

EXPERIMENTS IN NONISOTHERMAL DIFFUSION OF MOISTURE IN WOOD. PART II.¹

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ABSTRACT

This paper is the second in a series of papers reporting on experiments in nonisothermal diffusion of moisture in wood. Additional experimental steps to those series previously reported and one more series are included here. A reversal of flux direction was observed in all three series of experiments as the relative humidity of the warm side was increased.

The results were analyzed using the general sorption data presented in the USDA Wood Handbook using two equations. The first of each is based on a gradient of activated moisture content, and the second is based on a gradient of chemical potential which contains an additional term to account for the effect of the temperature gradient. Both equations predicted reversal of flux direction, but the second equation (chemical potential) generally provided the best fit to the experimental results.

Keywords: Diffusion, moisture content, flux direction, relative humidity.

INTRODUCTION

In the first paper (Siau et al. 1985) nine experimental steps were reported. Four of these were part of a series with diffusion cup temperature (T_{cup}) of 13.5 C and the remainder with T_{cup} of 18.0 C. In this paper, additional steps to the previous ones are reported so that the range of the warm-side relative humidities was increased. A third series with a $T_{cup} = 16.0$ C is also included. Additionally, the cool-side relative humidities and corresponding moisture contents and partial vapor pressures of the previously reported steps are reevaluated after recalibration of the humidity sensors.

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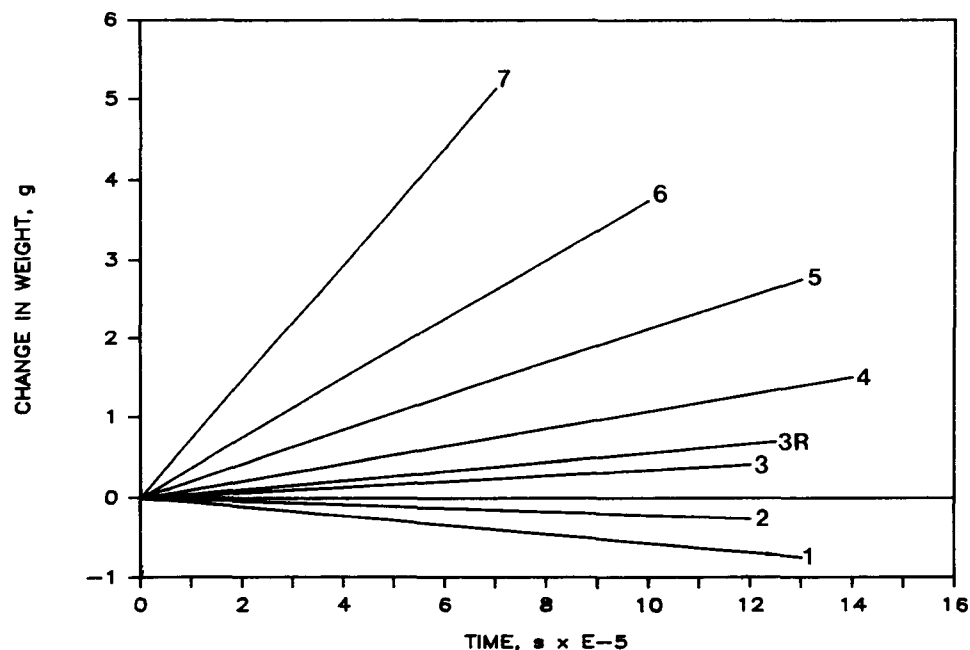


FIG. 1. Plot of change of weight of diffusion cup versus elapsed time for the A series.

TABLE 1. Summary of nonisothermal experiments.

Run	T_w	H_w	M_w	P_w	T_c	H_c	M_c	P_c	J_{exp}	J_{M^*}	J_u
A1	68.3	11.3	1.42	2.462	28.5	35.0	4.72	1.052	+3.63	-0.65	+3.00
A2	69.2	19.0	2.16	4.286	29.3	38.0	5.00	1.160	+1.40	-2.70	+1.80
A3	70.1	31.4	3.22	7.381	28.3	44.2	5.71	1.262	-2.20	-5.10	+0.07
A3R	69.7	31.2	3.20	7.186	29.2	35.6	4.76	1.100	-3.55	-6.20	-1.00
A4	69.7	38.3	3.81	8.839	29.2	35.9	4.79	1.168	-6.85	-8.10	-2.65
A5	69.9	46.4	4.52	10.770	29.2	39.5	5.16	1.200	-13.50	-9.95	-4.40
A6	69.6	45.2	4.42	10.367	28.4	50.6	6.47	1.467	-23.90	-7.95	-2.65
A7	69.5	62.2	6.23	14.211	29.8	55.0	6.98	1.734	-46.60	-13.20	-9.64
B1	70.0	10.9	1.38	2.533	27.9	41.9	5.47	1.176	+4.25	+0.20	+4.06
B2	70.6	17.9	2.06	4.239	28.5	43.1	5.58	1.256	+3.26	-1.80	+2.65
B3	70.7	17.7	2.04	4.249	29.2	41.9	5.42	1.273	+2.50	-1.90	+2.54
B4	71.3	26.2	2.77	6.477	29.6	42.1	5.43	1.310	-1.02	-4.12	+0.84
B5	70.1	36.8	3.67	8.639	28.0	51.0	6.53	1.443	-12.10	-5.60	-0.30
B6	70.0	42.9	4.20	10.020	28.8	48.8	6.23	1.447	-14.12	-7.70	-2.30
B7	70.1	57.7	5.68	13.534	30.5	46.5	5.88	1.522	-24.20	-12.90	-8.28
C1	67.0	8.7	1.14	1.774	27.6	49.5	6.36	1.371	+12.40	+1.90	+4.90
C2	70.0	19.2	2.18	4.473	27.8	48.9	6.28	1.370	+7.94	-1.40	+2.70
C3	69.8	32.3	3.29	7.500	27.9	49.2	6.32	1.386	+4.80	-4.60	-0.10
C4	69.9	40.3	3.98	9.342	28.1	49.8	6.38	1.417	+3.70	-6.60	-1.70
C5	70.3	48.5	4.72	11.482	28.9	49.7	6.33	1.485	-8.50	-9.10	-4.10
C6	69.9	61.3	6.11	14.256	29.7	62.8	8.14	1.967	-34.00	-11.00	-8.60
C3R	70.0	32.7	3.33	7.637	28.8	50.2	6.40	1.492	-0.23	-4.60	+0.05
C4R	69.9	40.1	3.96	9.321	29.6	50.5	6.40	1.568	-3.75	-6.50	-1.70
C5R	69.6	50.4	4.92	11.568	30.3	53.3	6.73	1.725	-19.60	-9.15	-4.60

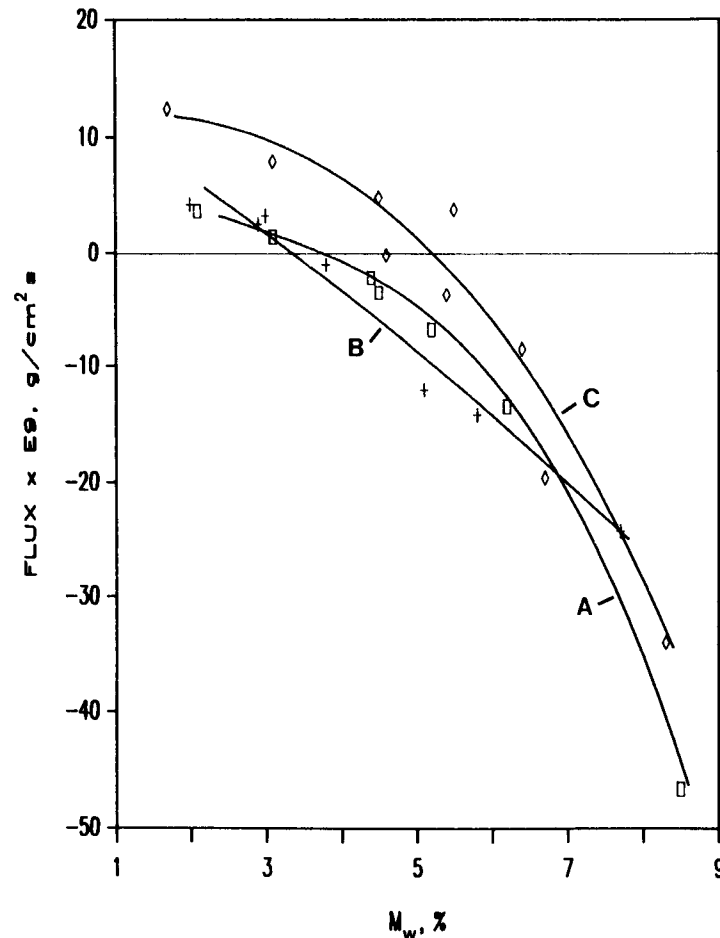


FIG. 2. A plot of experimental fluxes vs. M_w for A, B, and C series.

PROCEDURE AND RESULTS

The experimental procedure, the mathematical models and the data treatments were the same as those described by Siau et al. (1985) in the first paper of this series.

The three experimental series were named A, B, and C, corresponding to T_{cup} of 13.5, 16.0, and 18.0 C, respectively, for maintaining increasing cool-side vapor pressures. The cool-side temperature (T_c) was 29 C. The average relative humidities obtained on the cool-side of the three series (H_c) were 42%, 45%, and 52%, respectively. The warm-side temperatures (T_w) were 70 C with the relative humidities (H_w) increasing in 5 to 7 steps from 10% to 63%.

Table 1 shows the experimental values of the temperatures, relative humidities, EMC's, partial vapor pressures, and fluxes (experimental and theoretical) of all series. As can be seen, the moisture content of the warm-side (M_w) is always lower than that of the cool-side (M_c). Furthermore, the partial vapor pressure of the warm-side is always higher than that of the cool-side, indicating that the observed

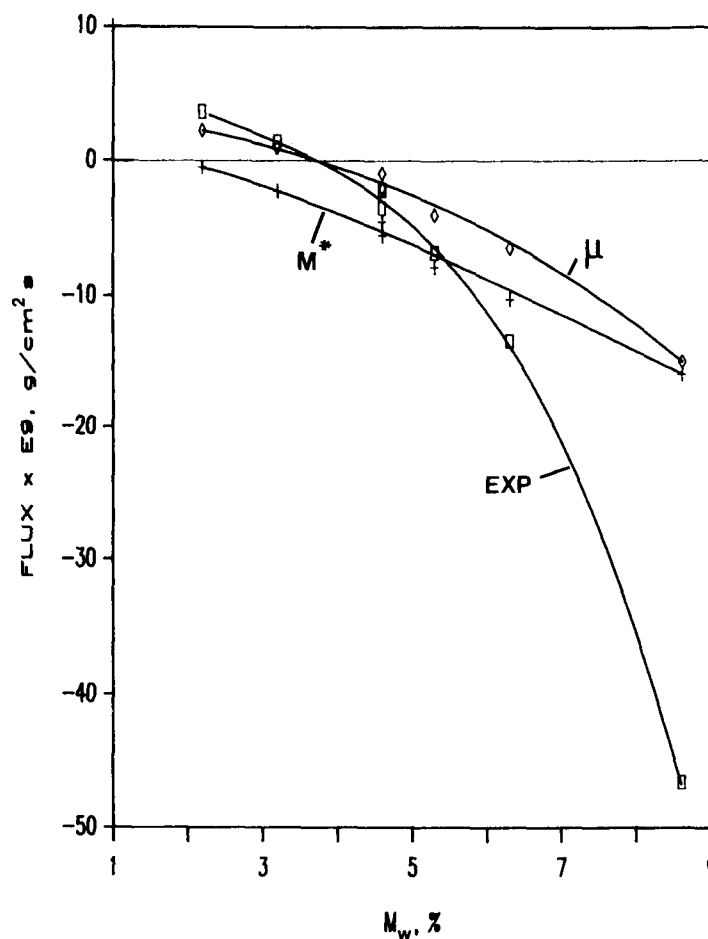


FIG. 3. A plot of experimental and theoretical fluxes vs. M_w for A series ($T_{cup} = 13.5$ C).

results cannot be explained solely on a basis of moisture content or partial vapor pressure gradients. The positive sign indicates that the moisture flux was from the cool- to the warm-side of the specimen. The flux reversal phenomenon is obvious from the table, but it is more obvious in Fig. 1 where the change of weight of the diffusion cup is plotted versus the elapsed time for the A series. The same phenomenon was also observed in the other two series. The data and results of the three series are presented graphically in Figs. 2 through 5.

Figure 2 shows the experimental fluxes obtained from the three series. The warm-side moisture contents where flux reversal occurred were 3.8%, 3.5%, and 5.3%, respectively. It is obvious that the higher cup temperature shifted the flux in the positive direction because of the higher EMC's on the cool surface of the specimens. Deviation from that trend of some intermediate negative fluxes of B series is attributed to leaks from the sealant around the specimen.

In Figs. 3, 4, and 5, the fluxes have been plotted versus the M_w of the three series. It can be seen that the chemical potential equation predicted zero flux at

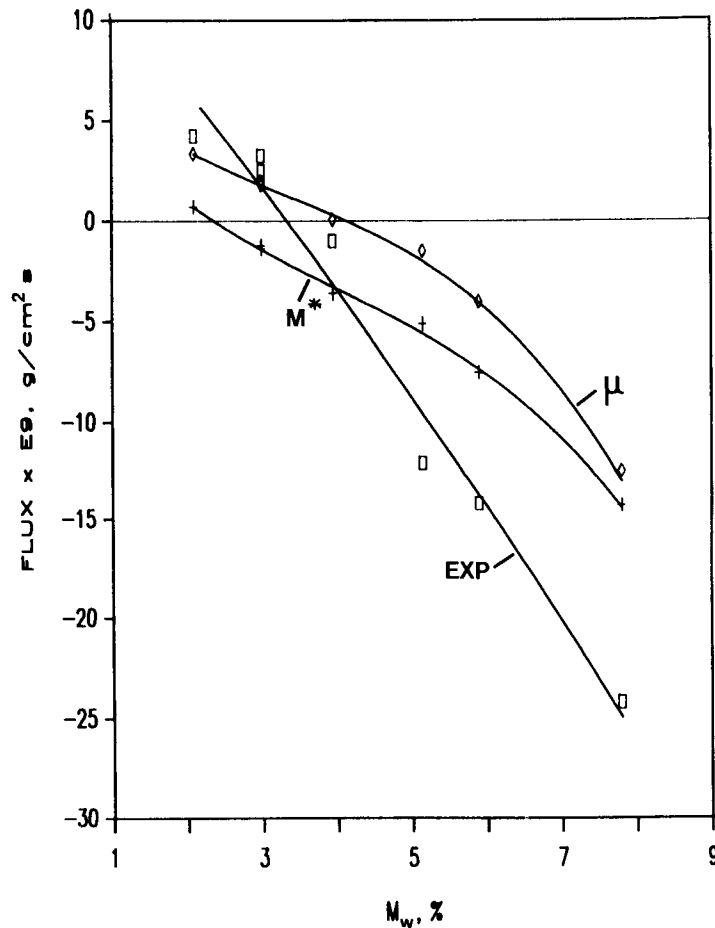


FIG. 4. A plot of the experimental and theoretical fluxes vs. M_w for B series ($T_{cup} = 16.0$ C).

$M_w = 3.8\%$ in agreement with the experimental value for the A series, whereas for the B and C series, the predicted values of M_w were 4.2% and 4.6%. Correspondingly, the activated moisture equation predicted flux reversal at $M_w = 2\%$, 2.3%, and 3%. It is obvious from these figures that the flux values predicted by the chemical potential equation are closer to the experimental ones for zero or positive fluxes, whereas the values predicted by the activated moisture equation are closer to the experimental at high negative fluxes.

Finally, Fig. 6 shows the moisture profiles predicted by the two equations inside the wood specimens for some experimental steps. In all cases, the EMC predicted by the activated moisture equation is higher than that predicted by the chemical potential equation. It also shows that in the A7 case a maximum EMC occurs within the specimen. This can be explained by a high negative flux and indicates the possibility of internal condensation, indicating a maximum practical experimental limit to the warm surface moisture content for the maintenance of controlled conditions.

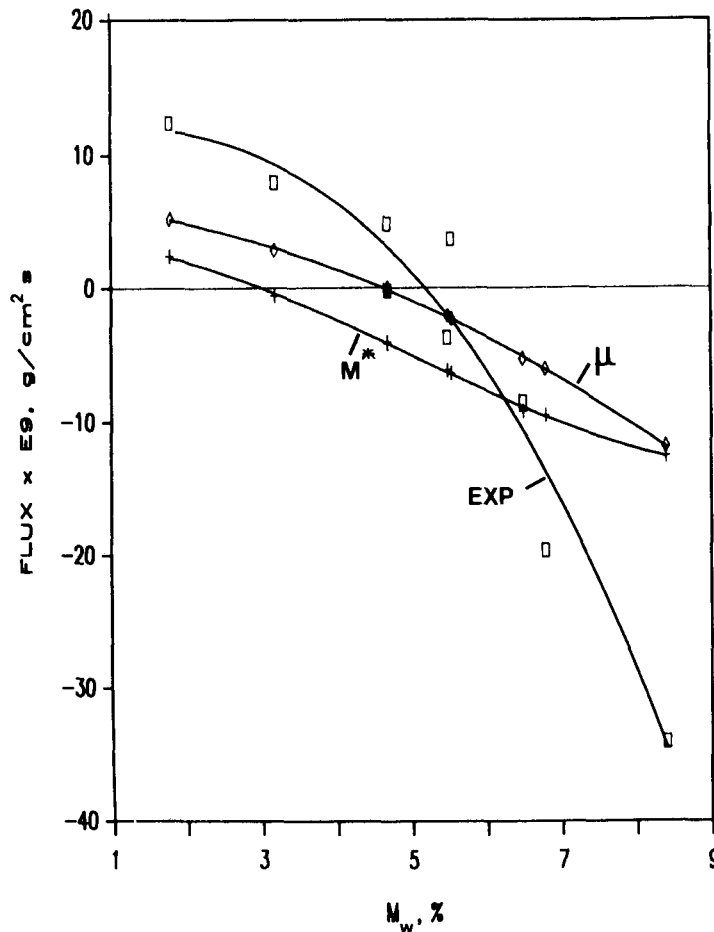


FIG. 5. A plot of the experimental and theoretical fluxes vs. M_w for C series ($T_{cup} = 18.0$ C).

CONCLUSIONS

Moisture can diffuse from low to high partial vapor pressure or from low to high moisture contents inside solid wood transverse to the grain under nonisothermal conditions. These phenomena are not predicted by the isothermal forms of Fick's first law. It can be explained by the principles of nonequilibrium thermodynamics and the general "thermodiffusion" phenomenon whereby a temperature gradient can result in mass transfer.

The chemical potential equation gave a better fit to the experimental data in all three series at positive and low negative fluxes, compared to the activated moisture equation. It must be emphasized that the diffusion coefficients, activation energies, and sorption isotherms used were taken from Stamm's (1959) and Choong's (1963) work and also from the general Wood Handbook (1955) sorption data, which may not be typical of the western white pine specimens used in these experiments. Sorption studies are now under way for the determination of these

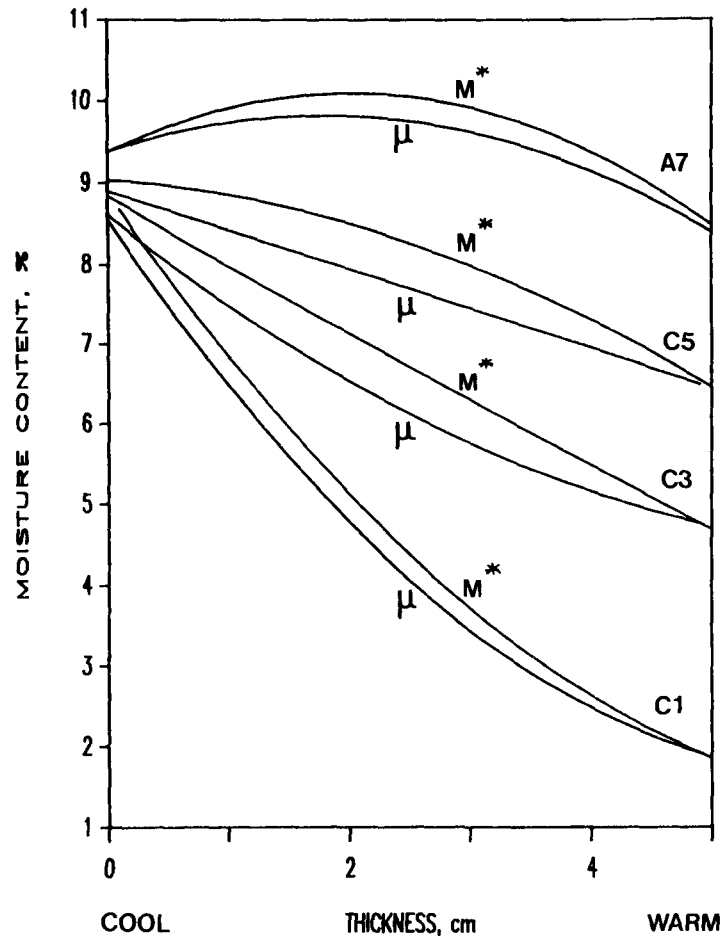


FIG. 6. Moisture profiles in Experiments C1, C3, C5, and A7 as calculated from Eqs. (1) and (2).

important parameters from specimens closely matched to those used in the experiments.

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