fibers used in the present investigation were procured from Kovalam near Trivandrum (India). The majority of the fiber samples sorted out were in the range of 0.2–0.3 mm in diameter. In all cases the samples were identically soaked for about 20 h in distilled water to remove the soluble

and adhering materials prior to conditioning the fibers at $27 \pm 2^\circ\text{C}$ and $65 \pm 2\%$ RH for about 12 h.

For moisture content determination, conditioned coir fibers in the form of bundles were initially weighed. Then the bundles were heated in an electric oven at 105°C for 100 min, cooled in a desiccator, and weighed at atmospheric conditions ($25\text{--}30^\circ\text{C}$ and $65\text{--}80\%$ RH) till constant weight of the fiber was observed. Weight loss was computed with respect to initial weight before heating of the conditioned fiber bundle. Similarly, moisture loss of the fibers at 53°C , 68°C , and 86°C were determined (both in controlled and uncontrolled humid conditions) by periodically removing the fibers after heating at these temperatures.

For moisture absorption/desorption studies about 10 g of conditioned fiber samples were loaded into specimen sockets of a semiautomatic Brabender moisture tester. The temperature of heating was preset, and the baskets containing specimens were loaded into the heating chamber. The specimen baskets were continuously rotated in the chamber. The weight of the specimen was monitored periodically after stopping the rotation of the specimens and bringing each specimen basket on to a weighing system by the use of suitable lever system. The weight loss was read directly as percentage of wet fiber on a calibrated scale.

Moisture regain of the fibers heated to various temperatures (53°C , 86°C , and 105°C) was computed with respect to saturation moisture content of the fiber bundle at each temperature.

In order to check for any preferential moisture absorption from the cut ends, long fibers (0.05–0.06 m) and chopped fibers (0.02 m) were loaded in separate weighing baskets and experiments were carried out. At different temperatures moisture lost from the specimens were determined.

Tensile Properties: Coir fibers of known fineness and gauge length (0.05 m) were subjected to tensile testing in an Instron testing machine at a strain rate of 0.2 m/min after heating the samples in an oven ($\pm 1^\circ\text{C}$ accuracy) at different temperatures for varying lengths of time and cooling in a desiccator. The time required for testing a fiber was about a minute.

RESULTS

Moisture Content: The moisture content of coir fiber at relative pressures (the relative pressure of the moisture in open atmosphere is equal to relative humidity at which the tests have been conducted) of 0.65 and 0.80 and at room temperature ($25\text{--}30^\circ\text{C}$) have been found to be 9% and 12%, respectively, which are in agreement with earlier work.¹⁰

Figures 1(a)–(c) show the relation between percentage moisture loss/regain and time at different temperatures at 65% and 80% RH. Similar curves have been observed for jute fibers.¹¹ It can be seen from Figures 1(a) and (b) that moisture content of fiber at 65% RH and at 68°C , 86°C , and 105°C have been found to be 1.5%, 0.4%, and 0.25%, respectively, while those at 80% RH and at similar temperatures are 2%, 1.4%, and 0.8%, respectively, i.e., the equilibrium moisture content at a given temperature is higher at 80% RH than that at 65% RH. Also moisture content of coir fiber at a given RH increases with increasing temperature (Table I). Similar observations have been made in the case of jute,¹² cotton,¹³ and paper board.¹⁴

Absorption Characteristics of Coir Fibers: From Figure 1(c) it can be seen that at test conditions the moisture regain increases with increase in temperature.

Effect of Cut or Open Ends on Moisture Intake: No significant change in the rate of weight loss was observed between fibers of 0.02 m length and 0.06 m length, both having identical weight. This suggests that there is no significant loss/regain of moisture from open or cut ends and the absorption and desorption is mainly through the cylindrical surface of the fibers.

Temperature Dependence of the Moisture Loss and Gain: From Figures 1(a-c) it can be seen that there are two distinct regions in desorption/absorption curves. Region I corresponds to the region of high rate of moisture loss/regain, while region II corresponds to the region of relatively lower moisture loss or gain with time at any temperature and at any relative humidity. In region II the fraction moisture loss/gain is related to time by the equation of type

$$w = -m/t + b_0 \tag{1}$$

where w is fraction moisture loss, t is time (min), and m and b_0 (equilibrium fraction moisture loss) are constants.

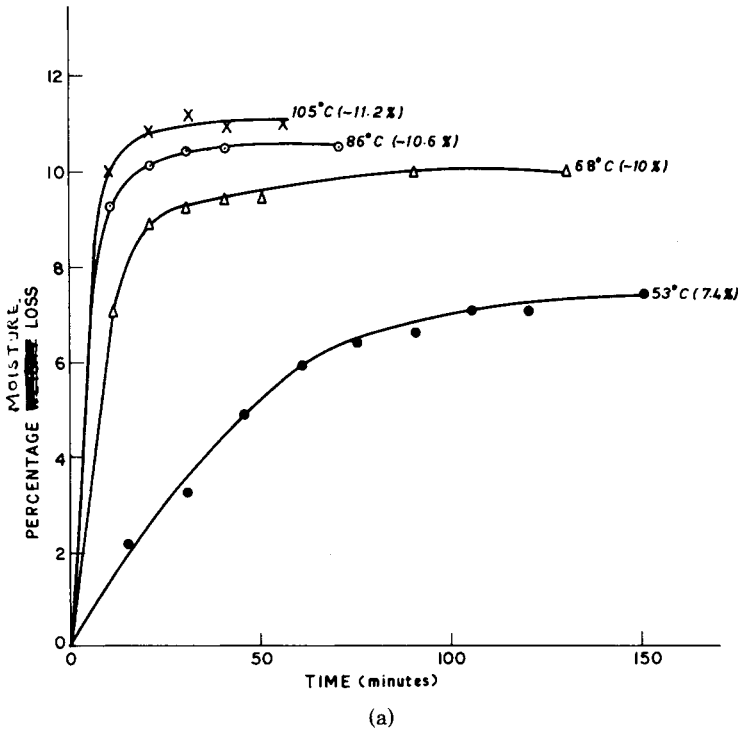
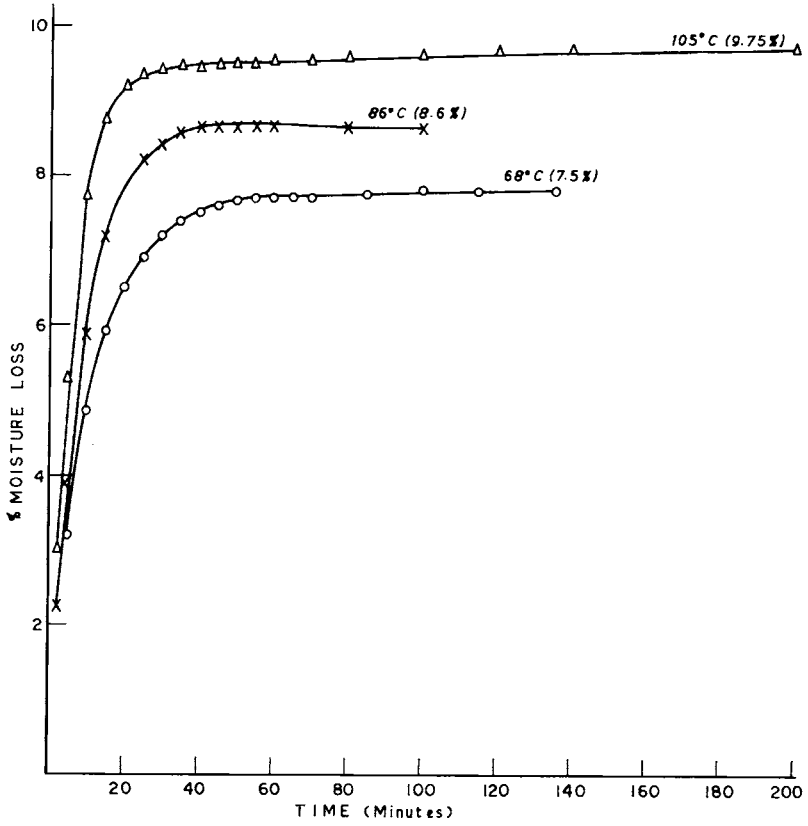
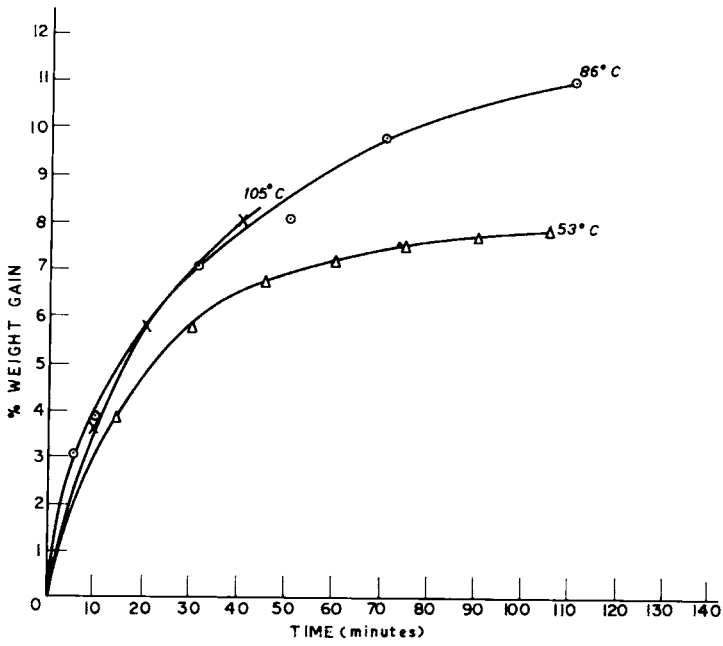


Fig. 1. (a) Plots of moisture loss vs. time for coir fiber after heating them to different temperatures at 80% RH. (b) Plots of moisture loss vs. time for coir fiber after heating to different temperatures at 65% RH. (c) Plots of regain at room temperature after heating coir fibers at different temperatures. (d) The relations between fraction moisture loss and time at different temperatures: (O) 53°C; (●) 68°C; (□) 86°C; (Δ) 105°C. General equation $w = -m/t + b_0$, where w is weight fraction loss, m is the slope, b_0 is the intercept, and t is time (min).



(b)



(c)

Fig. 1. (Continued from previous page.)

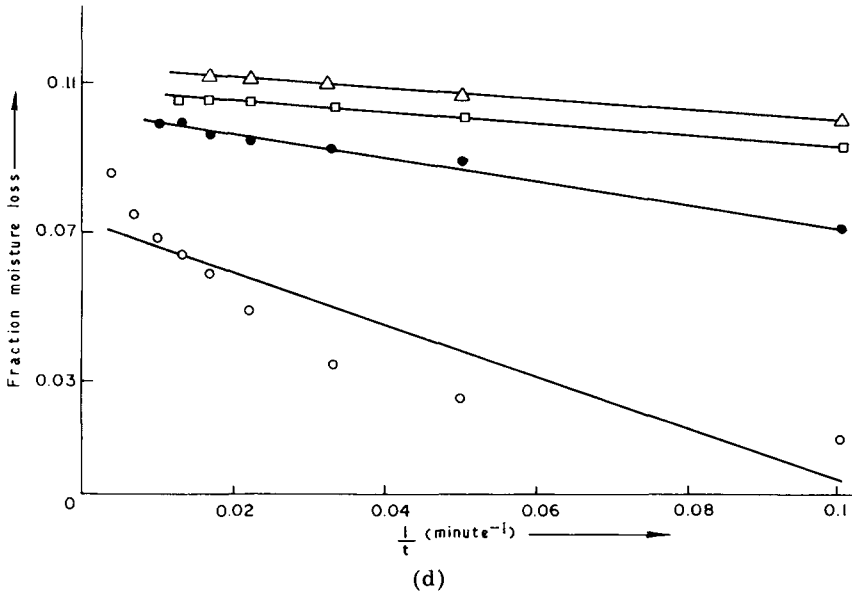


Fig. 1. (Continued from previous page.)

Figure 1(d) shows the experimental results plotted in terms of fraction weight loss (with respect to constant weight of the fibers at that temperature) against the inverse of time. At all temperatures investigated, eq. (1) shows good relations as can be seen from Table I. Table I also shows that the constants m and b_0 are dependent on temperature and m decreases with rise in temperature while b_0 increases with increase in temperature.

By differentiation of eq. (1) and rearranging, it follows that at a given temperature and RH, the rate of fraction of moisture loss or gain will become

TABLE I
Relation between fraction moisture loss (w) and time (t) at different temperatures

Equation	Temp (°C)	Slope (m)	Intercept b_0 fraction equilibrium moisture loss	Correlation coefficient $-r$
$w = -0.696/t + 0.0727$	53	-0.6960	0.0727	-0.8975
$w = -0.3164/t + 0.1031$	68	-0.3164	0.1031	-0.9945
$w = -0.1508/t + 0.1084$	86	-0.1508	0.1084	-0.9831
$w = -0.1316/t + 0.1140$	105	-0.1316	0.1140	-0.9978

Relation between fraction moisture gain (w) and time (t) at different temperatures

Equation	Temp (°C)	m	b_0 fraction equilibrium moisture gain	Correlation coefficient r
$w = -0.414815/t + 0.07622$	53	-0.4148	0.07622	-0.7580
$w = -0.3731/t + 0.0951$	86	-0.3731	0.09510	-0.8888

constant, i.e.,

$$\frac{dw}{dt} = \frac{m^3}{(b_0 - w_f)^2} \quad (2)$$

where w_f represents fixed fraction weight loss or gain at sufficiently small values of time of exposure.

Time Dependence of the Moisture Loss at Any Temperature: Figure 2 shows the relation between % moisture content (A) and temperature ($T^\circ\text{K}$) at different intervals of time. The relation is given as

$$A = A_0 e^{-B/T} \quad (3)$$

where A_0 and B are constants and both the values decrease with time. The constant term B may be considered as the Q/R , where Q is the activation energy and R is the gas constant. Table II shows the values of A_0 , B , and Q . The values of Q lie between 2.77 kcal/mol and 8.3 kcal/mol (heat of sorption of water on cellulose for the hydrogen bonding is between 3–8 kcals).

Moisture Dependence on the Mechanical Properties of Coir Fiber: Table II indicates the variation in tenacity and % elongation of fibers with loss of moisture. It can be seen that as the moisture decreases, the tenacity of coir increases while % elongation decreases.

DISCUSSION

The above results are explained below in terms of changes in structural arrangement of lignocellulosic materials on heating. It is well known that coir is a lignocellulosic material and lignin, hemicellulose, and cellulose contribute to hygroscopy as reported in the case of wood.¹⁵ It is also known that the water is preferentially absorbed in the noncrystalline region.

When the coir fibers (with equilibrium moisture content, at a given relative

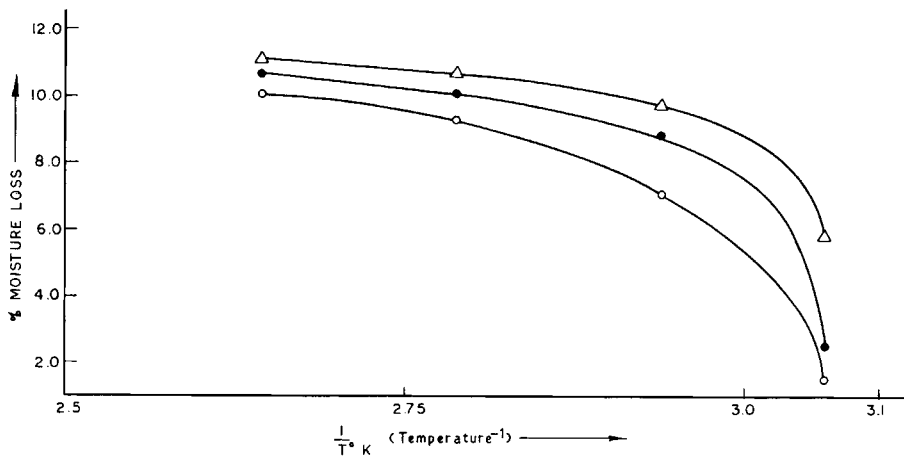


Fig. 2. Relation between % moisture loss and inverse of temperature at different intervals of time: (O) 10 min; (●) 20 min; (Δ) 60 min. General equation $A = A_0 e^{-B/T}$, where A is moisture loss, A_0 is e^n (n being the intercept of the curve $\ln A$ vs. $1/T$), B is the slope of the curve $\ln A$ vs. $1/T$, and T is the absolute temperature.

TABLE II
Relation between % Moisture Loss (A) and Temperature ($T^\circ\text{K}$) at Different Time Intervals

Equation ($A = A_0e^{-B/T}$)	Time (min)	$A_0 = e^n$	$-B$	Q (cal/mol) activation energy	Correlation coefficient r
$A = e^{(13.7612-4212.174)/T}$	10	947,137.9187	4212.174	8369.589	0.8700
$A = e^{(107246-3069.138)/T}$	20	45,469.5411	3069.138	6098.377	-0.8340
$A = e^{(9.1746-2491.793)/T}$	30	9648.9077	2492.793	4951.192	-0.9000
$A = e^{(7.2778-1794.919)/T}$	40	1447.7994	1494.919	3566.504	-0.8634
$A = e^{(6.1913-1395.731)/T}$	60	488.4807	1395.731	2773.317	-0.8741

pressure) are exposed to higher temperatures, moisture is lost from the fiber surface. An increase in temperature results generally in a decrease in the equilibrium moisture content in both wood and cellulose,¹⁵ although at a given relative pressure the amount of moisture retained even at temperatures above 100°C is a substantial fraction of that held at room temperatures. In the case of coir, the amount of equilibrium moisture retained is a substantial fraction of that held at room temperature and at a given relative pressure. From Figure 1(a) it may be seen that the initial rate of moisture loss is higher than at the subsequent stage at a given temperature. In the initial stage, the water which is in the condensed form (free water) is evaporating. It is well known that the rate of water evaporation increases as the temperature is increased at any given relative pressure. However, at a later stage, the rate of moisture loss is constant at a given temperature and at 0.80 relative pressure. The rate is given by eq. (2) and it is increasing with temperature. This may be attributed to the fact that when cellulose is dried, hydrogen bonds are formed between hydroxyl groups on adjacent chains. These bonds will not be of the same strength, because of stresses set up during drying. The energy evolved in removal of moisture (heat of desorption) is of the order of 3–8 kcal/mol and appears to be that of hydrogen bonding.¹⁵ However, in the present investigation, Table I(b) activation energy calculated at all temperatures and time intervals suggest that it is equivalent to that of desorption (2.7–8.3 kcal/mol). As the temperature is increased the thermal energy input at a given time is large enough to dislodge large amount of water molecules. Therefore, the rate of moisture loss increases at higher temperatures. From eq. (1) the equilibrium amount of moisture lost (b_0) may be calculated at any temperature.

It has already been stated that the drying of fiber increases the hydrogen bonding between adjacent chains and molecular chains are anchored. When such a structure is subjected to tensile loading, it shows higher load bearing capacity, and lesser elongation than the one with the lesser hydrogen bonding or moisture content. Table III is in concurrence with the proposed theory. It can be seen that as the moisture content in the fiber increases the tenacity decreases and percentage elongation increases.

CONCLUSIONS

From the absorption and desorption studies conducted on coir at different humidities and at different temperatures it may be concluded that:

1. Moisture content of coir fibers at relative pressures of 0.65 and 0.80 are

TABLE III
Variation of Tenacity and % Elongation with Loss of % of Moisture from Fiber

Dia of fiber (mm)	% Moisture removed	Tenacity (g/den)	% Elongation	Increase in % tenacity	% Decrease in elongation
0.30	0.0	1.640	42.880	—	—
0.25	0.0	1.665	36.940	—	—
0.30	3.2	1.880	23.120	14.62	53.91
0.30	4.9	1.860	18.960	13.41	55.78
0.30	6.4	1.840	27.770	12.19	35.23
0.30	7.0	2.022	17.240	23.00	59.79
0.30	7.1	1.950	21.200	18.90	50.56
0.30	7.3	1.820	24.311	10.98	43.31
0.30	7.4	1.970	28.222	20.12	34.18
0.30	9.0	2.380	17.912	45.12	58.23
0.25	10.1	2.320	16.666	39.34	54.88
0.25	10.5	1.990	18.720	19.52	49.32

found to be 9% and 12%, respectively. The equilibrium moisture content is higher at higher relative pressures and at a given temperature, but it decreases as temperature increases at a given relative pressure.

2. The percentage moisture removal at a given time may be given by an equation of type $A = A_0e^{-B/T}$. The constant B may be regarded as a function related to activation energy.

3. Activation of desorption is found to be of the order of 2.7–8.3 kcal/mol.

4. The fraction moisture loss or regain is related to time by an equation of the type $w = -m/t + b_0$ at all temperatures studied.

5. As the moisture content in the fiber increases, the tenacity of the fiber decreases while % elongation increases.

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