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Note on a formulation of a water adsorption process of wood

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In the previous report (Nakano 1994a, 1994b), the author tried to formulate moisture content during water adsorption of wood as a function of time. The reason is that the formulation is necessary for elucidation of the mechano-sorptive process, since the mechano-sorptive creep or stress relaxation depends upon a change of moisture content (Takemura 1967, 1968). The application of Fick's low was then examined. Babiak (1994) pointed out that there were a few problems in the reports. They are the followings: (i) the conclusions in the reports are misleading, since the analysis of Fick's description is not correct, (ii) the sample dimension is not appropriate for the examination of the derived equation, (iii) the boundary condition is not paid any attention. The author, however, cannot accept not all of his comments. Thus he will describe the opinion and comments for them.

The inappropriate description must be first corrected before the opinion is mentioned. In the report (Nakano 1994a), the description for the equation of moisture content derived from Fick's low is partly not appropriative. On the sentence in front of eq. (2) in the report, "For the surface of sheets as ± 1" should be replaced by "For the region between sheets at ± 1". The description in the part is the citation based on the treatment by Crank (1975), and Eq. (2) in the report was obtained with the same treatment as mentioned by Babiak (1994), which has been already described in detail by Crank (1975).

Fick's low has been generally applied to the water diffusion into wood or a water adsorption process. Some scientists, however, have examined the validity of the application of Fick's low for wood as a fundamental equation. Because there is the question for the application as has been mentioned by Babbitt (1977). In the reports (Nakano 1944a), the author showed an example for the problem of the validity of the application of Fick's low for a water adsorption process of wood. The equation of moisture content derived from the Fick's low causes the conflict when the theory of Yamada (1952) and Kajita (1959) is applied to a water adsorption process. The result from the low is not valid, considering the followings: (a) water adsorption of wood is monolayer adsorption, (b) a secondary internal surface is created as water adsorption processes. The author, therefore, tried to formulate moisture content in a water adsorption process by no use of Fick's low. Then, the following equation was obtained:

$$d(\delta W)/d(\log t) = r\delta W(1-\delta W), \tag{1}$$

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where δW is moisture content, r is constant, t is time. The approximate solution is represented by

$$\delta W = [1 + \exp(-r(\log t - a)]^{-1}. \quad (2)$$

This equation agreed with experimental results (Nakano 1994b). Eq. (2), however, should be applied only to the water adsorption into wood substance. Because the formulation was derived on the basis of a simple model no considering the pore diffusion and the distribution of moisture as mentioned in the report. The author expects that the model considering all conditions will be proposed in future.

The comment (i) by Babiak is not reasonable if the above revision is accepted. Because the equation for moisture content derived from Fick's low becomes Macbain's equation or Langumuir's equation. This shows that the derived equation cannot represent the experimental results of Yamada (1952) and Kajita (1959), who found that Langumuir's theory is not inapplicable to water adsorption of wood. Thus, the author pointed that the Fick's low is not appropriate for water adsorption of wood when the diffusion coefficient is constant at least. The treatment such as the dependence of diffusion coefficient on the concentration is considered has already been examined. The author also tried the approach by no use of Fick's low.

In the report (Nakano 1994a), the treatment for water adsorption of wood was discussed on the two Assumptions: (A) the creation of the new adsorptive sites and (B) the hindrance of water diffusion into wood substances as the water adsorption proceeds. These assumptions are based on the conclusion by Yamada (1952) and Kajita (1959). The contribution of the creation of the adsorption sites is represented from analogy with an auto-catalyzed reaction by

$$d(\delta W)/dt = k_0 \delta W (1 - \delta W) \quad (k_0 = \text{const.}) \quad (3)$$

The hindrance is introduced as weight which relates to activity of water adsorption. The weight is represented by

$$\Phi(t) = 1 - \exp(k_1/t) \quad (k_1 = \text{const.}) \quad (4)$$

Equation (1) is obtained from Eqs. (3) and (4). The weight, however, was not theoretically derived but inferred. Probably one of "the inspirative arguments" pointed by Babiak may be the introduction of eq. (4). The author accepts that the term should be theoretically derived and the more discussion is necessary. The discussion based on the assumptions, however, appears to be better for moisture content of wood rather than that on Fick's low. The reason is the following.

Fick's low is the fundamental equation for the description of the diffusion of materials. The validity of the application to many materials is also supported by the thermodynamics. Only the problem is whether the low can be the applied for wood. The diffusion into wood consists of two kinds of diffusion: the pore diffusion and the diffusion into wood substances. For the latter, the swelling of the substances should be considered, which creates the secondary adsorptive sites as pointed by Yamada and Kajita. Moreover, since the swelling causes the change of the shape of pores, the former may be also influenced. These conditions, which are based on characteristic properties of wood, are not clearly considered for the derivation of Fick's low. We should take into consideration that Fick's low was led from analogy with the movement of heat, though the low is available for many materials. This requires the other approach where the condition for water adsorption of wood is taken. Babiak points out that there is not the analysis of the boundary condition in the reports [comment (iii)]. Our problem,

however, is not the boundary condition but the derivation of Fick's low. The boundary condition relates only to the solution of the differential equation and not to the derivation of the formulation.

Babiak pointed out that the treatment in the report did not pay any attention to the dimension of the sample and that the dimension of the thickness in longitudinal direction 0.5 cm was inappropriate [comment (ii)]. As mentioned before, the author then inferred that the effects of the distribution of moisture content and the pore diffusion are little for dimensional change of the sample: the sample (Japanese ash) is hardwood and ring porous wood in rectangular dimensions of $0.5(L) \times 3.5(R) \times 3.5(T)$ cm. Although moisture content at the surface in cross section is probably different from that at the point 0.25 cm below the surface, the effect was neglected. The reason is due to the measurement method. The dimensional change was measured with a displacement transducer, which consists of a coil and a rod (a core) penetrated it. The tip of the rod is placed on the surface ($R \times L$) and the movement detects the dimensional change (T) of a sample. Probably this is general method for a dimensional change in one direction. Since the tip occupies some area around the center of the surface ($R \times L$): the measurement direction is tangential, the data should be the average change in the area of the tip and the around area which is proportional to moisture content. This method, therefore, is valid for the examination of the moisture change represented by eq. (2).

The author accepts not all of comments by Babiak as mentioned above. The proposed model and theory, however, remain some problems, for example eq. (4) as weight of the hindrance of water movement. They should be examined in more detail on the basis of the model considering the various conditions for characteristic properties of wood. The validity of the model should be examined by the other plural experiments.

The author appreciates the comments and opinion of Babiak and kind consideration of the editor.

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